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RESEARCH

Measuring the Cost-Effectiveness of New Technologies in Policing: The Case of Automatic License Plate Readers (ALPR)

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Abstract

Research Question Can research discover the true cost-effectiveness of new technologies in policing, such as automatic license plate readers (ALPR)?

Data We review the findings of many impact tests of introducing ALPR readers in predominantly US police agencies.

Methods We place the data in the context of the two key police mandates: public safety and public confidence. We then apply the logic of linking findings specific to the new technology with the two broad mandates.

Findings The effect of any technology on police outcomes depends heavily on how it is implemented in the larger context of organizational systems and culture. The effect is also conditioned by a broad body of evidence that the key mandates depend on far broader foundations than on any specific technology.

Conclusions Evidence-based policing cannot be built from isolated findings, such as marginal changes in outputs or outcomes associated with new technologies. Linking new technologies to joined-up systems of targeting, testing, and tracking is required before we can ask whether the technologies are cost-effective.

Keywords Technology · Automatic license plate readers (ALPR) · ANPR · Evidence-based policing · Effectiveness · Efficiency · Body-worn cameras · Police mandates

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Introduction: The Promise (?) of Technology in Policing

A variety of technologies have proliferated in policing in the last ten to fifteen years and have become a significant investment for law enforcement agencies and their jurisdictions. These technologies include license plate readers (ALPRs), closed-circuit televisions, body-worn cameras, gunshot detection devices, "next generation" computer-aided dispatch (CAD) systems, predictive policing software, real-time crime centers, and drones, to name a few. Relatedly, law enforcement agencies and community members alike have high and often different expectations for technologies. For example, while police agencies feel that technologies can help them more efficiently and effectively deliver public safety, citizens may believe technologies can help them and the police solve crimes faster or hold police more accountable for their actions.

However, after more than four decades of research on police technologies, it is not clear that technologies in policing have made police more effective or have helped community members realize their expectations of the police. For example, information technologies in policing (e.g., CAD systems, mobile computer terminals, and records management systems) can undoubtedly speed up some police processes (Boudreau & Robey, 2005; Chan, 2001, 2003; Colton, 1980; Ericson & Haggerty, 1997; Groff & McEwen, 2008; Harris, 2007; Ioimo & Aronson, 2004; Manning, 1992a, b; Mastrofski & Willis, 2010; Rosenbaum et al., 2011). However, research also shows that police technologies can reduce efficiency, yield ineffective results, or even create unintended (often negative) consequences (Chan et al., 2001; Colton, 1980; Danziger & Kraemer, 1985; Koper et al., 2013; La Vigne et al., 2011; Lum et al., 2011; Nunn, 1993, 1994; Roman et al., 2009; Zaworski, 2004).

Technology and organizational theorists suggest that the gap between the intended and actual outcomes of technology is the result of the way technologies are brought into the agency and how they are interpreted and used. While we do not review this extensive literature here, we highlight a few points. Orlikowski and Gash (1994) suggest that technological "frames" of agencies mediate the impact of technology on actual outcomes. They define frames as "the assumptions, expectations, and knowledge [members of an organization] use to understand technology in organizations. This includes not only the nature and role of the technology itself, but the specific conditions, applications, and consequences of that technology in particular contexts" (Orlikowski & Gash, 1994, p. 178; see also Orlikowski, 2000). These frames engulf employees' roles, experiences, values, and history in the organization and then shape technology use and outcomes (see also Boudreau & Robey, 2005; Orlikowski, 1992; Robey et al., 2000). Conceptually, technological frames align with Bandura's (1986) and Goffman's (1974) organizational frames or schema and Weick's (1995) sensemaking. Relatedly in policing, Manning (1992a, b, 1997), 2008) has argued that policing's structures and cultures have shaped technology use (not the other way around). As several have documented, such frames include excessive reliance on a case-by-case, process-based, reactive-response approach and defensive stance to both public safety and community interactions (see Harris, 2007; Koper et al., 2014; Koper et al., 2015; Lum et al., 2017; Manning, 2008; Sanders & Henderson, 2013; Sanders et al., 2015). In other words, the expectations of technology in policing—

including its costs and benefits—are often not realized in practice, as they are filtered through these organizational ways that limit and even distort their hypothetical intentions (Lum et al., 2017).

However, the challenge of realizing the potential of technology—including the realization of cost-beneficial outcomes—does not stop at organizational frames. The more critical question is whether policing's organizational frames, processes, mandates, deployments, and systems are what they should be in the first place. Suppose reactive, case-by-case, procedural, and defensive frames and approaches to policing distort and limit technology's effectiveness, as Lum et al. (2017) argue. Then what should be the organizational approach that technologies are adopted into? And, if policing is currently not in an optimal organizational approach, then cost-benefit or cost-effectiveness analysis for technologies could be premature at best and, at worst, a waste of effort. Yet, both researchers and police agencies alike have been prompted to analyze the cost-benefits of police technology. Funding solicitations by the National Institute of Justice (U.S. Department of Justice) and other organizations supporting justice-related research have pushed for more cost-benefit analysis of police activities and technologies. Agencies are almost always confronted with this question as well when purchasing technology, given procurement requirements from their respective jurisdictional governments.

