PROBLEM-ORIENTED GUIDES FOR POLICE
RESPONSE GUIDE SERIES NO. 14

GUNSHOT DETECTION

Reducing Gunfire through Acoustic Technology

Dennis Mares

This project was supported by agreement #2019-WY-BX-K001 awarded by the Bureau of Justice Assistance, U.S. Department of Justice. The opinions contained herein are those of the author(s) and do not necessarily represent the official position or policies of the U.S. Department of Justice. References to specific agencies, companies, products, or services should not be considered an endorsement of the product by the author(s) or the U.S. Department of Justice. Rather, the references are illustrations to supplement discussion of the issues.

https://bja.ojp.gov/

CNA Document Number: IIM-2022-U-033303

October 2022

TABLE OF CONTENTS

ABOUT THIS GUIDE

ABOUT THE SMART POLICING INITIATIVE PROBLEM-ORIENTED GUIDES

In 2013, the Bureau of Justice Assistance (BJA) funded CNA to work with the Center for Problem-Oriented Policing to develop a series of *Smart Policing Initiative (SPI) Problem-Oriented Guides for Police.* The purpose of these guides is to provide the law enforcement community with useful guidance, knowledge, and best practices related to key problem-oriented policing and Smart Policing principles and practices. These guides add to the existing collection of *Problem-Oriented Guides for Police.*

SPI is a BJA-sponsored initiative that supports law enforcement agencies in building evidence-based and data-driven law enforcement tactics and strategies that are effective, efficient, and economical. Smart Policing represents a strategic approach that brings more "science" into police operations by leveraging innovative applications of analysis, technology, and evidence-based practices. The goal of SPI is to improve policing performance and effectiveness while containing costs, an important consideration in today's fiscal environment.

The SPI is a collaborative effort between BJA, CNA (the SPI training and technical assistance provider), and over 40 local law enforcement agencies that are testing innovative and evidence-based solutions to serious crime problems.

For more information about the Smart Policing Initiative, visit www.smartpolicinginitiative.com.

ABOUT THE RESPONSE GUIDES SERIES

The *Response Guides* are one of three series of the *Problem-Oriented Guides for Police*. The other two are the *Problem-Specific Guides* and *Problem-Solving Tools*.

The *Problem-Oriented Guides* for Police summarize knowledge about how police can reduce the harm caused by specific crime and disorder problems. They are guides to preventing problems and improving overall incident response, not to investigating offenses or handling specific incidents. Neither do they cover all the technical details about how to implement specific responses. The guides are written for police—of whatever rank or assignment—who must address the specific problems the guides cover. The guides will be most useful to officers who

- understand basic problem-oriented policing principles and methods,
- can look at problems in depth,
- are willing to consider new ways of doing police business,
- understand the value and the limits of research knowledge, and
- are willing to work with other community and government agencies to find effective solutions to problems.

The *Response Guides* summarize knowledge about whether police should use certain responses to address various crime and disorder problems, and about what effects they might expect. Each guide

- describes the response,
- discusses the various ways police might apply the response,
- explains how the response is designed to reduce crime and disorder,
- examines the research knowledge about the response,
- addresses potential criticisms and negative consequences that might flow from use of the response, and
- describes how police have applied the response to specific crime and disorder problems, and with what effect.

The *Response Guides* are intended to be used differently from the *Problem-Specific Guides*. Ideally, police should begin all strategic decision-making by first analyzing the specific crime and disorder problems they are confronting, and then using the analysis results to devise particular responses. But certain responses are so commonly considered and have such potential to help address a range of specific crime and disorder problems that it makes sense for police to learn more about what results they might expect from them.

Readers are cautioned that the *Response Guides* are designed to *supplement* problem analysis, not to *replace it*. Police should analyze all crime and disorder problems in their local context before implementing responses. Even if research knowledge suggests that a particular response has proved effective *else*where, that does not mean the response will be effective *every*where. Local factors matter a lot in choosing which responses to use.

Research and practice have further demonstrated that, in most cases, the most effective overall approach to a problem is one that incorporates several different responses. So, a single response guide is unlikely to provide you with sufficient information on which to base a coherent plan for addressing crime and disorder problems. Some combinations of responses work better than others. Thus, how effective a particular response is depends partly on what other responses police use to address the problem.

These guides emphasize effectiveness and fairness as the main considerations police should consider in choosing responses but recognize that they are not the only considerations. Police use particular responses for reasons other than, or in addition to, whether they will work, and whether or not they are deemed fair. Community attitudes and values, and the personalities of key decision-makers, sometimes mandate different approaches to addressing crime and disorder problems. Some communities and individuals prefer enforcement-oriented responses, whereas others prefer collaborative, community-oriented, or harm-reduction approaches. These guides will not necessarily alter those preferences but are intended to better inform them.

These guides have drawn on research findings and police practices in the United States, the United Kingdom, Canada, Australia, New Zealand, the Netherlands, and Scandinavia. Even though laws, customs and police practices vary from country to country, it is apparent that the police everywhere experience common problems. In a world that is becoming increasingly interconnected, it is important that police be aware of research and successful practices beyond the borders of their own countries.

Each guide is informed by a thorough review of the research literature and reported police practice, and each guide is anonymously peer-reviewed by a line police officer, a police executive and a researcher prior to publication. CNA, which solicits the reviews, independently manages the process. For more information about problem-oriented policing, visit the Center for Problem-Oriented Policing online at ***www.popcenter.org***. This website offers free online access to:

- the *Problem-Specific Guides* series,
- the companion *Response Guides* and *Problem-Solving Tools* series,
- special publications on crime analysis and on policing terrorism,
- instructional information about problem-oriented policing and related topics,
- an interactive problem-oriented policing training exercise,
- an interactive *Problem Analysis Module*,
- online access to important police research and practices, and
- information about problem-oriented policing conferences and award programs.

ACKNOWLEDGMENTS

The *Problem-Oriented Guides* for Police are produced by the Center for Problem-Oriented Policing at Arizona State University. While each guide has a primary author, other project team members, CNA and BJA staff, and anonymous peer reviewers contribute to the guides by proposing text, recommending research, and offering suggestions on format and style.

The project team that developed the guide series comprised Herman Goldstein, Ronald V. Clarke, John E. Eck, Michael S. Scott, Rana Sampson, and Deborah Lamm Weisel. Members of the San Diego, California; National City, California; and Savannah, Georgia, Police Departments provided feedback on the guides' format and style in the early stages of the project.

Christopher Sun oversaw the project for CNA, and Sarah Lysaker at CNA edited this guide.

The author wishes to acknowledge the following people: Police Officers Nathan Dresch and James Binder, Lieutenant Michael McAteer (St. Louis Metropolitan Police Department), Chief Angela Coonce (Washington University Police Department), Sergeants Stefanie Torlop and Jennifer Mitsch (Cincinnati Police Department), Lieutenant Amy Gauldin (Winston-Salem Police Department), Professors Michael Scott and Scott Decker (Arizona State University), Christopher Sun and anonymous reviewers (CNA), and Sam Klepper and Ralph Clark (ShotSpotter).

INTRODUCTION

This guide describes best practices for the implementation and uses of acoustic gunshot detection systems (AGDS). These systems can instantaneously detect and report gunfire, facilitating the police response to gunfire incidents and assisting with evidence recovery. Over the last decade, many large- and medium-sized cities have deployed AGDS, including mobile and camera-integrated systems. Despite growing deployments of AGDS, most police agencies use these systems to facilitate only the immediate response and investigation of gunfire, but the technology can also potentially identify high-risk locations to receive targeted preventative interventions.[1]

SCOPE OF THE GUIDE

This guide covers the basic principles that drive the technology and the current state of research on what does and does not work, including approaches that are promising but have not specifically been implemented with AGDS. It does not cover the technical details of the technology, such as the algorithms to filter gunfire from other sounds.

Related Guides

AGDS is most likely to be useful in the context of the following policing problems, some of which are topics in the Problem-Specific Guides series (indicated by asterisks):

- Assaults in and around bars*
- Celebratory gunfire
- Drive-by shootings*
- Drug dealing in open-air markets*
- Gang versus gang violence
- Gun violence among serious young offenders*
- House parties
- Mass shootings
- Retaliatory violent disputes*
- Street racing*
- Unauthorized target shooting

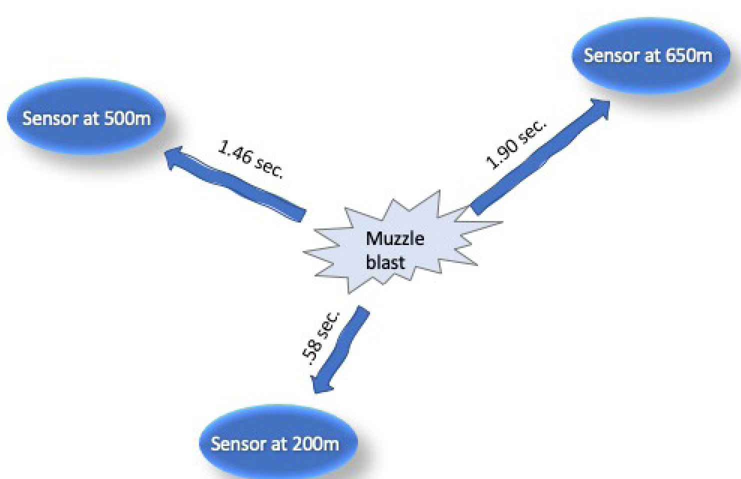
AGDS is also likely to be used in conjunction with other police responses, some of which are topics of other Response Guides (indicated by asterisks), such as the following:

- Crime and disorder in urban parks*
- Focused deterrence of high-risk offenders*
- Using civil actions against property to control crime problems*
- Video surveillance of public places*
- Automated license plate readers (ALPR)

HOW GUNFIRE DETECTION WORKS

Although gunshot detection can use either optical or acoustic monitoring, police typically do not use the former because it requires a direct line of sight.[2] Acoustic detection takes advantage of the sound waves produced by the muzzle blast or the sonic boom generated by a bullet as it travels through the air.[3] Most commercially available systems use muzzle-blast information because it enables better triangulation of the point of origin. Usually, an array of microphones forms a listening network. Detecting the point of the projectile impact is possible[4] but is of secondary interest, since casings are typically more abundant and therefore easier to match to a firearm than the projectile. In addition, many projectiles become too deformed or damaged to assist police in their investigation. Acoustic sensors are typically placed at specific intervals to create a grid with adequate coverage for the area of interest. In the grid depicted in Figure 1, the near-constant speed of sound waves (About 375 yards or 1,125 feet per second at 68 degrees Fahrenheit [a]) is leveraged to locate the point of origin for loud noises because the sensors pick up this noise at slightly different times.

