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Combating Auto Theft in Arizona: A Randomized Experiment with License Plate Recognition Technology*

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EXECUTIVE SUMMARY / ABSTRACT

License Plate Recognition Technology (LPR) is a relatively new tool for law enforcement that reads license plates on vehicles using a system of algorithms, optical character recognition, cameras, and databases. Through high-speed camera systems mounted on police cars or at fixed locations, LPR systems scan license plates in real time, and compare them against databases of stolen vehicles, as well as vehicles connected to fugitives or other persons of interest, and alert police personnel to any matches. Although the use of LPR technology is extensive in the United Kingdom and becoming more prevalent in the United States, research on LPR effectiveness is very limited, particularly with respect to how LPR use affects crime.

This report presents results from a randomized field experiment with LPRs conducted by the Police Executive Research Forum and the Mesa, Arizona Police Department (MPD) to target the problem of auto theft. The experiment sought to determine whether and to what extent LPR use improves the ability of police to recover stolen cars, apprehend auto thieves, and deter auto theft. We did this by examining the operations of a specialized 4-car MPD auto theft unit that worked in auto theft hot spots over a period of time both with and without LPR devices.

The experiment was conducted in two phases. Phase 1 of the study, which lasted 30 weeks, involved operations focused on "hot routes"—high risk road segments, averaging 0.5 miles in length, that we believed auto thieves were likely to use based on analysis of auto theft and recovery locations and the input of detectives. At randomly selected times over this 30-week period, officers worked 45 randomly assigned routes using the LPR equipment (each police car was equipped with an LPR system) and another 45 randomly selected routes doing extensive manual checks of license plates. An additional 27 routes were randomly assigned to serve as a control group for the analysis of trends in auto theft. (These routes received only normal patrol operations.)

In Phase 2, conducted over 18 weeks, operations shifted to larger "hot zones" of auto theft activity that averaged about 1 square mile in size. Fifty-four hot zones were identified and randomly assigned to the same conditions as in Phase 1. At randomly selected times during Phase 2 officers worked 18 zones using the LPRs and another 18 zones doing manual license checks. The remaining 18 zones served as a control group that received only normal patrol.

Each phase involved the same number of officers working approximately one hour a day in each LPR and manual route/zone for eight days spread over two weeks. (For purposes of surveillance, investigation, and pursuit, the auto theft unit operated as a team with all officers working in the same route or zone at the same time.) The main difference was that in Phase 2 the officers conducted more roving surveillance.

Experimental results showed that LPR use considerably enhanced the productivity of the auto theft unit in checking license plates, detecting stolen vehicles and plates, apprehending auto thieves, and recovering stolen vehicles. Combining results across both phases, the use of LPRs resulted in 8 to 10 times more plates checked, nearly 3 times as many "hits" for stolen vehicles, and twice as many vehicle recoveries. Further, all hits for stolen plates, all arrests for stolen vehicles or plates, and all recoveries of occupied vehicles were attributable to use of the LPRs (all arrests for stolen vehicles and recoveries of occupied vehicles occurred in Phase 1).

Across both phases, use of the LPRs produced 36 hits for stolen vehicles or plates, 5 arrests for stolen vehicles or plates, and 14 vehicle recoveries (4 of which involved occupied vehicles). These numbers are modest relative to the time officers spent using the LPRs (the officers worked 192 shifts over the course of the two phases, using LPRs approximately half of the time); however, the results were constrained by a number of factors, including limits on the data that were entered into the LPR system (which consisted primarily of state-level data on stolen automobiles), relatively low levels of auto theft in Mesa during the experiment, and, perhaps most importantly, the design of the experiment, which required the officers to work the locations according to a predetermined, randomized schedule (in order to ensure that the places and times worked with LPRs were comparable to the places and times worked without LPRs). Data from other operations by the auto theft unit suggest that officers using LPRs can improve hits for stolen vehicles considerably when targeting operations based on recent theft data and daily traffic patterns. Our experiment primarily demonstrates the improvements in productivity that police can achieve using LPRs relative to manual license checks under equal conditions.

LPR use did not reduce crime in the hot routes and zones, though note that the dosage of LPR intervention in each location was modest. However, the manual license check operations produced short-term reductions in auto theft during Phase 1 of the experiment. We speculate that the unit had a more visible presence when doing manual checks because they spent more time moving along the main routes as well as roaming parking lots, apartment complexes, and side streets—often at slow speeds and with frequent pauses. This may have made the officers more conspicuous and made it more obvious to onlookers that they were checking vehicles. These effects were likely intensified by the smaller locations the officers worked during Phase 1. When using the LPRs in Phase 1, in contrast, the officers were more likely to make quick passes through side streets and parking lots and then remain at fixed positions along the route. Finally, we did not find evidence of crime displacement or a diffusion of crime control benefits associated with either form of patrol in either phase.

We conclude by discussing limitations of the study, questions for future research, and policy implications of the results (such as how police might optimize the use of LPRs to improve recoveries of stolen vehicles and apprehension of auto thieves while also achieving the crime reduction benefits of the manual license check patrols).

1. INTRODUCTION

The field of vehicle theft research has been growing and receiving increasing attention by the research community in recent years (Clarke & Harris, 1992; Herzog, 2002; Kriven & Ziersch, 2007; Levy, 2008; Maxfield, 2004; Rice & Smith, 2002; Walsh, 2009; Walsh & Taylor, 2007a, 2007b). This is good news as this is an all too common offense (despite the recent downward trend) with around a million vehicle thefts occurring per year (ranging from 1.64 million in 1990 to just fewer than 800,000 in 2009 [FBI, 2010]). Also, research suggests that 90 percent of vehicle thefts are reported to the police, a rate much higher than for other types of thefts (Krimmel & Mele, 1998). The high frequency and high reporting rate of vehicle thefts leads to this being a sizeable portion of police work in many jurisdictions. According to the FBI's Uniform Crime Reports (UCR), property loss as a result of motor vehicle theft totaled $7.6 billion for 2005 (down to about $6.4 billion for 2008; FBI, 2009), accounting for 11% of Part I offenses recorded by the FBI (Lamm Weisel, Smith, Garson, Pavlichev, & Warttell, 2006). The volume of vehicle theft rose from the mid-1980s to the early 1990s and then began to decline (Newman, 2004). While the data indicate a downward trend in vehicle theft since the 1990s, this may be due to the results of a number of enhancements to vehicle security at the manufacturer level (Newman, 2004). However, motor vehicle theft remains a significant problem for the police across the U.S. Although about 57% of the value of vehicles stolen is recovered, most thefts do not result in an arrest (FBI, 2009). The arrest rate for vehicle theft nationwide was only about 10% in 2009 (FBI, 2010).

One recent innovation which could serve as a useful tool for law enforcement in addressing this serious problem is license plate recognition (LPR) technology. Like many new technologies, there is evidence that an increasing number of law enforcement agencies are turning to LPR equipment as a tool to address vehicle theft. However, this equipment is expensive and to-date there is little rigorous evidence of its effectiveness. While there may be some obvious efficiency gains from automating the process of checking license plates, it is unclear if this equipment is effective at driving down the number of vehicle thefts or increasing the arrest rate for vehicle theft. These are the key questions examined in this paper based on data collected during a randomized experiment with LPR equipment in Mesa, Arizona.

2. LITERATURE REVIEW

LPR is a relatively new technology in the U.S. but has been used since the 1980s in Europe to prevent crimes from vehicle theft to terrorism (Gordon, 2006). LPR is based on optical character-recognition technology originally developed in Italy for sorting letters and parcels and later extended to reading license plates. LPRs serve as a mass surveillance system for reading license plates on vehicles using a system of algorithms, optical character recognition, cameras, and databases. Through high-speed camera systems mounted to police cars, LPR systems scan license plates in real time, and compare them against databases of stolen vehicles, as well as vehicles connected to fugitives or other persons of interest, and alert police personnel to any matches. Under “Description of Intervention,” we provide a detailed description of LPR technology. The use of LPR technology is part of a broader movement in law enforcement to adopt new technologies such as surveillance systems (see Koper, Taylor & Kubu, 2009). An extensive literature has emerged on the use of surveillance systems, particularly closed-circuit television, or CCTV (see Welsh & Farrington, 2008). Based largely on studies in the United Kingdom, this technology appears to be effective in reducing vehicle crimes on public streets and in parking facilities. However, there has been little research to date on LPR surveillance technology.

In their detailed review of the LPR literature, Lum and colleagues (2010) identified two main types of evaluations of LPR technology. These include evaluations which assess (1) whether LPR physically and mechanically does what it is supposed to do (for example, how accurately and quickly it scans, reads, and matches license plates); and (2) whether the use of LPR actually results in greater detection and deterrence for preventing and reducing crime. In this first area of research, the outcome assessed included areas such as the number of plates accurately scanned within an hour, the number of accurate “hits,” and in some cases the number of arrests made by LPR units. These and other internal assessments within police agencies are largely concerned with how accurate and quickly the technology works compared to the previous manual, tag-by-tag approach (see Lum, Merola, Willis, and Cave, 2010) and include studies by Cohen, Plecas, and McCormick (2007), the Maryland State Highway Authority (2005), the Ohio State Highway Patrol (2005), the PA Consulting Group (2003, 2004) and the Home Office (2007). These studies on the efficiency of LPRs are reviewed below. The second line of research examines the effectiveness of LPR on crime outcomes. Currently, other than this PERF study, only one other study of the effectiveness of LPRs exists. This is the experimental evaluation conducted by Lum and colleagues (2010) from George Mason University. In that randomized controlled trial, also funded by the National Institute of Justice, Lum and colleagues examined both the efficiency of LPR units and their crime control effectiveness compared to other approaches. We will discuss the findings from the George Mason study later in this review.