Our question is whether the cost-effectiveness of any technology can be extracted from the larger systemic context in which it is implemented. Our answer is "no." We argue that agencies and their jurisdictions are likely wasting time, energy, and money on purchasing new technologies like license [number (in the UK)] plate readers, body-worn cameras, gunshot detection systems, etc., without linking them to the organizational context of implementation. These technologies cannot be meaningfully linked to basic police outcomes if they are not simultaneously joined to the infrastructure, systems, and deployments based on broader evidence-based approaches. Aligned with this argument is the question of whether any attempt at cost-benefit analysis of technology is elusive and illusive.

While we consider a range of new police technologies, we focus on automatic license plate readers (ALPR) in the USA. We build our argument using the example of license plate readers, exploring empirical research on their widespread adoption and appeal, what we know about their effectiveness in achieving public safety or legitimacy, and how lessons from evaluations of ALPRs make our point (although we could have just as well used body-worn cameras, gun-shot detection systems, or information technologies to make the same point).

We conclude by acknowledging that police agencies will continue to purchase these and other technologies. However, this analysis points to the gap of insufficient strategizing about how to optimize new technologies. We show that adjusting deployments toward more effective approaches for both public safety and police legitimacy will be critical to agencies seeking to get the most out of the technologies they purchase. Much more investment must be made in adjusting policing "frames" towards those supported by systematic study and science. Without doing so, police are blindly purchasing and using technologies without knowing whether those efforts work or even have harmful consequences.

Method: Analyzing Automated License Plate Readers (ALPR/ANPR)

Automated license/number plate readers (LPRs, ALPRs, or ANPRs) have been widely adopted across police agencies in both the United States and the UK. Indeed, before body-worn cameras burst onto the scene, the ALPR was one of the most rapidly diffusing technologies in American policing (Lum et al., 2019a). Lum et al. found that ALPR use was almost fully adopted in England and Wales as early as 2002, with US agencies quickly following suit. By the time of their first national survey of ALPR prevalence and use in 2009, Lum et al. (2010) found that over a third of all agencies in the United States with 100 or more officers had already adopted ALPRs. By their second national survey of ALPR prevalence and uses, Lum et al. (2019a) estimated that by 2016, prevalence had doubled and that between two-thirds to three-quarters of police agencies in the US with over 100 full-time sworn officers likely had purchased or had access to ALPRs. The two most recent Law Enforcement and Administrative Statistics (LEMAS) surveys conducted by the US Bureau of Justice Statistics in 2016 and 2020 confirm this widespread use.[1] The 2016 LEMAS estimated that about 64% of agencies with 100 or more full-time sworn officers were using ALPRs "on a regular basis." This proportion increased to about 72% in the 2020 LEMAS survey. Many jurisdictions and non-police entities also have long used ALPRs for automated toll and parking fine collection and regulation (although we focus on police uses of these technologies here).

The rapid adoption of ALPRs by police agencies is easy to understand. Plate readers have been seen as game changers for the police, as these systems can automatically read passing vehicles' license plates and run them against a variety of databases to detect if the plate is associated with a vehicle or person of interest to authorities (hence why they are now also used for toll collection on fast-moving highways). Contrast this to the not-so-distant past when officers would have to radio into dispatch one plate at a time, wait for the dispatcher to look up the license plate number in a motor vehicle database, and then take that information and check it against other databases to see if that plate or person was flagged as wanted, missing, stolen, etc. As late as the 1990s and early 2000s, officers were still receiving lists of stolen tags or vehicles on pieces of paper at the beginning of their shift with the hope that they might encounter those vehicles serendipitously.[2] Today, as Lum et al. (2019a) document, ALPRs provide those functions automatically and have several uses, from detecting stolen vehicles and license plates to assisting in criminal investigations. This appeal and relative advantage to manual approaches would make ALPRs rate highly on Rogers' (1995) attributes that spur innovation diffusion and adoption[3] and are often the reasons used to justify the purchase of ALPRs.

[1] The 2016 LEMAS question is 41c and asks, "As of June 30, 2016, did your agency use any of the following technologies on a REGULAR basis? [c. License Plate Readers (ALPR)]." The 2020 LEMAS question is 34 g and asks "As of December 31, 2020, did your agency use any of the following on a *regular* basis? [g. License Plate Readers (ALPR)]."