FIGURE 1. LOCATING MUZZLE BLASTS USING MULTIPLE SENSORS

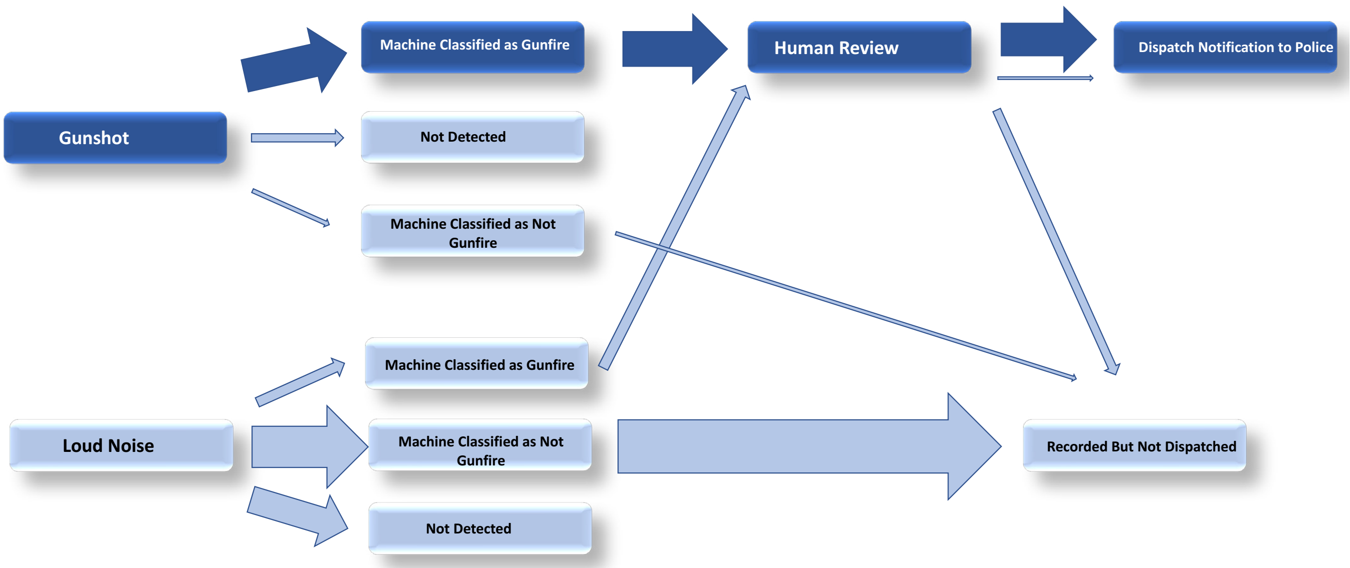


[a] ~343 meters per second at 20 degrees Celsius

Acoustic systems are activated by a range of loud noises. The systems subsequently process the sounds through a detection algorithm that identifies the type of sound (gunfire, fireworks, exhaust backfires, etc.). In some cases, loud sounds can be misidentified or mislocated[5] for a variety of reasons. For example, the algorithm may have difficulty identifying the sound, or weather may interfere. High wind, thunder, and rain can create background noises that drown out gunfire.

False positives (i.e., non-gunfire identified as gunfire) and false negatives (i.e., gunfire that is entirely missed or misidentified as another sound) do occur, although the exact error rate can be difficult to establish in real-life applications.[6] Some vendors, therefore, include additional human review before notifying the police. Depending on the system, the notification process can take between a few seconds for fully automated systems to about a minute for systems with human review (see Figure 2).

FIGURE 2. GUNFIRE DETECTION FLOWCHART FOR TYPICAL ACOUSTIC SYSTEMS WITH HUMAN REVIEW



Note: The arrow width is indicative of the number of alerts only; it is not exactly proportionate.

EFFICACY AND POLICE USES OF ACOUSTIC GUNSHOT DETECTION SYSTEMS

AGDS has primarily been used in the United States, although some systems have been deployed in South Africa and Latin America. The U.S. has high uptake largely because many U.S. cities have concentrated gun-violence problems that exceed levels seen in Europe and Asia. Also, the current high cost of the systems discourages their use in less wealthy nations.

Most U.S. agencies deploy fixed AGDS that either are integrated into computer-aided dispatch (CAD) systems or interface with mobile data terminals (MDTs) or smartphones, facilitating rapid deployment of officers to locations where gunfire has occurred with AGDS is unclear; however, the current market leader of this technology reports active contracts with over 120 U.S. law enforcement agencies, meaning that many of the larger U.S. agencies likely have a system in place.

Police expect to achieve benefits with the deployment of acoustic systems, but these *potential* benefits are not consistently documented in the peer-reviewed literature. Nonetheless, the advantages of deploying AGDS can include the following:

Faster response time. AGDS significantly reduce dispatch times. Some systems can bypass 911 systems and provide the gunfire alerts directly to officers. Police travel times to crime scenes might be reduced as well if AGDS alerts are assigned as the highest priority calls, since gunfire reported by residents is often assigned a lower priority.[8]

Victim assistance. A secondary benefit of reduced response times is that shooting victims may receive emergency medical treatment more quickly, either by being treated by police officers at the scene or arriving at a hospital more quickly.[9]

Accurate locations. AGDS tend to provide accurate locational data,[10,b] meaning that officers arrive at more precise locations. AGDS typically can provide both a location on a map (through an MDT or smartphone) and a physical address (if dispatch occurs through a 911 center). Vendors encourage users to rely on maps because those locations are slightly more accurate.

Enhanced evidence recovery. A secondary benefit of having a more accurate location of gunfire is that police are likely to collect more evidence (e.g., shell casings). How well AGDS enhances evidence recovery is not yet fully understood, although this metric may be overlooked in assessments.[11] AGDS use in Phoenix, though, has led to investigative benefits.[12] The police having a more accurate location appears to be connected to increased retrieval of shell casings and an improved ability to perform link analysis of firearms.

Enhanced reporting of gunfire. AGDS data analysis shows that citizens substantially underreport gunfire. Comparing citizen-initiated calls for service for gunfire against AGDS alerts reveals that about 80 percent of gunfire goes unreported by community members. Use of AGDS should therefore lead to more police responses to gunfire.[13] However, AGDS alerts involve a smaller percentage of assaults and homicides than do calls for service from residents, suggesting that acoustic alerts may lead to greater reporting of gunfire but not necessarily of gun violence (assaults and homicides).[14] Implementing AGDS can reduce community members' calls for gunfire. It is not clear whether that reduction represents an actual decline or merely a shift in reporting, with community members counting on the AGDS to report the gunfire they hear.[15] Faster police response times might result in police arriving before witnesses can place a call to police.[16]

Reductions in gun violence. For AGDS to reduce gun violence, it must deter people from shooting their guns when they otherwise would. It could do this by leading to the incarceration of frequent shooters or leading to the confiscation of their guns (assuming they could not easily replace them). Awareness of AGDS could also discourage people from using guns if they believe the system will increase their chances of being arrested. Evidence that AGDS deters gun violence is scant thus far. One study of an AGDS linked to pan-tilt-zoom cameras found that it had no effect on crime levels.[17] Two studies of AGDS in St. Louis found that it had no significant effect on crime levels.[18] In Cincinnati, however, AGDS did lead to a significant reduction in assaults with firearms.[19] Although gun-violence reductions in Denver were attributed to AGDS deployment, comparable communities that did not have AGDS displayed similar declines.[20] Some beneficial effects of AGDS on crime were also found in Milwaukee, Wisconsin, and Richmond, California,[21] but not in Wilmington, Delaware.[22] In short, the evidence for AGDS leading to crime reduction is mixed. Most studies focus on the response to gunfire alerts to understand the effect of AGDS on gun violence. A data-driven, problem-oriented approach has thus far been adopted in only East Palo Alto, California.[23] Results of this experiment found that preventative patrols in gunfire hotspots had no effect on crime levels. However, the study indicated that AGDS was not fully implemented because of shifts in organizational priorities. Implementation of practices and policies varies widely across agencies, though, and better implementation might lead to better results.

[b] Not all AGDS products have been studied, and the results may vary across platforms.

TYPES OF ACOUSTIC GUNSHOT DETECTION SYSTEMS AND THEIR APPLICATIONS

Multiple vendors supply AGDS, but they all operate with sensors that are designed to detect and report gunfire sounds. Whereas mobile devices and indoor systems are typically used for military and civilian applications, police rely primarily on fixed outdoor systems in which elevated sensors triangulate the location of gunfire.

Fixed systems can be stand-alone or integrate with closed-circuit television (CCTV),[c] ALPR, or even street lighting.[d,24] AGDS typically feed activations directly to dispatchers and can alert police officers' mobile phones through vendor-supplied applications. Fully mobile acoustic systems also exist, offering greater flexibility in deployment.[25] Mobile surveillance units, for instance, can often be outfitted with a gunshot detection system. However, gunshot detection boards in these units typically need recalibration after each move. In addition, feeding data from mobile systems directly to dispatch or patrol officers may not always be possible.

Synchronizing AGDS with camera networks may be helpful in some situations, but whether doing so reduces crime is still disputed.[26] In addition, limited camera coverage or other technical limitations can reduce the evidence-gathering potential of AGDS. Pan-tilt-zoom cameras, for instance, can be activated to focus on the source of gunfire, but in narrow city streets, sightlines are often blocked, depending on the height and angle of the camera.[27]

Numerous AGDS configuration options have police applications. Full-service systems typically require a minimum coverage of several square miles and thus make economic sense for larger agencies with long-standing gun-violence problems. Smaller, portable systems are more suitable for agencies experiencing occasional gunfire hotspots or rapidly shifting gunfire locations.

EXPERIMENTAL APPLICATIONS OF ACOUSTIC GUNSHOT DETECTION TECHNOLOGY

Although still largely experimental and not systematically implemented by police, acoustic surveillance can detect far more sounds than just gunfire. Sensors exist that monitor nightlife for sounds that indicate a fight may be developing,[28] detect screams, or even monitor illegal logging operations.[29] Additionally, sound-detection technology is available to detect breaking glass and car accidents.[30] Acoustic cameras provide an additional way to monitor sound. These listening devices are overlaid with video feeds and translate sound into visual heat maps. This technology can detect such things as lights and fans in illegal marijuana growing enterprises as well as aggressive voices on streets. Acoustic cameras can be integrated with other surveillance systems and can even adjust street lighting if fights appear to break out.[31] Commercial and police adoption of such systems remain limited at this time.

SMART POLICING INITIATIVE (SPI) IN WILMINGTON, DELAWARE: TARGETING VIOLENT CRIME.[32]

The National Police Foundation (now known as the National Policing Institute) evaluated the AGDS expansion in the Wilmington, Delaware, Police Department. In addition to expanding the coverage area of the AGDS, the police also integrated its acoustic system with CCTV, meaning that gunfire detection prompted nearby cameras to pan and zoom to that location.

Wilmington initially began using AGDS in 2013 and received a Smart Policing Initiative (formerly known as Strategies for Policing Innovation) grant in 2018 to increase the efficacy of AGDS in multiple areas. The objectives of the grant were as follows:

(a) Linking CCTV with AGDS to promote a faster response

(b) Providing better evidence recovery (e.g., casings) from offenders

(c) Increasing the clearance rate for firearm-related crimes, deterring gun violence, and improving public perceptions of police

Project planning began in 2019, with much of the technological upgrades being completed in 2020. Police survey responses about the technology were positive, reporting that it enabled quicker identification of a crime scene, enhanced evidence collection, facilitated prosecution, and provided faster aid to victims. Though the integration of cameras was viewed positively, police indicated that the zoom function sometimes hindered more than it helped. In addition, data analysis revealed that evidence recovery increased, but case resolution did not, and gun-related crimes increased post-implementation (the authors indicate that the latter findings could have been affected by the COVID-19 pandemic).

