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MOVING RADAR: AN ASSESSMENT OF ITS ROLE IN TRAFFIC LAW ENFORCEMENT

DEPARTMENT OF LAW ENFORCEMENT
OF ADMINISTRATION

MOVING RADAR:

AN ASSESSMENT OF ITS ROLE IN TRAFFIC LAW ENFORCEMENT

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Springfield, Illinois

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September 1981

ACKNOWLEDGEMENTS

Cooperation from the Division of State Police (also referenced as the Illinois State Police) made possible the collection of most data presented in this report. Assistance from Superintendent Ronald J. Miller and Deputy Superintendents Lawrence Scheufele and William Pierce was invaluable. Special acknowledgement is given to the District Commanders and troopers in ISP Districts 9 and 11. They allowed the author to ride, observe, and time various elements of the traffic stops. Comments and other information made by these officers also helped guide the direction of this report. Much of the data describing times and amounts of activity derived from the Traffic Information and Planning System operated by the Department of Law Enforcement through assistance of the Management Information Bureau. Sergeant Robert Kaylor of the Bureau of Planning and Development assisted with gathering data for fuel consumption and from traffic stops. Rose Krause, also of the Bureau, waded through the many revisions and typed each without complaint. Finally, Ellen Holdroyd of the Illinois State Library and the Transportation Library at Northwestern University and its librarian Ms. Mary Roy eased the search for background material, providing access to much of the literature reviewed.

TABLE OF CONTENTS

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TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

LIST OF ILLUSTRATIONS

TABLES

LIST OF ILLUSTRATIONS (cont'd)

FIGURES

MOVING RADAR:

AN ASSESSMENT OF ITS

ROLE IN TRAFFIC LAW ENFORCEMENT

EXECUTIVE SUMMARY

Police use of moving radar as a tool for enforcing the speed limit is increasing. At the same time, this equipment has come under criticism by a few courts and those persons opposed to any police use of doppler radar. There have been evaluations of the accuracy of moving radar, but none have addressed its effectiveness as well as its cost of operation. These aspects are addressed in this report.

Although wide publicity was given to the court in Dade County, Florida for its refusal to accept testimony based on the use of moving radar, this has been one of the few negative responses by the courts to this tool. With the exception of the case in Florida and another in Wisconsin, the courts have readily accepted testimony based on the use of moving radar. Historically, the judiciary has supported the use of a wide range of technical tools for the enforcement of speed limits - - moving radar is another tool. Two elements stand out. First, the equipment is reliable, and a competent operator can easily demonstrate its accuracy. Doppler radar measures the change in frequency of a signal returning from a vehicle and accurately converts that measurement into a reading which indicates the speed of the vehicle. Second, a properly trained operator of the equipment will obtain an accurate reading of a vehicle's speed; an improperly

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trained operator may assign a speed to the wrong vehicle. Such improperly trained officers who have used the equipment incorrectly have provided the basis for the negative rulings in both Florida and Wisconsin. Where operators have been trained in the correct use of moving radar, e.g. in Illinois, Kentucky, Michigan, and New Jersey, the convictions of violators have been upheld.

As demonstrated to the court in Dade County, and as discussed in many judicial opinions, there are certain characteristics of moving radar which can present unwanted readings. Because these characteristics may reduce the effectiveness of moving radar, they are described briefly in this report. The summation of their consideration is that as long as the operator first identifies the violator, such characteristics as "ghosting", "batching", "panning", "cosine effect", etc., will not interfere with the correct identification of a violator nor the measurement of the speed of his vehicle. If the operator is not performing his monitoring correctly, the effectiveness of moving radar is diminished.

A majority of the discussion centers on the evaluation of the equipment. This evaluation has both a subjective and objective aspect. Administrators of state law enforcement agencies and state police officers who operate the equipment were asked to address such questions as perceived reliability, ease of use, acceptance by the courts, and adequacy of training. Results described show that, in most respects, moving radar is superior to other methods of enforcing speed limits. The primary limitations already are known. Moving radar is not practical for use on multi-lane roads during periods of heavy traffic, roads divided by median barriers, and in heavily rolling terrain. On the other hand, except for the use of an airplane, which is substantially more expensive, the patrolling officer equipped with moving

radar is able to deter speeding over a longer section of highway and is more likely to stop the flagrant violator than by use of other methods.

The most difficult tasks facing police administrators is the proper training of operators. There is no universally agreed upon program of training, although the Federal Government has produced a suggested lesson plan. Some states require many hours of hands-on training in addition to those hours in the classroom. Agencies may also restrict use of moving radar during a probationary period. Some also give proficiency tests; others require recurrent training. The time spent on additional training represents a significant component of the cost of operating moving radar. With less sophisticated equipment, such extensive training apparently was not needed.

The final chapters show that moving radar is no more costly to operate than hand-held radar. It is less costly in terms of patrolling coverage because, with moving radar, the police officer is not tied to monitoring traffic at a single location. In terms of effectiveness for speed enforcement, its closest competitor is the airplane. However, a stop made as part of air surveillance is at least twice as expensive as one made with use of moving radar. Therefore, given the low cost and relatively high effectiveness, the use of moving radar appears to be the most cost-effective method of enforcing the speed limit. To enhance this position, a common program of training and some improvements in the equipment may be needed.

MOVING RADAR:
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INTRODUCTION

Mobile doppler radar or moving radar is one of the latest, and possibly the most effective, additions to the tools used by police for traffic law enforcement. The equipment allows the police officer to monitor the speeds of traffic while that officer is driving a patrol vehicle. Because moving radar generally is used to monitor speeds of traffic proceeding in the opposite direction, the officer effectively patrols both directions of the road at the same time. The flagrant speeder cannot drive with the same impunity as when officers operate radar from a fixed position. Unlike the use of Visual Average Speed Computer And Recorder (VASCAR), which is another instrument that can be operated in a mobile mode, the use of moving radar does not require the officer's attention fixed on the violator over a long period. The officer who is properly operating moving radar first identifies the speeding vehicle and second confirms the speed of that vehicle on the radar. The total amount of time required to complete the identification and confirmation generally is less than five seconds. Technologically, the concept behind moving radar is proven. However, because of the mobile environment, operation of the unit requires expertise beyond that traditionally held by officers who have used hand-held radar in the stationary mode.

The purpose of this report is to examine the strengths and weaknesses of moving radar and to compute the costs of using this tool for enforcing the speed limit. There are six chapters: judicial acceptance of radar, characteristics that affect readings on moving radar, assessment of its strengths and weaknesses by users, analysis of the operating costs, determination of cost-effectiveness, and the summary and recommendations. The first chapter describes the response of the courts to the use of radar for traffic law enforcement. The few negative cases referenced pertain to the misuse of moving radar by improperly trained operators. In general, the courts accept testimony based on the use of radar as prima facie evidence of speeding. Without this acceptance, the usefulness of moving radar, or any other tool, would be limited.

Because moving radar technically is more advanced than most other mechanisms used for traffic law enforcement, the characteristics which affect its use are important. An operator must have a thorough knowledge of these characteristics; their description and understanding are principal parts of training the officer in the use of the equipment. The characteristics which have been most likely to affect the use of the equipment are described in the second chapter.

The third chapter explores the strengths and weaknesses of the equipment based on responses to questionnaires from administrators of state police and highway patrols, and from the police officers who use it. When the responses are summarized, they present a positive picture of both the acceptance and the usefulness of moving radar.

Given acceptance of moving radar by the courts and users, is such use cost-effective? To answer this question the use by police officers has been observed, and the type of activity performed and its elapsed time recorded. From this, the cost of operating moving radar has been computed. The methodology and

assumptions used for these computations as well as the resultant costs are presented in chapter four.

Following this chapter are the comparisons of cost between moving radar and other methods of enforcing the speed limit. Two important findings are made:

1. The costs of completing a traffic stop based on the use of moving radar are as low as any methodology currently in use.
2. Citations issued for stops initiated through the use of moving radar are less likely to be contested in court. When contested, the violator is as likely to be found guilty as violators stopped by any other method of enforcing the speed limit.

As summarized in the final chapter, with the exception of congested locations, particularly on highways with median barriers, moving radar appears to be a superior tool for use by state police agencies. It is not only less costly to use, but it also helps the patrolling officer monitor the highway more effectively and detect and cite flagrant violations of the speed limit. There is a need for changes to the equipment to allow more efficient stationary use in those areas where the radar cannot be used effectively in the moving mode. Finally, the use of this equipment requires a properly trained operator. Courses of training must include sufficient theory of radar, information regarding characteristics that can interfere with proper use, court opinions, and most importantly, "hands-on" training with qualified instructors. Because of a greater need for technical expertise, tests of competency are needed to help identify those persons capable of properly using the equipment.

I. JUDICIAL ACCEPTANCE

ACCEPTANCE OF SPEED ENFORCEMENT METHODOLOGY

Judicial Notice of Speed Enforcement Tools

Mobile doppler radar is the latest of a series of technical advances since the speedometer was first accepted as a tool for enforcing the speed limit. Over the years, the speedometer, timing of vehicles over specific distances through use of a stop watch on the ground or from the air, pneumatic tubes, photography, VASCAR, and radar, both hand-held and moving, have been used. In Europe, instead of the wide-beamed, higher-powered radar used in the United States, a narrow beam, low-wattage radar has been employed with and without cameras for the enforcement of speed along very short sections of the highway.[1]

With the exception of the radar currently used in Europe, the use of all the tools for assisting police officers in the detection of speeding vehicles has been reviewed by the courts. The technical aspects and reliability of these tools have been accepted without the need for expert testimony - - given "judicial notice". However, this notice is only one of the three parts of the burden. Second, the testifying officer must show that the particular device was accurate and finally, that officer must be capable of interpreting the information correctly. Given these three parts, the speeds presented can be accepted as prima facie evidence.

The first tool for enforcement of the speed limit, the speedometer received judicial notice in 1917.[2] A trained officer using equipment judged accurate at the time of use could testify that the speed presented on the speedometer was sufficient evidence of the violator's speed. In reaffirming the 1917 decision, the

Connecticut Circuit Court in 1966 pointed to a 50 year history of the use of reliable mechanical devices for the measurement of violators' speeds and the acceptance of those speeds by the courts.[3] Fisher, in his texts on vehicle law, reiterates this point.[4] Judicial acceptance applies only to the reliability of the units. The testifying officer must show clearly that the equipment at the time of use was mechanically (and electrically) accurate, in proper working order, and that the operator had sufficient expertise in its operation. This theme is noted almost every time a case involving the use of radar is reviewed.

Radar Used For Speed Enforcement

World War II spawned an electronic device called **RA**dio **D**etection **A**nd **R**anging (shortened to RADAR) which sent radio signals and received responses from reflective objects. This radar used pulses of radio waves which reflected off an object, such as an airplane, back to a receiving antenna. Because the time taken for such response could be measured and because radio waves traveled at a known speed, the distance to the reflecting object could be computed. Speed could also be computed by measuring the change in distance during a given time. Based on the investigations of Christian Doppler in 1842, scientists also knew that if the object reflecting a continuous beam was moving to or away from the radar antenna, the frequency of the reflected radio wave would increase or decrease. The amount of shift in frequency readily could be converted to the speed of a target, the greater the shift in frequency the higher the speed. Doppler radar differs then from other radar in that speed is computed directly from a change in radio frequency rather than a change in the distance of the target from the receiver over time.

Earliest use of radar required expert testimony in each case. Kopper, writing in the North Carolina Law Review in 1955, was one of the first to thoroughly discuss the accuracy of doppler radar as used by traffic law enforcement agencies.[5] This helped lead to the courts taking judicial notice of radar as a reliable instrument for the measurement of speed. One of the first was the Supreme Court of New Jersey in State v. Dantonio.[6] This 1955 case also was important because the court pointed to the sufficiency of training as important in the operation of radar. However, this sufficiency only related to the training for a particular type of speed measuring device. What was needed for one type might not be satisfactory in operating another type. Today, this point is particularly important in regard to the correct operation of moving radar.

The step from a tripod mounted unit with a scale for reading speeds to a hand-held unit with digital readout awaited improvement in electronics. Such an improvement, however, did not require judicial notice.[7] When two radar units were combined into a singular unit which could be used in a moving mode, such notice apparantly was extended.[8] In this case, one unit measures the speed of the patrol vehicle; the other measures closing speed of patrol vehicle and approaching vehicle. Internal electronics subtract the speed of the patrol vehicle from the closing speed and the resultant reading should be the speed of the approaching vehicle. This premise is so simple that a Circuit Court in Wisconsin (1976) stated that judicial notice for moving radar was not needed because moving radar and stationary radar effectively were the same.[9] However, on appeal, this same case was reversed. The superior court argued that the particular type of moving radar unit, the MR-7, had not been in operation a sufficient time (three months).

Further, Wisconsin had never taken judicial notice of any radar.[10] On the other hand, Delaware clearly took notice of the K-55 manufactured by MPH Industries.[11] Finally, New Jersey, in 1979 reaffirmed its acceptance of moving radar on the same basis as it had upheld the use of stationary radar in Dantonio.[12]

NEED FOR TRAINING

Challenges in the Courts

The testing of the unit for accuracy has also been subject to numerous challenges - Honeycutt v. Commonwealth (Kentucky, 1966) is a good example of the courts' response.[13] Recent appellate and superior court rulings in Kansas, Colorado, Illinois, Kansas, and Massachusetts, have upheld the acceptance of proper testing as sufficient to show accuracy.[14] What constitutes sufficient testing is not defined clearly. In Illinois, Kansas, and Kentucky, for example, the use of a single tuning fork has been considered sufficient.[15] On the other hand in Colorado, the appeals court clearly noted that unless the singular fork had been certified within a year, two tuning forks were needed.[16] Missouri courts have taken a strict position that the devices used for testing in themselves must be shown accurate.[17] According to Dujmich (Fordham Law Review) if at least two tests are made -- tuning fork, certified speedometer, or internal circuitry check, in addition to periodic certification by laboratory technicians should be sufficient -- the court should accept the accuracy of the unit without reservation.[18]

The third element of the burden of proof is the need for a competent operator. With the exceptions of Dantonio in New Jersey, and Honeycutt in Kentucky, what had not clearly emerged from early court challenges was a thorough review of the amount of training given and its sufficiency to overcome some inherent weakness involved with the use of moving radar. That review was prompted by Judge Nesbitt of Dade County, Florida.[19] Although the presentations at the hearing were orchestrated for the media by persons opposed to the use of radar for traffic law enforcement, problems that can arise when untrained persons operate radar were made clear.[20] The defense showed that moving radar was subject to readings which might not be assigned to the correct vehicle. In the hands of improperly trained personnel, unwarranted penalties easily could be imposed. This case also served the media in the National Broadcasting System (NBS) television news magazine "Prime Time Saturday" found these inherent weaknesses material for use in their program.[21]

The subject of training also was important in the decision rendered in State v. Hanson. In this Wisconsin case, the officer using the equipment had received only one hour of training; the type of radar had been in use only three months. The court noted several failings. First, radar had never received judicial notice in Wisconsin; therefore, the lower court erred in giving such notice to moving radar. Second, the officer was not adequately trained in operation of a unit. The units themselves had not been in use for a sufficient period. Finally, and most importantly, the officer failed to verify the speed of the patrol vehicle which, as described in the next chapter, is a critical step in preventing improper assignment of speed to a motorist.

The expected wave of changes as a result of these rulings failed to materialize. Judge Nesbitt had not found that radar was inaccurate; rather, he had found improper use. In Hanson, the court laid out five guidelines, all of which were within the bounds of adequate training:[22]

1. That the officer operating the device has received adequate training and experience in its operation.
2. That the radar device was in proper working condition at the time of the arrest. This is established by proof that proper methods of testing the functioning of the device were followed.
3. That the device was used in an area where road conditions are such that there was a minimum possibility of distortion.
4. That the speed of the patrol car was verified. This is especially important where there is a reasonable dispute that road conditions may have distorted the accuracy of the reading, e.g., presence of large trucks, congested traffic, or the roadside heavily covered with trees and signs.
5. That the radar had been expertly tested within a reasonable proximity following the arrest and that such testing was done by means which did not rely on the internal calibrations of the device.

Other courts, though less specific about the elements that the officer must follow, have been equally clear on the need for a competent operator. Where training is sufficient, moving radar can be an accurately used tool. Two well written local decisions, Commonwealth v. Rose in Kentucky and State v. Leamer in Michigan presented these conclusions.[23] On appeals, the adequacy of training was upheld in City of Akron v. Gray (Ohio) and State v. Wojtkowiak (New Jersey).[24]

While there is still no complete agreement as to what constitutes adequate training (in fact recurrent training is even suggested in a recent New Hampshire ruling),[25] the courts are in agreement that training is crucial. Dujmich recommends both classroom and practical training. The operators need not be electrical engineers, but they must clearly understand the use of the device as well as its weaknesses.[26] Given judicial notice, proper testing, and a competent operator, the use of radar for speed detection and the speed observed still remains prima facie evidence. It can be challenged.[27]

Responses to the Challenges

Partly in response to the challenge in Dade County, the National Highway Traffic Safety Administration (NHTSA) has prepared a sample curriculum for use in training operators. The emphasis is to achieve greater commonality among agencies in their training. Many states also have been improving their curricula to meet the needs of better trained operators. A report by the Legislative Research Committee to the North Carolina Legislature in early 1981 proposed that North Carolina establish minimum standards for the training and certification of operators and their instructors and which would require periodic testing of the equipment.[28] In a survey conducted by the Illinois Department of Law Enforcement for this report (results described in the third chapter), many of the states that responded also submitted materials used for their training. Appearing as standard is a 40-hour course with additional hours of actual use in the field under the guidance of a trained operator. Tests of proficiency also are becoming common.

While these changes are occurring, those persons who oppose the use of moving radar continue their efforts. Too often, the rhetoric hides valuable recommendations. Examples include How to Beat Radar and Do It Legally by Power and articles in Overdrive and Police Chief.[29] Power's book came before the case in Dade County. Its most practical contribution is a shopping list of practical, impractical, and illegal gimmicks that can be used to detect or defeat radar. The author does not question the accuracy of radar or the training required to operate it correctly. Rather, he suggests a plethora to questions to be asked in court. The expectation is that the officer will become confused and make a mistake. While

there are some merits to the book, the inaccuracies and digressions limit its usefulness.