[2] One of the authors regularly used such lists as a former police officer in the late 1990s in a large urban agency.

[3] Rogers (1995) asserted from his empirical studies that five elements of innovations that make them especially prone to adoption: (1) *relative advantage* (as compared to previous approaches or technologies),

These aspects of ALPRs made their adoption seem like a no-brainer for law enforcement from a cost-efficiency perspective. Just the speed by which a tag can be processed makes purchasing ALPRs appealing. In fact, early studies and agency examinations of ALPRs showed they were undoubtedly faster, more efficient, and more accurate than humans in scanning license plates and discovering stolen automobiles (Cohen et al., 2007; Ohio State Highway Patrol, 2005; Ozer, 2010; P.A. Consulting Group, 2004; Potts, 2018; Taylor et al., 2012). Police believed that such efficiency could help them find stolen automobiles, apprehend car thieves, investigate other crimes and persons of interest associated with specific vehicles (and their license plates), and discover individuals (driving in flagged vehicles) who failed to comply with court orders or who had other violations. In other words, police adopted ALPRs because they believed that such efficiency could lead to several crime control benefits.

This rapid adoption of ALPRs also generated significant levels of public media and legal debate and discussion in the 2010s, mostly about privacy concerns related to what data would be collected and how long that data would be stored and used (Díaz & Levinson-Waldman, 2020; Merola & Lum, 2012). During this period, a handful of researchers also began evaluating the impact of ALPRs on crime control, trying to estimate the effectiveness and cost-benefits of the technology (reviewed below). ALPRs are expensive technologies, ranging from mobile units (on cars) costing ten to twenty-five thousand US dollars, with fixed units costing up to US $100,000 depending on where they are placed (Gierlack et al., 2014; Waddell, 2016).[4] From a cost-efficiency perspective, understanding if ALPR achieves public safety outcomes sought by communities and the police without eroding privacy rights, police legitimacy, or community trust in law enforcement has been at the heart of many of these inquiries.

In 2017, around the peak of ALPR interest, these questions of cost, effectiveness, and legal legitimacy of ALPR were the main foci of a special issue of the *Journal of Benefit-Cost Analysis*, led by the Policing Project at New York University's School of Law. The Policing Project convened a group of scholars (of which the first author was part) to examine the cost-benefits and cost-effectiveness of several policing activities, with ALPRs being one significant interest (see Carr, 2017; Geller, 2017; Goldstein, 2017; Ponomarenko & Friedman, 2017). In that issue, Ponomarenko and Friedman (2017, p. 309) asserted a well-known prerequisite of cost-benefit analysis of any policing technology or strategy—that "[t]he first question in any [benefit-cost analysis] is whether the intervention is efficacious. Does it yield any benefits? If not, there is no sense in pursuing the question further." Following this charge, the special issue focused on the methodological challenges of accurately determining the effectiveness

(2) *compatibility* (the technology fits existing values), (3) *complexity* (perceived difficulty in use—the less difficult, the more likely to be adopted), (4) *trialability* (can be experimented upon quickly), and (5) *observability* (where the benefits are easy to see by those adopting the technology).

[4] See also examples of procurement records, located at https://www.leonardocompany-us.com/ALPR/how-to-buy/procurement-contracts/txdir or https://procure.ohio.gov/static/pricelist/800067pricelist.pdf. See also a report by the National Law Enforcement and Corrections Technology Center on ALPRs here: https://www.ojp.gov/pdffiles1/nij/nlectc/238827.pdf.

of ALPR and other police technologies and practices as a precursor to determining their cost-benefits (e.g., Carr, 2017).

Findings: Are ALPRs Effective or Cost-Beneficial?

Recognizing the methodological concerns raised by others, our findings focus on whether ALPRs are effective in achieving the outcomes that police seek. We then turn to the question of whether the evidence shows that ALPRs are cost-beneficial. And, to use a related term, are they a cost-efficient technology? Our review shows that while ALPRs are certainly more *efficient* than the manual checking described above, the jury is still out on whether ALPRs are more *effective* in achieving public safety goals. Most of the early studies mentioned about ALPR above focused on efficiency, defined as the automation and speed of ALPR technology. They did not focus on ALPR effectiveness, defined as their link to crime control outcomes (see discussion by Lum, 2010; Lum et al., 2011). There have only been a handful of methodologically rigorous evaluation studies (experimental, quasi-experimental, and econometric) that have evaluated ALPR against several intended crime control benefits. Many of these studies are either equivocal or show limited effects of ALPRs on crime outcomes, even when conducted in very realistic contexts.