2.1. Efficiency Research on LPR Technology

The UK has the greatest amount of law enforcement related experience with LPR technology, which it used to aid in responding to attacks by the IRA in the 1990s (Manson, 2006). In fact, the Home Office made £32.5 million available to British police for the years 2005-07 for the use of LPR (see http://police.homeoffice.gov.uk). One of the first UK agencies to use LPR was Northamptonshire. In the first year of using LPR, officers stopped 3,591 vehicles which yielded 601 arrests, and produced £500,000 in revenue from untaxed vehicles (Innovation Groups, 2005). Also, a 17-percent reduction in vehicle-related crime was recorded in the first six months. In another UK pilot, officers used LPR to recover £2.75 million in stolen vehicles/goods, seize £100,000 worth of drugs, and achieve an arrest rate more than 10 times the national UK average (PA Consulting Group, 2004).

Currently in the U.S., LPR systems are being utilized at toll booths, in parking areas/structures, in traffic studies, and for building security. In a recent national survey of large law enforcement agencies

(LEAs) completed by the Police Executive Research Forum (Koper, Taylor & Kubu, 2009), about 38% of the sample of LEAs reported using LPR technology,[1] with only 5% reporting that their LPRs were obsolete and 63% reporting them to be effective at scanning license plates. Of the 62% of the sample not using LPRs, about one-quarter planned to acquire LPR technology and about one-third felt that the LPR would be a valuable technology for their agency and help them address an important operational need.

In 2004, the Ohio Highway Patrol became one of the early adopters of LPR technology and attached LPR devices to toll plazas (Patch, 2005). After four months, they recovered 24 stolen vehicles and made 23 arrests. When compared to the same time period in 2003, this represented a 50-percent increase in stolen vehicle recoveries with a combined total of $221,000 in recovered property. In a pilot test of LPR software conducted by the Washington Area Vehicle Enforcement Unit, that agency recovered 8 cars, found 12 stolen plates, and made 3 arrests in a single shift (McFadden, 2004). Anecdotally, we have learned that a small number of other agencies have implemented LPR technology in single police vehicles, with the Sacramento Police Department having nearly 3 years of experience with LPRs, and the Los Angeles Police having equipped 36 vehicles with LPRs.

Although LPR systems have documented benefits, there are also limitations. First, inaccuracies may arise due to plates that are bent, are covered with certain reflective material, are positioned high (as on certain trucks), are very old, or are obscured by common obstructions such as trailer hitches, mud and snow, and vanity plate covers (see McFadden, 2005). Some states have addressed these issues by making certain obstructions of license plates illegal. Next, one reason why the LPR system was successful in the UK is the uniformity of the UK license plate design. Plate designs in the U.S. vary by state and even within states. This results in false hits when plate numbers from one state match those of cars stolen in other states. The devices also sometimes misread plates, though this problem should decline as the

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[1] . In another national survey, Lum et al. (2010) found that 37% of large agencies and 4% of small agencies were using LPR as of 2009. However, the vast majority of agencies using LPRs—86%--had no more than 4 of the devices.

technology improves. Also, there may be some concerns about invasion of privacy issues, potential abuse, and erroneous traffic stops. However, an important advantage to this technology is that it does not raise concerns about racial or ethnic discrimination. As opposed to some profiling approaches, plates are examined for all passing vehicles, and the system only alerts the officer if the vehicle is stolen.

Another limitation to the use of LPR technology for apprehending vehicle thieves is that thieves may often abandon stolen vehicles before the cars are reported stolen and entered into police data systems. In Mesa, Arizona (our study location), we estimate that only one-third of car thefts are reported within three hours of occurrence, based on analysis of data from 2006 and 2007. These delays reflect lags in the discovery of vehicle thefts (e.g., a car stolen at night might not be discovered as missing until the following morning) as well as delays in reporting by victims after their discovery of a theft.[2] Further, some vehicle thieves switch the license plates of stolen vehicles with those stolen from other cars; victims who have had their plates swapped for those of a stolen car may be unaware of this for a long period, thus providing thieves with additional time to operate their stolen vehicles.

Despite these limitations, LPRs are a promising law enforcement technology with the potential to help police increase recoveries of stolen cars (and the speed with which stolen cars are recovered), increase apprehension of vehicle thieves, reduce vehicle theft (through incapacitation and deterrence), and apprehend other wanted persons (which may help to reduce crimes besides vehicle theft). In some instances, the devices may also help police solve criminal investigations by providing records of cars that were in or near a crime location around the time of a criminal act. The LPR also has the potential to help counteract the arrest avoidance strategies of vehicle thieves. Copes and Cherbonneau (2006) outline a number of strategies that vehicle thieves use to avoid being arrested and demonstrate that thieves are aware of how they drive and act to present an appearance of being a normal driver so that police and others pay them no attention. Using LPR equipment, police are not reliant solely on their ability to spot

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[2] Note that these are rough estimates because the exact time of many vehicle thefts cannot be determined.

suspicious activity because every driver is scanned and this technology may nullify the skills some vehicle thieves have developed.

Nevertheless, there have been only a small number of pilot evaluations of LPR programs, and only one other study using rigorous experimental methods (see below).[3] The potential benefits of LPR use must also be weighed against their costs, which could include financial costs (the devices range from $20,000 to $25,000 in price) as well as some loss of privacy for citizens whose plates are scanned (thus resulting in a record of where they were at a given time).[4]

2.2. Effectiveness Research on LPR Technology

Working with the Alexandria (VA) Police Department and Fairfax County (VA) Police Department, Lum and colleagues (2010) report on a randomized controlled trial involving auto crime hot spots and LPR deployment across two jurisdictions. Lum and colleagues (2010) tested for both specific deterrence of auto-related crimes and for general deterrence of crime. To do this, they randomly allocated LPR deployment in half of all hot spots (n=30) across two jurisdictions to test whether LPR use by a marked patrol unit yields a specific deterrent effect on auto thefts and a more general deterrent effect on crimes. Of the 30 hot spots, 15 were randomly assigned to receive the LPR deployment intervention, while the other 15 received "business as usual" policing (no change in the existing police activities in that area). To select approximately equal number of hot spots from each jurisdiction (13 of the hot spots fell in APD's jurisdiction

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[3] The situation has not been much better with regard to the evaluation of other vehicle theft prevention programs (e.g., use of bait cars). While they are greater in number (see Barclay, Buckley, Brantingham, Brantingham, and Whinn-Yates, 1995; Burrows and Heal, 1980; Decker and Bynum, 2003; Poyner, 1991; Maxfield, 2004; Mayhew, Clarke and Hough, 1980; Plouffe; Research Bureau Limited, 1977; Riley, 1980; and Sampson, 2004), none of these auto-related evaluations applied randomized experimental designs or rigorous quasi-experimental methods.

[4] A counter perspective on this issue, brought to our attention by an anonymous reviewer, is that while the lingering attitude (resentment over "Big Brother" technology) does present a public relations problem, LPR use is not an invasion of privacy when conducted on public roads. Some believe that there is no reasonable expectation of privacy in public spaces where no one can expect to remain invisible or unscanned.

and 17 in FCPD's jurisdiction), they block-randomized by jurisdiction, randomly selecting seven from Alexandria City and eight from Fairfax County.

The experiment was designed to last 30 officer working days for each of two officers. For each working day for each officer, they randomly selected five of the experimental hot spots per officer per day so that multiple hot spots per shift could be visited for 30-minute periods. Lum and colleagues (2010) found that the use of LPRs in auto theft hot spots did not result in a reduction of crime generally or auto theft specifically, during the period of time measured. This may be due to the relatively low intensity of the LPR intervention during the experiment (about 30 minutes per day for 10 non-consecutive days of intervention per LPR hot spot), which were limited by resources and shift constraints, or the timeliness and comprehensiveness of the base of data that the LPR units accessed.

3. GUIDING FRAMEWORK FOR THE STUDY

Our study was designed to advance the field of policing research through a large-scale randomized experiment in Mesa, AZ with LPR devices, grounded in a hot spot policing framework and the "journey-after-crime" literature, to study an understudied area of the effects of LPR devices on vehicle theft. Specifically, we sought to test the utility of LPR use at locations with heavy concentrations of vehicle theft transit activity identified through journey-after-crime analyses. In our study, we extend the concept of "hot spots" of crime to "hot routes" of crime. That is, transit routes that are used as thoroughfares to move stolen vehicles. Given that vehicle theft involves the rapid movement of the stolen property (i.e., the motor vehicle); we do not limit our analysis to the location of the vehicle theft but instead consider the route the auto thief took after stealing the vehicle. Focusing on these "hot routes," we examine how LPR use affects recoveries of stolen cars, apprehension of vehicle thieves, and levels of vehicle theft.