[c] See Response Guide No. 4, Video Surveillance of Public Places, 2nd Edition, for additional information.
[d] See Response Guide No. 8, Improving Street Lighting to Reduce Crime in Residential Areas, for additional information.

ACCURACY OF ACOUSTIC GUNSHOT DETECTION SYSTEMS

Accuracy can refer to whether the system "hears" gunshots and accurately distinguishes gunfire from other loud noises, such as fireworks, vehicle backfires, and construction noises (see Table 1). A gunshot detection system functions accurately when an identified gunfire alert is truly gunfire (true positive). At times, a system may misidentify other sounds for gunfire (i.e., a false positive). On other occasions, a system may miss or misclassify true gunfire (i.e., a false negative). False positives are a nuisance because they prompt a police response to a non-gunfire sound, but false negatives are more damaging because they fail to prompt a police response to actual gunfire. The rates of false positives and false negatives are unknown but likely depend on a particular system's configuration. Some systems retain data for alerts that are not deemed gunfire, meaning that investigators can still derive information from the system even though there is no immediate response, which might assist with evidence retrieval and crime-scene identification.

Accuracy can also refer to the precision with which the system can determine the location from which the gunshot was fired. Although hard standards for geographical accuracy do not exist, it is reasonable to expect a system to locate most gunfire incidents within an average spatial error margin of about 41 feet (12 meters).[33]

Because of the variety in AGDS, estimating their average accuracy is difficult. Their detection accuracy can also be affected by environmental conditions (e.g., snow, wind, thunder), topography, foliage, and the built environment. Accuracy is also somewhat dependent on the amount of gunfire in an incident, since fewer shots are more likely to go undetected than many shots fired in rapid sequence.[34] The caliber of the firearm also appears relevant, with lower calibers less frequently identified.[35]

AGDS pick up most gunfire with high accuracy. Both live-fire tests and agency findings demonstrate a detection accuracy of around 80 percent, ranging from 70 percent in St. Louis to 90 percent in Las Vegas.[36] As a result, roughly 20 percent of cases of true gunfire produce a false negative.

The proportion of false positives AGDS produce is unclear. Some have argued that the majority of AGDS calls for service are false positives,[37] which is almost certainly untrue. Some gunshot detection systems will identify sounds that resemble gunfire, and such systems may have difficulty filtering false positives, but the systems currently in use by the majority of large police agencies include incident reviews, which reduce false positives.[38] Certainly, some false positives are to be expected, especially during fireworks holidays, but no good method for assessing the relative frequency of false positives exists. Responding officers might be unable to determine what caused the sound detected by the AGDS. If the noise at the source location has ceased or if other evidence of gunfire, such as shell casings, has been removed prior to the arrival of officers, the true source of the noise might never be known. The same challenges exist for gunfire calls for service from the public. When police do suspect recurrent false positives, they should discuss them with their system vendor to help them improve the system's accuracy. A high false positive rate may explain why some early adopters of the technology have abandoned the technology, since it can discourage officers from responding promptly or investigating thoroughly.[39] At present, improved algorithms and human review of incidents appear to have reduced this issue.[40]

The geographical accuracy of AGDS may also vary by system, but most incidents are accurately pinpointed.[41] One system, for example, uses an 82-foot (25-meter) cone of uncertainty in locating gunfire incidents, indicating great confidence within this range.[42] The distance from the nearest sensors matters in the geographical accuracy of the alerts; gunfire within 500 feet of sensors will likely be more accurately pinpointed than gunfire that occurs 2,000 feet from sensors. As a result, the accuracy of a system is partly determined by the spacing and sensitivity of the sensors. However, the difference between geospatial coordinates and address-based locations is sometimes misunderstood.[43] Most acoustic systems will forward two location descriptors: latitude and longitude and a physical address. The physical address is typically based on parcel data, which can create unavoidable challenges when relaying locations to officers. Large parcels, such as parks or housing complexes, often are represented in address databases with a single address, which means the actual location of the gunfire may be some distance from the reported address. For this reason, police should respond to the geospatial coordinates on a map when possible. The implications of this issue for police response are described later in the section Responding to Gunshots.

TABLE 1. ACOUSTIC GUNSHOT DETECTION SYSTEM ERROR TYPES

	GUNSHOT IDENTIFIED	GUNSHOT NOT IDENTIFIED
Accurate	**True positive:** Actual gunshot detected and identified	**True negative:** No actual gunshot and not detected or identified
Inaccurate	**False negative:** Actual gunshot not detected or identified	**False positive:** No actual gunshot but detected and identified

ANALYZING ACOUSTIC GUNSHOT DETECTION SYSTEM DATA

Analyzing AGDS data serves at least four purposes:[c]

1. Understanding the dynamics of gunfire incidents
2. Optimizing response times to gunfire incidents
3. Determining whether the system is accurate
4. Understanding whether the system help reduce underlying gunfire problems

GUNFIRE INCIDENTS

AGDS data not only indicate the possibility that gunshots have occurred, but when thoroughly analyzed, these data also indicate the number of shots, guns, locations, and shooters. Knowing that multiple shooters at different locations fired guns can indicate an active shooting incident, and this knowledge can raise responding officers' situational awareness.

Figure 3 shows a variety of acoustic gunshot alert wave patterns. Pattern 1 shows multiple rounds fired from the same location and firearm; each spike in the wave pattern coincides with the initial muzzle blast, establishing a count for the total number of rounds fired. Pattern 2 begins in a similar fashion, but just past halfway, additional shooters join in and create a messier pattern of peaks. Pattern 3 shows two fully automatic bursts of gunfire, which are characterized by closely spaced peaks. Pattern 4, the reverse of Pattern 2, begins with multiple shooters firing together and ends with a three-round burst. Pattern 5 shows two shooters at different locations. It is a bit difficult to see, but the peaks at the beginning and end are one shooter, whereas the low peaks starting about halfway reveal another shooter at considerable distance from shooter one; these types of gunfire incidents are probably more likely to involve injuries as it points to gunfire exchanges. Pattern 6 shows ambient noise interference with only two actual gunshots. Exploring both the sounds and wave patterns can provide increased situational awareness and may also assist in investigations. Both responders and investigators should be trained in recognizing the patterns and their potential meaning. Analyzing the sounds can reveal the number of shooters and the number of rounds fired by each shooter. Such information can be crucial in verifying witness accounts and lead to a more accurate accounting of victims and offenders. Knowing whether an incident involves one or multiple shooters can assist in locating *all* victims and evidence (e.g., casings).

FIGURE 3. WAVE PATTERNS OF ACOUSTIC ALERTS

Pattern 1

Pattern 2

Pattern 3

Pattern 4

Pattern 5

Pattern 6

Source: ShotSpotter.

[c] See Appendix B for further discussion of the technical issues associated with AGDS data.

RESPONSE TIMES

One of the easiest things to do with AGDS data is to compare response times for AGDS alerts to community-reported gunfire incidents (i.e., "shots fired" calls for service).[44] Ideally, the technology will decrease the time between gunfire detection and police dispatch, but because of better geographic accuracy, the technology may also increase the investigative time. Because response times in call for service data often have a high number of outliers, you should use median-based measures to test for significance.[45] It is further important to determine which parts of the response (dispatch, travel, or investigation) are the most affected to understand how AGDS might improve response times. Police officer travel times are less likely to be affected by AGDS, unless the response priority between the two types of calls is substantially different. The time officers take to investigate gunshot incidents, by contrast, should ideally increase because they typically have more information about the shooting than is available from a community call for service. Such measures can provide important feedback to your agency on how well an agency's response procedures are implemented in practice. An important caveat is that most CAD systems do not record the time of the gunfire—they record the time the alerts were *received* from the vendor or residents.

SYSTEM ACCURACY

AGDS data can also be used to determine how accurately the system reports gunfire. Although one study[46] indicates that the majority of AGDS notifications in Chicago had no actionable results upon initial investigation, this conclusion confuses finding evidence of a crime with determining the accuracy of the AGDS. Calls for service data are not designed to determine criminal wrongdoing, and multiple data sources may need to be consulted for you to understand the investigative outcomes of acoustic alerts. False positives in AGDS data certainly exist; however, detecting and enumerating them with quantitative data alone is difficult, and officers would be required to thoroughly investigate each alert to find the source of the noise, which would be impractical.

Calculating false negatives, in contrast, is straightforward. Determining the number of gun violence incidents missed by AGDS is also more significant because false negatives leave police unaware of potentially dangerous gunfire; thus, false negatives provide more insight into the value of the system. As indicated above, AGDS typically miss around 20 percent of true gunfire cases.[47] An agency can estimate its false negative rate by working backward from crime incident data and identifying reported outdoor aggravated assaults and homicides involving gunfire victims. Those incidents can then be matched to nearby acoustic gunshot detections. Reading the narratives of the incidents provides the greatest accuracy because some victims may have been at the scene for a long time or may have been shot elsewhere but collapsed at the scene, which can make it difficult to find a matching AGDS alert.

UNDERREPORTING OF GUNFIRE

In addition to the immediate investigative use of acoustic gunshot data, the data can support police problem-solving. Problem-solving approaches rely on data analysis to identify hotspots of gunfire alerts. Such sites can be selected for additional preventative actions. Beyond additional patrols, these actions can also involve addressing nuisance properties and altering the immediate environment (adding lighting, removing trash, etc.). Few agencies currently use AGDS data in such a capacity, but a problem-oriented approach was part of East Palo Alto's SPI project.[48] The department responded to AGDS hotspots with two approaches: (1) additional patrols and searches and (2) community education and outreach. Results indicate that the project may have reduced shootings in the targeted areas by 52 percent (compared with a 41 percent reduction city wide), but the implementation was inconsistent, so the outcomes cannot be thoroughly assessed. AGDS data are not widely used in directing problem-solving approaches partly because these data are outside of normal police data systems, such as CAD or records management systems, so they are not routinely analyzed.

Another metric that can be examined with AGDS data is the level of underreporting of gunfire by citizens. Underreporting can be assessed by determining what proportion of acoustic incidents are also reported by a citizen. This can be done expediently in a spatial software package (such as ArcGIS, using the "find space/time matches" function), but some arbitrary choices must be made with respect to what constitutes a "good enough" match, which depends on the amount and spatial density of such calls for service. The implementation of AGDS has been related to reductions of residential calls for "shots fired," which suggests that that citizen reports of gunshots are preempted by an improved police response or that residents now rely on the system to bring police to the community.[49] Exploring underreporting can be useful in comparing neighborhoods' willingness or ability to report such offenses, and may help your agency develop targeted publicity campaigns to encourage citizen reporting.