Most research about ALPR effectiveness has primarily focused on the use of ALPRs in patrol. For example, an early study by Lum et al. (2011) began questioning the effectiveness of ALPRs. Using randomized controlled experiments, Lum et al. found that thirty-minute patrols using police cars outfitted with ALPRs conducted once every few days in randomly selected high-crime places for a period of two to three months did not reduce auto-related or other forms of crime in experimental locations compared to their control counterparts. Although the experimental dosage was low and the ALPR databases were limited to information on stolen vehicles, Lum et al. argued that these conditions reflected the contemporaneous state of ALPR use, providing a realistic evaluation of how ALPRs might actually be used given the way that police regularly deploy their patrol officers.

Around the same time, another early randomized experiment testing ALPRs was conducted in Mesa, Arizona (Koper et al., 2013, 2019; Taylor et al., 2012). In those studies, a small auto theft squad conducted short-term operations to detect stolen and other vehicles of interest at high-risk road segments that were identified as likely travel routes for auto thieves (based on a quantitative targeting analysis of auto theft and recovery locations and the qualitative input of detectives). The evaluation revealed that patrols both with and without ALPRs produced short-term reductions in crime at these locations (Koper et al., 2013), with more detection of stolen vehicles and auto thieves when ALPRs were used (Taylor et al., 2012). However, the study could not definitively isolate the crime prevention effects of the ALPRs from the more general deterrent effects of the patrols. This gap was due to several conditions: (1) the low number of ALPR arrests made by the officers, (2) the fact that the ALPR cameras were mounted on the cars even when not in use (thus potentially creating deterrent effects), and the fact that (3) officers varied their patrol tactics depending

on whether the ALPRs were activated. Nor was ALPR use linked with the deterrence of auto theft.

Both the early Mesa (AZ) and Virginia studies were limited by the short duration and low dosage of the interventions, the small numbers of ALPRs available, and the limited data fed into the ALPR devices. However, more recent field studies that correct for some of these issues seem to indicate that ALPR use, either in patrol or investigations, still may not necessarily lead to substantial benefits. For example, in a field study of ALPR use in a large mid-Atlantic jurisdiction, Koper et al. (2022) found once again that ALPRs may increase stolen vehicle recoveries but not necessarily arrests for those stealing cars. Unlike previous studies, that study took place in an agency with many ALPR units (more than 50 units), better reflecting the potential for cost-benefits to be reaped when more units are in operation. Koper and colleagues initially implemented a randomized controlled experiment, and officers were charged to patrol crime hot spots with and without ALPRs to see if the technology gave officers a crime control advantage.

Unfortunately, officers provided relatively low dosages of hot spot patrols when implementing the ALPR intervention. As most policing researchers know, this is a common challenge for field studies of patrol: asking officers to do something different (even if more effective) from their everyday deployment routines and approaches is challenging (see extensive discussions of this issue in Lum & Koper, 2017). Thus, the researchers opted to measure the initial and residual deterrent effect of each ALPR and non-ALPR visit to hot spots, focusing on a more realistic evaluation of use as supported by Carr (2017).[5] Still, their findings indicated that there was no significant difference between the initial or residual deterrence (Sherman, 1990) of ALPR versus non-ALPR patrol officer visits to high crime places. In other words, while officers may have deterred crime when they did patrol crime hot spots, the addition of ALPRs to their vehicles did not seem to make any difference to that deterrence effect.

Other studies that use quasi-experimental or time-series methods have similarly been equivocal in their findings or struggle with pinpointing the causal mechanisms that link ALPRs to public safety outcomes. For example, Ozer (2016) found that ALPRs seemed to be associated with an increased number of follow-up arrests per month for violence and property crimes after ALPRs were implemented in Cincinnati, but with unclear effects on deterrence of crime. Ozer also argues that ALPRs are cost-effective and "do the same job (produce follow-up arrests) with fewer officers compared with traditional policing." (Ozer, 2016, p. 130). Ozbaran and Tasgin (2019), using a pre-post implementation design, argued that ALPRs were responsible for increasing seat belt usage (although acknowledging that ALPRs cannot detect seat belt usage). Wheeler and Phillips (2018) found inconsistent results using different statistical methods in determining the impact that the use of ALPRs at roadblocks had on crimes, accidents, or calls for service, again challenged by explaining the causal link between ALPRs and these outcomes.

[5] Koper et al. measured *initial* deterrence based on the likelihood that a crime or disorder occurred in the location while the patrol unit was present. They measured *residual* deterrence (Sherman, 1990) based on the time to the next crime or disorder at the location after the unit left.

In sum, these studies seem to indicate that ALPRs may not consistently create the crime control benefits in patrol that were initially anticipated. Further experimentation and analysis will be needed to determine whether higher dosages of ALPR deployment or different uses of ALPR in patrol can be more effective in places where crime, disorder, and traffic problems are concentrated. But these studies reveal a more important point addressed below. That point is the widely observed difficulty of changing officer deployment routines carry out their patrols in proactive and place-based ways (a style of patrol that is known for being more effective than traditional patrol approaches: see Braga et al., 2020). That obstacle is a challenge in and of itself, with or without ALPRs.