Our study builds on work that has been done on hot spots of crime. This work has highlighted data which shows that crime is not evenly distributed across a city and that instead is concentrated in small areas (see Brantingham & Brantingham, 1981; Sherman, Gartin &. Buerger, 1989; Sherman & Weisburd,1995; Pierce et al., 1988). The studying of the relationship between crime and geography is not new and dates back to the 1800s (see Guerry, 1833; Quetelet, 1842) in Europe and in the U.S. to the "Chicago School" of sociology (see Burgess, 1925; Shaw & McKay, 1942). In the late 20th century work on crime concentrating in small places was rekindled in places like Boston (Pierce, Spaar & Briggs, 1986) and Minneapolis (Sherman, Gartin & Buerger, 1989). Additional evidence for crime concentration at places has been found for crimes such as burglary (Forrester, Chatterton, & Pease, 1988; Forrester, Frenz, O'Connell, & Pease, 1990; Farrell, 1995), property crime (Spelman, 1995), gun crimes (Sherman & Rogan, 1995b), and drug dealing (Weisburd & Green, 1995; Eck, 1994).

By locating the LPR equipment in our study in areas where auto thieves are most likely to travel we hoped to capitalize on this general criminological finding that there is something about a few places that facilitates crimes and something about most places that prevents crimes. The theoretical underpinning for hot spots is based generally on routine activity theory/situational crime prevention (Cohen & Felson, 1979; Felson 1994) and offender search theory (Brantingham & Brantingham, 1981). Routine activity theory and situational crime prevention can also facilitate understanding of hot spots policing by identifying whether policing strategies strengthen capable guardianship via increasing risks and efforts, reducing rewards and provocations or removing excuses for crime (Eck & Weisburd, 1995; Eck & Clarke, 2003). Offender search theory recognizes that crime is very opportunistic and that offenders respond to cues given out by the environment. These “releaser cues” stimulate the release of otherwise inhibited behavior, and hot spots policing focuses on reducing these opportunities (also known as opportunity blocking [Clarke, 1992; 1995]).

The existing body of research on other policing strategies based on hot spots has been impressive. In the Minneapolis Hot Spots Experiment (Sherman & Weisburd, 1995) the concept of developing a policing strategy on the location of hot spots was first formally tested. Sherman and Weisburd found that preventive patrol was more effective when it was more tightly focused on hotspots. More recently, Braga (2001, 2005) presents evidence from five randomized controlled experiments and four quasi-experimental designs that hot spots policing programs generate crime control gains without significantly displacing crime to other locations. These crime prevention effects were reported at general crime hot spots (Sherman & Weisburd, 1995), high-activity violent crime places (Braga, Weisburd, Waring, Green Mazerolle, Spelman, & Gajewski, 1999), gun violence hot spots (Sherman & Rogan, 1995a), and drug markets (Weisburd & Green, 1995; Sherman & Rogan, 1995b). While none of these studies were focused on reducing vehicle theft, we hypothesized that the same logic that led to successful outcomes for these hot spot interventions should apply to our experimental evaluation of vehicle theft and LPRs. As an intervention targeted at vehicle theft, LPR is a type of situational crime prevention (Clarke, 1995) and can serve as a type of approach that alters the environmental risks for vehicle thieves.

In considering the placement of LPRs in our study, we built on the existing literature on the geographic concentration of vehicle thefts (see Barclay, Buckley, Brantingham, Brantingham, & Whinn-Yates, 1995; Copes, 1999; Fleming, Brantingham, & Brantingham, 1995; Henry & Bryan, 2000; Plouffe & Sampson, 2004; Potchak, McCloin & Zgoba, 2002; Rengert, 1996; Rice & Smith, 2002). Spatial analyses of crime have generally examined two different but related aspects: (1) the spatial patterns of the offense locations (e.g., Craglia, Haining, & Wiles, 2000; Levine & Associates, 2000); and (2) the spatial patterns of the paths related to crime activities (also known as the "journey-to-crime") (e.g., Smith, 1976; Phillips, 1980; Costanzo, Halperin, & Gale, 1986; Wiles & Costello, 2000). Within the journey-to-vehicle theft literature, researchers have reported that most vehicle thieves travel relatively short distances to steal vehicles (Levine & Associates, 2000). Moreover, certain locations experience more vehicle thefts than do other locations (e.g., Kennedy, 1980; White, 1990), due to having environmental characteristics that are very attractive to vehicle thieves. For example, in a study in Chula Vista, CA, the researchers (Plouffe & Sampson, 2004) identified 10 hot spots that accounted for 23% of the city's vehicle thefts in 2001. Rice and Smith (2002) found that vehicle theft was higher in areas close to pools of motivated offenders, where social control mechanisms were lacking, and where there were suitable targets such as bars, gas stations, motels, and other businesses. A number of studies have identified non-residential locations as hot spots for vehicle theft, including: parking lots close to interstate highways (Plouffe & Sampson, 2004), high-traffic areas (Rice & Smith, 2002), areas near schools (Kennedy, Poulson & Hodgson, n.d.), mall parking lots (Henry & Bryan, 2000), and entertainment venues (Rengert, 1996).

Of direct relevance to our proposed project is a newer area of research in the criminal travel patterns literature, explored by Yongmei Lu, which examines the spatial patterns of stolen-vehicle recoveries and the "journey-after crime." The journey-after-crime is an offender's trip with the stolen vehicle in order to realize its expected utility, such as a trip to sell or strip the vehicle, a trip to another offense (e.g., a robbery), or a joy-ride (Lu, 2003). Dr. Lu demonstrated how GIS and Exploratory Spatial Data Analysis can be extended from journey-to-crime to journey-after-crime analyses in a study of 3,271 vehicle theft offenses in 1998 in Buffalo (see Lu, 2003). First, Lu (2003) drew theoretical support for her approach from Rational Choice Theory (Clarke, 1983; Cornish, 1993) and Routine Activity Theory (Cohen & Felson, 1979). Also, Lu (2003) built on the work of one of the only other published studies of spatial patterns of stolen-vehicle recoveries, completed by LaVigne, Fleury, and Szakas (2000), in which the researchers designed search strategies to track stolen vehicles taken to "chop shops." In Lu's analyses (2003) she found that vehicle thieves' trips from vehicle-theft locations to vehicle-recovery locations were mostly local in nature, with travel distances significantly shorter than randomly simulated trips, and she recommended that police responding to vehicle theft should check nearby locations first. Dr. Lu found that the difference in travel direction between observed and simulated trips was a combined result of both the criminals' spatial perception and the city's geography (e.g., street networks).

4. METHODS

4.1. Research Site

We conducted this study in the city of Mesa, Arizona with the Mesa Police Department (MPD) from 2008 to 2009. MPD has about 800 sworn officers. With a population of about 460,000, Mesa is one of the United States' fastest-growing cities (since 2000, it has had population growth of about 13%) and currently ranks as the 38th largest. The selection of a large urban area is important, for vehicle theft is predominately an urban problem (see Clarke & Harris, 1992). Households in urban areas have rates of vehicle theft that are more than three times the rate of rural areas (Bureau of Justice Statistics, 2004).

Like many large cities, Mesa has a considerable vehicle theft problem. According to sources in the auto insurance industry, the greater metropolitan area of Phoenix, Mesa, and Scottsdale, Arizona ranks fourth in the nation for auto theft (http://www.autoinsurancetips.com/car-theft-rates-state). There are a number of reasons that contribute to the vehicle theft problem in Mesa and the state of Arizona as a whole (Arizona Automobile Theft Authority, 2006). First, Mesa and other cities in Arizona have experienced a dramatic population increase over the past 20 to 25 years (Arizona Automobile Theft Authority, 2006), with transiency arising from the many multi-family housing units found in Mesa. In these types of residential areas, vehicles may be at greater risk to be stolen. Due to the dry, moderate climate in Arizona, vehicles also tend to maintain higher value than in other areas of the U.S. due to less weather/road-related wear on vehicles. Also, the close proximity with Mexico allows thieves to get easy access to a foreign shipping point. There are seven official ports-of-entry along the 354-mile Arizona-Mexico border, and major California seaports are less than eight hours away. Further, the public transit system is very limited in Mesa, and MPD officers believe that this also contributes to the city's vehicle theft problem.[5]

The number of vehicle thefts in Mesa since 1999 has gone up dramatically and then dropped again in most recent years. It has dropped about 35 percent since 2003 (FBI, 2009). In 1999 there were 2,851 vehicle thefts, which increased for three successive years until reaching a high of 5,089 in 2002 and

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[5] In the view of some MPD officers, many auto thieves simply steal automobiles as a form of transportation for getting from point A to point B (also see Copes, 2003 for the motivation of auto thieves).

dropping to 4,563 in 2003 and 3,745 in 2004 before increasing again in 2005 to 4,248. These numbers went down further to 3,654 vehicle thefts in 2006 and continued to decrease, dropping to 2,047 in 2008 (the year our study began) and 1,303 in 2009 (the year our study concluded) (see http://www.fbi.gov/about-us/cjis/ucr/ucr). With about 39 vehicle thefts per week in Mesa at the outset of the project, there was still a reasonable pool of cases on which the LPR could have a potential impact, making Mesa an attractive site from a research perspective. Later on in the discussion section, however, we consider the impact of conducting our study during a 10-year low in vehicle theft in Mesa. Also, like many police departments, MPD is able to arrest only a small percentage of the vehicle thieves—fewer than 6% in 2006 and 2007.[6]

4.2. Description of Intervention

LPRs are a mass surveillance system involving high-speed cameras that use optical character recognition and algorithms[7] to read and evaluate license plates on vehicles. There are a number of LPR devices on the market. MPD used the Remington Elsag Mobile License Plate System (REMLPS) (Model: MPH-900S) and deployed all four of its LPR devices for the study.[8] The REMLPS operates independently in the background and works at patrol and highway speeds, with the capability to handle oncoming differential speeds in excess of 120MPH and passing speeds in excess of 75MPH. Two infrared cameras mounted on a cruiser take photos of passing license plates. The cameras are triggered by the reflective material in the plate. A laptop computer uses character-recognition software to determine the letters and

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[6] This estimate is based on the number of vehicle thefts and vehicle theft arrests in Mesa from January 2006 through November 2007. The arrest figures include arrests for thefts that occurred in other jurisdictions, which is why we report the arrest rate in terms of its upper bound.