Accurate systems, however, are not necessarily *effective* ones. Increases in arrests or gun recoveries are only means toward the ultimate objective of reducing illegal gunfire and gun violence. Though the numbers of arrests and gun recoveries are typically easy to count, they are also driven by the amount of effort police put into achieving them, which can vary over time. Furthermore, arrests and gun recoveries are not necessarily the direct result of the AGDS and might result from other reporting and investigative methods.

Reductions in illegal gunfire are also difficult to measure because the implementation of AGDS may itself affect citizen reporting behavior. As a result, determining whether any reductions are real declines or just changes in reporting behavior is difficult. Gun-violence-event reductions are the most reasonable benchmark for efficacy, but they are rare and thus hard to detect statistically.

Because most acoustic systems require a substantial amount of contiguous coverage, running controlled experiments on AGDS is difficult, but evaluations should, at a minimum, include a comparable area without AGDS. In addition, when AGDS is initially set up in high-gunfire areas during high-gunfire periods, subsequent crime and gunfire reductions might merely be returns to normal levels that would have occurred even in the absence of AGDS (referred to as "reversion to the mean" in statistical language). All AGDS evaluations should be done with care and consideration of what the data represent and the context in which the police implemented the systems. Collaborating with academic partners versed in experimental analysis can help your agency achieve valid outcomes and conclusions about the efficacy and cost-effectiveness of AGDS. The SPI program at BJA has funded several AGDS-related projects that benefitted from such partnerships.[50] Even without such funding streams, it makes financial sense to rigorously evaluate the impacts of AGDS.

RESPONDING TO GUNSHOTS

GUNSHOT INCIDENTS

Once an AGDS is in place, officers and detectives will have to actively respond to and investigate the incidents. At present, there is little research-based guidance on what constitutes best practices, so most recommendations are based on practitioner experience.

Information

A good response begins with useful information. Dispatchers should receive training in determining the number of gunshots and whether multiple shooters are involved. If the gunshot detection information is limited to what is relayed to the field by dispatchers, it should include the following critical details:

- An accurate location description. An address by itself is useful only if the incident occurred on a residential street. If it occurred in a backyard or a park, officers should be made aware of this fact, especially if the responders do not have access to a map with exact locations.
- Information on the exact number of gunshots detected. Knowing about how many shots were fired allows officers to dedicate the appropriate amount of resources to finding evidence.[51]

If patrol officers have direct access to the acoustic data, the responding officer should:

- Respond to the mapped location of the detected gunfire to determine where to look for evidence
- Listen to the gunfire while responding or inspect the wave pattern if it is safe to do so (doing so requires a two-officer response). By doing so, they can gather crucial information about the number of rounds and the number of guns involved in the incident.

Response Time

Ideally, police will respond at highest priority to AGDS alerts. A fast response increases the chances of finding victims and witnesses and providing life-saving actions. Responding quickly to gunfire alerts, however, may not always be possible. Some agencies may not have the resources to assign the highest priority response to AGDS alerts, especially if they deal with high-volume gun incidents and frequent AGDS alerts. When compared to citizen gunshot reports, AGDS alerts do not lead officers to a higher percentage of assaults or homicides.[52] An emergency police response also may increase the risk for accidents and elevate responding officers' stress.[f] Clearly, AGDS responses may induce such stress, and more research is needed to examine whether such calls create unnecessarily dangerous conditions for citizens and officers.

If highest priority responses are not feasible for all AGDS alerts, agencies may consider developing a system for acoustic alerts that distinguishes between alerts that are likely tied to in-progress gun violence and those that are not. Alerts may not all be equal in their level of severity. In St. Louis, for example, alerts with more than seven rounds fired account for half of assaults and homicides, so the number of rounds fired may provide some justification for determining the urgency of the police response.[53] The occurrence of a 911 call for gunfire in addition to the AGDS alert may provide another indicator of seriousness. More research is needed to understand which types of alerts have a higher probability of indicating shootings that involve victims.

Most cases in which a victim is shot are called in by residents, but AGDS may improve the police response time and evidence recovery. Nonetheless, that improvement should be put in perspective. In Cincinnati, which has a relatively low number of gunfire cases (which receive high-priority police response), the average response time for gunfire alerts is between 4 and 5 minutes after receiving the notification (so a total of 5–6 minutes post-gunfire, accounting for incident review).[54] It is doubtful that many shooters and victims hang around for long after the firing of a gun, which may explain why the difference between citizen calls and AGDS alert response times is not likely to significantly affect arrest probabilities.[55] However, the geographic precision of AGDS could make a critical difference in successfully collecting evidence and locating victims in need of assistance.

Investigation

Thoroughly investigating gunfire incidents is arguably even more important than providing fast response times, both for solving and preventing the incidents. Collecting ballistic evidence and locating victims, offenders and witnesses are, of course, primary objectives. Consistently responding to and investigating AGDS alerts, and interacting with the public during these calls, can be deemed a form of hotspot policing,[56,g] but without more purposeful preventive action, it is unlikely to effectively reduce shootings at that location. Within the situational crime prevention framework, AGDS may help "increase the risk" of shooters being identified and punished.[h] Responding officers should talk with residents and the business community about the shooting incidents to identify the underlying conditions that might be contributing to them. Officers should understand the difference between conducting a criminal investigation of the incident (i.e., who fired this shot?) and an analysis of the problem (i.e., why are shots being fired at this location?). In Cincinnati, the difference in responses might

[f] In an experimental study of an active shooter incident, for example, roughly 20 percent of participants recalled seeing a firearm in the hands of the mock offender, even though the gun remained in the person's waistband (Hope et al., 2015).

[g] See Problem-Solving Tools Series, No 14. *Understanding and Responding to Crime and Disorder Hot Spots,* for further information

[h] See the Twenty-Five Techniques of Situational Prevention at https://popcenter.asu.edu/content/25-techniques.

explain why the city experienced substantial crime reductions after implementing AGDS but other sites have not.[57]

Locating shell casings or projectiles during the initial response is often difficult because shootings often occur at night. Good practice is therefore to return to the scene when visibility improves. Finding casings can be especially difficult because they may roll into pavement cracks, grass, or weeds or under vehicles (see Figure 4).

FIGURE 4. SHELL CASING IN ALLEY, HIDDEN AMONG DEBRIS AND WEEDS

Source: Photo by author.

Keeping track of the casings and the scene they belong to can be complicated as well. For example, many gunfire locations experience repeated incidents over time, meaning that casings could be from a prior incident. Given that this work can be time-consuming, good practice is to assign specific personnel to follow-up investigations and establish clear protocols for evidence collection and case attribution.

Link analysis and National Integrated Ballistic Information Network (NIBIN) identification are critical tools that allow agencies to connect guns to prior offenses and gunfire incidents.[58] Link analysis creates connections between bullets or casings that may have been used in prior shooting incidents. Forensic specialists can then examine the unique markings, specific to one firearm, from bullets and casings and link them using specialized software tools. In addition, retrieving fingerprints from some casings may be possible. Ballistic evidence gathered during responses to acoustic alerts can supplement NIBIN link analysis and enhance investigations in Crime Gun Intelligence Centers (CGIC).[59] Quick identification and linking of casings can improve case resolution, but the sheer volume of casings that acoustic systems can deliver can also be beneficial.[60] Indeed, though many casings discovered by acoustic alerts may not be from shootings with victims, preserving the records may help detectives investigate future assaults by providing locations where the gun was fired prior to the incident. Link analysis of casings can also assist in uncovering offender networks and provide insights into the life cycle of firearms.

Officers and detectives who investigate assaults and homicides should be trained in the use of acoustic data.[61] Some vendors provide training for their applications, but more involved training may be needed if raw data have to be manually extracted and mapped. Vendor data portals, for example, generate a wealth of gunfire data for an agency. In addition to gunfire detections forwarded to dispatch or officers in the field, sensor activations also include gunfire incidents outside the coverage area (which might be less geographically accurate) and even "non gunfire" incidents, some of which may have been falsely dismissed.[62] Such data can assist active investigations by allowing investigators to:

- Investigate incident locations to determine whether other recent gun-crime incidents occurred at the same site, which may be important if the casings retrieved do not match the firearms used in the incident and may also establish whether prior conflicts have occurred in the area.
- Verify victim, offender, or witness statements. Gunfire data from acoustic systems can be used to verify information and statements given during an investigation. Verification may be particularly important when victims are first contacted

CASE STUDY: EVALUATION OF PHOENIX CRIME GUN INTELLIGENCE CENTER[63]

In 2017, the Phoenix Police Department received funding to establish the Phoenix Crime Gun Intelligence Center (CGIC) and pilot a novel, cost-effective mobile gunshot detection system without incident review. Establishment of the CGIC was associated with enhanced ballistic processing and improved clearance rates, although prosecutorial outcomes were not affected. The study reveals the importance of CGICs in general, but here we focus on the pilot of the gunshot detection systems, which also proved worthwhile. Acoustic sensors were placed in the areas with the most reported shots-fired calls for service; two control sites were also assigned. After deployment of the system, only 12 percent of total gunfire alerts came from residents, indicating that gunfire had previously been substantially underreported. Prior to implementation, only 8.6 percent of gunfire incidents led to shell casings being detected, but during the experiment, that percentage increased to 25.2. Firearm recoveries and arrests also increased, but these results were not statistically meaningful. Response time to gunshot incidents decreased, but these results were not statistically significant given the small number of cases. Although these results must be seen as preliminary given the limited scope of the system implemented, they do suggest positive investigative outcomes.

in a hospital and if the crime scene is either unknown or contaminated. Gunshot victims are not always cooperative and verifying the veracity of their statements is important to quickly establish the accuracy of gunfire locations and save investigative time in the field.

GUNSHOT PROBLEMS

Preventative or problem-solving efforts may benefit from AGDS data. Most agencies use acoustic systems reactively—responding to incidents as they happen—but not to inform broader prevention efforts. Because gunfire problems tend to be highly concentrated in place and time (not widely diffused across a jurisdiction) and because AGDS does detect most gunfire,[64] AGDS data can help police detect the concentrated locations and times.

Compared to traditional gun-violence data, AGDS alert data provide greater numerical frequency, which can help to more rapidly identify specific properties or locations that present an ongoing gunfire problem. In addition, because much gun violence is retaliatory and victims are often uncooperative,[65] analysis of gunfire data can help identify emerging conflicts, particularly if casings are analyzed and traced to specific guns and their known owners.[66,i,j] Figure 5 is an image of gunfire hotspots showing 26 alerts and 76 rounds over a 3-month period near a specific (vacant) property (the street names were obscured by the author). Each yellow balloon notes a separate alert and the number of rounds fired.

FIGURE 5. IMAGE OF GUNFIRE HOTSPOTS

Source: Screenshot from ShotSpotter's Insight Portal.