Cost-Effectiveness of ALPR Use for Investigations. Given the equivocal results of the above outcome evaluations of the effectiveness of ALPR used on patrol, one might question the wisdom of undertaking a cost-benefit analysis of ALPRs at all. We do not dwell on the many challenges of cost-benefit calculations in crime prevention more generally, as they have already been explored extensively elsewhere (see, e.g., Cohen et al., 2004; Fackler et al., 2017; McCollister et al., 2010). Several police officials and academics have informally argued with the authors that ALPRs were never intended to control, reduce, or deter crime in patrol (a point with which we disagree, given the early documentation, selling points, and research on ALPRs).[6] Instead, they argue that ALPRs have much better uses for improving criminal investigations. Indeed, during the diffusion of ALPR technology in policing, many agencies began shifting their use of ALPRs from patrol deployment to investigations (Willis et al., 2018).

In many ways, calculating the cost-effectiveness of ALPRs for any given investigation seems possible by examining the cost of investigations per case closure with and without using ALPRs. Perhaps ALPRs can assist with an investigation by locating a person of interest more quickly or identifying vehicles (and presumably owners) who were in an area of a crime who might be essential witnesses (or suspects). If more clearances could be achieved or if time-to-clearance could be shortened with the use of ALPRs, then such use of ALPRs might be cost-effective, even if we cannot monetize the broader benefits of bringing an offender to justice, and even if in the aggregate, those arrests do not lead to a broader deterrence effect.

Koper and Lum's (2019) study of ALPR use in investigations is one case in point. They analyzed a large metropolitan agency that had a significant number of fixed ALPR units (approximately 100) situated around its jurisdiction on major roadways. These ALPRs were coupled with CCTV cameras and a real-time intelligence center able to process and deploy personnel based on alerts and information gathered. For example, vehicles associated with such individuals can be loaded into the ALPR system, and the large quantity of ALPR units in the jurisdiction increases the probability that an uploaded vehicle will be detected, narrowing the time and location of the possible person of interest. Collected ALPR data can also be searched for vehicles connected to persons of interest in investigations to see whether, when, and where an

[6] Unfortunately, we cannot find a public document where either police officials or researchers put this argument in writing. We only convey what several individuals have remarked to the authors in person at conferences and during extensive discussions of ALPR use and research.

ALPR unit may have captured the vehicle to help with searching for individuals of interest in investigations (also see Sidhu et al., 2017; Willis et al., 2018).

As an experimental study was not possible, the authors analyzed actual use – examining when ALPRs were denoted in the records management system as being checked for use in a criminal investigation. This type of study would be aligned with the arguments promoted by Carr (2017) and Doleac (2017) regarding evaluating the effectiveness of police technologies using nonexperimental methodological approaches. Koper and Lum found that case clearance occurred in about 19% of cases in which ALPRs were used. While this only amounts to about 1% of cases investigated that they examined, they believed this provided some indication that *if* ALPRs were used more frequently and systematically in serious crime investigations, they could *potentially* help to improve the resolution of cases. There was also some indication that clearance rates for auto theft and robbery improved in areas where ALPRs were concentrated.

However, one major limitation of this study was that Koper and Lum could not clearly isolate the effects of ALPR on the outcomes of any given investigation or on clearance rates more generally. While this could be interpreted as a methodological problem, this limitation is more substantive and relevant to our discussion here. The reason for the difficulty in isolating the impacts of ALPRs on investigation goes back to a similar problem in patrol: ALPR use varies widely amongst detectives. The reason for this is that traditional approaches to investigation—as with patrol—are marked by incredibly high levels of discretion and low levels of tracking or supervision. (We note that high discretion and low supervision are markers of the traditional organizational frames of policing—see Lum & Koper, 2017). For example, ALPRs might be used at the end of an investigation as a last-ditch effort to solve an impossible-to-solve case. An evaluation of such uses might incorrectly conclude that ALPRs were associated with a *lower* likelihood of impacting investigations. Conversely, ALPRs may be used to confirm evidence in an already solved (or soon-to-be solved) investigation, making it seem like ALPRs contribute to positive investigative outcomes (e.g., ALPR evidence might be used to complement and confirm witness testimony about a suspect's presence at a crime scene). The point is that ALPRs might be used in a variety of ways, for various purposes, and at different points within an investigation. These details are rarely documented systematically in case folders, and therefore, understanding the link between ALPR use and investigative clearance remains murky.