The article in Overdrive reviews several of the weaknesses of moving radar. While the article effectively points to problems (often labeled errors) that can occur, it fails to indicate that proper training has been accepted by the courts as more than sufficient in overcoming these problems. Finally, a critique by Dale Smith appearing in Police Chief describes the most serious problems including failure to use the doppler audio, improper use of automatic mode (now not accepted in proposed standards from NHTSA described below), improper use in heavy traffic, and failure to recognize the fact that a broad beam is transmitted. Some of Smith's remedies, however, such as removing the standby switch (so that it can continuously transmit to radar detectors), making long-life, heavy duty equipment (therefore more expensive), and narrowing the beam (which actually may lead to more improper readings) do not adequately address the problems that had been highlighted.

STANDARDS FOR MOVING RADAR

NHTSA also requested the National Bureau of Standards to devise a set of standards. The proposed notice of rulemaking was published in the January 8, 1981 Federal Register.[30] These standards, if incorporated, will require a strict level of accuracy under varying conditions. Important also will be the requirement to shield the units from spurious radio frequency transmissions such as those that were used to generate "moving trees" in Florida.[31]

The automatic lock and audio alert tone will be prohibited. As Dujmich clearly describes in his review of the court's acceptance, the use of the automatic lock easily can lead to the assignment of incorrect speeds to approaching vehicles.[32] A similar problem exists with the audio alert tone. When it is set to trigger at or above a specific speed, the patrolling officer does not need to identify the speeding motorist before taking a reading of the speed. Instead he can attempt to identify the violator after being alerted.

The research conducted by the National Bureau of Standards produced positive results. As was reported in the Federal Register, they conducted many tests of radar under different conditions. First, they concluded that radar was accurate. In none of the tests did speeds of vehicles differ by more than one mile per hour. Second, they paid particular attention to "inaccuracies" arising from such elements as acceleration or deceleration by the patrolling officer, radios operating outside the vehicles, traveling too close to large reflective surfaces, etc. While external elements could, at times, affect the readings, their conclusion was that these readings could easily be avoided by simple precautions such as proper installation and operation of the radar devices by trained individuals.[33]

SUMMARY

Radar is a tool whose principle of operation is considered reliable by all courts. While some courts also have given judicial notice to the reliability of moving radar, such is not yet universal. Even where judicial notice has not been given, the use of radar is prima facie in cases involving speeding, provided that the officer has demonstrated that the equipment was accurate, used properly, and that

the officer was properly trained. The courts have identified deficiencies. Tests conducted by the Federal Government have resulted in standards to correct most of the important deficiencies and help prevent some abuses. The incorporating of such standards in policies issued by operating agencies as well as in construction of the radar units themselves should strengthen acceptance in courts that are hesitant. Given this acceptance by the court, is the equipment effective, even with its limitations? Is it competitive to costs of other methods used for speed enforcement? The remainder of this report will be directed toward answering these questions.

II. OPERATING CHARACTERISTICS THAT AFFECT READINGS

CHARACTERISTICS ARE NOT ERRORS

The characteristics of moving radar that sometimes cause problems with its operation have been called "errors". This is not a correct description. Errors produced by radar come from malfunctioning circuitry and generally are discovered either during tests or immediately are apparent to the operator. When errors are discovered, the unit requires repair. On the other hand, readings may appear which are not consistent with the actions of the target. The operator is informed of a speed which does not apply to the target being observed. That speed is presented because of the interference from or interaction with some element external to the unit, e.g. radio frequency. No incidents have been discovered where the operator who is correctly using the equipment would fail to recognize the inconsistency.[34]

Operating characteristics that cause difficulty fall into four categories:

1. Radio and electrical interference
2. Interferences within the vehicle
3. Characteristics of use
4. Effects of geography

ELEMENTS THAT YIELD INCONSISTENT READINGS

Radio and Electrical Interference

All doppler radar units are susceptible to interference from radio and electrical equipment. While the proposed standards should eliminate many of these

interferences, some will remain. Within the vehicle, the operator's transmissions on any two-way radio can cause unwanted readings. Such interference does not appear to exist when transmissions on two-way radios, including CB radios, originate outside the vehicle.[35] The operator avoids these problems; he does not transmit while monitoring speeds of vehicles. Commercial radio transmitters and high voltage lines also generate noise that may cause unwanted readings. In the moving mode, such readings will occur temporarily and generally will be accompanied by a warbling or variable sound from the doppler audio tone. The officer knows where electrical interference exists and avoids or does not operate in those locations. Further, the moving radar clearly warns the operator when such unwanted signals are present.

Finally, the electrical system in the vehicle can create spurious electrical noise. Connecting the electrical supply for the radar directly to the battery should eliminate such problems.[36] Generally, a properly shielded power supply should prevent any electrical noise generated by the police vehicle from activating the radar. If the operator is in doubt of the source of the interference, signals generated by vehicle will disappear when the ignition is turned off.

Other Interferences from Within the Vehicle

One of the most common generators of spurious signals on any type of radar (including "hand-held" units) is the movement of air from the fan on the air conditioning/heater system. Generally, when the moving radar is pointed straight through the front window of the vehicle, the movement of the air will not affect the radar. When pointed to the side, however, this same movement can be read as a speed. There are no problems with this particular characteristic for two reasons. First, the operator quickly learns the "speeds" given off by the fans and can discount those speeds. Second, when a monitored vehicle is close enough to return a signal to the radar, that signal will override the one generated by the fan.

Components of the radar give off heat. If there is not enough circulation around the control unit, the build up of heat can produce unusual readings. Similar inconsistencies appear while the unit is warming up. Generally these inconsistent readings show in the patrol speed; no target speed is displayed. The problem is corrected by sufficient circulation of air and warm-up.

Finally, when the operator uses moving radar in a stationary mode, two other types of interference can occur. If the antenna is pointed at the control unit (the two pieces are combined in "hand-held" radar units and, therefore, no problem exists), an unpredictable reading will occur. This is called "panning effect" (from panning across the control unit). It is similar to the feed-back heard when a microphone is placed in front of the speaker. Correction is evident. The other problem is called "scanning effect" and occurs when the operator quickly rotates the antenna through the horizontal or vertical. The reading received comes from the movement of the unit, not from the target vehicle. Facing the antenna toward the target before making the reading eliminates this minor problem.

Characteristics of Use, Vehicle in Motion

There are a number of interferences that arise out of use of the unit in the moving mode. Each is quickly recognizable by the trained operator and should not cause difficulties. The ones of concern are:

- Cosine effect
- Shadowing
- Low-speed combining
- Batching
- Ghosting
- Target size

When mounted for use in the mobile mode, the antenna should be aimed as close to zero degrees from the centerline as possible and still monitor speeds in the opposing direction. The greater that angle from the centerline, the greater the likelihood of the "cosine effect" affecting the "patrol speed". Cosine effect always results in a reading of a speed lower than the actual speed.[37] When cosine effect applies to the speed of the target, the driver of that vehicle receives the benefit. The radar computes a speed lower than actual. When it affects the patrol speed, which could happen with an improperly aligned antenna, the moving radar computes a lower than actual patrol speed. Subtracting this low patrol speed from a closing speed would yield a target speed higher than actual. This could happen even with a correctly aligned antenna if the beam momentarily was reflected from a nearby surface at an extreme angle.[38] In any case, a comparison between the patrol speed shown and that given by the speedometer clearly will show a discrepancy.

The term "shadowing" applies to the computation of patrol speed based on a signal reflected from a moving object rather than a stationary object. This could occur when the patrolling vehicle is approaching a large and slow-moving vehicle from behind. The effect of the moving vehicle is to reduce the patrol speed computed by the radar. This has the same effect on patrol speed as does the cosine effect. It creates a condition where the target speed (the difference between closing and patrol speeds) is higher than actual. A comparison between the indicated patrol speed and speedometer will advise the operator of this condition.

"Low-speed combining" occurs when the speed of a slowly moving patrol vehicle is combined with that of the target vehicle to create a singular speed. Generally, this speed only appears in the patrol speed window and disappears as soon as the patrol vehicle reaches the speed at which a particular moving radar begins functioning accurately. It would not cause an incorrect reading for a target vehicle.

A problem which has occurred in the past but appears to have been corrected by improved circuitry within the moving radar units is called "batching" or "target-speed bumping". During acceleration or deceleration, the radar unit has stored the speed of the patrol vehicle a fraction of a second earlier than the reading for the closing speed. If the patrol vehicle is accelerating, this stored patrol speed will be lower than actual and the resultant target speed higher than actual. When the patrol vehicle is decelerating, this characteristic works in favor of the target.[39] A trained operator should never accept readings made during sudden changes in speed.

One characteristic that rarely causes problems is called "ghosting". Here the portion of the signal reflected from the target has bounced from a stationary or slowly moving object back to the target then to the radar (or from radar to object to patrol car to target to radar). The second reflection increases the frequency of the signal thereby increasing the speed computed by the radar. This effect creates very few problems because the signal usually is weak and will be replaced with any

stronger signal including a correct return from the target. Also, the reading generally would be twice the target speed. In the rural areas, this would give a speed that is obviously too high for the target vehicle as observed by the operator.

However, the Illinois State Police uncovered an example where a ghost reading was obtained from a relatively strong signal, and the computed speed was within reason. It occurred when the officer was driving within 20 yards along side of a slowly moving train headed in the same direction. The train, a very strong target, apparently returned the signal to the patrol vehicle then to the target. As a result, the speed given for the target vehicle was the combined speed of the train and that vehicle. Because of the reflective strength of the train, the target had to be close to the patrol vehicle before its actual speed was recorded. Long before this would have happened, the patrolling officer might have locked in an incorrect speed. While this was an unusual incident, it shows the need for an operator to be cognizant of the environment when operating moving radar.

Radar generally accepts the strongest returned signal. Strength of that signal is dependent upon the distance the target is from the signal and the "radar cross-section" (reflective features) of the target. This characteristic is clearly evident where a truck is following a small car. If the two vehicles remain in close proximity, the truck will continue to reflect the signal. The speed computed by the radar will belong to the truck. If there is substantial separation between the two approaching vehicles, as the smaller vehicle approaches its reflected signal should become stronger than that of the truck. At some point this smaller car is read by the radar. For an operator using radar in a stationary mode, differentiation among targets is not difficult. Generally the operator has the opportunity to measure the speed over a distance of 500 to 1,000 feet. Even if the violator is traveling at 70 mph, the operator has between 5 to 10 seconds to make a decision. In the moving mode, that time is cut in half. There is no longer sufficient time to accurately distinguish between the two vehicles. The trained operator either will take no action or, by the use of the audio doppler tone, will clearly associate the signal with the violator. Some radar units have a "read-through-lock" which allows the operator to lock the speed in violation while at the same time continue, by using a separate indicator, to monitor the speed of the approaching vehicles.

Effects of Geography

Finally, hilly terrain will work against effective use of moving radar. Because the beam from the radar transmits over line-of-sight, a signal can be returned from a vehicle some distance from the operator. The reflecting vehicle may not be noted immediately. By the time the observer makes the second check, some nearer vehicle not visible at the initial reading may now be in view and considered the violator. Similarly, many reflective surfaces, such as found in more developed areas, may reflect signals that do not belong to the target vehicle. This latter aspect alone causes reservations regarding the usefulness of moving radar in developed areas.

PREVENTION OF UNWARRANTED READINGS

Within this discussion there has been mention of both the operator's observations and supplementary use of the audio doppler tone. The ability of the operator is enhanced by proper training, a subject more thoroughly addressed in the

next chapter. The audio doppler tone and its companion "read-through-lock" can help the operator confirm that a reading belongs to the suspected violator. A steady or slowly changing tone comes from a strongly reflected signal, the higher the tone, the higher the speed. An unsteady tone generally happens when some form of radio or electrical interference is present.

Two of the controls on a moving radar have caused problems. First, by means of thumbwheels, the operator sets a speed which, when computed, triggers a warning buzzer. While this allows the operator to maintain radar operation while monitoring all traffic, it can cause an operator to "see" a violator that may not exist. Unless the operator first positively identifies a vehicle in violation and then verifies the reading, mistakes can be made. This problem is compounded when the operator sets the device in automatic mode. Not only is the operator alerted, but the reading is now locked. There may not be sufficient time for the operator to unlock the reading and take a second one. Further, the operator may not be willing to unlock a reading which shows an excessively high speed. Any spurious reading, however, can trigger the locking feature. The operator will probably act incorrectly and cite a driver, who under ordinary circumstances would not have been cited. The undesirability of this feature has been identified by the courts.[39] The recommended federal standards also prohibit both the automatic lock and alert tone.[41] The most obvious solution is the removal of both the automatic lock and alert tone.

As has been discussed, there are numerous ways in which the operator using radar can pick up an unwanted and improper reading on that radar. None of these readings are erroneous. They are products of what the radar is seeing under specific conditions. A trained operator has no problems with any of these characteristics; he will not arrest a person based on an incorrect assumption.

III. USE OF MOVING RADAR BY POLICE AGENCIES

SURVEY OF STATE POLICE AND HIGHWAY PATROLS

Use and Evaluations

In the course of completing this evaluation, the Bureau of Planning and Development, Illinois Department of Law Enforcement, conducted two surveys. Personnel from U.S. mainland state police and highway patrols, as well as troopers from the Illinois State Police, were asked to respond. The purpose of each questionnaire was to uncover benefits and weaknesses perceived by administrators and operators.

A questionnaire was sent to state agencies in 47 of the 48 contiguous states (California was not included because the State Legislature of California has refused to appropriate funds for the purchase of radar units for the Highway Patrol). Responses, received from 45 of the 47 agencies, are discussed briefly below. The questionnaire and summary of answers are given in Appendix A.

Of the 45 states that responded, only Pennsylvania and Rhode Island do not operate moving radar. Approximately three of every four states that operate the equipment have done so for more than five years. During this time, approximately 55 percent of the agencies have performed some evaluation of the equipment. Most of these assessments have been limited to a comparison of operating characteristics among the units or to the performance of the particular manufacturer's unit. The State of New York evaluated the accuracy of hand-held and moving radar. Their results showed no significant deviations in speed from actual speeds up to 90 mph.[42] This test supported the results found by the

Highway Safety Research Center at Chapel Hill, North Carolina, first in 1973 and again in 1975.[43]

In all except two of the responding states, the officers tend to select moving radar, when a choice is available, as opposed to hand-held radar. The two exceptions were Arizona and Connecticut. Arizona is just beginning to use moving radar and has too few units for an adequate comparison. Connecticut has many sections of highway where use is impractical because of traffic geography. In this situation, the hand-held unit appears to be more versatile. Somewhat tempering this enthusiastic response to the use of moving radar, however, is the significant pressure that has been placed on enforcement of the National Maximum Speed Limit during the time many states also have begun to use moving radar. There is more pressure to make stops for speeding, and therefore, a tendency to use equipment which is more likely to help meet this objective.

Acceptance by the Courts

An important question in the survey requested a perception of how the courts receive testimony based on the use of moving radar. Four of the 34 states that responded to this question, Connecticut, Florida, Wisconsin, and Iowa, believed that courts were less likely to accept testimony based on use of moving radar than the use of other methods. With the exception of Iowa, these states have been the site of significant court cases involving the use of radar.[44] On the other hand, Alabama, Missouri, and South Dakota, believed that testimony based on the use of moving radar was more likely to result in a guilty verdict than that based on hand-held radar. Even though substantial coverage was given the case in Dade County,

Florida, the ripples from that ruling appear minimal. As is shown subsequently in the discussion of responses by Illinois State Police, the problems that do occur in court generally bear no relation to those presented in Dade County.

Costs of Use and Training

The costs of operating moving radar were addressed in two ways: repair of equipment and vehicles, and additional training required. According to those responding, moving radar is less likely to require repairs than hand-held units. Because of the two piece construction and relatively permanent mounting of the equipment, it is not handled as often. Further, it is not as likely to be bounced around the vehicle during pursuit. On the other hand, the vehicles with the moving radar units appear to be receiving more damage to the suspension and exhaust systems. The patrol vehicle must turn around to pursue the violator. On the Interstate highway this requires crossing a median. Because the Federal Highway Administration has been trying to reduce the number of crossover points, the only spots available for crossing are the medians themselves. The slopes and ruts in the median easily can cause this vehicular damage.

Another cost is training. As shown in Table 1, 36.7 percent of the agencies spend sixteen hours or less on that training. For the remainder, the average is 48 hours. The most time spent in training is 100 hours of which 60 are spent in actual use of the equipment. Only nine agencies indicated a specific number of hours devoted to "hands-on" training. In addition to the initial training, five of the states conduct annual refresher training ranging from 4 to 16 hours.

TABLE 1

HOURS OF TRAINING BY STATE AGENCIES
IN USE OF MOVING RADAR

8 hours or less:	8	19.0%
9 to 16 hours:	7	16.7%
More than 16 hours*:	27	64.3%

*Average - 48 Hours

N = 42

A review of the training material submitted by a number of agencies showed two important elements in the training:

- Substantial attention is given to the characteristics of moving radar which can yield readings that do not accurately describe the speed of the target.
- Tests of competency are given. Often these tests come at the end of field training. The new operator has been using the equipment for several weeks but has not issued citations as a result of the speeds detected. The testing determines whether the officer can accurately detect a violator.

While many of the states had always trained personnel in the use of radar, often such training was minimal. First, the operator did not have to be an expert in the use of radar (and still does not have to be a technical expert). Second, the units in use seemed simple to operate. In the stationary mode, mistakes were hard to make unless traffic was heavy.

Finally, the courts often accepted radar as an infallible tool. Such thinking was transfered to the moving radar. It took <u>State v. Aquilera</u> to help change that

thinking. To overcome this change, however, has increased the costs of using moving radar, both through initial training and then through recurrent training.