[7] The algorithms provide for plate localization (finding and isolating the plate on the picture), plate orientation and sizing (compensates for the skew of the plate and adjusts the dimensions to the required size), normalization (adjusts the brightness and contrast of the image), character segmentation (finds the individual characters on the plates), optical character recognition, and syntactical/geometrical analysis (check characters and positions against local government-specific rules) (see http://www.cctv-information.co.uk/i/An_Introduction_to_ANPR for more detail on the technical elements of LPR technology).

[8] During the study period, the LPRs were used only by the officers participating in the experiment.

numbers of the license plate. That plate is then instantaneously checked against data on stolen cars, stolen plates, warrants, and/or other information accessible to the system (below, we discuss the data that MPD utilized for their LPR system). An alarm sounds for each possible match. The officer then verifies the accuracy by looking at the tag before taking any action. The REMLPS is able to read up to 4 lanes of traffic with a single vehicle and can read 8,000 to 10,000 plates in just one shift with just a single vehicle mount. The REMLPS also has a GPS/time stamping function which records the GPS coordinates and time for every plate it reads.

LPRs automate a process that in the past was conducted manually tag-by-tag and with much discretion (see Lum et al., 2010). Officers would see a car that appeared suspicious and provide that plate number to a dispatcher, who would check the plate against a database such as the National Crime Information Center (NCIC) to see whether the vehicle was stolen (Lum et al., 2010). As pointed out by Lum and colleagues, the effective use of LPR is primarily limited by three factors: the system's ability to read license plates accurately; the quality and relevance of the data accessed by LPR to compare with scanned plates; and the way in which police departments deploy the machines. While LPR's may be more efficient than manual checking approaches, the question still remains as to whether this technology is more effective in reducing, preventing, or even detecting crime (Lum et al., 2010). Especially with law enforcement technologies, efficiency is often mistakenly interpreted as effectiveness, which can perpetuates a false sense of security and a mythology that crime prevention or progress is occurring (Lum, 2010). The most accurate license plate readers might be used by law enforcement officials in ways that have no specific or general deterrent, preventative, or detection effect (Lum et al., 2010).

Based on prior experience with the LPRs and consideration of practices used by other agencies, MPD chose to deploy their LPRs with a specialized vehicle theft unit focused on the recovery of stolen cars, apprehension of auto thieves, and prevention of auto theft. The vehicle theft unit consisted of four police officers and one supervisory officer (not involved in the actual street work) working together in four cars;

two were unmarked smaller cars that did not look like police cars, one was an unmarked patrol car, and one was a marked patrol car without a light bar. The unmarked cars provided more investigative options (e.g., for surveillance) for the vehicle theft unit, while the patrol cars (particularly the marked one) were used for chasing uncooperative suspects. The unit was provided with four LPR systems (one for each car for each of the four non-supervisory officers, allowing for the simultaneous use of all four LPR systems). Each of the LPR systems used in our study contained two mobile cameras that were mounted on the rear of the vehicles. The use of a specialized vehicle theft unit also had some advantages in that all of the officers of the unit had specialized knowledge and training in vehicle theft and had developed increased proficiency in vehicle theft surveillance and investigation. Over time, the vehicle theft unit also developed more refined skills in the nuanced use of four LPR devices at once, and the unit was given the time to just focus on vehicle theft and did not have to respond to other calls-for-service.

The data loaded into the LPR systems consisted primarily of state-level data on stolen vehicles, stolen license plates, and other vehicles of interest (e.g., vehicles linked to robberies). The data also contained information on warrants for a few nearby localities (Tucson and Gilbert) but not for Mesa itself. The LPR systems did not have wireless, real-time connections; thus information was loaded into the system manually on a daily basis. However, officers could add information into the system based on recent alerts while they were in the field.

As described below, the research team worked closely with the MPD to design a two-phase randomized experiment in which the vehicle theft unit was assigned to work at particular locations and times using the LPR devices. They were also assigned to work at other comparable locations and times doing manual checks of license plates. This enabled us to compare the productivity and impacts of the vehicle theft unit when using LPRs and when not using LPRs.

4.3. Experimental Design

Among the flaws found in many policing intervention studies are designs with non-comparable comparison groups (see Mazerolle, Soole, & Rombouts, 2005). While there are exceptions, many policing intervention studies make little attempt to draw comparison groups in ways that maximize the likelihood that they will be similar to the intervention/treatment group. The problem with these types of studies is that although measured differences can be statistically controlled, the many unmeasured variables related to the outcome variable (e.g., susceptibility to change) cannot be controlled. Randomized controlled trials (RCTs) are typically thought of as the best method or the "gold standard for eliminating threats to internal validity in evaluating social policies and programs (Berk, Boruch, Chambers, Rossi, & Witte, 1985; Boruch, McSweeny, & Soderstrom, 1978; Campbell, 1969; Campbell & Stanley, 1963; Dennis & Boruch, 1989; Farrington and Petrosino, 2001; Riecken, Boruch, Campbell, Caplan, Glennan, Pratt, Rees, & Williams, 1974; Weisburd, 2003). RCTs provide the best counterfactual describing what would have happened to the treatment group if it had not been exposed to the treatment (Cook, 2003; Rubin, 1974; Holland, 1986). Our project, along with the Lum and colleagues study (2010), represents the first study of LPR equipment with an experimental design (specifically a place-based randomized control design).

4.3.1. Two-Phase Design

We conducted our study in two phases. In the first phase, conducted over 30 weeks from August 2008 to March 2009, we maximized the number of hot locations in our study to include 117 auto theft "hot routes"—i.e., high-risk road segments that we believed auto thieves were likely to use based on analysis of auto theft and recovery locations and the input of detectives. These 117 identified routes were randomly assigned to one of three conditions: the auto theft unit working with LPRs, the auto theft unit working without LPRs, or normal patrol with no LPR monitoring and no auto theft unit. In Phase 2, conducted over 18 weeks from April 2009 to August 2009, we moved to a smaller number of larger "hot zones" (n= 54) for auto theft activity.[9] Each of the 54 hot zones was randomly assigned to a similar set of three conditions. Each phase involved the same number of officers providing approximately one hour of treatment a day to each route/zone for eight days spread over two weeks. The main difference was that in Phase 2 the officers were able to do more roving surveillance, which the officers felt better corresponded to the way they would use the equipment after the study. Phase 1 provides for a more statistically powerful comparison of the LPR equipment, even introducing some artificiality in how the officers were constrained in their patrol activity to smaller hot spots and more fixed surveillance, to answer the theoretical question of does LPR have a measureable effect under the most controlled circumstances. Phase 2 provides a test of LPR use in what would likely be a more typical operational context for MPD. By conducting our study in two phases, we will have better data to help to improve LPR deployment strategies.

4.3.1.1. Design considerations for both phases. One of the first considerations we had to consider was where to use the LPR equipment. The MPD felt that if they just used the LPRs evenly across the city they would miss many stolen cars. There was broad agreement that the LPRs need to be used in places where stolen cars were most likely to be driven. Based on discussion with MPD, the lag time it takes before a vehicle is reported to the police as stolen and entered into the MPD database precluded our team from using the LPR device in the specific hot spots where vehicles are actually typically stolen. Instead, in planning for Phase 1 of the experiment, we used “journey-after-crime” spatial analyses and input from MPD personnel to identify all the main transit routes in Mesa (n= 117) where vehicle thieves are most likely to drive stolen vehicles (including dumping/destination points). In addition to using geographical analysis to determine our study locations, we also wanted to include a number of detective/officer nominated routes to assure that our routes were based on the latest intelligence collected by MPD, much of which is not reflected in official MPD crime statistics and is often of a more qualitative nature. To assure no

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[9] While phase 1 and phase 2 were carried out over different time periods, the same conditions were present for all the randomly assigned groupings and unbiased estimates can be derived for each assigned hot route/zone.

bias entered into our study, we used the variable of who designated the route (i.e., was the route selected based on geographical analysis or by designation by a detective/officer) as a stratification variable in our random assignment at Phase 1, assuring that all three study conditions had an equal proportion of routes designated through these different methods. We also analyzed the variable of who designated the route in our later statistical models and found this variable to be non-significant in all models. Thus, in defining our sample, we sought to strike a balance between having a sample large enough to provide reasonable statistical power, selecting routes that were sufficiently active (i.e., "hot"), accounting for officer intelligence, and garnering officer support for the project. As described below, the Phase 1 hot routes also provided the basis for the design of the hot zones in Phase 2.