Further, the effects of the ALPR use may be dependent on how and when ALPR was used in the investigation. For example, using ALPRs proactively at the early stages of a hard-to-solve investigation may be more fruitful than applying them reactively at the end of an investigation as a last-ditch effort. This would be one type of question that a randomized controlled trial could test. Unfortunately, experimental testing is not often possible in evaluations of investigative effectiveness, especially with technologies that are so easily used (such as ALPRs). Detectives assigned to major crimes might not be convinced to withhold ALPR use for an investigation if it only takes a few minutes to use the technology. At the same time, because of the relative advantage and ease of the use of this technology, detectives and patrol officers may also be lax in recording whether, how, when, and how repetitively ALPR

was used in an investigation. Further, they may also fail to record the outcomes or contributions of that technology to solving the case, thereby causing challenges with nonexperimental analysis of effectiveness. We emphasize that none of this actually gets at the mechanics of the investigation or whether that process was the most optimal, evidence-based approach to take in the first place to maximize the likelihood of solving the case.

We also note that even with Koper and Lum's careful analysis of records, and even at the height of ALPR use in the agency they studied, the data seemed to indicate that ALPR was used only about five to seven% of the total records studied. These investigations included Uniformed Crime Reporting "Part I" crimes, auto-related crimes (i.e., violence, theft, arson), and other ALPR-relevant crimes, including felony traffic offenses and missing persons. While some of those uses were by detectives, other uses were by patrol officers, and the reasons for this difference were unclear. This frequency of use might also be an undercount if ALPR use is so easy that officers or detectives simply do not record their use if no information or "hit" from the ALPR system is obtained. Koper and Lum tried to estimate this qualitatively by sampling 200 events from those crimes in which ALPR was used and reading each file. They found that ALPRs, when used in investigations, were primarily used to locate stolen tags or vehicles (about 46% of the time that ALPR was used). Another 41% of ALPR use was more specific to investigations (e.g., locating missing, wanted, or suspected persons and vehicles, attempting to follow or generate leads, verifying alibis, etc.). Further, 14% of the data turned out to be false positives. An ALPR keyword was detected when mining the data, but in those cases, ALPR had nothing to do with the investigation. Most significantly, for almost three-quarters of this sample where ALPR use was noted, ALPRs did not contribute in any meaningful way to the resolution of an investigation.

The bottom line is this: Determining the cost-effectiveness (or cost-benefits) of ALPR use in investigations or patrol is challenging, and not simply for methodological reasons. The complication arises because of the broad discretion that investigators have in carrying out criminal investigations, the discretion they or patrol officers have in using any technology for various purposes, the lack of tracking or recording of specific uses, and the various purposes for which technology is applied. These are unsurprising characteristics of how investigations are carried out in current models of police investigative deployment.

Conclusion: The Illusion of Calculating Cost-Benefits of Police Technology

The findings reviewed above arguably cause the definition of "effectiveness" of police work to be in question. Our logic in reaching that conclusion is based on both our research and that of others. Let us use that research to walk through the logic of the conclusion.

Let us say that we do find an effect of ALPRs on *arrest*s, as Ozer (2016), Taylor et al. (2011, 2012), Koper et al. (2013), and Koper and Lum (2019) have found (albeit modest), and we trust whatever research method was used to determine that effect.

Let us also assume we are able to calculate the cost-effectiveness of those technologies once an effect on arrest is found, as Ozer (2016) did for ALPRs. Even given those assumptions, we disagree with the initial logic as described by Ponomarenko and Friedman (2017, p. 309): "*[t]he first question in any [benefit-cost analysis] is whether the intervention is efficacious. Does it yield any benefits? If not, there is no sense in pursuing the question further.*" Our logical claim says otherwise. The exercise of estimating cost-effectiveness does not naturally follow from any effectiveness finding on a single measure of a policing outcome. Rather, the police mandate is arguably so broad that the value of any single metric—like arrest—depends on how that metric fits into the broader police mandates.

Here, we make a not-so-controversial assumption about the mandates of the police that we believe have broad agreement. Modern democratic police agencies primarily have two mandates (see, e.g., Bittner, 1970; Mastrofski, 1999): (1) to provide for public safety (which includes detecting, responding, controlling, preventing, and deterring public safety concerns like crimes, disorder, or even traffic accidents), and, (2) to do so lawfully and legitimately (which includes the equal protection of rights and ensuring their actions reflect distributive and procedural justice). Constitutional and representative democracies distinguish themselves from other types of regimes in that these two mandates are equally important (Lum & Nagin, 2017). Thus, in theory, ALPRs should promote public safety by increasing the probability of detecting, responding, controlling, preventing, and deterring crime and traffic infractions. They might contribute to the legitimacy that the public affords the police by helping the police resolve crimes and victimizations more quickly or successfully and by potentially reducing disparities or biases in enforcement, providing transparency, documentation, and accountability in policework when it comes to traffic enforcement or using vehicles to identify individuals of interest to the police.