Finding gunfire hotspots is the easy part; developing strategies that can successfully curb gunfire is harder. No studies currently offer concrete evidence-based practices specifically for using gunfire data to reduce gunfire.[67] Although hotspot patrols are a reasonable option for achieving at least short-term gun violence reductions, they are difficult to sustain and may strain or damage community relations. A careful problem-solving approach will likely be more effective if it can address some of the place-based opportunities that prompted the gunfire to concentrate. For example, vacant lots and overgrown alleys can provide cover for illegal gunfire. Greening, renovating, and tearing down vacant homes can reduce crime.[68,k] Identifying gunfire hotspots would be a good start to such efforts. Similarly, if police can identify individual problem properties, they can work with other agencies to improve management of the property.[l] Code enforcement, nuisance abatement, social services, and violence interrupters can also contribute to interventions at such locations, although whether such strategies are effective is currently unclear. As a stopgap, police can deploy additional technologies such as mobile surveillance trailers in gunfire hotspots. Initial results from St. Louis indicate that such units can strongly deter gunfire.[69] Naturally, the results of high-visibility technology may last only as long as the technology is deployed, and longer-term solutions may be required. Another option is to implement consent-to-search programs, which would allow police to seek residents' consent to search their homes for firearms in locations where gunfire levels are high.[70] Finally, many departments engage in public awareness campaigns to reduce celebratory gunfire.[71] Unfortunately, little is known about the efficacy of such programs. In short, at least seven responses to gunfire hotspots are potentially effective:

(1) Targeted preventive patrols
(2) Physical modification of the environment
(3) Property management improvement
(4) Targeted conflict resolution with violent retaliatory disputants
(5) High-visibility camera technology to deter offenders
(6) Targeted consensual searches of homes for firearms
(7) Crime prevention publicity campaigns (e.g., to discourage celebratory shooting on holidays).[m]

[i] See Problem-Specific Guide No. 74, *Retaliatory Violent Disputes,* for further information.

[j] One way to identify gunfire hotspots with acoustic data is by using the "optimized hotspot" function in ArcGIS. By using the option to create weighted points and selecting an appropriate distance band, a user can identify highly localized gunfire hotspots. In essence, the software will let a user select a threshold for the minimum of gunfire alerts to occur within a predefined area, returning the average spatial location. The quality of the results, of course, depends on the amount of data fed into the function.

[k] See Problem-Specific Guide No. 64, *Abandoned Buildings and Lots,* for further information.

[l] See Response Guide No. 11, *Using Civil Actions Against Property to Control Crime Problems,* for further information.

[m] See Response Guide No. 5, *Crime Prevention Publicity Campaigns*, for further information.

IMPLEMENTING ACOUSTIC GUNSHOT DETECTION SYSTEMS

Implementing AGDS seems straightforward, but agencies should explore numerous elements before committing to a system.

COVERAGE AREA

Your agency should determine whether the system is appropriate for its specific circumstances. Though vendors understandably would prefer to maximize the coverage area, doing so is not always in the best interest of the police or the public. Ideally, an agency would begin by analyzing existing gunfire and gun-violence data to determine which areas might benefit most. The next step would be to find two equivalent (by rate and trend of gunfire) but geographically separate areas and install AGDS in one but not in the other. Doing so would enable comparisons to determine whether the acoustic system is beneficial. Note that these systems do not necessarily reduce violence levels or improve case outcomes, so evaluation of what their actual benefits are should be part of sound implementation practices.

COSTS

Costs vary depending on the specific system, configuration, and options, but the typical cost for a leased system that includes vendor review of gunfire incidents is around $70,000–85,000 per square mile, per year. For this price, an agency will receive access to response applications and maintenance service. Leased systems often have minimum coverage requirements (1–3 square miles). Systems wholly owned by the department can therefore be more cost-efficient if the area to be covered is smaller. Still, the sensors themselves can cost anywhere from a few hundred to tens of thousands of dollars depending on the accuracy and interoperability options. One additional advantage of such systems is there is no annually recurring fee. However, maintenance and repairs often require specialized knowledge.

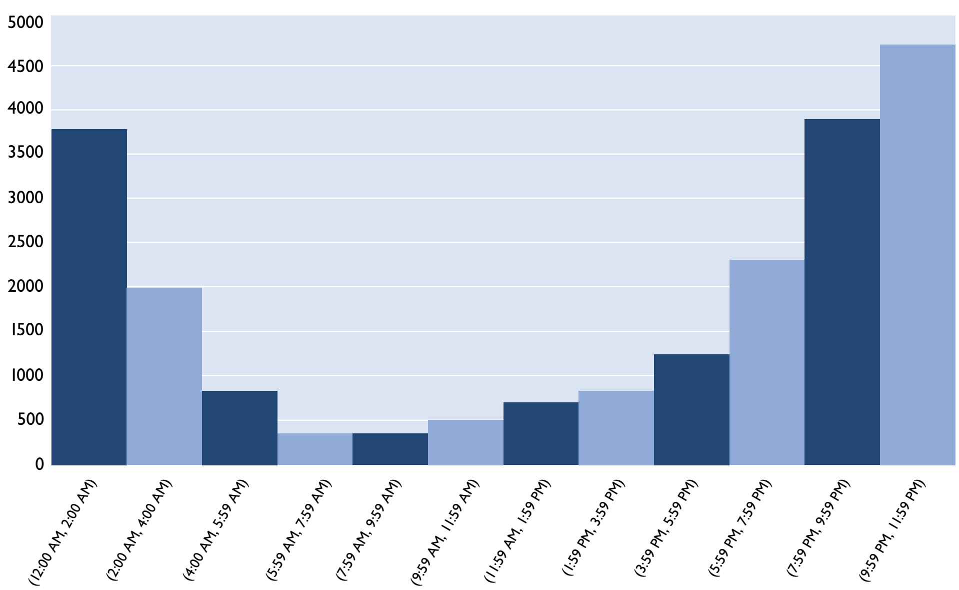
Cost calculations of AGDS should also include personnel costs, although these are harder to calculate. Nonetheless, it is reasonable to expect that uncovering and responding to more gunfire incidents would increase the demand on personnel and vehicles. The demand on forensic ballistic analysis is also likely to increase substantially.

PERSONNEL NEEDS

Installing an acoustic gunshot detection system can double or triple the volume of gunfire calls.[72] Your agency will need to plan for having enough officers available to handle not just overall call volumes but also call surges at peak times. Acoustic alerts tend to peak later at night (10PM–2AM) than calls made by residents (see the example in Figure 6). During this peak time, fewer officers are typically available to respond to the alerts, potentially causing delays. Particularly in large agencies with a significant gunfire problem, multiple unique and near-simultaneous AGDS alerts may demand attention from a limited number of officers. Inadequate staffing during distinct peak times may undermine the system's effectiveness. A recurrent staffing analysis should therefore be conducted to determine whether changes in personnel allocation are needed to accommodate the volume of calls.

FIGURE 6. ACOUSTIC ALERTS IN ST. LOUIS BY TIME OF DAY: SHOTSPOTTER DATA JANUARY 2017 THROUGH MARCH 2021 (N=21,700)

Source: St. Louis Metropolitan Police Department.



Gunshot detection data analysis is another important staffing consideration,[73] and agency analysts should be involved in planning discussions.[74] Agencies should also consider how the data generated by AGDS might be used more broadly for identifying and addressing crime hotspots.[n]

INTEROPERABILITY WITH OTHER SYSTEMS

Some AGDS can automatically send gunfire dispatch notifications to MDTs and officers' cell phones; others operate by notifying dispatch or a Real-Time Crime Center (RTCC). Paying for a system that can push notifications directly to officers makes sense only if the officers have the capability and willingness to receive these notifications, which may involve discussions with unions if the phones are not department-issued. In addition, if gunshot detections can be streamed to an RTCC, responding officers can draw on additional information from nearby cameras and ALPR to secure visual evidence.[75] Some systems can automatically activate nearby cameras and ALPRs to pan to the gunfire location. In such cases, it is important to review the coverage and interoperability of such technology prior to implementation.

TRAINING REQUIREMENTS

An increase in gunfire responses likely increases the risk of dangerous interactions between citizens and police, both from emergency responses to the scene and from interactions at them. Officers might need refresher training in how to approach gunfire locations, search for ballistic evidence, and interact with community members.[76] In addition, additional training in how to apply initial trauma care may be beneficial.[o] Investigators may need training in how to use the data for active investigations, although some vendors provide this training as part of their service. AGDS calls for service are substantially different from most calls for service, even shots-fired calls reported by residents. Officers are asked to respond to active gunfire without an expressed invitation from residents (since most alerts do not have a matching call for service from the public), potentially increasing adversarial encounters. Whereas gunfire calls for service by residents typically guide police to a street address, AGDS notifications often pinpoint gunfire into backyards, alleys, and other locations where responding officers are not necessarily welcome. Also, individuals near the scene of a shooting alert may not be involved in the incident; it is important to remember that AGDS identifies gunfire, not shooters.

OPERATING PROCEDURES AND POLICIES

The unique aspects of responding to AGDS alerts should be addressed in a dedicated AGDS standard operating procedure (SOP) and other policies. These documents should embody best practices in the field, adapted to your agency's unique circumstance. At a minimum, an AGDS policy should cover the following:

- Response to a notification
    - Source of a notification to be used by an officer (e.g., dispatch, MDT, application)
    - Personnel involved (e.g., how many officers respond and the role of a supervisor)
- Investigative procedures and collection of evidence
- Follow-up procedures
- Community interaction.

The Cincinnati Police Department, for example, adopted a comprehensive SOP that requires officers to sign in to the AGDS vendor's console on their MDT.[77] Each alert requires a minimum of two officers responding. Officers are also instructed to respond to the mapped incident location, not the address, thereby avoiding some of the discrepancies in an address-based response. Furthermore, officers are directed to search for evidence of gunfire in a 100-foot radius of the mapped location and attempt to contact residents in the eight nearest homes. Officers are also encouraged to request follow-up investigations if conditions precluded a thorough initial investigation.

STAKEHOLDER SUPPORT

Conversations about AGDS among patrol officers, the community, and political leadership must start early. These conversations should include an explanation of how the system works and what steps the police department is taking to mitigate concerns about use-of-force and equity. Concern about surveillance technology is widespread, but acoustic systems do not continuously record audio. The brief audio snippets of loud events that do get recorded in combination with the sensor placement above street level make it unlikely that recordings capture conversations. Similarly, concerns about over-policing and targeting of communities of color may be brought up by residents, making it crucial for the department to address how the implementation and location of the technology are based on data detailing the concentration of gun violence (e.g., homicides and aggravated assaults with firearms). It is also important to remind stakeholders that AGDS is not a complete substitute for citizens notifying police of gunshots, and that successful prosecution of offenders is unlikely to rely on AGDS data alone. Securing buy-in also usually requires transparency in sharing research findings and making data accessible. Community meetings can reach residents and solicit input while explaining what the system does and does not do. Engaging with the media and providing data and visualizations in an open data portal can also enhance transparency once implementation has begun.

[n] See Problem-Solving Tools Guide No. 14, Understanding and Responding to Crime and Disorder Hot Spots, for further information.
[o] One example is "Stop the Bleed" training: https://www.stopthebleed.org/.