4.3.1.2. Description of Phase 1 hot routes. For Phase 1, the hot routes were on average about a half mile in length, were a mixture of residential and business areas, and included different types of roads (interstate roads, highways, and residential streets).[10] Two-thirds of the 117 routes were selected based on geographic analysis of theft and recovery locations.[11] Using data on 1,668 automobiles that were both stolen and recovered in Mesa during 2007 and using the shortest travel time between each corresponding theft and recovery location as a likely estimate of thieves' journey after crime, we selected 78 roadways that had the highest number of estimated trips by vehicle thieves. However, the other one-third of the 117 routes was selected based on interviews with detectives and officers.

4.3.1.3. Description of Phase 2 hot zones. For Phase 2 of the study, the research team worked with the auto theft officers to divide the entire area encompassing the Phase 1 hot routes (and their and

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[10] In defining the routes, we divided roads into smaller segments based on natural divisions (i.e., intersections and other natural breaks).

[11] This approach is not without its limitations given that it was based on recovered cars only, leaving out a considerable percentage of vehicles that are never recovered. That is, it is possible that the routes used by thieves who steal cars that are never recovered may in fact be different from the routes of recovered cars. As a result, our methodology may be based on a non-representative sample of "hot routes." However, there is little that the research team could do about this (after all, the routes remain unknown because the vehicles were never recovered). Also, while this may affect the generalizability of our findings, it does not affect the internal validity of our study.

corresponding theft and recovery hot spots) into 54 zones of approximately equal size. The boundaries for these zones were determined based on both the Phase 1 GIS analysis and the officers' expert judgment and were designed around roadways and other natural divisions. The hot zones were on average about 1.2 square miles in size. Similar to the Phase 1 routes, they contained a mixture of residential and business areas and different types of roads (interstate roads, highways, and residential streets

4.3.2. Random Assignment and Intervention Delivery

In each phase, the hot locations (either routes or zones) were randomly assigned to a similar set of three conditions using computer generated random numbers (see Shadish, Cook & Campbell, 2002). We used a stratified random allocation procedure (see Boruch, 1997) and randomized hot routes and zones within statistical "blocks" to allow for the likely substantial variation across places (Weisburd & Green, 1995).[12] Routes and zones assigned to condition 1 received LPR enhanced patrol by the vehicle theft unit. Condition 2 involved assigning routes or zones to the same specialized vehicle theft unit for patrol and surveillance without the LPRs (in these routes and zones, the officers did manual plate checks through their car mounted computer terminals). Condition 3 was our control condition; these routes and zones received normal patrol only (i.e., no patrol by the auto theft unit, with or without LPRs). We used this third group of routes as a comparison group to assess how the operations of the auto theft unit affected trends in auto theft in the treated routes and zones. It is worth noting that all three conditions (LPR, manual license plate checking and the control group) received standard patrol services, except the control group received no

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[12] This type of randomized block design, of allocating cases randomly within groups, minimizes the effects of variability on a study by ensuring that like cases will be compared with one another (see Fleis, 1986; Lipsey, 1990; Weisburd, 1993). Pre-stratification ensures that groups start out with some identical characteristics and will ensure that we have adequate numbers of places in each of the cells of the study. For Phase 1, we used four stratification variables: length of the hot route, speed limit of the route, ease of surveillance for running plate checks (as graded by MPD officers/detectives), and whether the route or zone was determined based on geographical analysis or by designation by a detective/officer. For Phase 2, we stratified based on the size of the hot zone, whether or not the zone contained a major freeway, and the number of auto thefts in the zone during the prior year.

other interventions beyond standard patrol services. Our objective was to assess the effectiveness of LPR technology— not special units versus non-special units. Therefore, we included two types of control groups that would not use the LPR equipment: one group would be a specialized vehicle theft unit doing manual license plate checking and another group would be regular patrol units doing manual license plate checking. All of the assignments were followed carefully by the MPD in both phases.[13]

For Phase 1, 45 of the 117 transit routes were randomly assigned to receive LPR enhanced patrol by the vehicle theft unit, another 45 routes were assigned to the same specialized vehicle theft unit for patrol and surveillance without the LPRs, and 27 routes were assigned to normal patrol (the control condition).[14] We divided the 30-week intervention period into 15 bi-weekly periods. Routes selected for intervention by the vehicle theft unit (both the LPR routes and manual check routes) were randomly assigned to receive treatment during one of these bi-weekly periods (the officers worked 10-hour shifts 4 days a week, resulting in 8 days of treatment for each route). During each bi-weekly period, the unit worked three LPR routes and three manual check routes, each of which was patrolled daily for approximately an hour (each route received a approximately eight hours of intervention by four officers, or 32 officer-hours). The time of day during which the unit patrolled each route was also varied according to a preset schedule so that the unit would not work the same routes at the same time each day (the unit conducted their patrols Wednesday to Saturday from 3:00 p.m. to 1:00 a.m.).[15] Hence, both the bi-weekly

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[13] We discussed the option of an “override process” as a safety valve for the MPD. That is, if a location is deemed by the Chief of MPD to require the LPR intervention, then that place will receive it. Despite this option, no “overrides” were deemed necessary by the MPD in either phase.

[14] It is worth noting that all three conditions (LPR, manual license plate checking and the control group) received standard patrol services, except the control group received no other interventions beyond standard patrol services.

[15] The LPR and manual routes and zones were scheduled in alternating order each day (i.e., the officers would work an LPR route, followed by a manual route, followed by another LPR route, etc.). On some days, the unit could not work all scheduled routes or zones due to special circumstances (such as making an arrest that took the unit out of commission for the rest of the shift). In these instances, the unit resumed patrolling the next day according to the schedule set for that day. These deviations cancelled out over the course of the experiment so that the unit spent equivalent amounts of time working LPR and manual check routes and zones.

treatment period and time of day patrolled were determined randomly for each route. This type of design ensured that the places and times worked with LPR and without LPR were comparable.

When using the LPRs, the officers' general operating strategy was to "sweep" each route (checking parking lots and side streets within the targeted route) at the beginning of the shift and then conduct fixed surveillance on the route (with officers positioned along different sides and parts of the route). When working the manual check routes, the officers used the same initial sweeping strategy and then focused their efforts on particular parts of the assigned routes by roaming around these areas to maintain speeds with the local traffic or by parking at traffic lights to check plates. The officers doing manual checks were not able to remain stationary, for that limited their ability to see and check license plates of cars passing by rapidly.

For Phase 2, 18 of the 54 hot zones were randomly assigned to receive LPR enhanced patrol by the vehicle theft unit, another 18 zones were assigned to the same specialized vehicle theft unit for patrol and surveillance without the LPRs, and 18 routes were assigned to normal patrol (the control condition). We divided the 18-week Phase 2 intervention period into nine bi-weekly periods. Routes selected for intervention by the vehicle theft unit (both the LPR routes and manual check routes) were randomly assigned to receive treatment at a similar dosage as was provided in Phase 1 (8 days of treatment for each zone with approximately one hour of dosage per day by four officers, or 32 officer-hours). The time of day during which the unit patrolled each zone was also varied (as was done in Phase 1) according to a preset schedule so that the unit would not work the same zones at the same time each day. As with Phase 1, both the bi-weekly treatment period and time of day patrolled were determined randomly for each route in Phase 2. As noted earlier, officers put more emphasis on roving surveillance during Phase 2 in comparison to Phase 1.

4.3.3. Monitoring the Assignment Process

For both phases, procedures were established to monitor the integrity of the assignment process (and monitor for expectancy, novelty, disruption, and local history) and to measure and statistically control for any contamination (especially for hot spots contiguous with each other). We were able to use the LPR equipment, which provides a GPS coordinate for every license plate scan, to check that the officers were using the LPR equipment to assess the integrity of the treatment assignment process and assess if officers strayed out of their assigned areas (which none did, except for a few emergency cases in both phases where the vehicle theft unit was needed to provide backup in a few high-level calls-for-service related to violent crime). The officers also maintained logs to document their time at the hot routes/zones, deviations from the study protocol, and the nature and results of any "hits" from the LPR and manual checks (see the "measures" section below). In both phases, our team conducted detailed interviews and "ride-alongs" with the vehicle theft unit officers and other patrol officers to assess their use or non-use of the LPR equipment and conduct treatment integrity checks (e.g., query them on their adherence to the study protocols). No problems were revealed through these treatment integrity checks.

4.4. Measures

First, we collected a series of variables to describe the hot routes in our study based on public works/engineering data from the city of Mesa. Our length of route variable we categorized into three groups: short (.02 miles to .43 miles), medium (.44 miles to .89 miles) and long hot routes (0.9 miles to 2.01 miles). The shorter routes tended to be in more residential areas and the longer routes tended to be on highways or other major thoroughfares. We calculated the average speed limit of route and created three categories(1=25 or 30 mph, 2=35 or 45 mph, 3= 55 mph), We developed a four point rating scale to measure whether the hot route provided good opportunities for conducting surveillance (e.g., a large sign for the officers to hide their car behind). Two detectives used a four-point scale to assess each route in our study (1= very hard, 2= somewhat hard, 3= somewhat easy, and 4= very easy to do surveillance) and achieved high inter-rater reliability (over 0.9). We also recorded whether the hot routes were determined by geographical analysis (coded as 1) or by recommendation from an auto theft detective (coded as 0) that this was an area that was traveled by auto thieves frequently. For the large hot zones of the Phase 2 experiment we included some additional measures, including: the presence of a freeway(s) in the zone (yes or no), and the size of the zone (in square miles).

