Technological approaches to controlling random gunfire

Results of a gunshot detection system field test

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Abstract *Using a quasi-experimental design methodology, this paper reports the results from a controlled field evaluation of the ShotSpotter gunshot location technology in Redwood City, California. Results from this field test indicate that overall, the ShotSpotter system was able to annunciate (detect) gunshots in 81 percent of the field trial events (N = 25 of 31 shooting events) and triangulate (locate) gunshots in 84 percent of the field trial events (N = 26 of 31 shooting events) within an average margin of error of 41ft. We conclude this paper with a discussion of the policy implications associated with using gunshot detection technology as a problem-solving tool to detect, reduce and prevent incidences of random gunfire.*

Introduction

Law enforcement agencies across the USA and overseas have implemented a variety of technological tools to improve problem-solving efforts. Computerized crime mapping (or geographical information system – GIS) is being used extensively by many police agencies throughout the world. GIS assists law enforcement in pinpointing, and monitoring problem locations (Otto *et al.*, 2000; Martin *et al.*, 1998; Rich, 1998). Closed-circuit television aids law enforcement in the detection, reduction, and prevention of street crime and disorder (Mazerolle *et al.*, 2001 forthcoming; Chainey, 2000; La Vigne, 1994; Poyner, 1988). Autodialing systems and reverse 911 systems are yet two other technological

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tools used to assist law enforcement solve crime problems in communities and neighborhoods (Trilon Technology, LLC, Bradshaw Consulting Services, Inc. and Dialogic Communications, 2000; Canter, 1998).

One other piece of technology that can assist law enforcement in their problem-solving efforts is gunshot location technology. Defined as,“ acoustic sensing systems capable of identifying, discriminating, and reporting to the police gunshots within seconds of a shot being fired” (Page and Sharkey, 1995, p. 160), this technology is relatively new and could assist police agencies in more accurately identifying and locating incidences of gunfire in the environment. Moreover, this system could have an added benefit as a gunfire prevention tool if shooters are made aware that this technology accurately identifies and pinpoints the location of gunfire.

Police departments across the USA have implemented a variety of initiatives to control gun problems occurring in the context of serious criminal activity (e.g. see Kennedy *et al.,* 1996; Sherman and Rogan, 1995; Watkins *et al.,* 2000). Law enforcement agencies have also developed intervention programs that focus specifically on the problem of random gunfire. Departments concerned with random gunfire problems have implemented community awareness campaigns and increased police efforts to inform people of the dangers of random gunfire (Dallas Police Department Gunshot Awareness Program, 1995; New Orleans Gunshot Public Awareness Program; Redwood City Operation Silent Night Program; Los Angeles County Random Gunfire Reduction Initiative, 2000; and St Louis Town Criers Program). Recent efforts to reduce random gunfire problems have led some police agencies to try out technological devices to detect and alert the police to incidences of random gunfire. Adoption and use of this form of technology clearly rests on the system’s ability to accurately detect gunfire and pinpoint gunshot locations.

This paper presents the results from a field trial of the Shotspotter gunshot location technology. We begin with an overview of technological solutions aimed at enhancing police problem-solving efforts. We then discuss the problem of random gunfire and the range of strategies that have been implemented to address this contentious issue. Next, we discuss the gunshot location system developed by Trilon Technology and installed in Redwood City, California. We then describe the Redwood City test area, the rationale for selection of Redwood Village as the specific experimental test site, and the complexities of installing ShotSpotter in Redwood Village. Then, we outline the methodology for firing test shots to evaluate the accuracy of the ShotSpotter system under field trial conditions followed by a discussion of the results of the ShotSpotter field trial. The paper concludes with a discussion of how gunshot location technology can facilitate police problem-solving and crime prevention efforts.

Technology and problem-oriented policing

Over the last decade, police agencies have used a wide variety of technological tools to improve their problem-solving capabilities. Ranging from closed-circuit television technology to computerized mapping and crime analysis products to mobile computer terminals and multi-jurisdictional information technology infrastructures, law enforcement agencies around the world are embracing innovative forms of technology to aid in the identification and analysis of crime and disorder problems.

Commonly used among law enforcement and other public service officials, closed-circuit television assists in the scanning and monitoring of areas prone to crime and disorder. Moreover, the empirical research that examines the deterrent effects of closed-circuit television suggests that crime reduction can be realized (Mazerolle *et al.,* 2001 forthcoming; Brown, 1995; La Vigne, 1994; Poyner, 1988). Poyner (1988) indicates that closed circuit television (CCTV hereafter) cameras installed in city buses assisted transportation officials in identifying vandals. This information was used for suspect identification and subsequent prosecution. La Vigne (1994) also noted that CCTV aids law enforcement in problem identification and reduction. Examining police calls for service from 38 convenient stores in Austin, Texas, La Vigne (1994) indicated that gasoline drive-offs could be reduced upwards of 70 percent with implementation of CCTV technology. Furthermore, evidence suggests that CCTV technology is having an impact on crime and disorder problems in urban centers in the UK. In Dalston, Kingsland, this technology contributed to a 31.6 percent reduction in street robberies. Similar decreases in automobile thefts were realized in Dalston, Kingsland and London's borough of Hackney (Chainey, 2000). Furthermore, Brown (1995) reports on a time series analysis where the number of burglaries, auto thefts, and thefts from automobiles were compared in CCTV covered and uncovered areas 23 months prior to camera installation, four months during operation, and 14 months after implementation. Brown indicates that areas monitored by CCTV technology experienced an 18 percent decline in burglaries, a 9 percent decline in auto thefts, and an 11 percent decline in thefts from autos.

Geographic information systems (GIS) and computer crime mapping technology is rapidly becoming an integral component to all phases of police problem-solving efforts – problem identification, analysis, response, and assessment. Defined as "a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information" (USGS, on line: http://info.er.usgs.gov/research/gis/title.html), GIS technology provides law enforcement with a powerful tool to first, more efficiently manage data and information; second, improve the distribution of limited resources; third, identify crime and disorder hot spots; and fourth, aid in the development of solutions to crime and disorder problems.

In Cincinnati, Ohio, the Cincinnati Police Department joined forces with the Cincinnati Public Works Department, and a local homeowner's association to devise a strategy for attacking increasing incidences of theft and vandalism in one local neighborhood. Adopting a problem-oriented approach, police officials used GIS technology to display and analyze crime data in the target neighborhood before and after city officials temporarily restricted a neighborhood access route believed to be the source of the problem (Neumann and Ball, 2000). Police officials indicated that mapping the criminal incidents depicted a distinctive pattern of events that assisted community residents and the Public Works Department resolve the problem. A collaborative decision was reached to permanently restrict the access route between neighborhoods. This has effectively reduced incidences of theft and vandalism in the target neighborhood by 70 percent.

In Detroit, Michigan, GIS technology was used to analyze ten years worth of fire patterns during "Devil's Night"[1] periods and to pinpoint hotspot locations. Over 4,000 incidences were mapped and fire hot spot locations were identified and used to prioritize patrol deployment patterns. Martin *et al.* (1998, p. 9) report that, "There were far fewer fires in 1995, 1996 and 1997 as compared to 1994. The fire patterns were more random and not as concentrated, and the number of hot spots declined, and were somewhat limited."