<u>Weaknesses and Strengths</u>

Of final importance are the perceived weaknesses and strengths of the equipment. The greatest weaknesses are: the need for more training than given previously, less emphasis given by the officers to detecting other violations, incorrect identification of the violator, and lack of space to turn around. Some of these weaknesses have become the bases for restrictions on the use of moving radar. Five states (Illinois, New York, Ohio, Vermont, and Wyoming) prohibit the use of automatic mode to prevent unexplained readings from being presented and acted upon. Use is further restricted during inclement weather and in hilly terrain. Most states additionally require demonstrated competence in the set-up, testing, and use of the equipment.

While the weaknesses somewhat limit the use of moving radar, none have precluded general use. There are specific areas, for example along most urban Interstate highways and other expressways, where use of moving radar is impractical because of median barriers. On some Interstate highways, extremely wide medians, ditches, and other features limit use. Use in very heavy traffic generally is impractical; although, in such cases the vehicle traveling at an excessive speed will be obvious and the moving radar probably will give a reading which confirms the operator's suspicions.

The major benefits seen by the states apply equally to two-lane and multi-lane divided highway. Police mobility has increased; speeds are monitored while the officers maintain patrol. The use of radar detectors and CB radios by those who flagrantly violate the law is negated. With the use of moving radar, these violators are now being caught; before, they often escaped detection by the stationary patrol. Finally, the police administrators believe that the patrolling officers have become more productive.

RESPONSES BY ILLINOIS STATE POLICE TROOPERS

Questionnaire Used

A second questionnaire was distributed to troopers from the Illinois State Police (ISP). No attempt was made in this distribution to obtain a representative sample. In fact, the preferred respondent was one who used the moving radar regularly and who should be able to present an informed opinion, positively and negatively. Of the 114 responses expected, 111 were received. The responses indicated that this preference was met.

The questionnaire contained six parts with 28 questions; three questions required written responses, 17 required choices of answers, and eight required comparative ratings of five methods of enforcing the speed limit. Subjects included: length of time equipment used by the respondent, comparative qualities among different methods of speed enforcement, court presentation, operating characteristics, and training. Most respondents added additional comments and recommendations. The responses are analyzed below. Appendix B contains the copy of the questionnaire and summary of responses to all questions.

What the response showed, in general, was a high degree of acceptance of moving radar by the ISP. With few exceptions, the police officers found this

method of enforcing the speed limit better than any other method. They have not had problems in the courts nor in the operation of the equipment. While most of the officers pointed to some weaknesses with the moving radar, these weaknesses did not interfere with the usefulness of the equipment. The one area which received strong support was the need for comprehensive training.

Usefulness of Moving Radar

Of the 111 responding officers, 74.8 percent (83) have used the moving radar for more than 12 months. These officers consider the equipment better than hand-held radar, pacing, and VASCAR for the detection and apprehension of speeders. They are evenly divided between the usefulness of moving radar and aircraft assistance in the enforcement of the speed limit.

In general, the officers who are using the units are finding them to be as reliable as the hand-held units. The major source of complaint is the appearance of readings which do not represent the speed of a target vehicle. Characteristics which cause these readings were fully described in the previous chapter. The training and manual provided to all officers clearly underscores the potential problems and methods of avoiding erroneous acceptance of readings.

Few officers indicated increased vehicular damage (the lack of anonymity might have affected this response). This disagrees with commonly held conception that vehicles with moving radar are suffering increasing damage to the undercarriage and suspension system. The Illinois Department of Law Enforcement does not have records which can adequately document this subject; thus, the lack of response cannot be challenged.

Of the officers responding, 44 percent believed that they are driving more mileage to make their stops. On the other hand, records of vehicular use maintained by the Department show a slight decrease in mileage. What apparently is prompting these comments is the lack of flexibility in use of the MPH K-55 units. The troopers cannot readily convert from the moving mode to a covert stationary mode. This is apparent from the relatively high lack of acceptance by officers in the Chicago metropolitan region. Because of median barriers and very heavy traffic, most officers must use radar in a stationary rather than moving mode.

More than one-third of the officers believe that they are citing fewer violations of other traffic laws. This answer was given also in responses from the other state agencies. Whether this represents a serious decrement in traffic safety, is unknown. The research available does not clearly show what types of stops, particularly between stops for speeding and for other violations, are more likely to help reduce accidents.[45] However, this reduction in number of stops for other violations may not be simply a result of the use of moving radar. During 1980, because of increased pressure from the United States Department of Transportation, the ISP increased its efforts at enforcing the 55-mph speed limit. The objectives for traffic enforcement, in effect, were altered. Citations for other violations would have decreased with such a change even without the availability of moving radar.

There was some disagreement among officers on the question of how well the courts accept citations based on the use of moving radar. More than 20 percent of the officers believe that offenders are more likely to contest the citation. Once in

court, the officers also believe that it is harder to obtain a guilty verdict. This supposition is supported by actual occurrences in Cook County. It is not supported outside that county. Shown in Table 2 is a summary of the disposition of ISP speeding tickets for 1980. Three different modes of assistance are shown: moving radar, hand-held radar, and airplane. Tickets issued outside Cook County (Chicago and contiguous cities) in conjunction with moving radar resulted in the fewest number of contested citations, 3.6 percent. On the other hand, of those that contested the charge, 47.9 percent were found not guilty. This was the highest percentage of the three. For tickets issued as a result of using hand-held radar, more were likely to be contested than for those issued as a result of moving radar. A slightly lower percentage were likely to be found not guilty. Of those issued a ticket by the use of either type of radar, 98.3 percent of those caught with the assistance of moving radar and 98.0 percent with hand-held radar were found guilty.

Training

The greatest number of comments were directed toward training. The officers received an average of ten hours of training in the use of moving radar. This was a combination of in-service training which consisted of a four-hour lecture and field work and the training of new recruits. The latter received 24 hours of lecture and 40 hours of practical training. While those who had received the in-service training believed that this time was adequate for the material presented, a few felt that additional material could have been made available. The three areas that received mention were: the characteristics which give unwanted readings, presentation of

TABLE 2

PLEA AND DISPOSITION
OF SPEEDING CITATIONS
DURING 1980 IN ILLINOIS

MODE

	Moving Radar		Hand-held Radar		Airplane		Total	
	N	Percent	N	Percent	N	Percent	N	Percent
Total Cases*	168485	-	43867	-	26569	-	238921	-
Plead Guilty	162363	96.4%	42061	95.9%	25528	96.1%	229952	92.2%
Plead Not Guilty	6122	3.6	1806	4.1	1041	3.9	8969	3.8
Disposition - Not Guilty Plea								
Guilty	3190	52.1	946	52.4	574	55.2	4710	52.5
Not Guilty	2932	47.9	860	47.6	467	44.8	4259	47.5
Not Guilty as Percent of Total	-	1.7%	-	2.0%	-	1.8%	-	1.8%

*Cases involving citations issued in Cook County, Illinois are not included. The percentages shown above are statistically similar in 101 of the 102 counties. In Cook County, 23 percent of the cases were contested; 7 percent were found not guilty. Of those found guilty, 27 percent were placed on a form of probation (no record of the speed conviction on the drivers license) compared to less than two percent in the remainder of the state.

court cases including a review of pertinent cases, and hands-on training. Because a representative sample was not used, interpretation of these apparent needs is not possible. However each of the three areas are covered both in classroom and in the manual made available to each officer. More importantly, the new officers are receiving more than 60 hours of radar training.

Finally, one-half of the respondents recommended recurrent training. Complexity of the equipment and the changing acceptance by the courts were the reasons given for requiring recurrent training. This need apparently is being met by several state agencies which are conducting between 8 and 16 hours of retraining annually. There has been a suggestion by the court in New Hampshire that such recurrent training may be necessary. However, to date, other courts have not deliberated this point.

Comparative Rating of Speed Enforcement Tools

Part 3 of the questionnaire requested a comparative rating among five tools for speed enforcement: airplane, hand-held radar, moving radar, pacing in unmarked car, and radar/chase car.[46] The officers were asked to rank these methods from "1" meaning best to "5" meaning worst. It was the intention to force choices between 1 and 5 for each question. However, the directions were not clear on this point; thus, many officers ranked the methods either 1 or 5, or only one number in between. Only those responses where the numbers 1 through 5 appeared for each question were analyzed. Table 3 summarizes these responses, showing the average rating for each method. Analysis of variance among the response showed that the average ratings were significantly different. Thus, an average rating of 3.3 statistically could be considered a lower rating than an average of 3.1.

TABLE 3

RATING OF METHODS FOR ENFORCING THE SPEED LIMIT

Subject	N	Airplane	Hand-Held	Moving	Pacing	Radar/Chase
		Average Rating by Method				
a. Operational ease	86	2.3	2.7	1.9	4.2	4.0
b. Observing other violations	87	4.1	2.8	1.9	2.3	3.9
c. Flexibility	82	3.2	2.9	2.4	2.4	4.0
d. Catching blatant violators	81	2.2	3.5	2.0	3.1	4.1
e. Stopping most violators	74	1.8	3.3	3.1	3.4	3.4
f. Preventing flight by violator	85	1.0	2.3	2.9	1.8	2.0
g. Officer-violator relationships	66	2.9	2.7	2.6	3.0	3.8
h. Presentation in court	84	2.0	2.4	2.8	3.8	4.0
Overall Rating		2.4	2.8	2.4	3.0	3.7

Overall, airplanes and moving radar were considered the two best methods of enforcing the speed limit. Airplanes were considered superior to all other methods in three categories: stopping most of the violators, likelihood of preventing the violator from fleeing, and ease of presenting the case in court. Moving radar was considered superior in the other five categories: ease of operation, ease of detecting other violations, flexibility, opportunity to catch blatant violators, and officer-violator relationship. The last category is interesting because, based on the adverse publicity received by moving radar, the opposite might have been expected. That the moving radar also is readily accepted by most courts again suggests that the efforts to discredit this equipment have been unsuccessful. Finally, the lowest rated method was radar operation with catch cars; it was considered good only in preventing the violator from fleeing.

Written Comments

Several questions required written responses. Most of the officers who completed the survey added comments to one or more questions. The information given in Table 4 summarizes those comments, from the most frequent response to least frequent. Apparently, the two most important problems with the courts are improper testimony by the officer and the lack of an informed court. Both are correctable. In regard to use of the equipment, the lack of adequate median crossovers, median barriers, and heavy opposing traffic reduced the usefulness of moving radar in some areas. The recommendations regarding training appear to be covered sufficiently by the current training provided by the Department. The recent court cases are available to police officers throughout Illinois in the Illinois Law Enforcement Officers' Law Bulletin.

TABLE 4

COMMENTS RECEIVED FROM ISP TROOPERS

Reasons for Not Guilty Findings

1. Other vehicle present (25)*
2. Court not familiar with operation (19)
3. Lack of informed presentation by officer (14)
4. Judicial prejudice (9)
5. Difference of stories between violator and officer (9)
6. Improper use by the operator (5)
7. Problems with violator's vehicle (5)

*Number in parenthesis is the number of persons responding with this answer.

Major Drawback with Moving Radar

1. Lack of adequate or available median crossover (24)
2. Heavy traffic and lack of selectivity (16)
3. Dead spots (7)
4. Lack of convertibility to stationary patrol (7)
5. Unpredictable and unexpected readings (7)
6. Short range (5)
7. Obstruction of officer's vision (4)
8. Terrain (4)

TABLE 4 (continued

Elements Required For Training

1. Extensive review of characteristics that yield improper readings
2. Sufficient hands-on training including proper detection of correct vehicle
3. Relevant court cases
4. Practice testimony
5. Releases giving updated information on operation including current court cases
6. Pamphlet reviewing common problems and relevant court cases

Other Comments

1. Judges and states attorneys must become familiar with the equipment
2. More public information needed to counter negative images
3. Too much attention is being given to speed enforcement at the expense of enforcing other traffic laws
4. Proficiency tests should be given
5. Thumbwheel and alert tone should be removed (note: these will be eliminated under the proposed federal standards)
6. Increased hands-on training and refresher training needed
7. Better protection against unwanted signals needed
8. Most effective in unmarked cars

SUMMARY OF RESPONSES

Both the Illinois State Police and administrators of state police and highway patrols consider moving radar superior to any other tool for the enforcement of the speed limit. As shown in Illinois, it shares superiority with the use of an airplane except that the moving radar is more versatile. There are drawbacks. These include the need for more training, and the lack of usefulness in certain terrain, in heavy traffic, across wide medians, and on highways with median barriers. There are also some concerns with increased vehicular damage because of crossing the medians. This same crossover also creates a potential for vehicular collision. (Both of these problems could be remedied with the construction of more median crossing points.)

The greatest concern has been the courts. At the time of Aquilera in Dade County, the media mounted a strong push against use of the equipment. Yet this presentation apparently had no lasting effects. The courts have continued to uphold the use of moving radar in the hands of adequately trained officers. There remains a need, however, to identify those courts where reception is poor. A presentation on the operation of moving radar should be made to those courts.

Outweighing the negative are the advantages of moving radar. Probably most important is the increased mobility of the police officer with the accompanying increased deterrence to speeding. This is needed for controlling the speeds of those who deliberately and flagrantly avoid the speed limit. With the exception of VASCAR, other methods require the fixed placement of officers or at most the ability to monitor only singular vehicles (pacing). The violators who use CB radios and radar detectors are almost immune to arrest for speeding. On the other hand,

the patrol vehicle approaching from the opposite direction using moving radar in the squelched mode is virtually undetectable.[47] When the radar is activated, the reading is instantaneous and available long before the violator can react to the notice given by the detector. Locations given on the CB are obsolete within minutes when the patrol vehicle is moving. Further, the moving patrol unit has been shown in studies to have a substantial affect on speeds over relatively long distances.[48] Thus, the makers of radar detectors have reasons to discredit moving radar. According to the respondents, there are no areas (excepting city streets and urban expressways during peak traffic) where the moving radar does not appear to be the most effective method of enforcing the speed limit.

IV. COST OF USING MOVING RADAR

ELEMENTS OF THE COSTS

Use of moving radar to assist in enforcing the speed limit has a cost. Moving radar generally is operated while the officer is travelling in the opposite direction. To stop the violator, the officer must turn around. This takes time and usually means that the officer must engage in pursuit.[49] The time taken to issue a ticket and the time for appearances in court when the ticket is contested also are a cost. Finally, the officer has to be trained in the correct use of the equipment.

On the other hand, items such as the cost of ticket stock, administrative costs, etc. are not included because these costs are the same regardless of the method used for initiating the stop. Cost of driving on patrol also will not be included. There are two reasons. First, a primary component of traffic law enforcement is patrol to help identify suspected violations of the law. During this patrol, moving radar can be operated as an adjunct. In fact, the addition of moving radar appears to add a deterrence to speeding on both sides of the highway.[50] Second, as will be described in greater detail below, the time spent on patrol before making a stop can be so short that the costs assigned to that patrolling portion would be minimal. While some forms of speed enforcement, such as airplane assistance, do not use a moving vehicle, still have idling vehicles present. The costs of idling would, in part, offset the cost of patrolling the road.

For this report, costs of making the stop begin at the moment the officer initiates the stop and include an amortized amount for court and training. The computation of these costs is the basis for this chapter. The next chapter

describes the comparative costs among methods used for the enforcement of the speed limit.

To obtain the information for this analysis, several sources were used. Data including the number of citations, time spent completing the citations, and time attending court were obtained from the Illinois Department of Law Enforcement's Traffic Information and Planning System (TIPS). The activity for each sworn officer is maintained on the computer in real-time. Additionally, tickets, warnings, and other documents are recorded. The potential number of given specific traffic volumes, percent of stops made, and time to make the stops were recorded by the Department's Bureau of Planning and Development (P&D) in the field while riding with officers from the Illinois State Police. Observers recorded traffic and stops on Interstate highways and two-lane rural roads both during daylight and nighttime hours. A total of 70 stops were observed.

Measures of fuel usage also were obtained from special studies using an ISP patrol vehicle with fuel flow meter. Fuel consumed during accelerations, decelerations, and at constant speeds were recorded and converted to usage at various pursuit speeds.

ASSUMPTIONS

In order to adequately compute costs and draw comparisons, several assumptions are made:

- The data recorded from special studies of stops made by the ISP are representative (the recordings were taken on lightly and heavily traveled segments).
- Activity and the hours recorded on TIPS accurately reflect what occurs.

- Court appearances are randomly derived and equally likely to occur in any county except in Cook County (which will be excluded from the computations).
- The cost of a court appearance includes the cost of the officer in court as well as driving to and from court. Officers are assumed to be distributed evenly throughout a county; the average driving distance thus is equal to the square root of the area.
- Gasoline usage is derived from tests of a patrol vehicle. These tests are sufficient for the computation of fuel costs.
- Only those roads where the moving radar can be used effectively are considered in these costs. The roads in sections of Illinois, such as near Chicago and St. Louis where median barriers or heavy traffic prevent effective use are not taken into account. In those areas, radar is usually used in a stationary mode.

SUMMARY OF COSTS

The components of a police officer's enforcement of a traffic law include: training, pursuit, citation, and court. Each has a cost. Of these costs, an important question was the cost of pursuit. Some amount of pursuit is expected because the police officer, when using moving radar, is proceeding in the opposite direction from the violator. Tests which were conducted by P&D (and explained in greater detail later in the chapter) showed that regardless of the speed of the violator, pursuit took an average of one minute and 45 seconds. The average time on highways with two lanes was slightly higher than on four-lane, divided highways. Most of the stops on divided highways required pursuit; two-thirds of those stops on two-lane roads required this additional driving. This pursuit of driving, given the costs of fuel for acceleration and higher speed driving is computed to add 57 cents to the cost of a stop. Including costs for the officer's time, this first part of the stop for speeding cost 1.071 dollars.

Writing the citation adds another 2.99 dollars. Then there is the cost of appearing in court. While one trip to court will cost 40.60 dollars, only 3.6 percent of the stops are contested. On this basis, the cost of attending court averages 1.462 dollars. This brings the total cost of the three components, pursuit, citation, court, to 5.524 dollars. Finally, the cost of training the officer in the correct use of moving radar adds 61.6 cents. Each stop, therefore, costs 6.14 dollars.