Next, we collected a variety of traditional police outcome measures of enforcement activity for the hot spot transit routes/zones and surrounding areas, including calls-for-service (CFS) data for vehicle theft, incident/Uniform Crime Report (UCR) data on vehicle thefts, and arrest data on vehicle theft. We also worked with the MPD to develop a vehicle theft/LPR database to track police contacts and other activity associated with the LPR use and manual license plate checks. For both the LPR and manual check treatments, the vehicle theft unit collected data on the number of plates scanned or typed, the number of "hits" (i.e., matches to stolen plates and plates of stolen vehicles), date and time data on these "hits,", number of occupied and unoccupied vehicles recovered, number of persons arrested, and the number of hours spent scanning or checking license plates during each treatment of a route.[16]

For the Phase 1 analysis, we also created 500-foot and 2,500-foot buffers around each hot route. The 500-foot buffer was used to define the boundaries of the hot route; that is, a "hit" or a vehicle theft would "count" for a route for the purposes of our research if it occurred either on the specific street of each hot route or within 500 feet of the route. This allowed us to include parking lots along the route and other similar areas in the immediate proximity of the hot route that officers covered during their sweeps. The 2,500 foot buffer was used to measure potential crime displacement or diffusion of crime control benefits

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[16] The LPR devices collect much of this data automatically. They also store a record and GPS coordinates of each scan and each "hit."

into other micro areas surrounding the hot routes. (For Phase 2, we tested for possible displacement or diffusion effects based on changes in adjacent zones.)

Our auto theft outcome measures were collected for all pre-intervention, intervention, and post-intervention weeks of the study period. We focus on effects during the two-week period of the intervention for each route/zone and for the two-week period immediately after the intervention. Our post-intervention measure of only two-weeks was selected to correspond to the two-week intervention period and also because we hypothesized that the effects of the intervention were not likely to last beyond a short-time frame. That is, it is hard to imagine implementing a two-week intervention that could create effects beyond a short period of time. Therefore, we did not test for longer term effects unless there was evidence of change during the two weeks immediately following the intervention.

We have divided our results section into two parts: (1) Finding from Phase 1 and then (2) findings from Phase 2. In the discussion section we discuss and compare the results across the sections.

5. PHASE 1 RESULTS

The first sets of analyses (see Table 1 and 2) describe the key analytic variables and summarize the nature of the distribution of our data. Table 1 includes means and standard deviations for continuous/interval-level variables (with statistically significant analysis-of-variance results noted on the left side of the table). Table 2 presents counts, percentages and chi-square results for data with more limited distributions. Note that 15 hot routes corresponding to freeway segments were dropped from our analysis of the UCR and CFS data because they do not appear as location points within MPD’s data system. Consequently, our analysis of auto theft patterns is based on 102 hot routes.

TABLE 1

Phase 1: Means (standard deviations) for Three Study Conditions and Entire Sample

Variable	MEAN (SD)				N
	LPR	Manual Plate Checking	Control	All cases	
Number of CFS (911) for vehicle theft					
Before txt period	.78(1.6)	.41(0.7)	.83(1.3)	0.65(1.3)	102
During txt period	.65(1.1)	.38(0.6)	.57(0.8)	0.53(0.9)	102
2 weeks after txt	.70(1.8)	.08(0.3)	.35(0.8)	0.38(1.2)	102
Number of vehicle theft offenses (UCR)[17]					
Before txt period	.35(0.7)	.26(0.7)	.22(0.5)	.28(0.7)	102
During txt period	.30(0.6)	.26(0.4)	.26(0.5)	.27(0.5)	102
2 weeks after txt (F=4.7 [2,99] p<.01)	.25(0.4)	.05(0.2)	.04(0.2)	.13(0.3)	102
Number of plates checked for criminal activity (F=128.8 [1,88] p<.001)	10,164 (5,196)	1,313 (609)	_____	5,738 (5,774)	90
Average length of route in miles	.57(0.4)	.62(0.5)	.57(0.4)	.59(0.5)	117
Average speed limit of route	37(8.6)	36(9.1)	38(9.5)	37.1(8.9)	117
Average surveillance rating for route	2.8(1.1)	2.8(1.1)	2.8(1.1)	2.8(1.1)	117
Routes determined by GIS analysis	.64(0.5)	.69(0.5)	.67(0.5)	.67(0.5)	117

5.1. Analysis for Pre-Treatment Differences across the Three Study Conditions

As seen in Table 1, no pre-treatment differences emerged in our three study conditions based on the length of the routes, speed limit of the routes, potential for effective surveillance, whether the routes were determined by GIS analysis or officer/detective nomination, pre-treatment UCR crime levels, or pre-treatment CFS levels. The evidence from Table 1 suggests that our random assignment process worked as planned and created comparable intervention/control conditions.

Next, we examine whether the routes covered by the specialized vehicle theft unit with the LPR had more "hits" (positive detections of a vehicle theft crime), more arrests for vehicle theft crimes (stealing of vehicles and/or license plates), and more recoveries for stolen vehicles than the routes covered by the

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[17] There were 117 routes in the study. However, for our 15 highway routes we generally do not have UCR data measures (generally highway routes are not noted as location points within MPD's UCR database), leaving us with complete data for these measures on fewer cases (n= 102).

specialized vehicle theft unit with manual plate checking. These results are followed by tests of whether the routes covered by the specialized vehicle theft unit with the LPRs had reductions in vehicle theft compared to the routes covered by the specialized vehicle theft unit with manual checking and compared to standard patrol (no specialized unit and no LPR).

5.2. Bivariate Models

5.2.1. Effects of LPR, Compared to Manual Checking, on "Hits," Arrests, and Recoveries

The vehicle theft unit when using the LPR (457,369 total plates checked or 10,164 on average across the LPR covered routes) conducted statistically more (F=128.8 [1,88] p<.001) license plate checks (7.74 times more) than when the same unit (see Table 1 above) did manual plate checking (59,073 total plates checked or 1,313 on average across manual routes). The routes with the LPR had statistically (2.7 times) more total hits for stolen cars crimes (see Table 2 below) than the manual routes (16 versus 6; X^2= 3.7, p<.05).[18] The routes with the LPR had eight hits for stolen plates (see Table 2) compared to statistically fewer (zero) hits for stolen plates for the manual routes (X^2= 10.3 [1], p<.01). The routes with the LPR had three arrests for stolen cars (see Table 2) compared to statistically fewer (zero) arrests for stolen cars for the manual routes (X^2= 4.3 [1], p< .05). The routes with the LPR had one arrest for stolen plates (see Table 2) compared to zero arrests for stolen plates for the manual routes (a non-statistically significant result of X^2= 1.4 [1], p=.24).[19]

The routes with the LPR had four recoveries for occupied stolen vehicles (see Table 2) compared to (marginally) statistically fewer (zero) recoveries for occupied stolen vehicles for the manual routes

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[18] It can also be seen in Table 2, that the "hit" rate is larger than the combined total of stolen vehicles and stolen plates recovered (16 to 10 in the LPR category of Table 2 on page 25). This can be accounted for by the fact that some vehicles are identified as stolen by the LPR system but the auto theft unit is unable to stop the vehicle safely and it gets lost it in heavy traffic.

[19] Although our focus here is on hits and results related to auto theft, it is also worth noting that the auto theft unit obtained 5 hits for other matters (e.g., matches to the license plates of vehicles belonging to people wanted on warrants) when using the LPRs in contrast to only 1 such hit when doing the manual checks. Arrests for crimes not related to auto theft (e.g., arrests for warrants or other crimes witnessed by the officers) numbered 5 in both the LPR and manual check routes.

(Fisher's Exact Test, p<.05). The routes with the LPR had six recoveries for unoccupied stolen vehicles compared to a statistically similar number of recoveries (five) for unoccupied stolen vehicles for the manual routes (X^2= 1.5, n.s.). Thus, by nearly every measure, the productivity of the vehicle theft unit was several times higher when using the LPR devices.

TABLE 2

Phase 1: Comparison of Counts/Percentages for Key Analytic Variables

Variables	LPR	Manual Plate Checking	All cases	X^2[df]	N
Number of arrests					
Vehicle theft arrest	3 (6.7%)	0 (0%)	3(2.8%)	4.3 [1]*	90
Stolen plate arrests	1 (2.2%)	0 (0%)	1(1.1%)	1.4 [1]	90
"Hits" for crimes					
Stolen cars	16 (26.7%)	6 (13.3%)	22 (20%)	3.7[2]*	90
Stolen license plates	8 (15.6%)	0 (0%)	8 (7.8%)	10.3[2]**	90
Number of recoveries for stolen vehicles					
Occupied stolen vehicles	4 (8.9%)	0 (0%)	4 (4.4%)	5.7[1]*	90
Unoccupied stolen vehicles	6 (11.1%)	5 (11.1%)	11 (11.1%)	1.5[2]	90

5.2.2. Effects of LPR on Levels of Vehicle Theft: Intervention Weeks

Table 1 shows the average level of vehicle theft, as defined by 911 calls and UCR reports, for the LPR and manual check groups during three successive periods: the two weeks prior to the intervention, the two intervention weeks, and the two weeks following the intervention. To provide a comparator for the treated hot routes, control routes were also randomly assigned a "treatment" bi-weekly period (from among the 15 bi-weekly periods during which the interventions were implemented). Thus, we compare changes in vehicle theft in the treated routes during their intervention and post-intervention weeks (which were selected randomly) to changes in the control routes during randomly selected weeks.