Geographic information systems can also assist law enforcement in the design and development of interventions aimed at reducing crimes in problem areas. GIS technology can also be used to assess the impact of tried interventions. For instance, in Willowbrook, a suburb of Los Angeles County, California, law enforcement is using computerized crime mapping in conjunction with a citizen notification system to identify and respond to incidences of gunfire in the community (Bradshaw, 2000). GIS analysis assists dispatchers and patrol officers pinpoint quickly the location from where gunfire has occurred. Preliminary analyses indicate that incidences of random gunfire have been reduced from prior levels since the system has been implemented.

Another example of how GIS technology can aid law enforcement in developing interventions and solve problems occurred in Shreveport, Los Angeles. Crime analysts used computerized crime mapping to identify a series of burglaries and develop a burglary reduction intervention. Communication with school officials revealed that the school was riddled with truancy problems. Working together, the police and school officials tackled the truancy problem. La Vigne and Wartell (1998, p. 2) report that "this effort reduced burglaries from 58 incidences per month before the intervention to 19 per month after the intervention": a decrease of 67 percent.

The problem of random gunfire

A crime that is gaining the attention of law enforcement, city officials, and the public around the USA is the random discharge of weapons into the air (Watkins *et al.,* 2000). The New Orleans Police Department estimates approximately 570,000 rounds have been fired skyward from 1993 to 2000. In fact, random gunfire was responsible for the death of a Boston tourist in New Orleans in 1993. While on vacation in New Orleans, Amy Silberman was killed when a stray bullet crashed through the top of her head, traveled through her brain, and lodged in her neck.

In Redwood City, residents mobilized and leveraged city and police officials to do something about the random gunfire problem. The problem was significantly impacting the lives and movement patterns of Redwood City residents. Many residents indicated that there was . . . "fear of somebody's kid being shot due to the amount of gunfire daily" (*San Francisco Chronicle*, 30 August 1995).

The problem of random gunfire has also reached significant proportions in Dallas. Every year, the Dallas Police Department receives approximately 12,000 calls regarding random gunfire (Dallas Police Department Random Gunfire Reduction Proposal, 1995). The problem of random gunfire has also plagued communities in other areas of Texas as well as California. Headlines on 29 December 1995 in the *East Palo Alto News* read: "PUBLIC SAFETY: police won't tolerate gunfire." The East Palo Alto Police Department issued a zero tolerance stance on discharging weapons in local communities (*East Palo Alto News*, 29 December 1995). Similarly, headlines in the *Lubbock Avalanche* newspaper recently read: "Ringing in 1997 with bullets, bombs: police and fire officials prepare for illegal New Year's revelry." The article refers to the preparation made by El Paso, Texas, Police and Firefighters for the annual New Year's Eve celebratory showers of bullets. Officials in El Paso indicated that in recent years they have heard semi-automatic gunfire which implies a lot of lead coming back down to earth (*Lubbock Avalanche* – on-line).

Strategies aimed at reducing random gunfire

A variety of problem-oriented strategies have been employed to address the problem of persons indiscriminately discharging weapons into the air. In Dallas, examination of calls for service data revealed that considerable resources were being devoted to the problem of random gunfire. Consequently, the Dallas Police Department (DPD) developed a two-stage approach to address random gunfire in their city (Dallas Police Department Random Gunfire Reduction Proposal, 1995). First, the agency incorporated a new signal code into its computer-aided dispatch system to help delineate problem locations and deploy patrol units accordingly. Second, the DPD initiated a random gunfire reduction program that consisted of aired public service announcements, the distribution of fliers, an award program where residents would be provided monetary compensation for information leading to the apprehension of shooters, and roll call training to inform all patrol officers on newly constructed departmental procedures for handling random gunfire calls. (Dallas Police Department Random Gunfire Reduction Proposal, 1995).

The Board of Directors in the City of New Orleans established a program called the "New Year Coalition" which is responsible for a public awareness campaign comprising billboards and fliers that present messages to the public that random gunfire is dangerous and illegal. This program has television commercials that feature strong messages and images about the dangers associated with celebratory gunfire. While the organization is small and relatively new, the members indicate it is growing at a rapid pace. The chair of the Board of Directors stated that members of the "New Year Coalition" have begun to assist the police with the problem of random gunfire as the New Orleans Police Department does not have the resources to handle this problem alone (personal communication, Chair of New Orleans Board of Directors, 20 October 1997).

In Redwood City approximately four years ago residents of a small community (Redwood Village) mobilized to address the problem of random gunfire in their community. Community residents expressed serious concerns over the extent of random gunfire in the area. A group of community activists enlisted support from neighborhood residents, the upper administration within the Redwood City Police Department, members of City Government and the local television and radio networks. Through numerous news broadcasts both on the radio and on television, community leaders consistently expressed their concerns over the problem of random gunfire. Additionally, City Council as well as Redwood City Police Department's Administration were approached on a regular basis by the community group, stressing the importance of devising strategies to address the problem of random gunfire. The rigorous efforts lobbied by the community group resulted in the Redwood City Police Department initiating a public information campaign about the dangers associated with random gunfire and the punishments associated with performing such illegal activity[2] (Mazerolle *et al.*, 1998).

Gunshot location technology as a problem-solving tool to reduce random gunfire: Redwood City Council approves contract to test an urban gunshot locator system

Recent efforts to reduce random gunfire problems have led some police agencies to try out technological devices to detect and alert the police to incidences of random gunfire. Generically known as gunshot detection systems, the technology is defined as, "acoustic sensing systems capable of identifying, discriminating, and reporting to the police gunshots within seconds of a shot being fired" (Page and Sharkey, 1995, p. 160). Manufacturers of gunshot detection systems expect the technology to increase the ability of the police to get to the scene of a shooting quickly, to increase the number of people arrested for firing weapons, and to reduce the detrimental effects (e.g. injuries, fear, disinvestments) of shots being fired in urban settings.

Random gunshot location technology was implemented in Redwood City in 1997. This technology was designed and manufactured by Trilon Technology and it seeks to identify the location and time of gunfire in a specified target area through a series of acoustic sensor modules. The ShotSpotter system comprises acoustic sensors located in the Redwood City target area (see Figure 1), a central computer located in the Redwood City Police Department's dispatch center, and gunshot detection and location identification software.