One final point is considered, the added patrolling performed in order to use the moving radar. Two arguments are used to counter the inclusion of costs. First, one of the duties of any police officer engaged in traffic enforcement is patrol. The use of moving radar, in this respect, enhances that patrol. A stationary, hidden patrol vehicle can not perform that same patrol. Second, given the current percentage of motorists violating the speed limit, an officer on patrol with moving radar does not have to drive for more than five minutes to be in a position to stop a motorist for driving ten or more miles above the speed limit. The remainder of this chapter shows how the potential number of stops and costs were computed.

POTENTIAL FOR STOPPING VIOLATORS

Number of Violators

The potential number of stops appears to be directly related to traffic volume up to the point where the average running speed decreases substantially as a result of congestion. Studies conducted by the American Association of State Highway and Transportation Officials (AASHTO) which show the running speeds have been incorporated in their "Blue Book" of highway design.[51] As computed from the Blue Book, the average running speed on Interstate highways will fall below 55 mph as one-way traffic volumes exceed 500 vehicles per lane per hour. Because most Illinois, rural Interstate highway are four-lane roads, this translates to a one-way traffic volume of 1000 vehicles per hour. On two-lane roads, a one-way volume of 250 vehicles per hour is the critical point. If 25 percent of the average daily traffic (ADT) occurs during the traditional four peak hours (am and pm), the ADT required to have traffic above the critical value at all times is 27,000 on Interstate highways and 7000 on two-lane roads. These volumes exist only in Cook County (Chicago) and in parts of the surrounding counties of Lake, DuPage, and Will and within a 10 mile radius of St. Louis, Missouri.

A count of opposing traffic also was done during the observations made by the P&D staff. The speed of that traffic was recorded. Based on these observations, 79 percent of the vehicles on Interstate highways and 57 percent on two-lane roads were exceeding the speed limit. The distribution of these speeds is shown in Table 5.

TABLE 5

DISTRIBUTION OF SPEEDS
ON HIGHWAYS

Exceeding	Percent of Interstate	Traffic Volume Two-Lane
55 mph	79%	57%
60 mph	38	20
65 mph	10	6

These percentages are less than those reported to the ISP in 1980 (91 and 73 percent respectively) as part of an aircraft assisted speed study.[52] They are higher

than those historically reported to the Federal Government. The reasons for these differences is that the airplane and moving radar are not readily detected by the motorist. Up until the past year, the Federal Government took their information from stationary radar which was always detected and, therefore, presented inaccurate data. A more comprehensive discussion of these inaccuracies is found in a report prepared by Raub and Wolfson.[53]

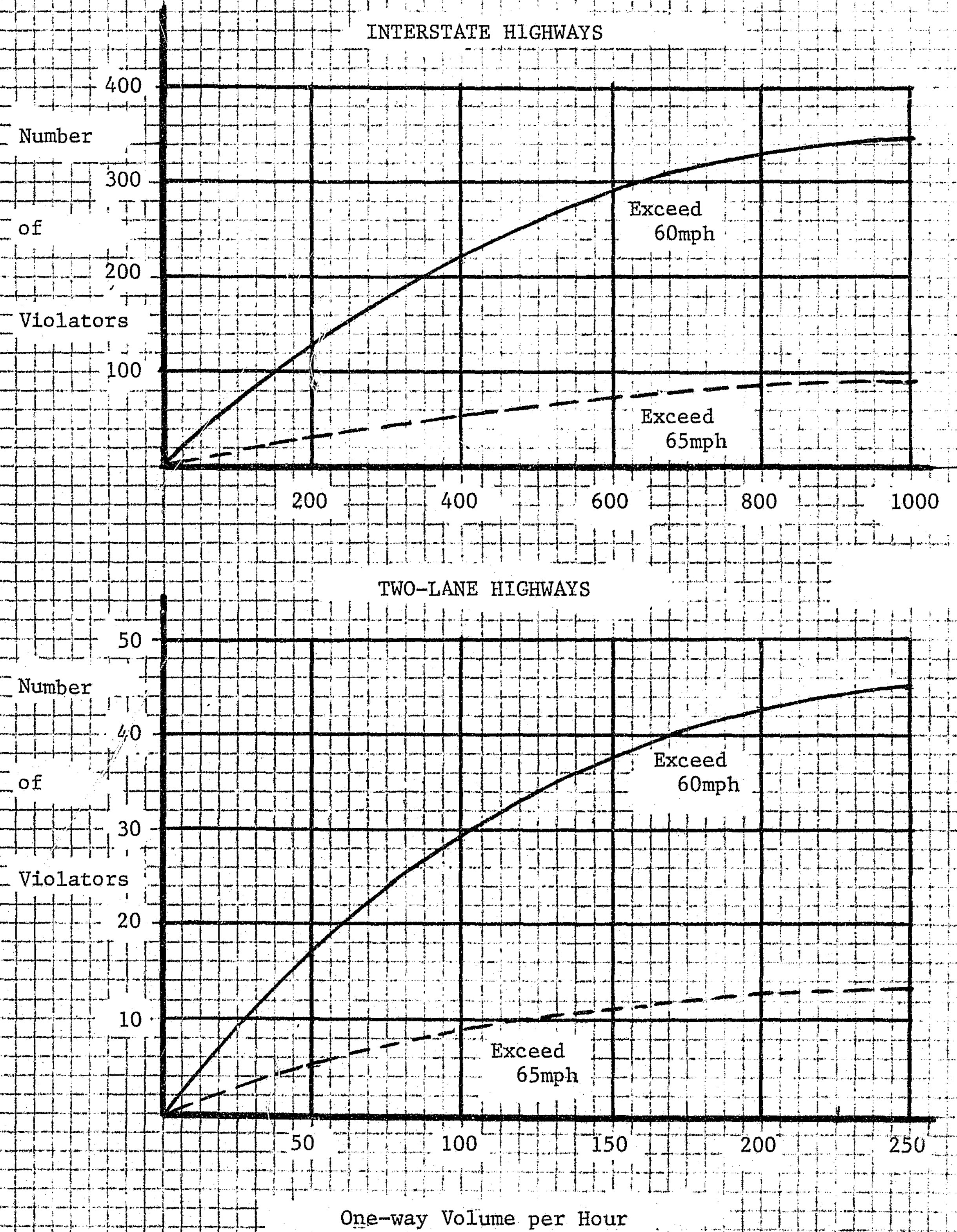
Figure 1 shows the potential number of violators traveling in the opposite diection who will pass an officer patrolling at 50 miles per hour (mph). The computations used account for the decrease in running speeds as volumes increase. Two curves are shown: violators above 60 mph and violators above 65 mph. Nothing between 55 and 60 mph is shown because of the many motorists who are driving at the speed of 60 mph or greater. According to Figure 1, on an Interstate highway at a volume of 300 vehicles per hour, at least 174 violators traveling 60 mph or higher will pass the patrolling officer every hour. At a volume of 600 vehicles per hour this will increase to 287 violators per hour.

Number of Stops Possible

Although there may be a relatively large number of violators that pass a patrol vehicle moving in the opposite direction (even if the officer allows a 10 mph tolerance) not all violators will be detected by the officer with the radar unit. First there are platoons of vehicles, as well as, two or more vehicles passing at approximately the same speeds. Where the radar can not distinguish, it will not present a reading, or the officer may not be able to identify clearly the

FIGURE 1

NUMBER OF MOTORISTS VIOLATING 55 MPH SPEED LIMIT



violator. Second, of those that the officer is able to identify clearly, not all can be stopped. Traffic and lack of turnaround space will prevent the pursuit. During the study of stops initiated by the Illinois State Police, the observers were able to record the number of violators who could not be stopped because of inadequate or unsafe turnaround.

The number of those passing motorists who can be stopped are computed by subtracting those who are part of platoons or are passing another vehicle and those for which adequate turn around does not exist. A Poisson distribution is used for computing the number of platoons or in the process of passing. On Interstate highways a platoon is assumed for two or more vehicles in a two-second period. A four-second period is used on two-lane roads. The results of the computations appear in Table 6. For example, as the volume approaches 1,000 vehicles per hour one-way on an Interstate highway, the percent of vehicles traveling in platoons increases to 42.6 percent. The points, 1,000 and 250, are selected as a cutoff because above those volumes running speeds decrease below the 55-mph speed limit.

Those violators who can not be stopped because adequate and safe turnaround is not available are computed from observation. Out of 108 identified speeding vehicles, 35.2 percent (48) were not stopped. Table 7 shows the reasons. On Interstate highways a greater percentage of violators were disregarded: identification of violator was not sufficiently positive, traffic was too heavy for a safe turn, or there was no adequate crossover. On two-lane roads, lack of positive identification constituted the primary reason. Table 8 shows the same data based on volume of traffic.

TABLE 6

DISTRIBUTION OF
VEHICLES TRAVELING IN PLATOONS

Interstate Highways			Two-Lane Highways		
One-way Volume Per Hour	Percent of Platoons*	Percent of Volume in Platoons	One-way Volume Per Hour	Percent of Platoons**	Percent of Volume in Platoons
200	0.6%	10.5%	50	0.1%	5.4%
400	2.1	19.9	100	0.6	10.5
600	4.9	28.3	150	1.2	15.4
800	7.4	35.9	200	2.1	20.0
1000	10.7	42.6	250	3.2	24.4

*Occasions in which there are two or more vehicles during a two-second period, the minimum needed.

**Two or more vehicles based on four-second spacing.

TABLE 7

STOPS MADE AND NOT MADE
DURING OBSERVATIONS

Stops Not Completed	Interstate Highway	Two-Lane Highway	Total
Violator Not Clearly Identified	9	5	14
Traffic	10	3	13
Lack of Turnaround	10	-	10
Other	-	1	1
Total	29	9	38
Stops Completed	46	24	70
Percent Completed	61.3%	72.7%	64.8%

TABLE 8

STOPS ATTEMPTED AND COMPLETED
DEPENDENT ON VOLUME

Stops on Interstate Highway

Hourly Volume	Attempted	Made	Percent Completed
200	8	7	87.5%
400	16	12	75.0
600	35	22	62.9
1000	10	4	40.0
1200	6	1	16.7
Total	75	46	61.3%

Stops on Two-Lane Highways

Hour by Volume	Attemped	Made	Percent Completed
50	10	9	90.0%
100	17	13	76.5
150	6	2	33.3
Total	33	24	72.7%

Application of a least-squares analysis was done using the volume as the independent variable and percent of stops completed as the dependent variable. For this analysis, the percent of stops made was forced to approach 100 as volume approached zero vehicles per hour. The quadratic equations shown in Figure 2 resulted (P is the number of stops that can be made based on volume V).

FIGURE 2

PERCENT OF STOPS MADE

- Interstate Highways

  $P_4 = (10.0 - 0.64V)^2$

- Two-lane Highways

  $P_2 = (10.0 - 2.5V)^2$

  where: V - One-way traffic volume in hundreds of vehicles per hour.

  P - Percent of stops made out of those violators that can be properly detected.

All of the data shown are combined into the equations shown in Table 9. The final equations give the number of speeding vehicles an officer patrolling at 50 mph can stop. Table 10 results from substituting passing traffic volume for the formulae in Table 9. Figure 3 is a graphic representation of the same data. As the Figure shows, a maximum number of stops can be made on four-lane highways at a volume of 400 vehicles per hour. Above that volume, there is a rapid decrease, especially for those violators exceeding 60 miles per hour. On two-lane roads, the maximum is reached at a volume of 100 vehicles per hour.

Clearly shown is the potential for a substantial number of speeding arrests made by an officer using moving radar, even when volumes are low. For example, on an Interstate highway at a volume of 200 vehicles per hour, an officer patrolling at 50 mph could make a maximum 21 stops for speeds in excess of 65 mph (even

TABLE 9

FORMULAE USED TO COMPUTE POTENTIAL NUMBER OF STOPS

a. Number of speeding vehicles passing a patrolling vehicle.

$$N = p_s W \ (1.0 - r_s \ W) \ (V + 50) / V$$

where: N - Number of violators per hour

P_s - Percent of vehicles exceeding either 60 mph or 65 mph by type of highway, s, as shown in Table 5

r_s - Constant, representing proportionate reduction in running speed dependent upon volume. According to AASHTO this is approximately 0.05 per 100 vehicles for Interstate highways and 0.2 per 100 vehicles for two-lane highways

W - One-way volume in hundreds of vehicles

V - Average velocity of violators for those exceeding 60 mph, V = 62.5 mph; for those exceeding 65 mph V = 67.5

b. Percent of violators in platoons

$P_m = F(x \; ; \; W)$: Poisson distribution dependent upon volume. P_m can be taken directly from Table 8 dependent upon one-way volume and type of highway.

c. Percent of identified violators that can be stopped.

$$P_s = (10.0 - q_s \ W)^2$$

where: P_s - Percent stopped dependent on type of road

q_s - Slope of best fitting curve dependent on type of road: 0.64 on Interstate highways, and 2.5 on two-lane roads

d. Number that can be stopped.

$$N_s = N \ (100.0 - P_m) \ P_s / 10000$$

FIGURE 3

POTENTIAL NUMBER OF STOPS FOR SPEEDING

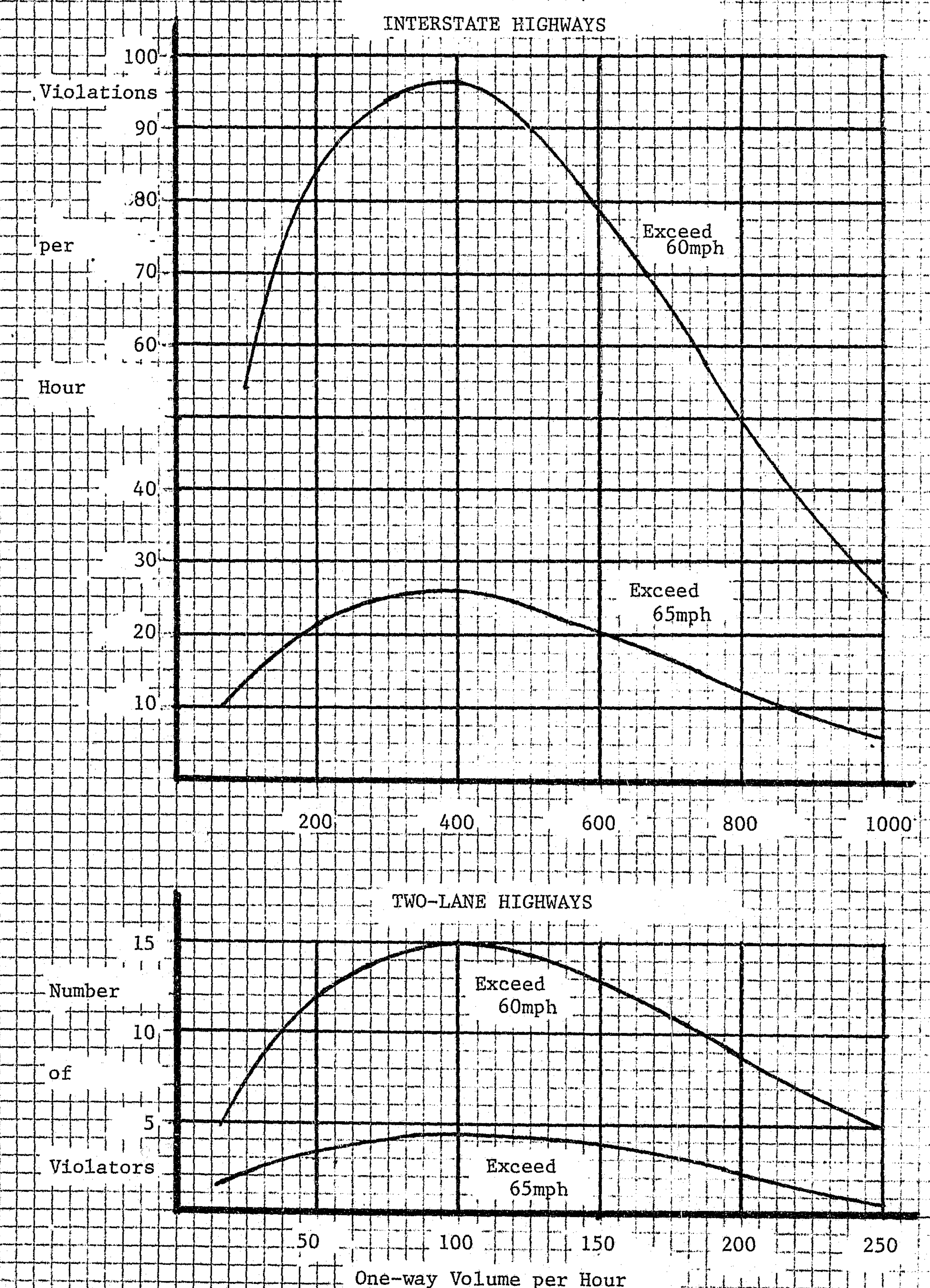


TABLE 10

NUMBER OF STOPS POSSIBLE BY A PATROLLING OFFICER

Interstate Highways			Two-lane Highways		
	Number of Stops			Number of Stops	
One-Way Volume	Exceeding 60 mph	Exceeding 65 mph	One-Way Volume	Exceeding 60 mph	Exceeding 65 mph
200	84	21	50	12	3
400	97	25	100	15	4
600	78	20	150	13	4
800	50	13	200	9	3
1000	26	6	250	5	0

though this is not physically possible). This is one violator every three minutes of patrol. Even at a volume of 800 vehicles per hour, a violator which clearly can be identified and stopped will pass the patrolling officer once every five minutes. On two-lane roads, the potential number of violators decrease, but here the officer probably will lower any tolerance given.

PURSUIT

Time Taken to Stop Motorist

That there is a potential for sufficient activity has been demonstrated; the costs associated with that activity must be computed. The first part of the computation applies to pursuit. Here costs are dependent on the time taken and fuel used to stop the motorist from the time the violation is detected by the patrolling officer until the violator comes to a stop.