ALPRs may indeed be effective at some outcomes, including detecting stolen automobiles more quickly and maybe even helping with arrests. But we return to Ozer's comment to make our point. He states that ALPRs are cost-effective because they "do the same job (produce follow-up arrests) with fewer officers compared with traditional policing." (Ozer, 2016, p. 130). Now, we may well believe that increasing arrests is the approach that achieves the public safety mandates of the police (which in democracies includes their legitimate authority with the public). In that case, the question is closed.

The problem is that the scientific evidence about police practices does not point to arrest as a consistently effective means of achieving either the public safety or public legitimacy mandates of modern, democratic policing agencies. Over fifty years of amassed knowledge challenges the notion that traditional policing approaches that rely on reactive, response-oriented, procedurally-based, and case-by-case approaches can achieve these two mandates. We now know that reactive patrol, rapid call response, traditional investigations, and increasing arrests are insufficient, either to *create public safety* effects (see reviews by Durlauf & Nagin, 2011; Nagin, 2013; Nagin et al., 2015) or to *improve trust*, *confidence*, *and legitimacy* of the police. Instead, research has indicated that the most effective way for police to achieve these two mandates is often the opposite of traditional policing approaches—through proactive, place-based, targeted, tailored (problem-solving), and community-engaged

activities (see reviews by Lum & Koper, 2017; National Research Council, 2004; National Academies of Sciences, 2018; Ratcliffe, 2019; Sherman, 2013; Sherman et al., 2002; Weisburd & Eck, 2004). Aligning police practices to this scientific knowledge has become known as the pursuit of "evidence-based policing" (Sherman, 1998, 2013), similar to evidence-based medicine. However, much of day-to-day policing is not evidence-based and continues to be reactive, general, and individual-focused, relying on tactics, strategies, and programs that we know are not effective. While some progress has been made, empirical studies of police proactivity (see Koper et al., 2020; Lum et al., 2020b), as well as the ALPR field studies discussed above, indicate that evidence-based policing is not regularly practiced and still resisted in most agencies. In Koper and Lum's studies, just getting officers to patrol places where crime concentrates (a basic foundation of effective policing) was a challenge.

Further, the "intervention" is not the presence or absence of the use of ALPR. Rather, the intervention being tested is the *action of the police* using the technology. ALPR is just the scalpel, not the surgeon. The effectiveness of the sharpest and most advanced scalpel still depends on *how* the doctor does the surgery (and the underlying justifications for doing surgery in the first place). The effectiveness of technology, therefore, is contingent on the effectiveness of the agency in implementing patrol or investigative deployment strategies that are known to be effective in achieving public safety mandates. If an agency's ability to effectively reduce crime is hampered by the *deployment* approaches it implements, the question of the effectiveness of ALPR by itself is a *non sequitur*. If an agency primarily follows a case-by-case, 911-driven, reactive arrest-based approach, then by definition, it is not acting in effective ways. It could, therefore, never optimize "effectiveness" (whatever technology is being used) so that *cost*-effectiveness (or even benefits-costs) could even be imagined.[7]

Thus, for the police to reap any cost-benefit or cost-effectiveness of any technology, they would first need to regularly use effective deployment approaches. Those approaches would themselves be based on evidence of what steps can get the police closer to effectively achieving their mandates that use those technologies (Koper et al., 2014, 2015; Lum et al., 2017). This would require adjusting deployment approaches—and the infrastructure that supports, facilitates, and reinforces those approaches—towards ones that are more effective and evidence-based. For example, for ALPRs to be effective, they would need to be used in proactive, place-based, targeted, tailored, and community-engaged ways and not just for reacting to crimes already committed. Even if they are used for crimes already committed (for example, in investigations), the knowledge about effective investigations indicates that agencies may need to rethink the way they are doing investigations to be more aligned with what we know about effective investigations (see Braga & Dusseault, 2018; Lum et al., 2024; Prince et al., 2021; Wellford et al., 2019). The deployment choices are arguably essential for optimizing the use of ALPRs within those investigations.

[7] Arguably, cost-effectiveness could still be improved with technology even if the agency is not pursuing evidence-based strategies. For example, a technology like ALPR could make traditional patrol more cost-effective by increasing apprehensions and auto recoveries per officer hour. But we still argue that it wouldn't be the most optimal use of technology. Hence, we could underestimate a technology's potential for cost-effectiveness, and it certainly would be less likely to produce cost-beneficial effects.