The acoustic sensors include microphones, acoustic sensing elements, and gunshot identification electronics. They resemble birdhouses and heating vents and they are enclosed in weatherproof containers that are approximately one cubic foot in size. Six sensors were installed on rooftops of various businesses and residences in the experimental target area (see Figure 1). The sensors are designed to detect muzzle blasts from gunfire or other explosions and then

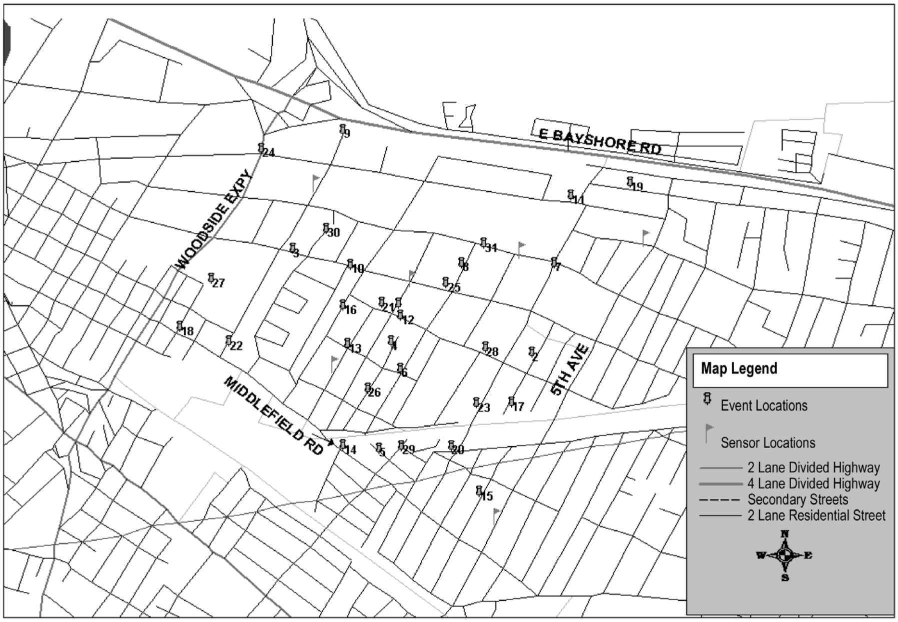

Figure 1.
Event and sensor map

transmit the sound of the gunfire via telephone line or radio to a central computer located in the Redwood City Police dispatch center. The parameter settings of the ShotSpotter software determines the system's level of sensitivity: if the thresholds are set quite high, then background noise is less often identified as gunfire. Conversely, if the thresholds are set quite low, then more background noise has more potential to be incorrectly identified as gunfire[3]. Once the sensors detect a sound and transmit the information to the central computer, the ShotSpotter software discriminates against most other community sounds (such as car backfires, jack hammers, thunder, and barking dogs) and identifies the location of gunfire and explosions. Gunshot events are displayed on a computer map in the police dispatch center within approximately 15 seconds of the noise being made. The computer map distinguishes properties' boundaries including front or side yards, curb sides or street corners (see Figure 2).

The information transmitted from the acoustic sensors in the target area was received by a Sun Microsystems SparcStation 20 computer located in the dispatch center of the Redwood City Police Department. The Sparc 20 system contains an SB-MIO multi-function card from National Instruments which runs the Trilon Software. The Sun Microsystems SparcStation 20 was selected as the operating system due to its ease of connectivity, information processing capabilities, and memory capabilities. The ShotSpotter system stores all waveforms for every detected gunfire event and six seconds of audio from each detecting acoustic sensor. Each potential gunfire event takes up approximately 2.3 megs of memory. As such, a significant amount of hard drive space and system memory is required when numerous gunfire events occur

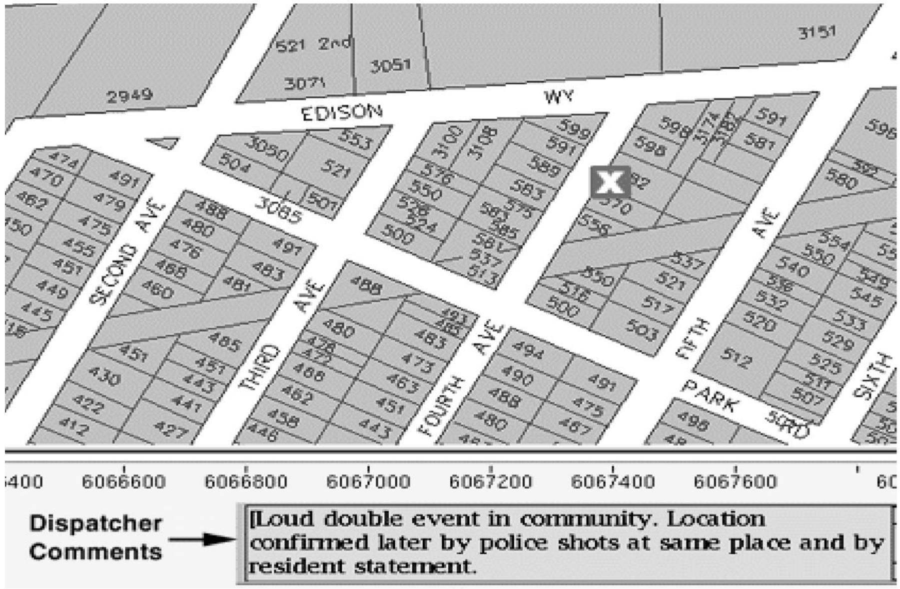

Figure 2.
ShotSpotter computerized map screen

simultaneously or when many noises are relayed to the system in quick succession (i.e. New Year's Eve or 4 July).

Determination of the precise location of gunfire events is conducted through a series of iterations of triangulation algorithms. The system can generate an overview map which presents locations of historical shootings to discern patterns in space or time. The ShotSpotter computer can be placed in a dispatch center with stand-alone or integrated outputs, or it can be at a remote site.

The software routines developed and used by Trilon Technology to detect and identify the location of random gunfire are written in LabVIEW. The LabVIEW software monitors all channels for gunshot sounds and then computes the relative time delays between the detections on the different sensors. The triggering system is programmed to respond when any channel (each acoustic sensor has its own channel) exceeds the programmed threshold levels. The system then checks the event for characteristics of gunshot sounds such as short waveform rise times, abrupt onset of impulses, and variable secondary echoes at each detecting sensor. The locating software does not analyze the other channels unless the trigger signal could be a gunshot. Once the system registers a potential gunshot on one channel, it searches other channels for confirmation of the sound. If four channels register the sound[4], the software then triangulates the system data to identify the gunshot location and displays it on a neighborhood map using LabVIEW's Picture Control Toolkit. Once the ShotSpotter system detects a shot and reports this location on the computer screen, dispatchers can play back a six second snippet of sound from any sensor to assist them in determining what they believe to be the true source of the sound: firecracker string, multiple gunshots, shotgun blast, backfire.

The ShotSpotter system was installed in the Redwood Village target area for 18 months. Trilon was contracted (installation and maintenance) by the Redwood City Police Department and the San Mateo County Sheriff's Office to field test the ShotSpotter system. The University of Cincinnati evaluation team conducted an independent field test of ShotSpotter during June 1997.

Redwood City as a research site

Redwood City is located on the Bay Area peninsula halfway between San Francisco and San Jose, home to approximately 70,000 people covering roughly 23 sq. miles. It is the oldest Bayside City in San Mateo County and has been the County Seat since 1856. The median population age is 33 years old with nearly 70 percent of the population ranging between 18 and 64 years of age. Redwood City's population is 66 percent white, 4 percent African American, and 24 percent Hispanic origin. The unemployment rate in Redwood City is 4.1 percent.