The staff from Planning and Development timed 70 stops for speeding on Interstate and two-lane highways. These stops were made by ISP officers during both daytime and nighttime. When the individual times were compared, there appeared to be no significant difference in the time taken to turn and pursue dependent either on time of day or on density of traffic. The only measurable difference was by type of highway. For the discussion, times are shown in two categories: turn around and pursuit.

Summarized in Table 11 are the results of the observations. Of the 70 stops recorded, 58 required pursuit. On the Interstate highways, pursuit accounted for 93.5 percent of the stops; on two-lane roads, pursuit accounted for 66.7 percent. The time taken by the police officer to change direction ranged from 2 seconds (a median crossover on the Interstate) to 30 seconds on a two-lane road. The averages were 13 seconds and 20 seconds for the two types of highway. Actual pursuit averaged 89 seconds on Interstate highways and 92 seconds on two-lane roads. Total time required to make the stop including turnaround, was 102 seconds and 112 seconds respectively. In no case, did a violator attempt to flee. There are no statistically significant differences in the time taken for pursuit dependent on the speed of the violator.

The lack of variation in the time taken for pursuit appears to have two logical explanations. First, the pursuing officer adjusts his speed to a specific rate of closure. This was evident during pursuits of violators of other laws who were traveling at slower speeds where the total time for pursuit was similar to those for speeding motorists. Second, at the higher speed (in excess of 70 mph) the violator may be more aware of the police vehicle. While he does not initiate the stop voluntarily, he appears to reduce his speed substantially, thereby obviating the need for an excessively long pursuit.

TABLE 11

TIME REQUIRED TO STOP VIOLATORS

Speed of Violator	N	Interstate Highway Avg	Interstate Highway Deviation	N	Two-lane Highway Avg	Two-lane Highway Deviation
62	1	1.13 min	0.0 min	1	1.65 min	0.0 min
63	3	1.30	0.15	-	-	-
64	3	1.42	0.28	1	1.42	0.0
65	8	1.51	0.26	3	1.26	0.22
66	8	1.41	0.43	4	1.57	0.39
67	5	1.64	0.38	2	1.63	0.13
68	4	1.70	0.51	2	1.88	0.65
69	6	1.67	0.42	1	1.30	0.0
70	3	1.44	0.67	1	1.40	0.0
71	-	-	-	1	1.52	0.0
75	1	0.97	0.0	-	-	-
Unk	1	-	-			
Total	43	1.49 min	0.39 min	16	1.53 min	0.31 min
Time to Turn Around	46	0.22	0.10	24	0.34	0.17
Total		1.71 min			1.87 min	
Total Stops		46			24	
Requiring Pursuit		43			16	
Percent		93.5%			66.7%	

Fuel Consumption of a Patrol Vehicle

The amount of fuel consumed by a patrol vehicle during acceleration, deceleration, and at steady pursuit speed is needed to compute the cost of pursuit. While fuel economy for vehicles has been computed by the U.S. Environmental Protection Agency, these data are not useful for the analyses required. The U.S. Department of Transportation also has conducted tests of changes in fuel usage dependent on speed. Although more relevant, they do not apply to a vehicle with the added air resistance of light bars or at high rates of acceleration. Finally, there have been studies of fuel economy with different types of light bars.[54] However, these studies were performed at a simulated patrolling speed; they did not account for high speeds. Therefore, P&D conducted a test of fuel consumption by a patrol vehicle to help estimate use at different speeds and changes during acceleration and deceleration.

The police vehicle used for the test of fuel consumption in this study was a 1977 Dodge equipped with a light-bar and a fuel flow-meter capable of measuring in 1/1000ths of a gallon. Members of the P&D staff conducted the tests on a relatively level portion of an Interstate highway east of Springfield. Fuel consumption during acceleration, deceleration, and at steady speeds were computed for speeds from 40 through 90 mph. A total of 40 runs were made, two at each speed in each direction.

The results of these tests are shown in Table 12. In addition, Figure 4 shows the changes in miles per gallon dependent upon the speed of the vehicle, and Figure 5 shows changes in fuel usage for accelerations. Fuel usage during deceleration was found to be constant at the rate of 0.0012 gallons for each second

of deceleration. Thus for a deceleration rate of 9.5 feet per second, a stop from 60 miles per hour (88 feet per second) would take 9.3 seconds. The vehicle would use 0.0112 gallons of fuel.

An examination of Figure 3 shows a dramatic increase in fuel consumption from 50 to 60 miles per hour. This increase resulted from the increase in carburetion from two-barrels to four-barrels that occurred in this ten mph range. For this report, the use of fuel is shown as a smooth curve for the entire range. Even though these data are specifically applicable to this one vehicle, the changes are believed to be sufficiently descriptive of any police vehicle. The difference with newer vehicles would be a general improvement in fuel economy but with lesser capabilities in acceleration.

COSTS OF MAKING A STOP

Costs of Pursuit

The costs of making a stop include those of pursuit, writing the citation, and attending court. The first cost, pursuit, is derived from the fuel used during acceleration, pursuit, and deceleration and is dependent upon the average speed of the violators. Summarized in Table 13 (from a more extensive formulation in Appendix C) are the requisite formulae for computing these costs of driving. The time required to make the stop, was shown to be 1.71 and 1.87 minutes on Interstate and two-lane highways respectively. Distance covered is equal to the average speed of the violator multiplied by the average time to make the stop.

From TIPS was derived a summary of citations issued by ISP during 1980 for violations of the 55-mph speed limit. This summary is limited to citations issued as

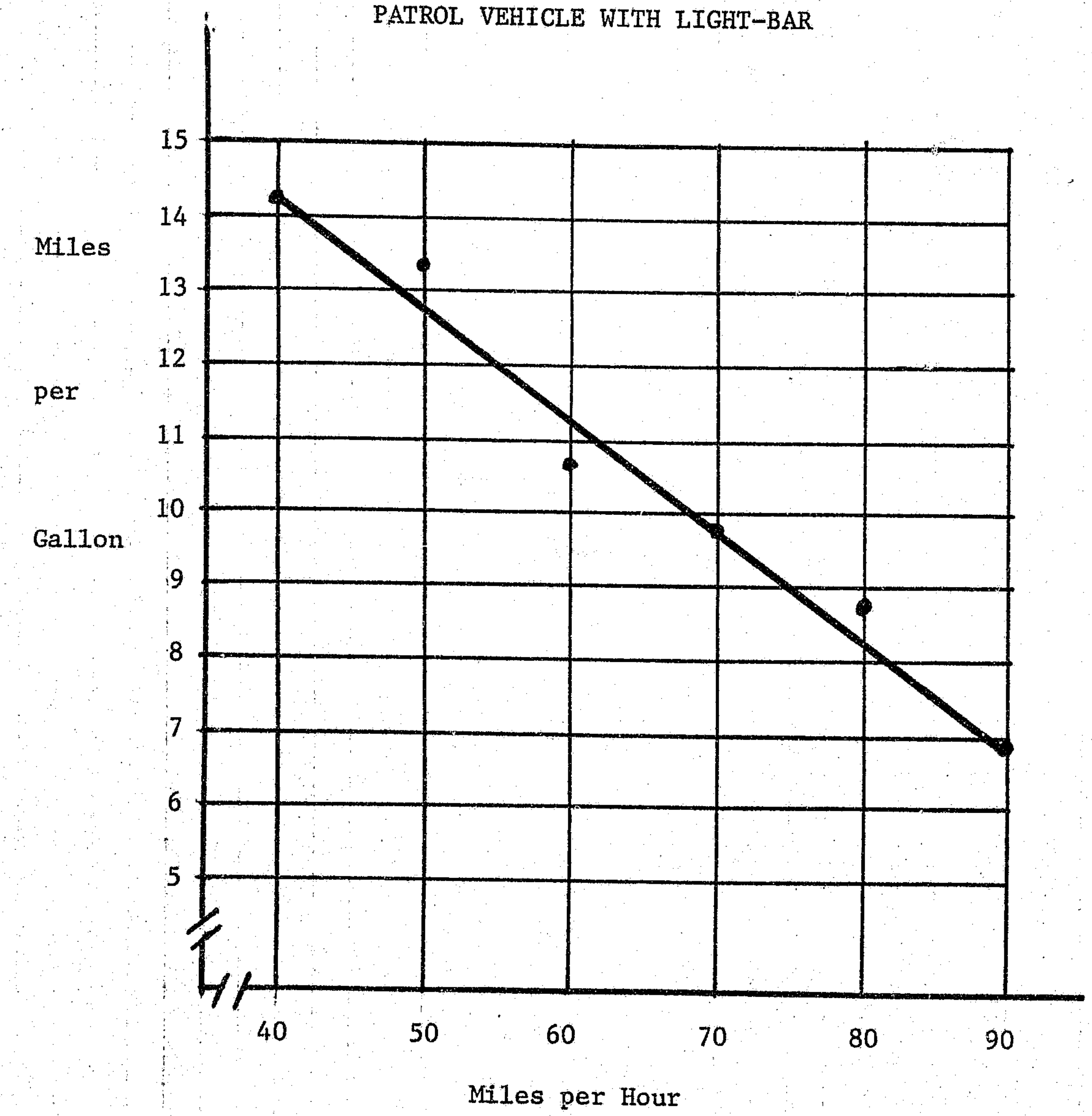
TABLE 12

FUEL USAGE FOR A POLICE VEHICLE

Test	Pursuit Speed 40 mph	50 mph	60 mph	70 mph	80 mph
Steady-Speed					
Gallons/minute	0.047	0.060	0.096	0.120	0.150
Percentage increase	-	28.2%	60.0%	25.0%	25.0%
Miles per gallon	14.28	13.46	10.53	9.77	8.75
Acceleration					
MPH/second (avg)	4.49	4.22	3.88	3.52	3.00
Gallons/minute	0.186	0.210	0.222	0.276	0.312
Percent change	-	12.9%	5.7%	24.3%	13.0%
Gallons used					
20 mph to speed	0.014	0.025	0.038	0.065	0.104
0 mph to speed	0.028	0.041	0.057	0.091	0.139
Deceleration					
MPH/second (avg.)	6.44	6.44	6.44	6.44	6.44
Gallons/minute	0.072	0.072	0.072	0.072	0.072
Gallons used					
Speed to 0 mph	0.007	0.009	0.011	0.013	0.015

FIGURE 4

FUEL CONSUMPTION
PATROL VEHICLE WITH LIGHT-BAR



Source: 1977 Dodge Monaco with Federal Light-bar

$Y = 20.2 - 0.15X$

$R^2 = 0.96$

FIGURE 5

ACCELERATION DATA

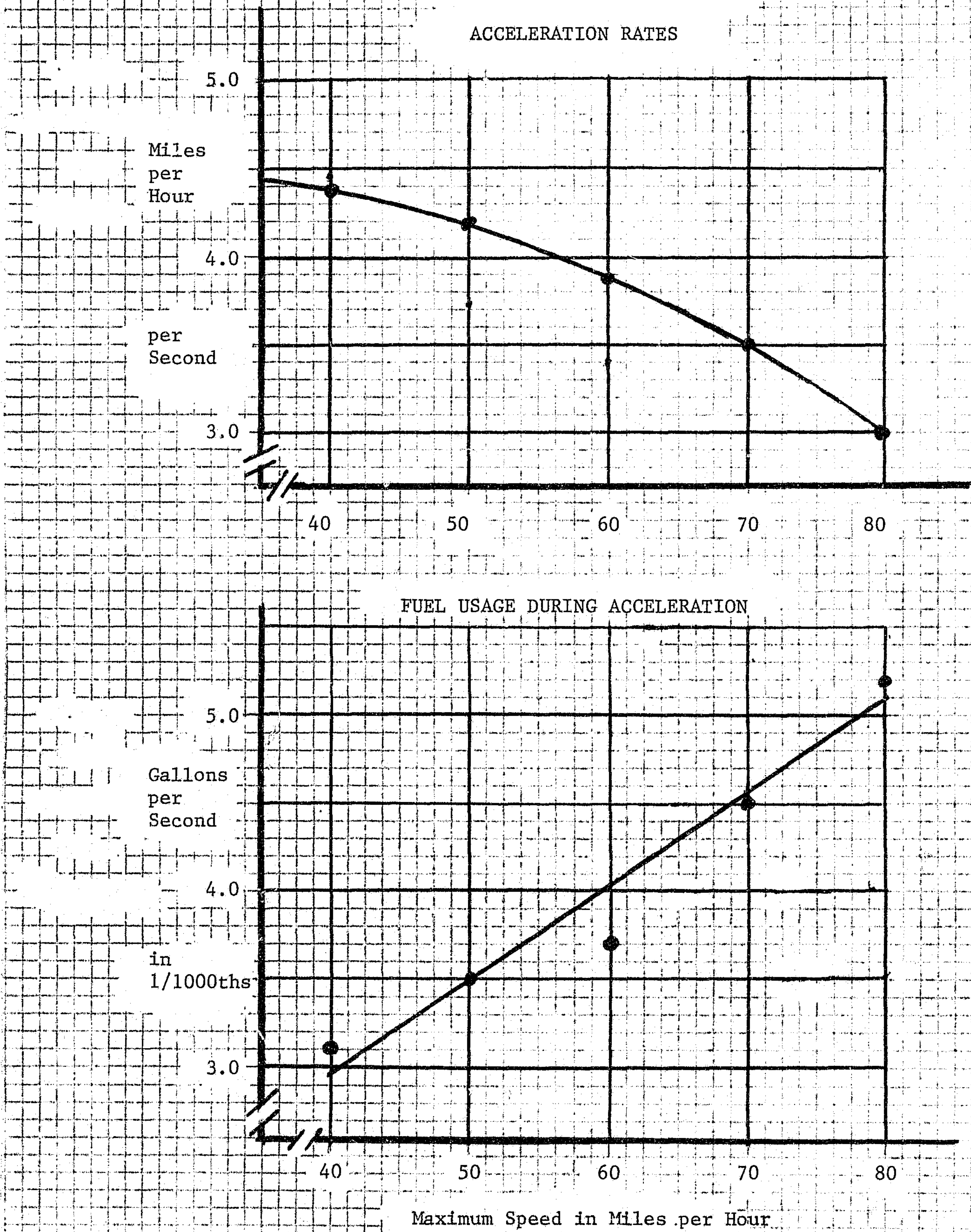


TABLE 13

FORMULAE USED FOR COMPUTING COSTS OF PURSUIT

	Interstate Highway	Two-lane Highway
Pursuit Speed:		
V_p=	(865 - 748225 - 3670V) / 2	(865 - 748225 - 3815V) / 2
Time Used:		
Acceleration -		
t_a=	$(V_p - 30) / (8.5 - 0.035V_p)$	$V_p / (8.5 - 0.035V_p)$
Deceleration -		
t_b=	$V_p / 9.5$	$V_p / 9.5$
Pursuit*		
t_p=	$89 - t_a - t_d$	$92 - t_a - t_d$
Gallons Used per Second:		
Acceleration -		
t_a=	$0.0008 + 0.00004V_p$	$0.0008 + 0.00004V_p$
Pursuit -		
f_p=	$(0.0015 + 0.00045V_p)^2$	$(0.0015 + 0.00045V_p)^2$
Total Gallons Used:		
G=	$0.0007 + 0.001\ t_d + t_a f_a + t_p f_p$	$0.028 + 0.001\ t_d + t_a f_a + t_p f_p$

where: V - Speed of violator in feet per second subject to a maximum speed of 100 mph.

* Time of pursuit (t_p) subject to a minimum of 45 seconds of pursuit.[55]

the result of using moving radar. Because of the type of patrol conducted by the ISP, more than 90 percent of the citations were issued in zones posted with a 55-mph speed limit. As is seen from Table 14, less than 15 percent of the stops on Interstate highways and approximately 20 percent of the stops on two-lane roads were made for speeds of 65 mph and lower. On the other hand, more than six percent of the stops were for speeds in excess of 75 mph on both types of highways.

The formulae for fuel consumption and the number of citations issued are sufficient for computing the amount of fuel used to make a stop for speeding. The results of these computations for Interstate and two-lane highways, as well as both highways combined appear in Table 15. The estimated amount of fuel used for pursuit on the two-lane roads is 22.4 percent higher than that estimated for pursuit on Interstate roads. This arises because the pursuit on a two-lane road covers more distance even though the average speed of the violator is one mph lower. On the two-lane road, the pursuing officer takes more time to turn around and must accelerate from a stop instead of a speed of 20 mph which occurs when the officer crosses the median of an Interstate highway. At 1.50 dollars per gallon, fuel for the average pursuit will cost 57.0 cents.

In addition to the cost of driving, there are the costs of maintaining the automobile, its depreciation, and the time that the officer requires to make the pursuit. The operating costs are derived from the monthly automobile summary kept by the Department's Bureau of Logistics. Depreciation is based on a current cost of purchasing a vehicle at 7,400 dollars with no salvage value and a useful life of 72,000 miles. The combined costs of maintenance and depreciation, as shown in Table 16, is 13.3 cents per mile. When applied to the average distance of 2.08 miles, these costs add an additional 27.7 cents to the pursuit.