COMMUNITY CONSIDERATIONS

Thus far, limited research has been done on residents' views on or uses of acoustic technology. A survey conducted in Cincinnati's neighborhoods that are outfitted with AGDS indicates that most respondents believe acoustic technology provides a deterrent and is linked to a lower number of shootings.[78] Unfortunately, the survey results were drawn from a non-representative population composed primarily of older White residents. Similarly, community surveys in Wilmington, Delaware, indicate that 85 percent of polled residents reported that AGDS makes them feel safer, and only 5 percent conveyed concerns about privacy invasion.[79] A survey of the general U.S. population reports that over 60 percent of Americans support acoustic technology, with only 11 percent indicating some opposition to its use.[80]

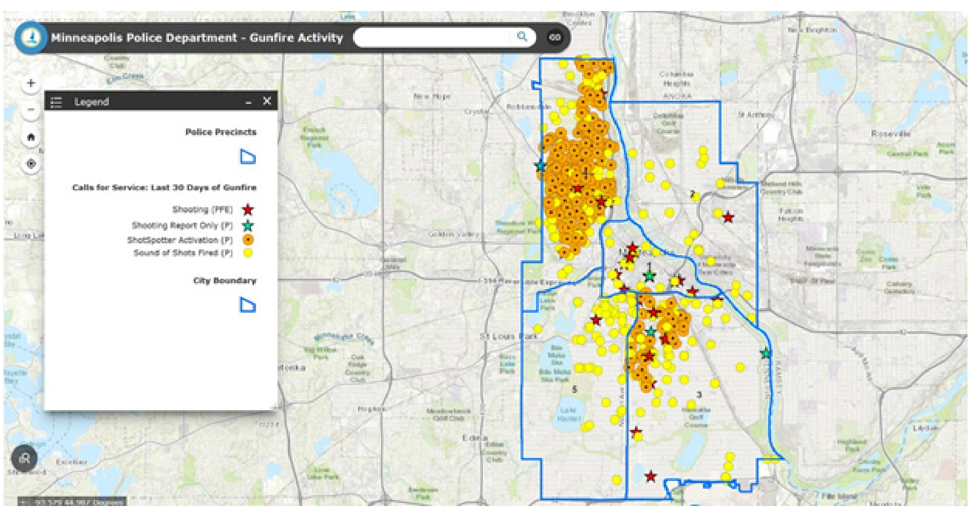
However, in recent years, public and political voices have become more skeptical of police technology in general, with acoustic technology often singled out as an example of poor police practices.[81] Although initial concerns of civil rights groups—such as the ACLU—focused on the surveillance capacities of AGDS, recently attention has shifted to the potential of acoustic systems to lead to over-policing of communities of color.[82] Such representations, however, might be rooted in a general lack of understanding of how acoustic technology works, as well as concerns over the perceived high number of false-positive alerts.[83]

Police must be transparent about the technology, including what it does and how data are collected and stored. Sharing data with the public should be part of this transparency. Such discussions must stay within the bounds of vendor user policies, however, and your agency should provide these data limitations to the community. Producing and sharing maps or dashboards and making them available to the public is one way toward the transparency objective. Transparency helps counter unfounded criticism, especially if the limitations of the data and police efforts to measure (and publicize) the efficacy of such systems are explained. As an example of data transparency, Figure 7 provides gunfire data from Minneapolis, Minnesota, displaying AGDS alerts (ShotSpotter) and resident-reported gunfire incidents (shootings and shots fired).

Residents are typically not given much of a voice in the implementation of acoustic technology, or indeed the implementation of surveillance cameras and ALPRs. Most deployments of acoustic technology are based on police analysis of historical gunfire data, since it makes sense to put technology where it will provide the most actionable intelligence. However, AGDS alerts will inevitably bring police into a greater number of high-stress situations, which may rankle some residents. Calls for gunfire are fundamentally different than many other calls patrol officers handle. Officers often must rush at high speed into an active gunfire situation with little time to think or reflect on the scene encountered. No hard data yet address the way that acoustic systems affect officer-involved shootings, and the evidence we have now is largely anecdotal. Community concerns about the police response to AGDS notifications must be addressed through policies, procedures, and training—all of which should be shared with the community.

An unintended consequence of installing AGDS in high-crime areas is that more AGDS will be installed in communities of color, which has the potential to heighten pre-existing perceptions of inequities and may raise questions of fairness, such as whether it is reasonable to subject communities of color to higher levels of surveillance.[84] Soliciting community input regarding installation decisions, carefully considered policies, and proper officer training can help address such concerns.

FIGURE 7. EXAMPLE OF DATA TRANSPARENCY: GUNFIRE DATA FROM MINNEAPOLIS, MINNESOTA



Source: City of Minneapolis Open Data.
Note: Current data can be retrieved at: https://www.minneapolismn.gov/resident-services/public-safety/police-public-safety/crime-maps-dashboards/shots-fired-map/.

CONCLUSION

AGDS triangulates the sound of gunfire from multiple sensors to provide an accurate location to police. AGDS are on track to become a common technology, especially in communities with elevated levels of gunfire. Though the benefits of such systems are not yet fully understood, most studies report faster police response times and an increase in evidence recovery (casings). The full effects of AGDS on gun violence are not yet clear, but adherence to best practices is likely to yield the best results. System costs vary depending on options, but typical costs are about $80,000 per square mile, per year.

Both the response to and investigation of AGDS alerts are critical aspects of best practices. A timely response and a thorough investigation of the mapped alert are essential. Relatedly, developing sound policies and operating procedures that prioritize the response and investigation is an important aspect of implementation. AGDS data can not only aid in investigative aspects of the response but also be used to develop preventative strategies for gunfire hotspots. In addition, these data can be used to gain a fuller understanding of the time and place of gunfire because the data are not affected by underreporting.

Even though deploying AGDS provides many potential upsides, not everyone will be in favor of such systems. For example, some are concerned that implementing AGDS may lead to over-policing in communities of color. Therefore, engaging community stakeholders and creating transparency are essential in the use of AGDS.

APPENDIX A

STUDIES EXPLORING ACOUSTIC GUNSHOT DETECTION SYSTEMS' EFFICACY TO REDUCE GUN VIOLENCE

CITY	YEARS AND TYPE	TARGETED OFFENSE	HOW EFFECTIVE	RESEARCH DESIGN	STUDIES
St. Louis, Missouri	2006–2009 ShotSpotter	Part I Gun Offenses	No significant effects. Reductions and increases occurred randomly in both experimental and control sites	Interrupted time-series	Mares and Blackburn (2012)
Philadelphia, Pennsylvania	2015–2016 SENTRI sensors with CCTV	Gunshots calls for Service	259% increase in gunshot notifications, but no significant increase in founded incidents	Block randomized controlled experiment, multi-level difference-in-difference	Ratcliffe et al. (2018)
Denver, Colorado	2008–2016 ShotSpotter	Gun crime calls for service and Part I crimes	No significant changes in crime levels or calls for service	Quasi experimental interrupted time series	Lawrence, La Vigne, and Thompson (2019)
Milwaukee, Wisconsin	2008–2016 ShotSpotter	Gun crime calls for service and Part I crimes	Significant increases in gun crime calls for service; no significant reductions in reported gun crimes	Quasi experimental interrupted time series	Lawrence, La Vigne, and Thompson (2019)
Richmond, California	2006–2015 ShotSpotter	Gun crime calls for service and Part I crimes	Significant increases in gun crime calls for service; no significant reductions in most restrictive models but some in less restrictive models (around 30%)	Quasi experimental interrupted time series	Lawrence, La Vigne, and Thompson (2019)
St. Louis, Missouri	2005–2018 ShotSpotter	Calls for service for gunfire and gun violence	Significant reductions in gunfire calls for service; some reduction in gun violence initially but none significant	Quasi-experimental multi-level difference-in-difference	Mares and Blackburn (2021)
68 Metropolitan Counties	1999–2016 ShotSpotter	Gun homicides, gun arrests, homicide arrests	No significant reductions in any metrics	Cross-sectional time series analysis	Doucette et al. (2021)
Wilmington, Delaware	2014–2020 ShotSpotter/ CCTV integration	Homicides and shootings	No significant reductions	Interrupted time-series analysis	Vovak et al. (2021)
Cincinnati, Ohio	2015–2020 ShotSpotter	Calls for service shots fired and reported Gun assaults	Significant reductions (45% in shots fired and 46% in gun assaults)	Block matched quasi-experimental multi-level difference-in-difference	Mares (2021a)

APPENDIX B
USING ACOUSTIC DATA

Some clarification on the nature of acoustic alert data is necessary, especially for those interested in conducting AGDS research. Acoustic alert data do not represent all gun violence, since only a fraction of the cases ends up being linked to serious assaults and homicides. In fact, AGDS notifications may not even fully indicate criminal behavior since they may capture justified uses of firearms, including by police. It is reasonable, however, to conclude that AGDS notification data represent outdoor firearm use. It is also true that AGDS data from multiple cities may not be comparable because the context in which firearm discharges occur (such as population density), the local availability of firearms (and legality of carrying firearms), and opportunities for firearm use (such as the number of vacant properties that offer opportunities for target practice) may differ substantially. Additionally, data from different AGDS systems are unlikely to be comparable, and careful contextualization is necessary to foster meaningful comparisons. For example, some systems produce an alert for each round, whereas others group all gunshots without a significant pause (typically 5+ seconds) into one alert. Even in the latter case, multiple alerts may result from one criminal incident.

Despite these caveats, police-operated AGDS almost invariably provide data that can be used within your agency. These data can typically be pulled directly from the system itself. Though some vendors "own" the data from their systems, their user policies allow police to use the information for investigative *and* internal research purposes. Restrictions on use generally apply only to sharing data outside your agency, so agencies must understand the terms of your contracts with the vendor. It is also important to understand that once an alert becomes a logged call for service, the call for service data are *not* subject to the vendor terms and can be more easily shared with external parties.

Nonetheless, vendor and CAD gunfire data are significantly different. In most cases, vendor data include the near-exact time gunfire occurs and provide exact geospatial coordinates of the likely point of origin. Metrics such as weather conditions and round counts may be attached as well. CAD data may mirror time and location, but often not precisely.

To give a more concrete example, consider the differences between how a AGDS generates data versus how data are typically coded in CAD. Consider a scenario in which five gunshots ring out at 23:55:20 in the backyard of a house at 1432 Main Street. The AGDS finishes its review in 48 seconds (23:56:08) and pushes the notification to the dispatch center, where it is entered in the CAD system 90 seconds later (23:57:38). Because this agency dispatches to addresses and because the backyard of 1432 Main Street is deeper than that of the abutting neighbor, the closest address ends up being 1433 2nd Street, one block from Main Street. As a result, the CAD data do not match the exact time of the gunfire and may contain small spatial discrepancies. Relying on the vendor data is important for investigative purposes because these data provide the most exact time and location. General research (internal and external to an agency) can comfortably rely on CAD data, but users should be aware of its limitations.