The community comprises commercial, residential, and industrial land usage and nearly 50 percent of housing in Redwood City comprises single-family structures. The average housing cost for a three bedroom, two bathroom house ranges from $350,00 to $390,000 and the average monthly rent for a two bedroom apartment is $1,025.

Experimental site selection

The Redwood City Police Department and the San Mateo County Sheriff's Office agreed to pilot test the ShotSpotter gunshot location system in the Redwood Village area of Redwood City. The experimental test area is policed by both the Redwood City Police Department and the San Mateo County Sheriff's Office. The experimental target area comprises mainly residential housing units mixed with light industrial/commercial enterprises. The terrain in the Redwood Village community is predominately flat and couched between three major thoroughfares: Bayside Freeway, Woodside Expressway and Middlefield Road.

Official data from both the Redwood City Police Department and the San Mateo County Sheriff's Office indicate that the reporting areas comprising Redwood Village were over-represented in total calls for service for random shots fired. Random gunfire calls for service represent less than 1 percent of all calls citywide ($N = 345$ of 72,821 total calls), yet of all random gunfire calls for service citywide 26 percent occurred in the Redwood Village experimental area ($N = 90$) in 1996. Furthermore, random gunfire calls represented 2 percent of all calls in the experimental area (1,279 per 100,000 population) whereas random gunfire calls represented just 0.4 percent of all calls across the rest of Redwood City (367 per 100,000 population).

ShotSpotter field trail design

The primary purpose of the ShotSpotter field trial was to identify its utility as a problem-oriented policing tool. In other words, is this technology a viable system that could aid law enforcement in the identification of random gunfire hotspots? To determine the technology's ability to pinpoint the location of gunfire incidences, it was important to be aware of the possible outcomes that could be generated by the system. The ShotSpotter technology is subject to four possible outcomes: two of these potential outcomes are correct and two constitute errors. When functioning ideally, the detection device emits a warning when confronted with the appropriate stimulus (true positive) and it remains inactive in the absence of the stimulus (true negative). Errors occur when the device emits a warning in the absence of the appropriate stimulus (false positive) or it fails to emit a warning when the stimulus is present (false negative).

To assess whether or not the ShotSpotter technology could accurately identify and locate random gunfire, we originally proposed a controlled field trial of ShotSpotter involving the shooting of blanks and the igniting of 1" firecrackers. Use of both firearms and firecrackers under field trial conditions would have enabled the evaluation team to determine whether or not the gunshot location technology could identify alleged gunfire and delineate between types of discharges. However, due to criminal ordinances against fireworks in Redwood City we were unable to release firecrackers in the experimental test area under field trial conditions. By disallowing firecrackers to be part of the ShotSpotter field trial, we were unable to directly ascertain the false positive rate of the system. Nonetheless, direct measures of true positives, false negatives, and to a lesser extent true negatives were sought from our field trial. This section describes our field trial design and discusses the parameters of the field trial method.

The field trial parameters

Firing test blanks under controlled field trial conditions in order to test the performance of ShotSpotter was approved by the Redwood City Police Department in June 1997. The University of Cincinnati evaluation team worked with the Redwood City Police Department personnel to select weapon types, the number of shots to be fired, and the times and locations from where test shots would be discharged. Based on the most common weapons typically fired in the experimental area, the Redwood City Police Department suggested that three weapon types be used: an MP5 9mm assault rifle, a 12-gauge shotgun, and a .38 caliber pistol. The Redwood City Police Department suggested that the 9mm cartridge is the most common caliber weapon used in the commissions of crime. Furthermore, they also indicated that a 9mm caliber weapon, a 12-gauge shotgun, and a .38 caliber pistol would be a representative cross-section of the caliber of weapons most commonly fired by offenders in the Redwood City area.

Negotiating the field trial

The Redwood City Police Department allowed the evaluation team to conduct the field test during two time periods: 10.00 a.m. to 3.00 p.m. and 7.00 p.m. to

10.00 p.m. These times were set by the Police Department in conjunction with Trilon Technology because they avoided heavy traffic hours (rush hour in the morning and rush hour in the evening) and they would not interfere with the majority of residents' sleeping patterns. Avoiding heavy traffic hours decreased the possibility of false positive alerts during our field trial as reduced levels of background noises were somewhat artificially restricted (i.e. car backfires and car horns) through this process. We acknowledge that, in real life situations, such background noises cannot be ignored. However, given the fact that blanks were used as opposed to live rounds (blank rounds result in the ShotSpotter system registering of wave forms characterized by lower amplitudes) and that the evaluation team wanted to provide the best possible atmosphere for system validation, it was determined that these hours were adequate for our field trial.

Two major factors were considered in our negotiations with the Redwood City Police Department about the number of gunshot events in the ShotSpotter field trial: how many total gunshot events would be needed to provide a fair test of the ShotSpotter system; and how many rounds could be discharged without creating an uproar in the Redwood Village community? The Redwood City Police Department, the evaluation team, and Trilon Technology agreed that 32 test events[5] would be a fair compromise. Once the types of weapons to be used, the number of shots to be fired, and the time frames were agreed upon, the evaluation team had to determine the location of each shot, the type of weapon to be used at each location, as well as the number of rounds to be discharged at each location.

Sample

To determine the location of the test shots, the evaluation team employed a multistage random sampling design. We started with an extensive examination of the locations of random gunfire in the Redwood City calls for service data that corresponded to the address ranges in the experimental test area. The call data revealed both hot spots and cold spots for random gunfire in the experimental area. Hot spots were defined as face blocks or intersections with one or more random gunfire incidents in the past year. Alternatively, cold spots were defined as face blocks or intersections with no incidences of random gunfire in the past year. The evaluation team identified 134 intersections and face blocks with at least one call for service for a random gunfire incident and 164 intersections and face blocks with no calls for service for a random gunfire incident from 1 January to 31 December 1996 in the Redwood City test site. We proceeded to randomly select 22 hot spots from the 134 hot locations and ten cold spots from the 164 cold spots to generate the 32 test face blocks and intersections for the field trial ($N = 32$)[6].

Once these 32 locations were identified, the evaluation team had to select specific addresses (either on a face block or an intersection) from these hot and cold spot locations in order to specify the precise location from where test rounds would be fired. Of the 22 hot spots we randomly identified 19 face block addresses and three intersections as the locations where shots would be fired. Similarly, from the ten cold spots, eight face block addresses and two intersections were selected as test shot locations.

Similar to the random assignment of shot location, the evaluation team randomly assigned the type of weapon to be discharged as well as the number of test rounds for each unique test location. With 32 test locations established and 80 test rounds permitted to be fired, the evaluation team determined, through random assignment, which locations would receive one shot or bursts of two, three, or four shots. Similarly, weapon types were randomly allocated across the 32 test locations. As such, the evaluation team knew a priori where each weapon would be discharged as well as the type of weapon and number of rounds to be discharged at each randomly selected address.