Who Gets ALPR: Luck of the Draw, **not Planned Deployment**. To emphasize our point, Lum and colleagues have found that many agencies do not have a specific strategy for deploying ALPRs, even when using them within the traditional models of policing. Instead, ALPRs are treated as a resource that is often equally divided amongst police districts or jurisdictions. Similarly, the assignment of ALPRs to officers often appears to be the luck of the draw or whoever is assigned a car outfitted with an ALPR. Again, no particular strategy or guidance is given to officers. In the Lum et al. (2019a) national survey, 59% of agencies using ALPRs in patrol gave officers complete discretion over how they use their ALPR units without any specific guidance. Only 5% said they "almost always" provided strategic guidance. Making matters worse, most agencies that use ALPRs do not collect or track performance measures or usage, thereby rendering the agency incapable of generating an informed strategy. As Sherman (2013) has emphasized, tracking, targeting, and testing are critical in implementing an evidence-based approach.

Improving apprehensions and deterrence with ALPRs (either with patrol or investigative actions) also depends on other operational decisions that still require much more systematic research and experimentation about these decisions (an assertion aligned with an evidence-based approach). For example, police currently deploy more than half of their ALPRs on patrol vehicles, and deploy most of the remainder in fixed locations (Lum et al., 2019a). Yet the difference in the effectiveness of these two approaches is not known. These differences would matter if research points to more targeted, place-based approaches as more effective in achieving crime prevention results. Studies of CCTV and red-light cameras, for example, suggest that fixed deployment at hot spots might be effective (Koper et al., 2020).

Technology Effects Depend on Implementation Strategies. All of this suggests that the question of whether ALPRs are cost-effective or cost-beneficial is premature. Even in those cases where cost-effectiveness was calculated or could be calculated, those calculations are based on assumptions that actions by the police (arrest, reaction, etc.) are what the police should be doing. These less-than-effective deployment approaches are stubbornly persistent and continue despite the availability of this knowledge. Thus, purchased technologies *could* help to advance current reactive deployment approaches but would likely have a zero, if not negative, cost-benefit to policing and society, given what we know about how police can achieve public safety and legitimacy. Pointing out this problem is not merely semantic or academic. The existence of this cost-benefit deficit (and the lack of its acknowledgment), along with the "shiny-ness" and excitement of police technology, allows wasteful agency purchases to continue while neglecting what is really needed—investment in changing operations toward more evidence-based approaches to be able to reap outcomes from technology use.

The same is true for so many other technologies used today by police agencies. For example, body-worn cameras, while adopted to improve police-citizen interactions, reduce force, potentially reduce disparity, or even improve police legitimacy with the public, are primarily used to support criminal investigations of suspects, not the police (Merola et al., 2016; White et al., 2018). Police officers also support body-worn cameras as a way to protect themselves from what they see as unwarranted public complaints against them (Lum et al., 2019b). The effects of cameras

on the use of force are equivocal and dependent on policies and practices regarding the accountability of camera usage (see, e.g., Ariel et al., 2016, 2017; Braga et al., 2020; Martain et al., 2021; White et al., 2018). The promise of body-worn cameras to improve police-citizen interactions, reduce force, and improve accountability or legitimacy likely depends on whether agencies have effective practices, systems, and organizational frames in place that could ensure that these goals could even be reached (Lum et al., 2020a). These considerations would obviously complicate any consideration of the cost-effectiveness of body-worn cameras. The same logic can be applied to information and analytic technologies, which often are adopted for crime prevention purposes.

With regard to the equally important policing mandate of police legitimacy, the same logic applies. Studies have indicated that trust in police to use a new technology depends on pre-existing levels of trust (Merola & Lum, 2012, 2013; Merola et al., 2014; Merola et al., 2018). In other words, people who are *less* trusting of the police are also *less* likely to believe the police will use technologies properly (for body-worn cameras, see, e.g., Crow et al., 2017; Kerrison et al., 2018; Sousa et al., 2018). It is therefore putting the cart before the horse to attempt to determine if new technologies, such as ALPRs or body-worn cameras, have harmful or beneficial effects on public trust.[8] Agencies could be better off spending their time building trust and confidence with their communities than trying to accomplish these things by purchasing technologies to accomplish these things.

Our broad hypothesis is that technology is not the primary innovation in which police agencies should invest. We propose that innovations for meeting the two mandates of safety and legitimacy may depend less on technologies and more on building the foundations, infrastructures, policies, deployment, management, accountability, training, and leadership systems of police organizations. In sum, technology alone is no substitute for a systemic and cultural change to evidence-based policing. Without these foundations, adopted technologies will always be at a disadvantage in exhibiting any cost-benefits or cost-effectiveness.

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Declarations

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[8] Indeed, while our discussion of cost efficiency has mainly focused on costs and benefits associated with preventing and solving crime, the impacts of technology on public attitudes towards police, for better or worse, are additional considerations that further complicate the task of evaluating police technologies from a cost efficiency perspective.

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