TABLE 14

DISTRIBUTION OF ISP CITATIONS
FOR SPEEDING (MOVING RADAR)
Calendar Year 1980

	Interstate Highways		Two-lane Highways	
Speed	Number	Percent	Number	Percent
56-59	108	0.1%	64	0.1%
60-61	604	0.7	581	0.7
62-63	2147	2.4	3330	3.8
64-65	10267	11.4	13945	16.1
66-67	14936	16.7	18443	21.3
68-69	16776	18.7	16525	19.1
70-71	17220	19.2	13145	15.2
72-73	10161	11.3	7776	9.0
74-75	10473	11.7	7483	8.6
76-77	1819	2.0	1377	1.6
78-79	1576	1.8	1123	1.3
80-81	1232	1.4	888	1.0
82-83	765	0.9	597	0.7
84-85	744	0.8	551	0.6
86-89	378	0.4	330	0.4
90+	465	0.5	447	0.5
Total	89671	100.0%	86605	100.0%

Average Speed	70.0 mph	69.1 mph
Total Citations	176,276	

TABLE 15

AVERAGE AMOUNT OF FUEL USED FOR PURSUIT

	Interstate Highway		Two-Lane Highway		All Pursuit	
Fuel Used						
- Turnaround	0.007	gal.	0.028	gal.	0.017	gal.
- Acceleration	0.145		0.206		0.175	
- Deceleration	0.013		0.014		0.013	
- Pursuit	0.178		0.172		0.175	
	0.343	gal.	0.420	gal.	0.380	gal.
Pursuit						
- Average Length	1.99	miles	2.18	miles	2.08	miles
- Time	0.028	hours	0.031	hours	0.029	hours
- Average Speed	86.8	mph	89.4	mph	88.1	mph

TABLE 16

OTHER OPERATING COSTS
FOR VEHICLES AND PURSUIT

		Per Mile
Maintenance Cost		3.0 cents
Depreciation		
Cost	$7400	
Cost of 72,000 miles		10.3 cents
Other Costs		
Repair of undercarriage	$ 50 per year	
Officer Salary (10-year, with 10% benefits)	$12.11 per hour	

Another cost of maintenance is repair of damage to the undercarriage of vehicles. Such damage to alignment, suspension, exhaust systems, and tires arises from crossing the median. Although the response to the surveys described in Chapter 3 did not show a widespread problem, there were indications that a problem exists. Lack of easily retrievable records kept by the Department of Law Enforcement preclude establishing an accurate cost. For this report, the damage is assumed to be 50 dollars per year per vehicle. With approximately 800 squad cars equipped with moving radar and 176,276 citations issued (a rate of 220 per unit), the cost of damage for each stop would be 22.7 cents.

Finally, the officer takes an average 0.029 hours (1.74 minutes for Interstate and two-lane highways combined) from the time he makes the decision to pursue until the violator stops. At an average salary plus benefits of 12.11 dollars per hour, the cost of manpower is 35.1 cents. Including the time spent by the officer, the total cost of initiating the stop of a speeding motorist is 1.425 dollars. This is shown in Table 17.

Writing the Citation

Once the stop is made, the officer writes a citation for speeding in excess of the 55 mph limit. The time taken to write that citation is part of the stop, therefore, part of the cost of making that stop. While officers must spend this time for every stop regardless of how it is generated, in some situations, such as speed enforcement directed by airplane, the officer is assigned specifically to that function. Therefore, all of his time spent is part of the cost rather than the amount required to write a citation.

TABLE 17

TOTAL AVERAGE COST
OF PURSUIT

Driving Costs	
Gasoline	$0.570
Depreciation and Maintenance	0.277
Total	$0.847
Officer	.351
Total Sub-Total	$1.198
Repairs	0.227
Total	1.425

According to data from TIPS, the officer spends an average of 10.4 minutes for each contact with a motorist. Approximately one half of these contacts result in a written warning. An assumption is made that the average time spent completing activity for a written warning is six minutes. Therefore, the average time for writing a citation is 14.8 minutes. At a compensation of 12.11 dollars per hour, the average cost to write the citation and thereby complete the traffic stop is 2.99 dollars.

Appearance in Court

Some of the citations written will be contested. The officer will be required to appear in court. This is another cost of enforcing the traffic laws. There are two elements: time actually spent in court, and time and mileage to and from court. Shown in Table 18 are the number of ISP arrests for all actions that were

contested in 1980. The time taken for these appearances was 76,223 hours. Using the basis of 36,681 contested citations and arrests, the average time spent in court was 2.1 hours per appearance. At the compensation of 12.11 dollars per hour, each appearance in court costs 25.43 dollars.

TABLE 18

ISP COURT ACTIVITY
FOR 1980

	Activity	Percent Contested	Number Contested
Speed Citations (Aircraft, Radar)	297,471	7.1%	21,120
Other Citations	155,053	15.0	23,258
Criminal Arrests	11,303	100.0*	11,303
Total	463,827	-	36,681
Time in Court	76,223 hours		
Time per Appearance	2.1 hours		

*While not all arrests for criminal activity require appearance by an officer, the time spent often is longer than that for traffic citations, therefore, 100 percent is used in lieu of knowing the actual time.

To make the appearance in court, the officer must drive. Assuming that officers are located randomly throughout any county, their driving distance to and from court is equal to the square root of the area of that county. The average size of a county in Illinois weighted for population density is 761.8 square miles.[56] On the average then, the officer will drive 27.6 miles. He will make this drive in 37 minutes at a speed of 45 mph. At 27.9 cents per mile, the drive costs 7.70 dollars for mileage plus an additional 7.47 dollars for officer's time, a total of 15.17

dollars. Adding the cost of driving to the 25.43 dollars for time in court, yields a cost of 40.60 dollars for each court appearance.

Training

Finally, the officer requires training in the proper use of the radar equipment. From the survey of state agencies reported in Chapter 3, the patrolling officer receives an average 34 hours of training. Illinois now provides 40 hours. If the larger amount is used, at a salary of 12.11 per hour, training costs $484.40. For purposes of this report, the 40 hours will be amortized over a period of ten years. Recurrent training of eight hours per year starting the second year will add another 96.88 each year bringing the total cost for ten years to 1356.32 dollars. An amount for travel to and from training as well as housing during that training could be added but is not. There is an assumption made that many of these costs would be incurred for other training which could be given at the same time as training in use of radar. Thus, only the incremental costs are considered for this report. Also the overhead for training, instructors, space, materials, etc., are needed for other training and would be incurred regardless.

In a previous section describing costs of damage to the vehicle, the officers were shown to average 220 stops per year. In ten years, therefore, each officer will make 2200 stops. Amortized over these stops, the average cost for training is 61.7 cents per stop.

TOTAL COST OF MAKING THE STOP

The total cost of making a stop for speeding assisted by moving radar is an average of 6.14 dollars. The costs for stops on each type of highway are

summarized in Table 19. These costs have been derived for activity on a 55-mph highway because a large portion of the Illinois State Police patrol is directed toward these types of roads. The only difference on lower speed roads would be in the cost of pursuit. It would decrease slightly because of lesser distances driven. Given the information shown in Table 19, the Illinois State Police during 1980 would have spent 1.082 million dollars on using moving radar to help enforce the speed limit.

The cost of the citation on two-lane highways was 39 cents less than for one on Interstate highways. This occurred because a lower percentage of the stops on this type of highway required pursuit and because there would be no damage to the undercarriage of patrol vehicles. How this average cost of 6.14 dollars per stop compares with other methods is the subject of the next chapter.

TABLE 19

TOTAL COSTS OF MAKING A STOP ON 55 MPH HIGHWAYS

	Interstate Highways	Two-Lane Highways	All Highways
Citations Issued	89,671	86,605	176,276
Percent Requiring Pursuit	93.5%	66.7%	80.3%
Percent Contested	3.6%	3.6%	3.6%
Cost for Each Pursuit			
Number of Pursuits	83,842	57,766	141,550
Cost per Pursuit	$ 1.118	$ 1.295	$ 1.191
Cost for Each Stop			
Pursuit	$ 1.045	$ 0.864	$ 0.956
Damage to Vehicle	0.227	0.000	0.115
Writing Citation	2.990	2.990	2.990
Training	0.616	0.616	0.616
Total for Each Stop	$ 4.878	$ 4.470	$ 4.677
Court Cost			
Citations Contested	3228	3118	6343
Driving	$ 15.17	$ 15.17	$ 15.17
In Court	25.43	25.43	25.43
Total per Citation Issued	$ 1.462	$ 1.462	$ 1.462
Summary			
Cost of Making Stop	$437,415	$387,124	$824,539
Court Cost	131,099	126,616	257,715
Total Cost	$568,514	$513,740	$1,082,254
Cost per Citation	$ 6.34	$ 5.93	$ 6.14

V. COMPARATIVE COSTS OF ENFORCING THE SPEED LIMIT

METHODS

Four methods used to help enforce the speed limit are considered in this comparison. Each is assigned a cost. The methods are:

1. Moving radar
2. Stationary (hand-held) radar
3. Radar and chase car
4. Airplane assisted (airspeed check)

Two other methods, VASCAR and pacing are not included because their use is limited in Illinois. The cost of VASCAR would be similar to the cost of moving or stationary radar with one exception: a greater percentage of the stops probably would be contested. Any greater frequency of contested cases, given all other costs equal, would substantially increase the total cost above that of moving radar.

The costs used for comparative purposes are derived from two sources. Those for moving radar have been shown in the previous chapter. For hand-held radar, the costs should be similar; the computation of differences is shown in the next section. An analysis of aircraft costs prepared by Raub and Henry contains the basis for estimating costs for airspeed checks.[57] It includes a method for assigning cost to radar with chase cars. The costs shown in that report are updated.

DESCRIPTIONS OF COSTS FOR OTHER METHODS

Hand-Held Radar

The steps required to stop a violator by an officer who is using hand-held radar are similar to those required for moving radar. Generally, there is pursuit;

the citation is written and occasionally contested in court. Also training is required, although, the amount has traditionally been less than that required for the operation of moving radar.[58]

The cost of pursuit is dependent upon the number of pursuits required. On Inte ... highways, because the patrol vehicle generally is not hidden, fewer pursuits would be required than for using moving radar. On two-lane roads the opposite is assumed. In both cases, the pursuing officer must start from a stop. The time required for pursuit, therefore, would be similar to that for moving radar on two-lane roads. As was shown in Table 11, on page 55, pursuit required 1.53 minutes with an additional 0.34 minutes for turn around. For this section, 1.75 minutes are assumed.

Another assumption is that 75 percent of the stops on Interstate highways and 95 percent of the stops on two-lane roads require pursuit for an average of 85 percent. The cost of pursuit for an average violator's speed of 69.5 mph (from Table 14 and 15 on pages 63 and 64) would be 63.0 cents for fuel, 37.5 cents for the officer's time, and 29.0 cents for other vehicular costs. These amounts, shown in Table 20, equal 1.295 dollars. Additionally costs include: writing the citation - - 2.99 dollars (the same as used for moving radar), training - -0.24 dollars (eight hours of training with four hours refresher training, amortized over ten years), and court - -1.66 dollars (based on 4.1 percent of the citations being contested as shown in Table 2 on page 32).

The cost of making a stop by using hand-held radar is 5.99 dollars. It is 2.4 percent less than the 6.14 dollars required for moving radar. If the training for use of hand-held radar required the same time as that for use of moving radar, then the operation of hand-held radar would be 3.7 percent higher.

TABLE 20

COST OF HAND-HELD RADAR

Number of Citations (1980)	78,594
Percent with Pursuit	85.0%
Percent Contested	4.'%
Cost per Pursuit	$ 1.295
Cost per Appearance in Court	$40.600
Cost per Citation	
Pursuit	1.10
Writing citation	2.99
Training	0.24
Court	1.66
Total	$ 5.99

What is not included in the cost of hand-held radar is the cost of the officer's time waiting for a violator to pass the stationary position of the patrol vehicle. There is some merit to the argument that the stationary officer is monitoring traffic. However, this monitoring is limited both in terms of the types of violations that can be detected and the distance over which that officer's presence influences traffic. According to a study performed by the Illinois Department of Transportation,[59] the officer monitoring traffic with radar from a stationary position will detect only 18 percent of the violators of the speed limit. Applying this to a traffic volume of 600 vehicles per hour, ten percent of which are exceeding 65 mph, gives a potential rate of detection of 10.8 vehicles per hour. This is one vehicle every 5.5 minutes as opposed to one every three minutes for moving radar as was shown in Table 10 on page 53. If included, this extra waiting time would increase the cost of operating stationary radar to 7.10 dollars, 15.6 percent higher than the cost of operating moving radar.

TABLE 21

COST OF RADAR AND CHASE CARS
Two-Hour Period

Driving to and from location per officer at $11.03/officer	$44.12
Operation at 12.11/hour/officers	96.88
	$141.00
Citations issued at 2.7 per officer - 16.2	
Cost per citation	$ 8.70
Court cost per citation*	$ 2.92
Total cost per citation	$11.62

*A court cost of 1.462 dollars per citation is derived from Table 19 on page 69. Two officers must attend; thus, the costs are 100 percent higher than shown in that table.

Stationary Radar With Chase Cars

One type of team effort is the use of a radar operator and "chase cars" (in effect, the officers are interceptors and rarely performing a pursuit). Table 21 shows the components of the cost of using a radar operator with chase cars. It is based on the use of one radar operator and three chase cars.[60] Because the operation of radar with chase cars requires a fixed location for number of vehicles, in addition to the actual operation, there is a cost of driving to and from that location. A decrease in the number of chase cars would substantially increase because the hourly cost of the radar operator is amortized over a smaller amount of activity. For the chase cars, an average of 2.7 contacts per hour appears to be

an adequate estimation of the actual productivity. If productivity were higher, the cost per citation would decrease at a rate of approximately 6.5 percent for every ten percent increase in productivity.

The cost for conducting an operation with a radar operator and chase car is estimated at 11.62 dollars for each citation issued. This is 89 percent higher than the cost of operating moving radar. In addition to the increased expense, such an operation suffers the same disadvantage as stationary operation. The location radar operator rapidly becomes known to many motorists. Those drivers with CB radios and radar detectors are not likely to be stopped for speeding.

Air Speed-Check

As originally computed by Raub and Henry, the cost of using the airplane was 19.93 dollars per stop.[60] Since that study was completed, the ISP have used the aircraft more efficiently and the officers on the ground have become more productive. On the other hand, operating costs have increased. Table 22 shows current costs of 19.81 dollars per stop. There has been a minimal decrease since the previous computation of 19.93 dollars per stop. Even though more costly to operate, the air speed-check may be productive in terms of stopping the flagrant speeder.

COMPARISON OF COSTS

As shown in Table 23, the lowest cost tool for the enforcement of the speed limit appears to be the hand-held radar at 5.99 dollars per stop. However, adjusting the costs of using hand-held radar for additional training and for the

TABLE 22

COST OF AIRSPEED CHECKS
(Three Interceptors)

Two-Hour Period

Stops - - 3.7 per officer, 22 stops	
Cost of flying - - $114.97/hour	$298.92
Cost of support personnel	105.76*
Total Cost	$404.68
Cost per stop	$ 18.25
Court cost per stop	1.58
Total cost per stop	$ 19.81

*Setup 11.03 dollars per officer; hourly costs, 12.11 dollars per hour.

relatively non-productive time while the officer is stopped, increases this cost to 7.09 dollars. In this perspective moving radar becomes the least costly method of detecting violators of the speed limit. The most costly is the airplane at 15.88 dollars per stop. To bring the costs of radar with chase cars to a level compatable to that of moving radar would require an increase in productivity of each chase officer to 7.3 stops per hour. The aircraft would require an increase from 3.7 to 14.8 stops per hour. Neither increase is feasible. Therefore the use of radar with chase cars or aircraft should be considered as special purpose, not on a competitive level with moving radar.

TABLE 23

COMPARATIVE COSTS OF
MAKING A STOP FOR SPEEDING

Cost Per Stop

Moving Radar	Stationary Radar	Radar Chase Car	Air Speed Check
$6.14	$5.99	$11.62	$19.81

Caution is advised when considering the comparisons. First, an argument can be raised that moving radar, as discussed here, requires the patrol vehicle be in motion. Therefore, the cost of fuel and the officer's time on patrol must be included. While there may be merit to this argument, there are two counterarguments. First, the officer is maintaining patrol and visibility, something not done with other methods. This patrol is still considered a primary function of traffic police. Second, even when included, the cost per mile is not substantial. Vehicular costs are 27.9 cents and the officer's cost at 50 mph is 24.2 cents for a total of 52.1 cents per mile. As was shown in Figure 3 on page 52, the potential number of contacts on an Interstate highway at a volume of 400 vehicles per hour is 25 vehicles exceeding 65 mph. Thus at a patrol speed of 50 mph, the officer, on the average, would drive 2.0 miles before encountering another contact. Including the cost of driving would only increase the cost of making a stop from 6.14 dollars to 7.18 dollars. This is the same as the cost of operating stationary radar when increased training has been considered. On the other hand, even though slightly more expensive, stationary radar has been shown to be far less productive than moving radar.[61]

The air speed-check serves a specific purpose. It allows the ISP to stop a large number of violators during one period. It can, if used properly, make very effective use of resources. Because the airplane is usually not detected, most violators and paticularly those who are using means to help them avoid a citation, often are not aware of the operation until it is too late. Though more costly, when used productively it can be shown cost-effective for its specific purpose.

Finally, the use of radar and chase cars, though not as costly as the airplane, appears to be the least productive. The most likely group of violators not stopped by this method are those who are using radar detectors and CB radios--often the flagrant violators. This operation thus shares the problems of the solitary officer operating stationary radar. In addition, because of the number of officers involved, the operation is not as flexible as the single officer.

Based on the data presented up to this point, two conclusions are apparent. First, the operator of moving radar is more likely to initiate a stop for speeding than by any other method. The rate of flagrant speeders detected appears to be similar to that of an air speed-check. Other methods are not as effective. Second, the use of moving radar is as inexpensive as those compared. Combining these two points yields the conclusion that the use of moving radar appears to be the most cost-effective method now in operation by which police can monitor and enforce the speed limit.

VI. SUMMARY AND RECOMMENDATIONS

SUMMARY

Despite several attempts to discredit its use, moving radar remains as one of the most important additions to the tools used by traffic police for the enforcement of the speed limit. As the courts have indicated, the principle of radar is not in question. Mechanically it is sound; the speed that it presents derives from the information it has received. It is the officer operating the equipment who must correlate the speed observed with the apparent violator. While there are many other elements that can yield a reading which does not belong to a violator, the elimination of these readings is not difficult. It requires competence on the part of the operator.

Where the judicial has taken exception to the use of moving radar, it has arisen from clearly defined circumstances. The one in Wisconsin represented a situation where the unit had not been in use for a sufficient time and the operator had not used it properly. Incorrect use and inadequate training also was the reason for the ruling in Dade County, Florida. The notoriety associated with this latter case arose from its apparent orchestration. In fact, one of the "expert" witnesses for the defense was later discredited in another court because of his apparent inability to separate fact and fiction. There have been no other negative cases cited. On the other hand, there have been many cases where the validity of correct use has been upheld.