Methodology

One member of the evaluation team was stationed in the police dispatch center with a Trilon technician. Another member of the evaluation team was in the field with a sworn officer from the Redwood City Police Department. The person on site with the Trilon technician was in constant contact with the researcher in the field by means of cellular phone. The field researcher's responsibility was to verify the location, weapon type, and number of rounds to be fired based on the sampling decisions. This enabled the evaluation team to compare data recorded in field notes from the actual shot locations against data generated by the ShotSpotter system. The primary responsibilities of the researcher in the field were to: direct the officer to each randomly selected address; instruct the officer as to the type of weapon to be discharged; and direct the officer as to the number of rounds to be fired at each location. The researcher in the field kept in constant contact with the researcher in the dispatch center to ensure that locations and times were correct, weapon selections were correct, and number of rounds fired was correct. The police officer in the field, the dispatchers, and Trilon Technicians did not know where the shots would be fired from, when the shots would be fired, the types of weapon, or number of rounds prior to arrival at each test site.

Field problems

One of the six sensors malfunctioned during our field trial causing ShotSpotter to fail three times. These three events were repeated and we count the repeat test shots in the write up of our results. This type of adjustment offers important insights into the field reality of a gunshot detection device like ShotSpotter. Technically, our evaluation team could have counted all gunshot events that were scheduled to occur during the period of the downtime as false negatives if indeed the system failed to detect the gunfire events. There was a high probability, however, that one of the other functioning sensors would have detected the shot anyway. Since our evaluation team was limited to very few field trial events ($N = 32$) over the course of just two days, we chose to postpone the scheduled trial shots until the one malfunctioning sensor was back on line.

Our caveat, therefore, in reporting these field trial results is that the amount of downtime of a system like ShotSpotter could significantly impact the rates of system failures to detect gunfire[7].

Field trial results

The performance of the ShotSpotter system was assessed based on the following outcomes. First, did the ShotSpotter technology automatically annunciate and triangulate the shot location (true positive) or completely fail to annunciate or triangulate the shot location (false negative)? Second, did the technology annunciate the shot yet fail to triangulate the true shot location? If triangulation failure occurred, could Trilon technicians take the information received from the system, adjust the software and then re-triangulate the shot location manually (system experts could adjust system triangulation algorithms provided a shot was annunciated and then attempt to re-triangulate to identify shot event locations). Next, we assessed the margin of error (in feet) in the gunshot location system's identification capabilities. Finally, we explored the effect of the number of shots fired per location on the likelihood of system detection and identification.

Table I provides a case by case description of each gunfire event in the ShotSpotter field trial by date, and time of shot, location and type of location, number of rounds fired, type of weapon used, the system parameter settings for each gunfire event, whether the shot was annunciated by the system, whether the system triangulated the event, and the margin of error in feet.

A total of 81 shots were discharged across 32 event locations in the Redwood Village field trial. The evaluation team only reports 78 shots from 31 event locations as legitimate tests of the ShotSpotter system due to media coverage and interference with the first three test shots. All parties involved agreed from the outset that the media could be present at the initiation of the ShotSpotter evaluation. This agreement was made given the demands by the community to be involved in the field trial of the gunshot location technology. More importantly, for purposes of the field trial, Trilon Technology was aware of the time and location of the first three shot test event prior to its occurrence. For this reason we do not include the first shot event in our evaluation of the gunshot location system.

Table II presents the results of the field trial, examining the breakdown of results for each weapon type and each of the evaluation outcomes (identification, triangulation, error margin). Table II shows that of the 31 gunshot events, five consisted of MP5 assault rifle rounds, 11 consisted of .38 caliber pistol rounds, and nine consisted of 12 gauge shotgun rounds. Overall, the ShotSpotter technology annunciated 81 percent of the shot events ($N = 25$). Specifically, the technology annunciated 12 gauge shotgun events at the highest rate (90 percent) followed by pistol event (85 percent) and MP5 9mm assault rifle events (63 percent).

To determine the system's ability to triangulate shot event locations, we examined whether the system identified a gunshot location on its own (automatically), with assistance from a Trilon technician (manually), or was

Table I.
Event by event description of ShotSpotter field trial

	Date of event	Time of event (military time)	Event location	Event location type	No. of shots per event	Event weapon type	Annunciation Yes No	Triangulation Auto Manual Missed	Margin of error (in ft)
Event 1[a]	26.6.97	1854:57;1855:02;08	1061 Douglas St.	Face block	3	Rifle	No	Missed	–
Event 2	26.6.97	1925:35;38	711 3rd Av.	Face block	2	Shotgun	Yes	Manual	25
Event 3	26.6.97	1929:16	2424 Spring St.	Face block	1	Rifle	No	Missed	–
Event 4	26.6.97	1949:32;34	2820 Crocker Av.	Face block	2	Pistol	Yes	Auto	45
Event 5	26.6.97	1942:32	644 Stanford Av.	Face block	1	Shotgun	Yes	Manual	13
Event 6	26.6.97	2002:53:54	Warrington/Halsey	Intersection	2	Shotgun	Yes	Auto	13
Event 7	26.6.97	2010:10;11;13	888 2nd Av.	Face block	3	Pistol	Yes	Manual	154
Event 8	26.6.97	2015:14;15	861 Warrington Av.	Face block	2	Rifle	Yes	Manual	162
Event 9	26.6.97	2020:23;25	Charter at Cul de Sac	Intersection	2	Rifle	No	Missed	–
Event 10	26.6.97	2027:37;39	2524 Spring St.	Face block	2	Pistol	Yes	Manual	20
Event 11	26.6.97	2038:52;39;03	475 Broadway	Face block	2	Rifle	No	Missed	–
Event 12	26.6.97	2049:11;12;15	2742 Fair Oaks Av.	Face block	3	Shotgun	Yes	Auto	16
Event 13	26.6.97	2055:35;38;45	McArthur/Halsey	Intersection	3	Rifle	Yes	Manual	27
Event 14	26.6.97	2106:32;33	Pacific/Middlefield	Intersection	2	Pistol	Yes	Auto	27
Event 15	26.6.97	2114:29;30;32;34	473 4th Av.	Face block	4	Rifle	Yes	Manual	15
Event 16	26.6.97	2129:11:13	765 Douglas Av.	Face block	2	Shotgun	Yes	Auto	22
Event 17	27.6.97	1142:39;40	622 3rd Av.	Face block	2	Pistol	Yes	Manual	10
Event 18	27.6.97	1159:55;56	2205 Middlefield Av.	Face block	2	Shotgun	No	Manual	200
Event 19	27.6.97	1211:04;05;05	3117 Hoover St.	Face block	3	Pistol	No	Missed	–
Event 20	27.6.97	2023:21;22;22	3051 Edison Way	Face block	3	Pistol	Yes	Auto	30

(continued)

Table I.