No statistically significant differences were observed (see Table 1) across the control, LPR and manual groups based on CFS[20] (control= .57, LPR= .65, and manual= .38; F= 0.956, df=2,99; p= 0.39, n=

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[20] We note that the category of CFS is uniformly larger than the UCR report data. The reason for this is that the CFS database includes a broader group of cases than the UCR database which only counts actual reported crime. For example, the CFS

102) or UCR crime reports (control= .26, LPR= .30, and manual= .26; F= 0.081, df=2,99; p= 0.92;n= 102) for vehicle theft during the intervention weeks.

5.2.3. Effects of LPR on Levels of Vehicle Theft: Post-Intervention Weeks

During the two post-intervention weeks, CFS related to auto theft were lowest in the manual check routes (0.08), followed by the control routes (0.35) and the LPR routes (0.70). These differences had marginal levels of statistical significance (F= 2.64, df=2,99; p= .08, n= 102). However, we observed a statistically significant difference (see Table 1) across the control, LPR and manual groups based on UCR crime reports (control= 0.04, LPR= 0.25, and manual= 0.05; F= 4.73, df=2,99; p = .01, n= 102) for vehicle theft during the two week post-intervention period. The LPR group had a slightly higher number of vehicle thefts (based on UCR) in the two week period post intervention compared to the manual plate checking group or control group.[21] Table 1 also shows that the direction of changes in vehicle theft from the two-week pre-intervention period to the intervention weeks and from the intervention weeks to the post-intervention weeks were not indicative of treatment effects from LPR use. Vehicle theft dropped in all three groups from the pre-intervention to the intervention weeks. In the post-intervention weeks, the LPR routes had a slight increase in vehicle theft, while the manual and control routes experienced further declines.

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database can include reports of stolen autos that turn out to be unfounded because the person found their lost car that they thought might have been stolen.

[21] In our later multivariate models, where we control for pre-intervention levels of vehicle theft, we no longer observe a difference between the LPR route and the control group on this measure. However, the manual group does emerge as having lower two-week post intervention vehicle theft levels (based on UCR data) than the control group.

5.3. Multivariate Models

Although not strictly necessary because we are working with experimental data, we will also introduce a set of covariates to our vehicle theft crime models.[22] Introducing covariates is increasingly common in analyzing data from randomized experiments (Patel, 1996). The introduction of covariates allows us to assess the role of substantively interesting variables on vehicle theft and simultaneously improve the precision of the treatment comparisons and correct for any major imbalances in the distribution of these covariates across the treatment and control groups that may have occurred due to chance (Armitage, 1996). Adding covariates also can help adjust for the natural variation between cases within the comparison groups (Gelber & Zelen, 1986). To follow is an examination of the effectiveness of the LPR equipment in reducing vehicle theft (UCR) incidents and CFS for vehicle theft using a count model approach (in one case Poisson regression and the other case negative binomial regression based on the distribution of the data). In order to enhance the statistical power and precision of these models, we created a panel database pooling data from all routes over the 15 bi-weekly intervention periods, the two weeks before the experiment, and the two weeks after the experiment.[23] This yielded a total of 102 * 17 = 1,734 data points after the removal of the freeway routes (discussed earlier).[24]

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[22] We do not use multivariate modeling with our other outcome measures ("hits," arrests and recoveries) for a number of reasons. First, some of these other measures have little or no variability to assess with multivariate modeling. For example, all of the stolen plate hits were generated using the LPR (n=8) compared to no stolen plate hits for the manual plate checking routes. Also, for some of the measures (e.g., "hits") we do not have pre-intervention measures thus removing the inclusion of substantively interesting covariates.

[23] We included data points for the weeks before and after the experiment in order to examine pre-post changes and lagged effects for routes that were treated during the first and last periods of the experiment.

[24] Hence, for the treatment routes, we included weeks before, during, and after the intervention. Pooling the data in this fashion also allows us to simultaneously examine effects during the treatment and post-treatment periods.

5.3.1. Impact of LPR on Vehicle Theft (UCR) Incidents Based on Count Modeling

In Table 3, we present the results of the impact of the randomly assigned treatment on UCR vehicle thefts within a Random Effects Poisson count model,[25] controlling for time period, adjacent hot routes, and a number of hot route characteristics, including length, visibility, and prior levels of vehicle theft.[26] Note that our measure of lagged vehicle theft for each route and bi-weekly period corresponds to that route's level of vehicle theft during the same bi-weekly period of the prior year. We used this seasonally lagged measure rather than the immediately prior two weeks because of the possibility that the latter measure would be contaminated by displacement or diffusion effects stemming from interventions in nearby routes. As one measure of possible displacement or diffusion effects, the adjacent route indicator represents, for each route and time period, the number of adjacent routes that were being treated simultaneously (i.e., receiving LPR or manual patrol by the vehicle theft unit). The bi-weekly indicator controls for common time trends (vehicle theft was declining in Mesa throughout the study period).

Statistically significant predictors of vehicle thefts were the prior seasonal vehicle theft count and the length of the hot route.[27] Hot routes that had higher rates of vehicle theft one year prior had more vehicle thefts, while mid-length routes (.45 to .9 miles) experienced fewer vehicle thefts, relative to short-length hot routes (under .45 miles). This model also includes two treatment effects, each of which is estimated separately for the LPR and manual check interventions: the impact of assigned treatment during the treatment weeks and the impact of assigned treatment in the two weeks after treatment (changes in both groups of treatment routes are interpreted relative to those in the control routes). After controlling for

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[25] The random effects approach assumes that unmeasured differences between routes are distributed as a random variable and uncorrelated with the variables in the model. Most importantly, our estimate of the treatment effect should be uncorrelated with these unmeasured differences by virtue of our experimental design.

[26] All subsequent models were estimated using STATA 10.1 xt commands for cross-sectional time series data.

[27] An additional hot route characteristic was the speed limit of the hot route. Due to colinearity with other predictors this variable was dropped from the analysis. As noted earlier, we also confirmed in preliminary modeling that there was no association between the outcome measures and the method by which each route was chosen (GIS analysis versus selection by detectives).

other factors, we see a statistically significant 75% reduction in the odds of a UCR vehicle theft in the two weeks after treatment in manually treated hot routes (p=.05) compared to the control group. Additional modeling (not shown) indicated that this effect faded after the initial two weeks following the manual check patrols.[28]

TABLE 3

Phase 1: Poisson (Count Model) Regression for UCR Vehicle thefts Incidents

	Odds Ratio	Std. Err.	Z	P>|z|
Lag UCR Vehicle theft	1.22	0.06	3.14	0.002
Biweekly Time Trend	0.98	0.01	-1.49	0.137
LPR Treat Period	1.25	0.30	0.74	0.46
Manual Treat Period	1.15	0.33	0.42	0.672
LPR Post 2 Weeks	1.00	0.33	0.00	1.000
Manual Post 2 Weeks	0.25	0.71	-1.93	0.052
Mid-length Hot Route	0.61	0.22	-2.26	0.024
Long Hot Route	1.10	0.24	0.38	0.701
Good Visibility	1.09	0.11	0.79	0.427
Adjacent Treated	0.97	0.14	-0.21	0.833
Intercept	0.19	0.41	-4.01	0.000
/lnalpha	0.57	0.23		
alpha	1.78	0.13		

Likelihood-ratio vs. pooled: chibar2(01) = 74.21 Prob>=chibar2 = 0.000
N. observations= 1,734; N. groups=102, Per group observations= 17;
Wald X^2(10)= 27.16; Log likelihood= -925.73069; Prob > X^2= 0.0025

5.3.2. Impact of LPR on Vehicle Theft Calls-for-Service (CFS) Based on Count Models

The impact of assigned treatment on vehicle theft CFS is presented in Table 4. As in Table 3, treatment impact is assessed through two variables, one for the period of treatment delivery and the other corresponding to the two-week period post-treatment. Similar to the results for UCR reported vehicle theft,

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[28] More specifically, we tested whether this effect persisted throughout the observed post-intervention period and found that this was not the case.

the seasonal one year prior vehicle theft CFS rate is significantly related to the number of calls. Hot routes with higher vehicle theft rates in the prior year continue to have more CFS for vehicle theft. In addition, mid-length hot routes tend to have fewer vehicle theft CFSs, relative to shorter hot routes. Also, our time trend variable is statistically significant, indicating that as the experiment progressed the incidence rate of CFSs for vehicle theft generally declined across all routes. The assigned treatment (either manual or LPR) did not have a statistically significant impact on vehicle theft CFSs relative to controls during the treatment period. However, although LPR hot routes do not see a significant change during the post two-week period, the manual group witnessed a statistically significant decline. Manual hot routes in the post two-week period after treatment had decreased odds of having a call-for-service for vehicle theft by 75% (1 minus the odds ratio of .25) compared to the control group. As with the UCR data, subsequent modeling (not shown) revealed that this effect was temporary.[29]

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[29] As in the UCR analysis, we tested whether this effect persisted throughout the observed post-intervention period and found that this was not the case.