The users, themselves, are satisifed with the equipment. Only two state law enforcement agencies alluded to serious problems. One of the states, Connecticut,

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1 OF 2

has a substantial number of roads where the use of moving radar is not practical. Many of these roads have median barriers; on others, the traffic is too heavy; and on many, tight curves and rolling terrain unduly limit the range. In its response, the State of Oregon also intimated problems with use of moving radar for two reasons. First, use is restricted to Interstate highways, and there are many sections where the use is not practical. Second, the state is in the process of preparing an adequate program of training. Because sufficient training has not yet been introduced in Oregon, this may have affected the attitude of personnel toward the use of the equipment.

The greatest number of limitations to the use of moving radar occur on Interstate highways. In the following situations moving radar does not appear to be a practical tool: traffic volumes in excess of 500 per lane per hour, highways with median barriers, and highways with very wide medians (the study by Lacey et. al. indicated that medians in excess of 100 feet might cause problems). The lack of an adequate number of median crossovers also subject the vehicles and medians to greater than normal damage and cause potential conflict between the turning police vehicle and oncoming traffic. On the other hand, observations of actual use of the equipment, as well as surveys of the users, indicate that moving radar is the best possible tool for most sections of Interstate highways and all rural two-lane roads.

The observations made with the assistance of officers from the Illinois State Police showed that the operator easily used moving radar under most conditions on most types of road. There were limitations when it was raining or during other inclement weather. However, during these times need for its use also decreased.

The operators had no problems correctly identifying the violator. When there was a question, the suspected violator was not stopped; the next violator generally was another mile down the road. Even though the violator has a head start on the officer, there has been no apparent increase in the number of chases. Most importantly, the users are impressed with the equipment. It is the first tool that does not require an airplane and team of police to detect and stop the flagrant violators. The solitary officer on patrol now can detect this motorist driving at excessive speeds and thereby help decrease this most dangerous violator.

The records kept by the ISP show that once the violator has been identified by moving radar, the resulting citation has a low probability of being contested. When contested, the violator is as likely to be found guilty as by any other method.

What is unexpected from the analysis is the relatively low expenses associated with the use of moving radar. Currently a stop by the Illinois State Police will cost 6.14 dollars. Even if all of the patrolling mileage is included, the costs still are no different than those for stationary radar. Other methods that use more than one officer such as radar and chase cars or the airplane are at least 90 percent more costly. They also have the added disadvantage of lacking mobility. This is not to say that other methods should not be used; they have a place. Overall, however, the use of moving radar appears to be the best method to detect violators on any type of highway by a solo police officer. It also is the best method at the lowest cost.

RECOMMENDATIONS

The most often stated requirement for the proper use of moving radar is training. The courts have reiterated this theme many times as those cases referenced in this report clearly show. Like so many other programs, those who conduct the training are describing a specific number of hours needed for proficiency. However, the proper use of moving radar may not require a specific number of hours as much as a need for proficiency and testing of that proficiency. Three elements must be clearly understood and retained by the operator:

- Detect the violator before the speed is read from the radar unit.
- Understand the characteristics which can cause unwarranted readings.
- Learn the judicial precedent and how to testify properly in court.

The ability of the operator in these three important areas can be tested. Such testing may be needed annually, perhaps, as indicated by ISP officers, in conjunction with annual refresher training or as an indicator of the need for refresher training.

A second set of recommendations deal with the equipment. Most older units still have automatic lock and an alert tone to notify the operator that a violator has been detected. Both devices will not be permitted on new units when the federal standards for radar are adopted. The potential for improper issuance of citations when using automatic lock is so great that it should be physically disconnected from every unit now in operation. As an incentive, the courts can refuse to try cases where the officer testifies to the use of the automatic lock. In the hands of a properly trained operator, the use of the alert may be helpful. However, its potential for abuse is almost as substantial as that of the automatic lock. Even the properly trained officer who has not been monitoring oncoming traffic properly might be tempted to assign a violation signaled by the alert tone to a vehicle, even though he had not clearly identified the violator. Disconnecting the alert should cause no severe handicap.

The one addition that would assist all operators is the read-through-lock. This facility allows the operator to monitor speeds even after he has locked in the violation. Without the read-through-lock, the officer has two options, either lock the speed of violation and make the stop on the basis that he correctly identifed the violator, or continue to monitor the speed at the risk of losing the violator's speed shown on the unit. However, most officers will not make a stop if they lose the reading of the speed. Thus, while monitoring the vehicle until it is past is the surest method of confirming the speed, the risk of losing the reading generally outweighs the need for assurance.

There is the serious problem of an inadequate number of places to turn around on Interstate highways. In order to make the stop, most of the time the officer must turn across a median provided the slopes are not too steep. Making this turn risks damage to the undercarriage and damages the medians. Most importantly, it exposes the officer and oncoming traffic to the risk of collision. Most motorists would not expect a vehicle to emerge suddenly from the median. Additional crossovers are needed. Here, however, an increase in median crossovers appear to conflict with the goals of the U.S. Department of Transportation. Fewer crossovers apparently reduce the potential for accidents caused by drivers turning around across the median. Yet in this policy of preventing a few violations, the Department of Transportation works against another and possibly more critical need, the reduction of extreme speeds.

Finally, there are courts where the prosecuting attorneys and judges are not familiar with the use of moving radar. Such lack of familiarity means that the prosecutor can not present a proper case and that the judge can not render an informed verdict. This works against both the motorist and the police officer. The judge and prosecuting attorney who understand the moving radar are also more likely to insist on correct operation by the officer. The risk of penalizing a motorist who does not warrant penalty is reduced. The police agencies themselves must take the initiative to introduce the courts to the correct operation of moving radar and to demonstrate its use on the road.

None of these recommendations are difficult to incorporate. They will, however, enhance the use of moving radar. It is this equipment which, from the review of literature, survey of users, and the analyses of costs, appears to be the most effective and the least costly tool for the enforcement of the speed limit yet devised. To ensure the proper use of moving radar will maintain this superiority.

NOTES

1. Midwest Research Institute of Kansas City, Missouri, has been evaluating various types of European radar equipment for the National Highway Traffic Safety Administration. State law enforcement agencies in Illinois, New Jersey, and Maryland have been assisting. See W. Glauz and R. R. Blackburn, Technology For Use In "Automated" Speed Enforcement, Midwest Research Institute, Kansas City, Mo., June 1980.

2. City of Spokane v. Knight, 96 Wash. 403, 165 page 105 (1917).

3. State v. Tarquino, Jr., 3 Conn. 566; 221 A. 2d 595 (1966).

4. See E. C., Fisher, Legal Aspects of Speed Measurement Devices, (1967) and Fisher and R. H. Reeder, Vehicle Traffic Law (1974), Northwestern University, The Traffic Institute, Evanston, Illinois.

5. J. M. Kopper, "The Scientific Reliability of Radar Speedmeters", 33 North Carolina Law Review 343 (1955).

6. State v. Dantonio, (N.J.), 18 N.J. Supr. 570; 115 A. 2d 35 (1955). There are others, e.g.:
   - State v. Tomanelli, (Conn.), 153 Conn 365; 216 A. 2d. 625 (1966).
   - People v. Abdallah, (Il.), 82 Il, App. 2d 312; 226 N.E. 2d 408 (1967).
   - People v. Barbic, (Il.), 105 Il. App. 2d 360; 244 N.E., 2d 626 (1969).
   - State v. Gerdes, (Minn.), 291 Minn. 353; 191 N.W. 2d 428 (1971).
   - State v. Graham, (Mo.), 372 S.W. 2d 188 (1959).
   - City of East Cleveland v. Ferell, (Ohio), 168 Ohio St. 298; 154 N.E. 2d 630 (1958).

   Further many states including Florida, Maine, Maryland, Minnesota, Mississippi, Montana, Nebraska, North Dakota, Ohio, Oklahoma, Pennsylvania, Virginia, and West Virginia by their statutes take judicial notice of the reliability of radar.

7. State v. Donohoo, (Il.), App. 5th District, 75-443 (1977).

8. State v. Boyington, (N.J.), 159 N.J. Super. 426; 388 A. 2d 276 (1978). State v. Shelt, (Ohio), 46 Ohio App. 2d 115; 346 N.E. 2d 345 (1976).

9. State v. Hanson, (Wisc.), 85 Wis. 2d 233; 270 N.W. 2d 212 (1978).

10. Ibid, p. 216.

11. State v. Newton, (Del.), 421 A. 2d 920 (1980).

12. State v. Wojtkowick, (N.J.), 170 N.J. Super. 44; 405 A. 2d 477 (1979).

13. Commonwealth v. Honeycutt, (Ky.), 408 S. W. 2d 421 (1966). Cases also referenced include: City of Little Rock v. Everight, (Ark.), 326, S.W. 2d 796. State v. Graham, State v. Tomanelli, and East Cleveland v. Ferell, supra.

14. State v. Primm, (Kan.), 606 P. 2d 112 (1980).
People v. Walker, (Col.), 610 p. 2d 496 (1980).
Commonwealth v. Wynaught, (Mass.), 384 N.E. 2d 1212 (1979).
People v. Bell, (Il.), 395 N.E. 2d 400 (1979).

15. Commonwealth v. Honeycutt, State v. Primm, and People v. Bell, supra.

16. People v. Walker, supra.

17. City of Ballwin v. Collins, (Mo.), 534 S.W. 2d 280 (1976).

18. Louis C. Dujmich, "Radar Speed Detection: Homing In on New Evidentary Problems", 48 Fordham Law Review, p. 1164.

19. State v. Aquilera, (Fla.), 48 Fla. Sup. 207 (Dade County 1979). 25 Criminal Law Reporter 2189, (1979).

20. The opponents included the company that produces FuzzBusters. This company subsequently was caught by Car and Driver magazine deceptively demonstrating a competitor's radar detector as its own. Some of the tests conducted in Dade County were questionable. An excellent example was the so called "moving trees" and "moving billboards" which showed up when an observer whistled into the CB of the vehicle carrying the moving radar. The media ignored the deception; no officer would whistle in the CB radio while operating the radar. It further failed to note that CB radios outside the vehicle created no interference. Unfortunately the Dade County prosecutor was not in a good position to dispute these demonstrations; the police had not received adequate training.

21. National Broadcasting Company, Radar on Trial, Prime Time Saturday, March 8, 1980 (television broadcast).

22. State v. Hanson, p. 219.

23. Commonwealth v. Rose, (Ky.), (Gallatin County) 80-7-014, (1980). State v. Leamer, (Mich.), 79-3781, Michigan 2nd Judicial District (1980).

24. City of Akron v. Gray, (Ohio) 397 N.E. 2d 429 (1979). State v. Wojtkowiak, supra.

25. State v. Page, (N. H.), Laconia District, 80-CR-1108G (1980).

26. Dujmich, p. 1164.

27. K. L. Ward, "Techniques for Radar Speed Detection", Traffic Digest and Review, Sept. to Nov. 1966 (unit publication 7367), The Traffic Institute, Northwestern University, Evanston, Illinois.

28. "Police Traffic Radar", Report to the Legislature, State of North Carolina Legislative Research Commission, Jan. 14, 1981, pr C-8 to C-10.

29. The three are: R. Power, How To Beat Radar And Do It Legally, Publishing Co, New York, 1977 D. T. Smith, "Why Radar Went on Trial", Police Chief, 64:11, Nov. 1979, pages 50-51 "Report on the Inaccuracies of Police Radar", Overdrive, 19:5, May 1979, pages 84-86.

30. The Federal Register, 46:5, Jan. 8, 1981, pages 2097-2120.

31. When the vehicle with moving radar was passing a tree, the observer whistled into the vehicle's CB microphone. As a result of this radio transmission, a reading of 86 mph appeared on the radar. According to the media, the tree was "moving" at 86 mph.

32. Dujmich, p. 1162.

33. The Federal Register, page 2098.

34. Commonwealth v. Rose, State v. Leamer, and Dujmich, supra.

35. "Police Traffic Radar", Issue Paper, U.S. Department of Tranpsortation, National Highway Traffic Safety Administration, February 1980, reprinted in Tests of Six Speed Measuring Radar Units, Interim Report, National Bureau of Standards, Washington, D.C., January 1980.

36. "Performance Standard for Speed Measuring Devices", National Bureau of Standards, Preliminary Draft, September 15, 1980. Also Federal Register, supra.

37. The speed seen by the radar is equal to the actual speed times the cosine of the angle between the direction faced by the antenna and tangent of the vehicular direction. An angle up to 15 degrees has negligible effect; the cosine equals 0.966. In other words, the speed read is 96.6 percent of actual speed, or approximately 2 mph lower at an actual speed of 55 mph. At 30 degrees, the cosine error is 0.866. If this error affected a "patrol speed" of 55 mph, that speed would be read as 47 mph. If the target was proceeding toward the patrol vehicle at 55 mph (a closing speed of 110 mph), that target would be seen by the radar as traveling 63 mph (110 minus 47). Thus, the driver might be subject to a citation for speeding.

38. This temporarily low reading would normally not affect the operator's use of the radar because of its extremely short duration (such reflection would last at most one ~~seconds at~~ 55 mph). However, if the operator is using the unit in automatic mode, the false reading is locked in, and the operator begins searching for a violator.

39. In the tests performed by the National Bureau of Standards, this characteristic could not be replicated (see "Police Traffic Radar").

40. State v. Leamer, and State v. Wojtkowiak, supra.

41. Federal Register, supra.

42. S. Belardo, "Radar for Controlled Access Highway", Task Force Interim Report No. 2, New York State Police, Albany, N.Y., February 1, 1978.

43. J. Lacy, R. Daniel, and B. J. Campbell, Evaluation of Moving Radar, Highway Safety Research Center, University of North Carolina, Chapel Hill, N.C., February 1973. W. W. Hunter and H. L. Bundy, Moving Radar Evaluation - Project Report, Highway Safety Research Center, University of North Carolina, Chapel Hill, N. C., March, 1975.

44. Florida - State v. Aquilera, Connecticut - State v. Tarquino, Jr. and State v. Tomanelli, and Wisconsin - State v. Hanson, supra.

45. C. Berroyer, Concentrated Traffic Enforcement Program, Illinois State Police, Evaluation of First Year, Illinois Department of Transportation, Springfield, Il. This report showed a correlation between a reduction in accidents and an increase in stops for speeding only on rural Interstate highways. On all other roads, there was a negative correlation.

46. Illinois State Police do not operate enough VASCAR units to allow for a meaningful comparison between this method and the use of moving radar.

47. In the "squelched mode" the operator turns off the transmitting antenna until such time as the officer visually detects a vehicle moving at excessive speed. The offender who is using a radar detector does not receive a signal until the transmitter is turned on. By then it is too late. Such squelching of the transmitting beam has no effect on the reliability of the equipment or readings made by the operator.

48. K. B. Joscelyn, T. H. Bryan, and D. M. Goldenbaum, A Study of the Effects of Enforcement on Traffic Flow Behavior, Institute For Research in Public Safety, Indiana University, Bloomington, In., January 1971.

49. The word "pursuit" used in this report means that the officer must travel at a speed above that of the violator in order to catch and stop the violator.

Pursuit, in the sense of flight, was not observed during the recording of data. Additionally, respondents to the questionnaire did not consider fleeing a problem.

50. Joscelyn, Bryan, and Goldenbaum, supra.

51. A Policy on Geometric Design of Rural Highways, (1965), American Association of State Highway and Transportation Officials, Washington, D.C., 1977, p. 96.

52. During January and February of 1980 several speed studies were conducted from an ISP airplane. They were used to help ISP management review the policies of speed enforcement. Of 1,729 vehicles recorded at seven locations on two-lane roads, 73 percent were exceeding 55 mph. On Interstate highways, where 710 vehicles were recorded, an average of 91 percent were traveling in excess of 55 mph.

53. R. A. Raub and B. J. Wolfson, Comparison of Aerial and Ground Speed Studies, Illinois Department of Transportation, Springfield, Il., September 1978.

54. Three tests of fuel economy with light bars are referenced:

W. E. Hilding, "Investigation of Increased Aerodynamic Drag and Resultant Loss of Fuel Economy Caused by the Installation of Roof Light Bars on a 1979 Ford LTD Police Cruiser Package", Energy Center, University of Connecticut, Storrs, Conn., July 18, 1979.

Y. Nishimura, J. Friedel, and S. R. Gwilt, Aerodynamic Drag of Automobiles with Roof-Mounted Equipment, National Aeronautical Establishment, National Research Council of Canada, Ottawa, Canada, May 1980.

"Smith and Wesson: A Test of Light-Bar Fuel Economy", Transportation Research Center of Ohio, East Liberty, Ohio, June 1978.

55. There reaches a point where the time for pursuit would become constant or even increase for two reasons. The maximum speed of a police vehicle with light bar is below 110 mph. Secondly, speeds in excess of 100 mph are more likely to be driven only in emergencies. More importantly, however, violators traveling at the higher speeds appeared more cognizant of the police vehicle. They apparently slow down slightly thereby reducing the need for excessively high pursuit speeds over long distances.

56. The number of traffic stops made in a county are correlated quite strongly with traffic volume as measured in vehicle miles. This in turn is correlated to population of the county. Thus, the area of each county is weighted by its population to account for more driving to court in the more populous counties.

57. R. A. Raub and B. C. Henry, Cost of Aircraft Used for Traffic Law Enforcement by the State Police of Illinois, Illinois Department of Law Enforcement, Springfield, Il., May 1980, also published as "Cost of Using Airplanes in Traffic Law Enforcement: A Case Study," Traffic Quarterly, 35:1, January 1981, pages 69-84.

58. N. Darwick, Enforcement of the National Maximum Speed Limit, Enforcement Practices and Procedures, International Association of Chiefs of Police, Gaithersburg, Md., June 1977.