	Date of event	Time of event (military time)	Event location	Event location type	No. of shots per event	Event weapon type	Annunciation Yes No	Triangulation Auto Manual Missed	Margin of error (in ft)
Event 21	27.6.97	2034:45;46	2663 Fair Oaks Av.	Face block	2	Rifle	Yes	Manual	30
Event 22	27.6.97	2039:51;52	560 Charter Av.	Face block	2	Pistol	Yes	Auto	15
Event 23	27.6.97	2043:35;36	615 2nd Av.	Face block	2	Shotgun	Yes	Auto	25
Event 24	27.6.97	2050:54;55	Woodside/Broadway	Intersection	2	Shotgun	Yes	Auto	45
Event 25	27.6.97	2051:38;39;39	2793 Spring St.	Face block	3	Pistol	Yes	Auto	25
Event 26	27.6.97	2101:23;24	540 Stanford Av.	Face block	2	Shotgun	Yes	Auto	50
Event 27	27.6.97	2113:23;24	1109 Hilton St.	Face block	2	Shotgun	Yes	Auto	15
Event 28	27.6.97	2121:33;34;35	2965 Fair Oak Av.	Face block	3	Rifle	Yes	Manual	10
Event 29	27.6.97	2128:38;39;39	451 Dumbarton Av.	Face block	3	Pistol	Yes	Auto	25
Event 30	27.6.97	2134:47;48	871 Kaynyne Av.	Face block	2	Pistol	Yes	Auto	15
Event 31	27.6.97	2137:24;24;24	2766 Bay Rd.	Face block	3	Pistol	No	Missed	–
Event 32	27.6.97	2144:38;38	708 Hurlingame Av.	Face block	2	Pistol	Yes	Manual	20
Totals	Two days			26 face blocks; five intersections	78 test shots	Ten shotguns; 13 pistols; eight rifles	25 events + annunciation; six events – annunciation	14 events auto; 12 events manual; five events missed	41ft (average margin error)

Notes: [a]Event 1 is not included in the calculation totals because the time and location of the gunshot event was known a priori by Trilon Technology. This was done primarily to permit media coverage

Table II. Field trial results by weapon type

	Total gunfire events	Number of events annunciated annunciated	Percent of events annunciated	Number of events triangulated			Percent of events triangulated			Error margin (in ft)		
				Auto	Manual	Missed	Auto	Manual	Missed	Auto	Manual	Missed
Rifle	8	5	63*	0	5	3	0*	63*	37*	–	48[a]	48
Pistol	13	11	85*	7	4	2	54*	31*	15*	26	51[b]	35
Shotgun	10	9	90*	7	3	0	70*	30*	0*	27	79[c]	41
Total	31	25	81	14	12	5	45	39	16	26.5	59[d]	41

Notes: [a]Removal of event 8 (162ft error in manual location) results in error rate of 22ft for manually located rifle events; [b]removal of event 7 (154ft error in manual location) results in error rate of 17ft for manually located pistol events; [c]removal of event 18 (200ft error in manual location) results in error rate of 19ft for manually located shotgun events; [d]removal of events 7, 8 and 18 (154, 162 and 200ft errors in manual locations) results in overall error rate of 19ft for manually located events; *Phi = 0.407 $p < 0.07$

unable to identify the shot location (missed). Automatic triangulation refers to the system identifying the location of gunfire through a series of algorithmic iterations given the established parameters of the system. Alternatively, manual triangulation refers to the system identifying the location of gunfire only after a Trilon technician adjusts the system parameters. The system was then allowed to reexamine those sensors for shot locations through a similar series of algorithmic iterations given the newly established parameter settings. Finally, we documented those instances where the ShotSpotter system was unable to identify shot locations.

Overall, the system was able to triangulate shot locations 84 percent of the time within an average margin of error of 41ft (see Table II). In terms of automatic identification, ShotSpotter was able to isolate shot locations 45 percent of the time with a margin of error of 26.5ft. With assistance from a Trilon technician, ShotSpotter was able to locate an additional 39 percent of the gunshot events within an average range of 59ft. Shotgun rounds had the highest rate of triangulation at 100 percent ($N = 10$ out of ten events) with an overall margin of error of 41ft. Pistol rounds were triangulated 85 percent of the time ($N = 11$ out of 13 events) within a 35ft margin of error followed by the MP5 assault rifle which was triangulated 63 percent of the time ($N = 5$ out of eight events) within a 48ft margin of error)[8].

Table III presents the results from the analysis of hot and cold spots of random gunfire by identification type. This table shows that the ShotSpotter technology was more likely to identify shot event locations in areas with high incidences of random gunfire as compared to areas with low incidences of gunfire. We notice two striking findings from Table III. First, the ShotSpotter technology was much more likely to identify shot events occurring in hot areas than in cold areas. Specifically, two of 21 shot events were missed (whether the system identified the shot on its own or after adjustment) in citizen-identified hot areas as compared to four of ten shot events in citizen-identified cold areas. Second, when the system did not automatically identify the gunshot event in cold areas, it was less likely that adjustment of the software would yield a location for the shot event than when adjustments were made to triangulate the shot location for hot spots. That is, only two more shot events could be

	Automatically identified	Software adjusted and identified	Missed and not identified	Total
Hot spots	10	9	2	21*
Percentage	48	43	9	
Cold spots	4	2	4	10*
Percentage	40	20	40	
Total	14	11	6	31
Percentage	45	36	19	100

Note: *Phi = 0.361 $p < 0.05$

Table III. Hot spots/cold spots by identification type identified in cold areas (20 percent increase) as a result of software adjustment as compared to a 43 percent increase in hot areas.

Table IV examines whether type of weapon discharged in a hot or cold area increases or decreases the likelihood of detection. The table reveals that both pistol events (11 out of 12) and shotgun events (nine out of ten) were the weapon types most likely to be detected. Alternatively, gunshot events where the assault rifle was discharged were least likely to be detected (five out of nine) by the ShotSpotter system.

Finally, we explored the system's detection and identification capabilities when the number of shots varied across events. Table V indicates that of the 31 events where test shots were fired, one event consisted of four shots, nine events consisted of three shots, 19 events consisted of two shots and two events consisted of one test shot. Comparison of detection rates based on the number of shots fired per event indicate that detection was most likely when more than one shot was fired. Specifically, 100 percent of the four shot events were detected, 84 percent of the two shot events were detected, 78 percent of the three shot events were detected, and 50 percent of the one shot events were detected. Close examination of Table V also indicates that when multiple shot events

Table IV. Hot spot/cold spots by weapon type

	MP5 (assault rifle)		Pistol (.38 caliber)		Shotgun (12 gauge)		
	Detect	Not detect	Detect	Not detect	Detect	Not detect	Total
Hot spot events	5	1	6	0	8	1	21*
Percentage	24	5	28	0	38	11	100
Cold spot events	0	3	5	1	1	0	10*
Percentage	0	30	50	10	10	0	100
Total	5	4	11	1	9	1	31
Percentage	18	3	39	3	36	0	100

Notes: *Phi = 0.359 $p < 0.10$

Table V. Detection/identification by number of shots per event

Shots per event	Number of events	Event weapon type	Annunciation Yes	Annunciation No	Triangulation Auto	Triangulation Manual	Triangulation Missed
4	1	1 Rifle	1	0		1	
Total			1 (100%)	0 (0%)			
3	9	2 Rifle	2	0		2	
		6 Rifle	4	2	3	1	2
		1 Shotgun	1	0	1		
Total			7 (78%)	2 (22%)			
2	19	4 Rifle	2	2		2	2
		7 Pistol	7	0	4	3	
		8 Shotgun	7	1	6	1	1
Total			16 (84%)	3 (16%)			
1	2	1 Rifle	0	1			1
		1 Shotgun	1	0		1	
Total			1 (50%)	1 (50%)			

occurred, shotgun events were automatically triangulated at the highest rate (seven out of nine events or 78 percent) followed by pistol events (seven out of 13 events or 54 percent) and rifle events (nought out of seven events or 0 percent). Furthermore, rifle events were most likely be missed when the system tried to automatically triangulate the location of an event (three out of eight rifle events or 38 percent versus 15 percent for pistol events and 10 percent for shotgun events).