Some AGDS do not forward all captured noises to dispatch. An AGDS from one of the leading vendors, for example, will forward confirmed gunfire to dispatch, but it also captures two other classes of data that are not forwarded and thus do not appear in CAD records. Gunfire detected outside coverage areas can be found in the AGDS data portal, but the locational accuracy is limited and the incidents are not reviewed, meaning they likely contain false positives. In addition, noises that initially trigger the AGDS but are machine- or reviewer-classified as non-gunfire can also be found in the AGDS portal. In rare instances, true gunfire can be found among these dismissed cases. For investigative purposes, reviewing both sources of data is essential, especially if gunfire is known to have occurred. For researchers, non-gunfire data are likely of little value.

Anyone analyzing acoustic data must recognize that raw AGDS data are not necessarily incident-level data, but rather event data of a discrete number of gunshots. For example, a homicide or assault in which multiple shooters at multiple locations shot firearms can lead to multiple AGDS alerts. As mentioned above, different systems can either report each noise separately or, more typically, group them in defined time chunks. Both approaches can generate a fair number of duplicate alerts for what are technically elements of the same incident, thereby inflating the perceived number of gunfire incidents. For example, a single homicide may be associated with three or four acoustic alerts. Many agencies may label such cases as duplicates in their CAD system, but the thoroughness with which labeling occurs can vary. For this reason, any aggregate analysis done with AGDS data should develop a procedure for handling duplicates.

There is no set guidance on how duplicates should be handled,[85] since this process may be dependent on the nature of the coverage areas (density, grid layout, etc.), but it is reasonable to combine cases that occur within 5 minutes and 500 feet of one another. The easiest way to do so is to use spatial software such as ArcGIS (using the "find space and time matches" function) to identify duplicate cases. Duplicates can be discarded if one is strictly interested in the number of incidents, or they can be aggregated if one is interested in the average number of rounds per incident. Recognizing the limitations of the acoustic systems in place is critical. Because each system has unique features deployed in a unique policing context, assessing the relative reliability of the system and its data is important prior to thorough analytical assessments.

REFERENCES

ACOEM. 2020. Gunshot and Acoustic Threat Detection. Retrieved Oct. 20, 2021, from https://www.acoem.com/wp-content/uploads/2020/03/Brochure.-ACOEM-Gunshot-Acoustic-Threat-Detection-brochure-2020.pdf.

Aguilar, J. R. 2018. "Sistemas de Detección de Disparos: ¿Son Eficaces para Controlar la Violencia con Armas de Fuego en América Latina? (Gunshot Detection Systems: Are They Effective in Controlling Firearms Violence in Latin America?)." *Revista Latinoamericana de Estudios de Seguridad* 23: 128–141.

Atos. 2016. *CityPulse: Using Big Data for Real Time Incident Response Management.* Retrieved Oct. 20, 2021, from https://atos.net/wp-content/uploads/2016/06/atos-ph-eindhoven-city-pulse-case-study.pdf.

Blackburn, E., and D. Mares. 2019. "The Hidden Costs of Police Technology: Evaluating Acoustic Gunshot Detection Systems." *Police Chief Magazine.* https://www.policechiefmagazine.org/the-hidden-costs-of-police-technology/.

Braga, A. A., A. V. Papachristos, and D. M. Hureau. 2014. "The Effects of Hot Spots Policing on Crime." *Justice Quarterly* 31: 633–663.

Brooke, M. A., S. Kaplanes, and G. P. Victorino. 2017. "Automatic Acoustic Gunshot Sensor Technology's Impact on Trauma Care." *Critical Care and Trauma* 225: S50–S51.

Brunson, R. and B. A. Wade. 2019. "'Oh Hell No, We Don't Talk to Police': Insights on the Lack of Cooperation in Police Investigations of Urban Gun Violence." *Criminology* 18: 623–648.

Carr, J. B. and J. L. Doleac. 2016. "The Geography, Incidence, and Underreporting of Gun Violence: New Evidence Using ShotSpotter Data." Retrieved Oct. 20, 2021, from https://ssrn.com/abstract=2770506 or http://dx.doi.org/10.2139/ssrn.2770506.

Chacon-Rodriguez, A., P. Julian, L. Castro, P. Alvarado, and N. Hernandez. 2011. "Evaluation of Gunshot Detection Algorithms." *IEEE Transactions on Circuits and Systems* 58: 363–373.

Chicago Office of Inspector General. 2021. *"The Chicago Police Department's Use of ShotSpotter Technology. Chicago, IL."* Retrieved Oct. 20, 2021, from https://igchicago.org/wp-content/uploads/2021/08/Chicago-Police-Departments-Use-of-ShotSpotter-Technology.pdf.

Cheinet, S., and T. Broglin. 2015. "Sensitivity of Shot Detection and Localization to Environmental Propagation." *Applied Acoustics* 93: 97–105.

Choi, K., M. Librett, and T. J. Collins. 2014. "An Empirical Evaluation: Gunshot Detection System and Its Effectiveness on Police Practices." *Police Practice and Research* 15(1): 48–61.

Cincinnati Police Department. 2017. 12.541 ShotSpotter Gunshot Location System. Internal document.

Decker, S., and R. Rosenfeld. 2004. *The St. Louis Consent-to-Search Program.* Washington, DC: National Institute of Justice. https://www.ojp.gov/pdffiles1/nij/191332.pdf.

Doucette, M. L., C. Green, J. N. Dineen, D. Shapiro, and K. M. Raissian. 2021. "Impact of ShotSpotter Technology on Firearm Homicides and Arrests among Large Metropolitan Counties: A Longitudinal Analysis, 1999-2016." *Journal of Urban Health.* DOI: 10.1007/s/11524-021-00515-4.

Feathers, T. 2021. "Police Are Telling ShotSpotter to Alter Evidence from Gunshot-Detecting AI." *Vice.* Retrieved Aug. 2, 2021, from https://www.vice.com/en/article/qj8xbq/police-are-telling-shotspotter-to-alter-evidence-from-gunshot-detecting-ai.

Goldenberg, A., D. Rattigan, M. Dalton, J. P. Gaughan, J. S. Thomson, K. Remick, C. Butts, and J. P. Hazelton. 2019. "Use of ShotSpotter Detection Technology Decreases Prehospital Time for Patients Sustaining Gunshot Wounds." *Journal of Trauma and Acute Care Surgery* 87(6): 1253–1259.

Haberman, C., E. Ruhland, J. Frank, J. Kelsay, and J. Desmond. 2020. *Cincinnati Police Department: Price Hill ShotSpotter Survey Evaluation Report.* Cincinnati, OH: Institute of Crime Science.

Hollywood, J. S., K. N. McKay, D. Woods, and D. Agniel. 2019. *Real-Time Crime Centers in Chicago: Evaluation of the Chicago Police Department's Strategic Decision Support Centers.* Santa Monica, CA: RAND.

Hope, L., D. Blocksidge, F. Gabbert, J. Sauer, W. Lewinski, A. Mirashi, and E. Atuk. 2015. "Memory and the Operational Witness: Police Officer Recall of Firearms Encounters as a Function of Active Response Role." *Law and Human Behavior* 40(1): 23–35.

Huebner, B. M., T. S. Lentz, and J. A. Schafer. 2020. "Heard Shots – Call the Police? An Examination of Citizen Responses to Gunfire." *Justice Quarterly.* DOI: 10.1080/07418825.2020.1799063.

Irvin-Erickson, Y., N. La Vigne, M. Levine., E. Tiry, and S. Bieler. 2017. "What Does Gunshot Detection Technology Tell Us About Gun Violence?" *Applied Geography* 86: 262–273.

Kiktova, E., M. Lojka, M. Pleva, J. Juhar, and A. Cizmar. 2013. "Comparison of Different Feature Types for Acoustic Event Detection System." In Dziech, Andrzej, and Andrzej Czyżewski, eds. *Multimedia Communications, Services and Security. MCSS 2013. Communications in Computer and Information Science* 368: 288-297. Berlin, Heidelberg: Springer.

King, W., W. Wells, C. Katz, E. Maguire, and J. Frank. 2013. *Opening the Black Box of NIBIN: A Descriptive Process and Outcome Evaluation of the Use of NIBIN and Its Effects on Criminal Investigations, Final Report.* Washington, DC: National Institute of Justice. https://www.ncjrs.gov/pdffiles1/nij/grants/243875.pdf.

Koren, D. 2018. *ShotSpotter Pilot Assessment.* Las Vegas, NV: Las Vegas Police Metropolitan Police Department.

Lawrence, S. 2015. *Using a Place-Based Technology to Address Shootings in East Palo Alto, California.* Berkeley, CA: University of California Berkeley.

Lawrence, D., N. La Vigne, and P. Thompson. 2019. *Evaluation of Gunshot Detection Technology to Aid in the Reduction of Firearms Violence.* Washington, DC: Urban Institute.

Loeffler, C. E., and S. Flaxman. 2016. "Is Gun Violence Contagious?" arXiv:1611.06713v1.

MacDonald, J., V. Nguyen, S. T. Jensen, and C. C. Branas. 2018. "Reducing Crime by Remediating Vacant Lots: The Moderating Effect of Nearby Land Uses." *Journal of Experimental Criminology.* doi:10.1007/s11292-020-09452-9.

Makinen, T., and P. Pertila. 2010. "Shooter Localization and Bullet Trajectory, Caliber, and Speed Estimation Based on Detected Firing Sounds." *Applied Acoustics* 71: 902–913.

Manes, J. 2021. "The State of Illinois v. Williams (Amicus Brief)." Retrieved Oct. 20, 2021, from https://www.macarthurjustice.org/case/the-state-of-illinois-v-williams-amicus-brief/.

Mares, D., and E. Blackburn. 2012. "Evaluating the Effectiveness of an Acoustic Gunshot Location System in St. Louis, MO." *Policing: A Journal of Policy and Practice* 6: 26–42.

Mares, D., and E. Blackburn. 2021. "Acoustic Gunshot Detection Systems: A Quasi-Experimental Evaluation in St. Louis, MO." *Journal of Experimental Criminology* 17: 193–215.

Mares, D. 2021a. "Evaluating an Acoustic Gunshot Detection System in Cincinnati." In E. Groff and C. Haberman, eds. Forthcoming. *The Study of Crime and Place: A Methods Handbook.* Philadelphia, PA: Temple University Press.

Mares, D. 2021b. *False Negatives in Acoustic Gunfire Detection: A Comparison of Gunfire Events and Calls for Service.* St. Louis, MO: St. Louis Metropolitan Police Department.

Mares, D. 2021c. *Mobile Surveillance Trailers in St. Louis: A Midpoint Evaluation, 2021.* St. Louis, MO: St. Louis Metropolitan Police Department.

Mares, D. 2021d. "Op Ed: ShotSpotter Criticism Distracts from a Real Debate About Police Technology." *St. Louis Post Dispatch.* Sept 30, 2021. https://www.stltoday.com/opinion/columnists/mares-shotspotter-criticism-distracts-from-a-real-debate-about-police-technology/article_bc5afca4-6109-584c-932e-65a1c3360879.html.