59. Raub and Wolfson, Appendix C-4.

60. Raub and Henry, Cost of Aircraft, page 26.

61. Raub and Wolfson, supra.

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APPENDIX A

RESPONSES TO QUESTIONNAIRE

SENT TO STATE LAW ENFORCEMENT AGENCIES

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APPENDIX A

QUESTIONNAIRE ON THE USE OF MOVING RADAR

Return by March 1, 1981 to:

Bureau of Planning and Development
Research and Analysis
400 Armory Building
Springfield, Illinois 62706

District ________

ID ________

Date ________

PLEASE ANSWER ALL QUESTIONS. THEY APPLY TO MOVING RADAR AND YOUR OPINIONS REGARDING ITS USE. OTHER COMMENTS ARE WELCOME IN QUESTION 7.

1. How many months have you used moving radar?

_______ Less than 6 Months

_______ 6 to 12 Months

_______ 12 to 24 Months

_______ More than 24 Months

2. (Compare moving radar to other methods you have used to enforce the speed limit.) **As a tool for enforcing the speed limit, do you feel that moving radar is better, the same, or worse than?**

a. Stationary (Hand-Held) Radar

_______ Better
_______ Same
_______ Worse
_______ Not Applicable

b. Airplane

_______ Better
_______ Same
_______ Worse
_______ Not Applicable

c. Pacing

_______ Better
_______ Same
_______ Worse
_______ Not Applicable

d. Vascar

_______ Better
_______ Same
_______ Worse
_______ Not Applicable

3. Under each subject are five (5) modes of enforcing the speed limit - airplane, hand-held radar, moving radar, pacing, and radar/chase car. Rank each method based on its comparative ease or superiority. A "1" means "easiest", "best", or "most likely"; a rank of "5" means "hardest", "worst", or "least likely".

a. Ease of operation

_______ Airplane
_______ Hand-held Radar
_______ Moving Radar
_______ Pacing (Unmarked Car)
_______ Radar/Chase Car

b. Opportunities to observe other violations

_______ Airplane
_______ Hand-held Radar
_______ Moving Radar
_______ Pacing (Unmarked Car)
_______ Radar/Chase Car

c. Flexibility for use in various types of traffic

_______ Airplane
_______ Hand-held Radar
_______ Moving Radar
_______ Pacing (Unmarked Car)
_______ Radar/Chase Car

d. Likelihood of catching blatant violators

_______ Airplane
_______ Hand-held Radar
_______ Moving Radar
_______ Pacing (Unmarked Car)
_______ Radar/Chase Car

e. Likelihood of stopping most violators detected

_______ Airplane
_______ Hand-held Radar
_______ Moving Radar
_______ Pacing (Unmarked Car)
_______ Radar/Chase Car

f. Likelihood of violator fleeing

_______ Airplane
_______ Hand-held Radar
_______ Moving Radar
_______ Pacing (Unmarked Car)
_______ Radar/Chase Car

g. Resulting officer/violator relationship

_______ Airplane
_______ Hand-held Radar
_______ Moving Radar
_______ Pacing (Unmarked Car)
_______ Radar/Chase Car

h. Presentation of case in court

_______ Airplane
_______ Hand-held Radar
_______ Moving Radar
_______ Pacing (Unmarked Car)
_______ Radar/Chase Car

4. **Presentation of cases in court**

a. Compared to hand-held radar, what percent of drivers do you believe plead not guilty to arrests for speeding made with moving radar?

_______ Higher Percent _______ Same _______ Lower Percent

b. Compared to hand-held radar, how do you believe the courts accept the use of moving radar?

_______ Easier to obtain guilty verdict

_______ Same

_______ Harder to obtain guilty verdict

c. For cases where arrests were made with moving radar, what are the most frequent reasons why drivers have been found not guilty? (NOTE: Use Question 7 to expand answers.)

1. ____
2. ____
3. ____

5. **Operation of the moving radar.**

a. Do the moving radar units appear to be electrically and mechanically reliable?

_______ Yes _______ No _______ Always used Moving Radar

b. Are the moving radar units more frequently repaired than hand-held units?

_______ Yes _______ No _______ Always used Moving Radar

c. Has the vehicle with the unit had more repairs since the unit was installed?

_______ Yes _______ No _______ Always used Moving Radar

d. What major drawbacks have you noticed? (NOTE: Use Question 7 to expand answer.)

____

e. To make the number of stops you made using other methods, are you doing more driving?

_______ Yes _______ No _______ Always used Moving Radar

f. Approximately what percentage of time is moving radar used in stationary mode?

_______ Less than 10% _______ 25 to 50%

_______ 10 to 25% _______ More than 50%

g. Since you started using moving radar, has your percentage of arrests for other violations decreased?

_______ Yes _______ No _______ Always used Moving Radar

6. **Training given in the use of moving radar.**

a. How many hours of training did you receive?

_______ Less than 8 Hours _______ 24 to 40 Hours

_______ 8 to 16 Hours _______ More than 40 Hours

_______ 16 to 24 Hours

b. Was the time given to training?

_______ Too Long _______ Adequate _______ Not Long Enough

c. When you finished training, did you feel confident in the immediate use of the moving radar?

_______ Yes _______ No

If no, how many hours of patrol did you feel were needed to obtain this confidence? _______

d. Should there be yearly refresher training?

_______ Yes _______ No

e. What elements should be added to the training, or information should be made available to users? (NOTE: Use Question 7 to expand answers.)

1. ____
2. ____
3. ____

7. **Comments and expansion of other answers.**

____
____
____
____
____
____
____
____
____
____
____

TABLE A-1

SUMMARY OF RESPONSES
QUESTIONNAIRE ON MOVING RADAR

1.

Sent:	47		(Including Illinois)
Received:	45	95.7%	
Use moving radar:	43	95.6	

2. How many years have you operated this type of equipment?

N = 43		
Less than one year:	0	0.0%
1 to 2 years:	2	4.7
3 to 5 years:	10	23.3
More than 5 years:	30	72.0

3. How many hours of training on this equipment is given to each officer?

N = 43		
None:	0	0.0%
4 hours or less:	3	7.0
5 to 8 hours:	5	11.6
9 to 12 hours:	3	7.0
13 to 16 hours:	4	9.3
More than 16 hours:	28	65.1

4. Have the courts accepted the speeds measured by moving radar?

N = 35		
More often:	3	8.6%
Same:	28	80.0
Less often:	4	11.4

5. In relation to hand-held radar, do the officers use the moving radar?

N = 31		
More than:	26	83.8%
Same:	3	9.7
Less than:	2	6.5

TABLE A-1 (continued)

6. Are the moving units repaired?

N = 31		
More often:	3	9.7%
Same:	20	64.5
Less often:	8	25.8

7. Who does the repair?

N = 43		
Police radio laboratory	28	65.1%
Other governmental agency	4	9.3
Private firm	3	7.0
Manufacturer	8	18.6

8. Are the repairs satisfactory or unsatisfactory?

N = 43		
Satisfactory	41	95.3%
Unsatisfactory	2	4.7

9. Do the vehicles with moving radar units sustain more damage than other vehicles?

N = 42		
Yes:	7	16.7%
No:	35	83.3

10. Has your department completed any evaluations or other studies of moving radar?

N = 42		
Yes:	19	45.2%
No:	23	54.8

11. Do you have restrictions regarding the method of using the unit, locations where it can be used, or time when it can be used?

N = 40		
Yes:	22	55.0%
No:	18	45.0

TABLE A-1 (continued)

Types of Restrictions

Manual mode only (5)*
No use during inclement weather (4)
Locking mechanism removed or violator speed set at 99 (2)
No use in heavy traffic (2)
No use in hilly terrain or steep grades (2)
Patrol unit must be visible (2)
No use on Interstate highways (1)
No night use on Interstate highways (1)
Use on Interstate highways only (1)
Minimum patrol speed of 35 mph (1)
Target speed must be 10 mph greater than patrol speed (1)
Inside mounted antenna only (1)
Cannot use as prima facie evidence (1)

*Number of states indicating this restriction

12. What are the greatest benefits and greatest weaknesses of the unit?

Benefits

Increase mobility
Monitor speeds and maintain patrol
Maximum exposure of patrol vehicle
Increased productivity
Arrest for more flagrant speeds
More likely to apprehend flagrant or habitual violator
Defeats use of CB and radar detectors
Best tool for speed enforcement
Less fuel for enforcement
Allows use in areas where stationary patrol not practical

Weaknesses

Requires more extensive training
Less emphasis given other traffic violations
Difficulty in correctly identifying violator
Need for turn-around areas on divided highways
More easily affected by environment
More likely to give inappropriate readings
Reluctance of acceptance by courts
Greater expenditure of fuel
More vehicular damage
Not usable in heavy traffic
Use limited on Interstate highways

APPENDIX B

ILLINOIS STATE POLICE QUESTIONNAIRE

ON THE USE OF MOVING RADAR

APPENDIX B

MOVING RADAR QUESTIONNAIRE

Name of Agency ______________________________

Name of Responder ______________________________

Division/Bureau/Section ______________________________

Please Return by **February 1, 1981,** to:

Section Director
Analysis and Research
Bureau of Planning and Development
Illinois Department of Law Enforcement
400 Armory Building
Springfield, Illinois 62706

1. Does your department use moving (or mobile Doppler) radar?

   Yes _____ No _____

   If **YES,** please answer questions 2 through 10.
   If **NO,** please return questionnaire in the enclosed envelope.

2. How many years have you operated this type of equipment?

   _____ Less than one (1) year _____ Three (3) to five (5) years
   _____ One (1) to two (2) years _____ More than five (5) years

3. How many hours of training on this equipment is given to each officer?

   _____ None _____ 9 to 12 hours
   _____ 4 hours or less _____ 13 to 16 hours
   _____ 5 to 8 hours _____ More than 16 hours, how many? _____

Questions 4 through 6 compare Moving Radar to Hand-Held (only) Radar

4. Have the courts accepted the speeds measured by moving radar

   _____ More often than hand-held radar
   _____ As frequently as hand-held radar
   _____ Less frequently than hand-held radar

5. Do the officers use the moving radar?

   _____ More than hand-held radar
   _____ The same as hand-held radar
   _____ Less than hand-held radar

6. Are the moving units repaired?

   _____ More often than hand-held units
   _____ The same as hand-held units
   _____ Less often than hand-held units

7. Who does the repair?

   _____ Police radio laboratory or police officer
   _____ Other repair operated by government
   _____ Private firm
   _____ Manufacturer

8. Are the repairs?

   _____ Satisfactory
   _____ Unsatisfactory

9. Do the vehicles with moving radar units sustain more damage than other vehicles?

   Yes _____ No _____

   If **YES,** what is the most prevelant type of damage?

   ____

10. Has your department completed any evaluations or other studies of moving radar?

Yes ______ No ______

If **YES**, check the subject(s) studied and, if possible, enclose a copy of the report or summary of the findings.

______ Accuracy
______ Reliability
______ Training
______ Costs
______ Effectiveness as a speed control device
______ Judicial acceptance
______ Other ________________________________

11. Do you have restrictions regarding the method of using the unit, locations where it can be used, or time when it can be used?

Yes ______ No ______

If yes, please describe: ________________________________

____

____

12. What are the greatest benefits and greatest weaknesses of the unit (please list)?

BENEFITS:

____

____

____

WEAKNESSES:

____

____

____

Please include any information that you feel may be helpful in our evaluation of moving radar.

TABLE B-1

SUMMARY OF ALL RESPONSES TO ISP SURVEY

1. How many months have you used moving radar?

N	l.t. 6 Months	6-12 Months	12-24 Months	g.t. 24 Months
111	4 3.6%	24 21.6	72 64.9	11 9.9

2. As a tool for enforcing the speed limit, do you feel that moving radar is better, same, or worse than?

	Better		Same		Worse		N/A
Hand-held	92	82.9%	6	5.4%	13	11.7%	0
Airplane	51	50.0	36	35.3	15	14.7	9
Pacing	100	93.4	3	2.8	4	2.8	4
VASCAR	51	80.9	9	14.3	8	4.8	48

N = 111

3. Comparative superiority of methods for enforcing the speed limit.

a. Ease of operation

N	Airplane	Hand-Held	Moving	Pacing	Radar/Chase
86	2.29*	2.70	1.86	4.19	3.97
	Chi Square =		145.55**		

b. Opportunities to observe other violations

N	Airplane	Hand-Held	Moving	Pacing	Radar/Chase
87	4.13	2.80	1.87	2.31	3.89
	Chi Square =		133,45		

c. Flexibility in traffic

N	Airplane	Hand-Held	Moving	Pacing	Radar/Chase
82	3.20	2.89	2.41	2.43	4.07
	Chi Square =		61.43		

TABLE B-1 (continued)

d. Likelihood of catching blatant violator					
81	2.23	3.54	2.02	3.11	4.09
	Chi Square =		98.9		
e. Likelihood of stopping most violators					
74	1.84	3.26	3.11	3.38	3.42
	Chi Square =		51.71		
f. Likelihood of preventing flight by violator					
85	1.01	2.65	2.14	3.24	2.96
	Chi Square =		66.04		
g. Resulting officer/violator relationship					
66	2.88	2.68	2.62	3.00	3.82
	Chi Square =		24.52		
h. Presentation in court					
84	2.01	2.44	2.81	3.75	3.99
	Chi Square =		96.25		

*1 = Best to 5 = Worst
**All Chi Square values exceed the 0.001 level

4. Presentation of case in court.

	N	Higher		Same		Lower	
Plead not guilty	109	24	22.0%	71	65.2%	14	12.8%
Ease of obtaining guilty verdict	110	9	8.2	80	72.7	21	19.1

5. Operation of units

	N	Yes		No	
Reliable	111	73	65.8%	38	34.2%
More repairs	108	18	16.7	90	83.3
More vehicular repairs	110	3	2.7	107	97.3
Decrease in other arrests	107	37	34.6	70	63.4

TABLE B-1 (continued)

6. Training given in the use of moving radar

a. Time

N	l.t. 8 Hrs		8-16 Hrs		16-24 Hrs		g.t 24 Hrs	
109	29	26.6%	72	66.1%	6	5.5%	2	1.8%

b. Sufficiency of Time

N	Too Long		Adequate		Too Short	
111	6	5.4%	100	90.1%	5	4.5%

	N	Yes		No	
c. Confidence in immediate use	111	75	67.6%	36	32.4%
d. Recurrent training needed	110	54	49.1%	56	50.9%

APPENDIX C

COMPUTING FUEL USAGE FOR PURSUIT

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APPENDIX C

COMPUTING FUEL USAGE FOR PURSUIT

Result of Testing

Acceleration:

- Rate

$a = 8.5 - 0.035V_p$ fps^2

- Fuel Used

$f_a = 0.0008 + 0.00004V_p$ gps

Deceleration:

- Rate

$d = 9.5$ fps^2

- Fuel Used

$f_d = 0.001$ gps

Driving (Fuel Used):

$f_p = (0.0015 + 0.00045V_p)^2$ gps

Where:

- a - Acceleration in feet per second squared
- d - Deceleration in feet per second squared
- f_a - Fuel used during acceleration in gallons per second
- f_d - Fuel used during deceleration in gallons per second
- f_p - Fuel used at top speed in gallons per second
- V_p - Top speed of patrol vehicle in feet per second

Note: Feet per second is found by multiplying mph by 1.47.

Computations for Pursuit

Distance and Speed:

- Distance Driven by Violator (in feet)

$S = 102V$ 4-Lane Divided Highway

$S = 112V$ 2-Lane Undivided Highway

- Maximum Pursuit Speed (in feet per second)

$V_p = (865 - \sqrt{748225-3670V}) / 2$ 4-Lane Divided

$V_p = (865 - \sqrt{748225-3815V}) / 2$ 2-Lane Undivided

Times:

- Turnaround Time

t_r = 13 second 4-Lane Divided

t_r = 20 seconds 2-Lane Undivided

- Acceleration Time

$t_a = (V_p - 30) / a$ 4-Lane Divided

$t_a = V_p / a$ 2-Lane Undivided

- Deceleration Time

$t_d = V_p / d$ (all roads)

- Pursuit Time

$t_p = 102 - t_a - t_d - t_r$ 4-Lane Divided

$t_p = 112 - t_a - t_d - t_r$ 2-Lane Undivided

Note: Pursuit is subject to a minimum of 45 seconds at a maximum speed of 100 miles per hour

Fuel Used in Pursuit (in gallons):

- Turnaround

$g_r = 0.007$	4-Lane Divided
$g_r = 0.028$	2-Lane Undivided

- Acceleration

$g_a = t_a f_a$	(all roads)

- Deceleration

$g_d = 0.001 +_d$	(all roads)

- Pursuit

$g_p = t_p f_p$	(all roads)

- Total Usage

$G = g_r + g_a + g_p + g_d$	(all roads)

Examples

Violator Speed - 70 mph (103 feet per second)

4-Lane Highway

Turnaround

$t_r = 13$ seconds

$g_r = 0.007$ gallons

Pursuit Speed:

$V_p = 128\ fp^s$ (87 mph)

Acceleration:

$a = 4.0\ fps^2$

$t_a = 24.5$ seconds

$f_a = 0.0059$ gps

$g_a = 0.145$ gallons

Deceleration:

$d = 9.5\ fps^2$

$t_d = 13.5$ seconds

$f_d = 0.001$ gps

$g_d = 0.014$ gallons

Pursuit:

$t_p = 51$ seconds

$f_p = 0.0035$ gps

$g_p = 0.179$ gallons

Fuel Used:

0.345 gallons

2-Lane Undivided Highway

Turnaround:

t_r = 20 seconds

g_r = 0.028 gallons

Pursuit Speed:

V_p = 134 f_{ps} (92 mph)

Acceleration:

a = 3.8 fps^2

t_a = 35.3 seconds

f_a = 0.0062 gps

g_a = 0.219 gallons

Deceleration:

d = 9.5 fps^2

t_d = 14.1 seconds

f_d = 0.001 gps

g_d = 0.014 gallons

Pursuit:

t_p 45.0 seconds

f_p = 0.0038 gps

g_p = 0.171

Fuel Used:

0.432 gallons

END