Conclusion

The ShotSpotter gunshot location system was installed in Redwood City, California by Trilon Technology in 1996. The University of Cincinnati evaluation team conducted a field test of the ShotSpotter system in June of 1997. Redwood City, and in particular Redwood Village, was selected as the site for which this technology would be tested due to its high annual incidence of random gunfire: the rate of random gunfire in the test site (1,279 per 100,000 people) was substantially higher than the city wide rate (367 per 100,000 people). Field testing in Redwood Village comprised the installation of six acoustic sensor modules on various rooftops of residences and buildings in the experimental target area and a base station computer installed in the Redwood City Police Department's dispatch center.

Using police calls for service data, the Cincinnati evaluation team randomly selected 32 event locations from where test rounds would be discharged. Of these 32 event locations, shots were discharged from 27 face block addresses and five intersection addresses. The Redwood City Police Department, under the supervision of the Cincinnati evaluation team, discharged blank rounds into the air at the selected face block and intersection addresses. In addition to the random selection of shooting event locations, three types of weapons and the number of rounds to be fired from each weapon were randomly assigned to each of the selected locations. The weapons used in the ShotSpotter field trial were a .38 caliber pistol, a 12 gauge shotgun, and an MP5 9mm assault rifle. Finally, the number of shots fired at each event varied from one to four shots.

System performance

Results from the firing of test rounds indicated that overall, the gunshot location technology was able to detect gunshots at 81 percent of the event locations. Specifically, the technology annunciated shotgun rounds at the highest rate (90 percent) followed by pistol rounds (85 percent) and the assault rifle rounds (63 percent). Moreover, the firing of test rounds revealed that ShotSpotter was able to triangulate (locate) gunshots at 84 percent of the event locations within an average margin of error of 41ft. Shotgun events had the highest rate of triangulation at 100 percent with an overall margin of error of 41ft. Pistol events were triangulated 85 percent of the time within a 35ft margin of error followed by the MP5 9mm assault rifle which was triangulated 63 percent of the time within a 48ft margin of error.

Further, examination of ShotSpotter's ability to triangulate shots at designated event locations when broken down by type of location (hot versus cold spot) indicated two striking findings. First, the ShotSpotter technology was more likely to identify gunshots fired in hot spot locations rather than in cold spot locations. Specifically, only two of 21 shots (less than 1 percent) were missed in citizen identified hot areas as compared to four out of ten shots (40 percent) in citizen identified cold areas. Second, when the system did not automatically identify the gunshot in cold areas, it was less likely that adjustment of the software would yield a location for the shot fired than when adjustments were made to triangulate the shot location for hot spots. That is, only two more shots could be located in cold areas (20 percent increase) as a result of software adjustment as compared to the location of an additional nine shots in hot areas (43 percent increase).

Finally we assessed the system's ability to detect and identify single versus multiple shot events. The results of the analysis indicate that detection was most likely when more than one shot was fired. Specifically, 100 percent of the four shot events were detected, 84 percent of the two shot events were detected, 78 percent of the three shot events were detected, and 50 percent of the one shot events were detected. Furthermore, the field trial indicates that when multiple shot events occurred, shotgun events were automatically triangulated at the highest rate followed by pistol events and rifle events.

Overall, our field trial shows that the ShotSpotter system has a high degree of accuracy both in terms of detection and the margin of error when:

- the system is not malfunctioning;
- the system is located where propagation paths are less likely to be blocked (e.g. places that repeatedly identify random gunfire (hot spots) as opposed to those places that appear to be cold spots); and
- more system sensors pick up the sound wave and enable more data to triangulate the precise location of the gunfire.

With these caveats in mind, we offer some important insights into the range of uses for gunshot location technology in law enforcement.

Based on the results from the field trial and the data collected from focus groups, and from officer surveys, we propose that gunshot location technology could enhance police problem-solving capabilities. Moreover, this technology could contribute to the reduction and prevention of community crime and disorder.

Gunshot location systems as a problem-solving tool

Problem-oriented policing requires the police to scan an area (police beat, city, suburban area) for problem hot spots, analyze the dimensions of the problem, develop responses to tackle the problem, and then assess the impact of the responses (see Eck and Spelman, 1987; Goldstein, 1990). Using gunshot location systems as a problem-solving tool is consistent with the recent paradigm shift in policing away from traditional, rapid response-type approaches to policing toward community policing and problem-solving. As opposed to traditional reactive practices, law enforcement might embrace gunshot technology to assist them in identifying and responding to gunfire hot spots within a problem-oriented policing context.

First, gunshot location technology could assist law enforcement in the scanning phase in two fundamental ways. It could aid law enforcement in their efforts to accurately identify and pinpoint the locations of recurring gunfire problems. Specifically, these systems could quickly and more effectively provide accurate information about the near exact location from where a shot was discharged. Citizens, unless actually observing a particular suspect discharging a weapon, may not provide accurate location information or may elect not to report the incident. This technology could also be used to identify and generate information about potential emerging gunfire hot spots. In this instance, it is imperative that gunshot location technology consist of components that are highly portable. The acoustic sensors used to identify gunfire and its respective location must be easily moved to a number of different areas across a city landscape to accommodate localized problems or newly emerging problems. Furthermore, the repeaters that receive and transmit sensor information must also be easily relocated to different problem locations.

Second, gunshot systems have the potential to improve police problem-solving efforts by providing accurate gunshot location data that could be used to help analyze and generate solutions for curtailing community gunfire. Specifically, weekly and monthly maps of gunfire distributions generated by the system could be merged with police data (e.g. citizen calls about random gunfire, random gunfire incident reports, arrests for random gunfire, field interrogation reports), physical features of problem areas (e.g. trees, buildings, playing fields, road networks), and social features of target areas (e.g. ethnicity, income, gun ownership levels) to provide a comprehensive picture of the problem. Analysts and investigators could then use these multiple data sources to identify innovative responses to the problem. One innovative response could be the integration of gunshot location technology with a reverse 911 dialing system. More specifically, the gunshot location technology could alert the reverse dialing system as to the location of gunfire that in turn could contact residents or commercial/industrial business owners and inform them that shots were fired in the immediate vicinity.