Mazerolle, L., C. Watkins, D. Rogan, and J. Frank. 1999. *Random Gunfire Problems and Gunshot Detection Systems. Research in Brief* (NCJ 179274). Washington, DC: National Institute of Justice.

Mazeika, D. M., and L. Uriarte. 2019. "The Near Repeats of Gun Violence Using Acoustic Triangulation Data." *Security Journal* 32: 369–389.

Mazeika, D. M. 2021. "The Effect of Unreported Gun-Related Violent Crime on Crime Hot Spots." *Security Journal.* https://doi.org/10.1057/s41284-022-00329-2.

Nix, J., A. N. Arnio, and R. Spohn. 2019. *Assessing the Effectiveness of ShotSpotter in Omaha: Addendum to Project Safe Neighborhoods 2016 Final Evaluation Report.* Omaha, NE: School of Criminology and Criminal Justice, University of Nebraska Omaha.

Novak, K. J. and W. R. King. 2020. *Evaluation of the Kansas City Crime Gun Intelligence Center. Final Report.* Washington, DC: The National Crime Gun Intelligence Center Initiative. https://crimegunintelcenters.org/wp-content/uploads/2020/10/KC-CGIC-Final-Report-2020.pdf.

Police Executive Research Forum. 2017. *The "Crime Gun Intelligence Center" Model: Case Studies of the Denver, Milwaukee, and Chicago Approaches to Investigating Gun Crime.* Washington, DC: Police Executive Research Forum.

Ratcliffe, J. H., M. Lattanzio, G. Kikuchi, and K. Thomas. 2018. "A Partially Randomized Field Experiment on the Effect of an Acoustic Gunshot Detection System on Police Incident Reports." *Journal of Experimental Criminology.* doi.org/10.1007/s11292-018-9339-1.

Shaw, N. 2018. "South Africa Adopts New Audio Tech to Find Location of Gunshots and Immediately Alert Police." *Global News.* Retrieved Sept. 22, 2021, from https://globalnews.ca/news/4446595/south-africa-shotspotter-gun-tech/.

ShotSpotter. 2014. *Gunshot Detection Technology. Gunshot Technology – Hammers or Pliers? Depends on the Task at Hand.* White Paper. Retrieved Oct. 21, 2021, from https://www.shotspotter.com/system/content-uploads/mediakit/Gunshot-detection-WP.pdf.

Shoham, A., A. Katz, and Y. Nemirovsky. 2018. "CMOS-Based Gunshot Optical Detection Systems Performance Prediction Model." *IEEE Sensors Journal* 18: 5090–5097.

Stanley, J. 2012. "Gunshot Detectors: The ACLU's View." New York, NY: ACLU. Retrieved Feb. 13, 2021, from https://www.aclu.org/blog/national-security/privacy-and-surveillance/gunshot-detectors-aclus-view.

Stanley, J. 2021. "Four Problems with the ShotSpotter Gunshot Detection System." New York, NY: ACLU. Retrieved Feb. 13, 2021, from https://www.aclu.org/news/privacy-technology/four-problems-with-the-shotspotter-gunshot-detection-system/.

Sun, D., X. Liang, H. Dang, Z. Cheng, H. Zheng, L. Zhang, F. Zhang, D. Sun, and Y. Liu. 2019. "Study on Large Scale Projectile Impact Point Positioning Method Based on Trajectory Shock Wave." *Proceedings of the 23rd International Congress on Acoustics.*

Swatt, M. L., C. D. Uchida, and A.Q. Land. (n.d.) *The Effects of ShotSpotter on Gun-Crime in Denver: An Impact Evaluation. Justice & Security Strategies Inc.*

Teale, C. 2021. "3 in 5 Adults Back the Use of Gunshot Detection Technology Generally. Even More Support Its Use by Law Enforcement." *Morning Consult.* Retrieved Feb. 13, 2021, https://morningconsult.com/2021/09/13/data-privacy-security-gunshot-detection-technology-poll/.

Uchida, C. D., M. L. Swatt, A. Q. Land, K. Anderson, and S. Hock. 2020. *Focus on Gun Violence and Evaluation of Denver's CGIC and RAVEN Programs.* Justice and Security Strategies.

Valenzise, L., M. Gerosa, F. Tagliasacchi, F. Antonacci, and A. Sarti. 2007. "Scream and Gunshot Detection and Localization for Audio-Surveillance Systems." *2007 IEEE Conference on Advanced Video and Signal Based Surveillance:* 21–26. doi: 10.1109/AVSS.2007.4425280.

Vovak, H., T. Riddle, T. Taniguchi, K. Hoogesteyn, and Y. Yang. 2021. *Strategies for Policing Innovation (SPI) in Wilmington, Delaware: Targeting Violent Crime.* Washington, DC: National Police Foundation.

Watkins, C., L. G. Mazerolle, D. Rogan, and J. Frank. 2002. "Technological Approaches to Controlling Random Gunfire: Results of a Gunshot Detection System Field Test." *Policing* 25: 345–370.

Wheeler, A. P., D. Kim, and S. W. Philips. 2018. "The Effect of Housing Demolitions on Crime in Buffalo, New York." *Journal of Research in Crime and Delinquency* 55: 390–424.

Wheeler, A.P., M. Gerell, and Y. Yoo. 2020. "Testing the Spatial Accuracy of Address-Based Geocoding for Gunshot Locations." *Professional Geographer* 72: 398–410.

Zhou, Z., Y. Xu, S. Zhang, and M. Li. 2021. "Detecting Escalation Level from Speech with Transfer Learning and Acoustic-Lexical Information Fusion." ArXiv:2104.06004v1.

ABOUT THE AUTHOR

DENNIS MARES

Dr. Mares is a professor of Criminal Justice at Southern Illinois University Edwardsville. Mares' research focuses on spatial and temporal aspects of violent offending, and his work has been published in criminological and interdisciplinary journals such as the *Journal of Experimental Criminology*, the *Journal of Urban Health*, and *Environment and Behavior*. He actively works with law enforcement agencies' evaluation gunshot detection systems and other types of police technology. He is currently working on two Smart Policing Initiative (SPI) projects, evaluating the efficacy of mobile surveillance trailers in St. Louis and developing a problem-oriented approach with acoustic gunshot detection systems. Mares received his M.A. and Ph.D. in criminology and criminal justice from the University of Missouri, St. Louis, and he completed his undergraduate work in cultural anthropology at Utrecht University, the Netherlands.

ENDNOTES

[1] Lawrence (2015).

[2] Shoham, Katz, and Nemirovsky (2018).

[3] ShotSpotter (2014); Makinen and Pertila (2010).

[4] Sun et al. (2019).

[5] Chacon-Rodriguez et al. (2011); Cheinet and Broglin (2015).

[6] Mares (2021b).

[7] Aguilar (2018); Shaw (2018).

[8] Choi, Librett, and Collins (2014); Koren (2018); Lawrence, La Vigne, and Thompson (2019); Mares (2012; 2021).

[9] Brooke, Kaplanes, and Victorino (2017); Goldenberg et al. (2019).

[10] Wheeler, Gerell, and Yoo (2020); Irvin-Erickson et al. (2017); Mazerolle et al. (1999); Watson et al. (2002).

[11] Nix, Arnio, and Spohn (2019).

[12] Katz et al. (2021).

[13] Carr and Doleac (2016); Koren (2018); Mares (2021b); Katz et al. (2021).

[14] Blackburn and Mares (2019).

[15] Mares and Blackburn (2021).

[16] Blackburn and Mares (2019).

[17] Ratcliffe et al. (2018.)

[18] Mares and Blackburn (2012, 2021).

[19] Mares (2021a).

[20] Swatt, Uchida, and Land (n.d.).

[21] Lawrence, La Vigne, and Thompson (2019).

[22] Vovak et al. (2021).

[23] Lawrence (2015).

[24] Vovak et al. (2021).

[25] Katz et al. (2021); Mares (2021b).

[26] Ratcliffe et al. (2018); Vovak et al. (2021).

[27] Vovak et al. (2021).

[28] Atos (2016).

[29] Valenzise et al. (2007); Zhou et al. (2021).

[30] ACOEM (2020); Kiktova et al. (2013).

[31] Atos (2016).

[32] Vovak et al. (2021).

[33] Watkins et al. (2002).

[34] Mares (2021b).

[35] Mazerolle et al. (1999); Watkins et al. (2002).

[36] Mazerolle et al. (1999); Watkins et al. (2002); Koren (2018); Mares (2021b); Katz et al. (2021).

[37] Manes (2021); Feathers (2021); Chicago Office of Inspector General (2021).

[38] Lawrence (2015).

[39] Ratcliffe et al. (2018); Vovak et al. (2021).

[40] Lawrence (2015).

[41] Katz et al. (2021); Wheeler, Gerell, and Yoo (2020).

[42] ShotSpotter (2014).

[43] Wheeler, Gerell, and Yoo (2020); Feathers (2021).

[44] Mares (2021a); Mares and Blackburn (2021).

[45] Mares and Blackburn (2021).

[46] Manes (2021).

[47] Koren (2018); Mares (2021b); Katz et al. (2021).

[48] Lawrence (2015).

[49] Blackburn and Mares (2019); Mares and Blackburn (2021).

[50] Lawrence (2015); Hollywood et al. (2019); Katz et al. (2021); Vovak et al. (2021).

[51] Lawrence (2015).

[52] Koren (2018); Mares (2021b).

[53] Mares (2021b).

[54] Mares (2021a); Blackburn and Mares (2019).

[55] Nix, Arnio, and Spohn (2019).

[56] Lawrence (2015); Braga, Papachristos, and Hureau (2014).

[57] *cf.* Mares and Blackburn (2012; 2020); Mares (2021a); Ratcliffe et al. (2018); Vovak et al. (2021).

[58] King et al. (2013); Police Executive Research Forum (2017); Vovak et al. (2021).

[59] Novak and King (2020).

[60] Uchida et al. (2020).

[61] Lawrence (2015); Lawrence, La Vigne, and Thompson (2018); Vovak et al. (2021).

[62] Mares (2021b).

[63] Katz et al. (2021).

[64] Lawrence (2015); Loeffler and Flaxman (2016).

[65] Brunson and Wade (2019).

[66] Mazeika (2021).

[67] See Lawrence (2015).

[68] Wheeler, Kim, and Philips (2018); MacDonald et al. (2018).

[69] Mares (2021c).

[70] Decker and Rosenfeld (2004).

[71] Watkins et al. (2002).

[72] Blackburn and Mares (2019).

[73] Lawrence (2015); La Vigne et al. (2019).

[74] Katz et al. (2021).

[75] Hollywood et al. (2019); Vovak et al. (2021).

[76] La Vigne et al. (2019).

[77] Cincinnati Police Department (2017).

[78] Haberman et al. (2020).

[79] Vovak et al. (2021).

[80] Teale (2021).

[81] Feathers (2021).

[82] Stanley (2012); Stanley (2021).

[83] Mares (2021d).

[84] Stanley (2021).

[85] Huebner, Lentz, and Schaefer (2021); Mazeika and Uriarte (2019).