Finally, gunshot location technology could assist police in the last phase of the problem-solving venue: response analysis. The data from the gunshot location system could be used along with citizen call data to develop baseline measures of a location's gunfire problem. Then, over time, data could be compiled to help gauge the impact of tried interventions on this problem. Results from the response analysis could then be used to improve upon implemented problem-solving interventions or lead to the construction of new gunfire reduction and prevention approaches.

Gunshot location systems as a crime prevention tool

An added benefit of gunfire location technology could be its contribution to law enforcements' crime reduction and prevention efforts. As a crime prevention tool, gunshot location systems could be implemented in neighborhoods or hotspots that are identified as places in decline (see Skogan, 1990; Wilson and Kelling, 1982). These places may not necessarily have high rates of random gunfire, but the demographic trends (e.g. age, ethnicity, rate of gun ownership) and emerging crime patterns would suggest that the neighborhood street or block could be in the early stages of decline. Gunshot location systems could be implemented for short periods of time in these types of neighborhoods in order to extend the ability of police to monitor, respond to, and prevent criminal behavior.

The use of gunshot location systems for crime prevention purposes, like its applicability as a problem-solving tool, necessitates system portability. Assuming the adaptation of the technology for portable use, we imagine that gunshot location systems could be utilized for crime prevention purposes through several types of initiatives: first, akin to burglar alarm signs (or crime prevention signs generally), we propose advertising areas with gunshot location system pole units (or acoustic sensors) as gunshot detection zones; second, we suggest that community knowledge and involvement in the installation of a gunshot location system in a high risk area could deter some categories of offenders; third, moving gunshot location system pole units from location to location on a strategic basis could effectively increase the surveillance zone of the gunshot location technology without increasing many of the costs involved in leasing or purchasing the system. We explore these possible crime preventive uses of gunshot location systems below.

Advertising the presence of a crime preventive measure is an emerging strategy in the fight against crime. Such an approach supplements the actual implementation of security measures. For instance, it is not uncommon to see Neighborhood or Block Watch signs posted on utility poles in residential communities throughout the USA. Similarly, signs advertising residential burglar alarms and car theft alarms are also commonplace in today's society. As Lab (1997, pp. 6-7) indicates, "the idea behind such approaches is that, potential offenders will not commit a crime if they perceive citizen activity, awareness, and concern in an area." This idea supports Wilson and Kelling's (1982) and later Clarke's (1992) claims that setting rules demonstrates that someone cares. We propose that the benefits of gunshot location systems could be extended by strategically locating signs reading gunshot detection zone in chronic problem areas or in areas determined to be newly emerging problem zones. The implementation of technological innovations not only helps the police detect and respond to deviant behavior, but the accompanying advertisement of technology is value-added to the potential effectiveness of the technology in that it may prevent deviant behavior.

A second example of how technology can be used to gain a crime prevention effect is through eliciting support and involvement from the community. We argue that the introduction of technology can act as a deterrent when a community embraces the use of technology to control crime problems. Whether the technology has a real and positive impact on the crime problem becomes a secondary concern when the perceived effect of technology among local community members is that it can reduce the crime problem.

The strategic locating of surveillance technology, such as speed cameras, is a third example of how technology can be used for crime preventive purposes (Bourne and Cooke, 1993). In Victoria, Australia, for example, speed cameras were introduced, along with several other programs, in an effort to reduce the amount of driving-related deaths and injuries. However, since the cost of speed cameras prohibited installation of cameras on every street, the Victorian Police Department implemented a program to locate periodically the cameras in areas identified as speed zones. This method extended the geographic area covered by the technology and had the potential to increase the crime control effects of the technology. The innovative use of the speed cameras reduced both the number of traffic fatalities and the number of speeders (Bourne and Cooke, 1993). Law enforcement could embrace a similar approach with gunshot location technology. Agencies could relocate gunfire location systems to areas determined to be problem gunfire areas as determined by citizen calls for service, citizen complaints, and other informational sources.

While the addition of new technologies to police departments may or may not enhance police effectiveness, technological innovations can perhaps involve unwanted police entrance into the private lives of citizens. The use of various video devices or listening devices raises laudable concerns about violations of individuals' Fourth Amendment rights. Specifically, in *Katz* vs *US* (1967) it was established that, "... any form of electronic surveillance, including wiretapping, is a search and violates a reasonable expectation of privacy." The use of video surveillance and audio surveillance equipment in the context of detecting random gunfire is done in a public setting. As such the intent is clearly on monitoring public places not people, and is consistent with the Supreme Court's interpretation that the Constitution protects people and not places. Certainly, if these forms of surveillance become commonplace in police departments in the USA, it can be expected that the constitutionality of monitoring public places will become an issue for debate. For now, however, programs for policing places with random gunfire problems should be developed and implemented with three main questions in mind: how should target areas be selected; what techniques work; and under what conditions can these programs provide a fair, yet successful, means to control incidences of random gunfire?

Notes

1. Devil's Night occurs at the end of October prior to Halloween. This night frequently consists of many individuals engaging in deviant behaviors ranging from vandalizing automobiles to setting fires.
2. The Redwood City Police Department issued a challenge to all residents in the gunshot riddled community of Redwood Village. Every resident that turned in a neighbour who was illegally discharging a firearm would be rewarded with $500.

3. Muzzle blasts from gunfire have distinctive waveforms as do the sounds from other similar sources. However, the setting parameters determine what level of extraneous noise will trip the system. Hence, the more rigorous the parameter settings, the less likely it is that jack hammers, thunder and car backfires will set the system off (increase the rate of true negatives). Alternatively, the less rigorous the parameter settings, the more likely it is that extraneous noise will trip the system (increase the rate of false positives).
4. The ShotSpotter system in Redwood City used the four channel criteria as a basic system parameter. The system can be set so that only one channel is required for system initiation. Alternatively, the system can be set so that many channels are required to initiate the system (theoretically, as many channels of sensors as required before the system will register a gunshot – eight in the case of Redwood City).
5. In establishing that 32 test events would be acceptable the Redwood City Police Department agreed that 80-test shots could be discharged across the range of 32-event locations.
6. Thirty-two test locations were selected as sites to fire rounds. However, given the extensive media coverage of the first test location, the evaluation team chose to exclude the first shot location from this analysis. As such, this analysis reports from 31 test locations.
7. We have asked Triton Technology for data on the system downtime. However, to date we have been unable to obtain such information. The software for the system appears to be such that routines to download the downtime information is not written and thus the company cannot supply this information at this time. We note that estimates of downtime for another gunshot detection system that was pilot tested in Dallas, during 1996 indicates that the system was down approximately 11.9 percent of the time that it was being monitored (10,349 minutes of total running time of 76,740 minutes). We have no way of estimating, however, the similarities or differences between downtimes across sites or systems (see Mazerolle *et al.,* 1998).
8. While it appears that the system may more accurately locate pistol rounds than shotgun rounds (35ft versus 41ft) it must be observed that automatic triangulation of both events suggests nearly identical error rates (26ft versus 27 ft). Further, when excluding the two problematic cases (seven and 18) comparison of manually triangulated shot locations suggest nearly identical error rates (17ft versus 19ft).

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