TABLE 4

Phase 1: Poisson (Count Model) Regression for Calls-for-service (CFS) Vehicle thefts Incidents

	Odds Ratio	Std. Err.	Z	P>|z|
LAG CFS Vehicle theft	**1.10**	0.02	**3.76**	**0.000**
Biweekly Time Trend	**0.96**	0.01	**-5.35**	**0.000**
LPR Treat Period	1.13	0.23	0.52	0.600
Manual Treat Period	1.11	0.28	0.39	0.700
LPR Post 2 Weeks	1.15	0.24	0.57	0.568
Manual Post 2 Weeks	**0.25**	0.58	**-2.35**	**0.019**
Mid-length Hot Route	**0.52**	0.22	**-2.97**	**0.003**
Long Hot Route	1.01	0.25	0.06	0.956
Good Visibility	0.98	0.12	-0.17	0.867
Adjacent Treated	0.97	0.11	-0.33	0.742
Intercept	4.45	0.49	3.08	0.002
/ln_r	9.00	0.26		
/ln_s	1.40	0.19		
r	8111.52	2.35		
s	4.06	0.26		

Likelihood-ratio vs. pooled: chibar2(01)= 205.8 Prob>=chibar2 = 0.00;
N. observations= 1,734; N. groups=102, Per group observations= 17;
Wald $X^2(10)$= 61.1; Log likelihood= -1,417.972; Prob > X^2= 0.0000

5.4. Assessment of Potential Displacement and Diffusion of Benefits

To conclude this section we assess if vehicle theft crime displacement or diffusion of benefits occurred from our targeted routes to areas adjacent or near these routes. Given the general lack of effects in the models above, particularly for the LPR treatment, displacement and diffusion seem unlikely. The statistical non-significance of the indicator for treatment in adjacent routes also provides some indication that neither displacement nor diffusion occurred. As an additional check, we also examine changes in the areas adjacent to our study hot routes that are beyond the 500 foot buffer of the hot route but also within

2500 feet of the respective hot route. If displacement or diffusion occurred, we would expect there to have been statistical changes in these areas immediately adjacent to the hot routes from the two week period before the intervention to the intervention period and possibly to the two weeks post-intervention. Table 5 presents the results for the area immediately adjacent to the route. We observed no statistically significant differences for any of the three conditions in these areas from the pre-period to the intervention period or two-week post period. For example, our data on CFS for the LPR route revealed little change from the period prior to LPR treatment (3.05 CFS) to the period of LPR treatment (2.44 CFS) to the period two-weeks post treatment (2.46 CFS). Also, the reduction in post-intervention incidents and calls in the manual check routes does not seem to have produced clear displacement or diffusion patterns; UCR incidents in areas adjacent to the manual routes went up during these weeks, while CFS went down.

TABLE 5

Phase 1: Visual Assessment of Potential Crime Displacement and Diffusion of Benefits

		Areas adjacent to hot routes beyond the 500 foot buffer of hot route but within 2500 feet of hot route	
Randomly Assigned Treatment	Period	UCR Vehicle theft	CFS Vehicle theft
Control Route	2 Weeks Pre-Treatment	.82	1.82
	Treatment Period	1.13	1.72
	2 weeks Post-Treatment	1.38	2.80
LPR Route	2 Weeks Pre-Treatment	1.68	3.05
	Treatment Period	1.49	2.44
	2 weeks Post-Treatment	1.36	2.46
Manual Route	2 Weeks Pre-Treatment	1.44	2.47
	Treatment Period	1.37	2.71
	2 weeks Post-Treatment	1.46	2.29

6. PHASE 2 RESULTS

The first sets of analyses for Phase 2 (see Tables 6 and 7) describe the key analytic variables and summarize the nature of the distribution of our Phase 2 data. Table 6 includes means and standard deviations for continuous/interval-level variables (with statistically significant analysis-of-variance results noted on the left side of the table). Table 7 presents counts, percentages and chi-square results for data with more limited distributions.

TABLE 6

Phase 2: Means (standard deviations) for Three Study Conditions and Entire Sample

Variable	MEAN (SD)				N
	LPR	Manual Plate Checking	Control	All cases	
Number of CFS (911) for vehicle theft					
Before txt period	1.06 (1.3)	1.39 (1.9)	1.39 (1.3)	1.28 (1.6)	54
During txt period	1.72 (1.6)	1.33 (1.9)	0.94 (1.5)	1.33 (1.6)	54
2 weeks after txt	1.28 (1.4)	1.89 (2.3)	1.50 (1.9)	1.56 (1.9)	54
Number of vehicle theft offenses (UCR)					
Before txt period	0.56 (0.8)	0.33 (0.6)	0.61 (0.8)	0.50 (0.7)	54
During txt period	0.72 (0.8)	0.67 (1.1)	0.67 (1.2)	0.69 (1.0)	54
2 weeks after txt	0.39 (0.7)	0.78 (1.6)	0.72 (1.0)	0.63 (1.1)	54
Number of plates checked for criminal activity F = 30.95 (1,36) p ≤ .000	16,342.50 (9,412.9)	1,692.06 (735.1)	---------	9,017.28 (9,924.2)	
Average area of zone in square miles	1.21 (0.5)	1.17 (0.4)	1.12 (0.3)	1.16 (0.4)	54
Percent of Zones near or contains a Freeway	50.0%	44%	44%	46%	54

6.1. Analysis of Pre-Treatment Differences across the Three Study Conditions

As seen in Table 6, no pre-treatment differences emerged in our three study conditions based on the size of the zones, presence of highways in the hot zone, pre-treatment UCR crime levels, or pre-treatment CFS levels. The evidence from Table 6 suggests that our random assignment process worked as planned and created comparable intervention/control conditions.

Next, we examine whether the zones covered by the specialized vehicle theft unit with the LPR had more “hits” (positive detections of a vehicle theft crime), more arrests for vehicle theft crimes (stealing of vehicles and/or plates), and more recoveries for stolen vehicles than the zones covered by the specialized vehicle theft unit with manual plate checking. These results are followed by tests of whether the zones covered by the specialized vehicle theft unit with the LPRs had reductions in vehicle theft compared to the zones covered by the specialized vehicle theft unit with manual checking and compared to standard patrol (no specialized unit and no LPR).

6.2. Bivariate Models

6.2.1. Effects of the LPR, Compared to Manual Checking, on "Hits," Arrests, and Recoveries

The vehicle theft unit when using the LPR (294,165 total plates checked or 5,550 on average across the LPR covered zones) conducted statistically more (F=30.95; df=1,33; p<.001) license plate checks (9.65 times more) than when the same unit (see Table 6 above) did manual plate checking (30,457 total plates checked or 574 on average across manual zones). The zones with the LPR had 6 times more total hits for stolen cars crimes (see Table 7 below) than the manual zones (12 versus 2; X^2= 4.7, p<.05). The zones with the LPR had seven hits for stolen plates (see Table 7) compared to statistically fewer (zero) hits for stolen plates for the manual zones (X^2= 8.3, p<.019). The zones with the LPR had five hits for stolen cars (see Table 7) compared to fewer (two) hits for stolen cars for the manual zones (X^2=n.s.).

The zones with the LPR had zero arrests for stolen cars (see Table 7) compared to zero arrests for stolen cars for the manual zones. The zones with the LPR had one arrest for stolen plates (see Table 7) compared to zero arrests for stolen plates for the manual zones (a non-statistically significant result). The zones with the LPR had four recoveries for unoccupied stolen vehicles compared to two for unoccupied stolen vehicles for the manual zones, but this difference was not statistically significant (p = .658).The zones with the LPR had zero recoveries for occupied stolen vehicles (see Table 7) compared to zero recoveries for occupied stolen vehicles for the manual zones. Thus, by at least some of our measures, as in Phase 1, the productivity of the vehicle theft unit was several times higher when using the LPR devices.[30]

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[30] In addition, the auto theft unit obtained 3 hits for other matters (e.g., matches to the license plates of vehicles belonging to people wanted on warrants) when using the LPRs and 1 such hit when doing the manual checks. Arrests for crimes not related to auto theft (e.g., arrests for warrants or other crimes witnessed by the officers) numbered 5 in the LPR zones and 2 in the manual check zones.

TABLE 7

Phase 2: Comparison of Counts/Percentages for Key Analytic Variables

Variables	LPR	Manual Plate Checking	All cases	Fisher's Exact Test	N
Number of arrests					
Vehicle theft arrest	0 (0.0%)	0 (0.0%)	0 (0.0%)	----------	36
Stolen plate arrests	1 (5.6%)	0 (0.0%)	1 (2.8%)	P = .999	36
"Hits" for crimes					
Stolen cars	5 (27.8%)	2 (11.1%)	7 (19.4%)	P = .402	36
Stolen license plates	7 (33.3%)	0 (0.0%)	7 (16.7%)	P = .019	36
Number of recoveries for stolen vehicles					
Occupied stolen vehicles	0 (0.0%)	0 (0.0%)	0 (0.0%)	----------	36
Unoccupied stolen vehicles	4 (22.2%)	2 (11.1%)	6 (16.7%)	P = .658	36

6.2.2. Effects of LPR on Levels of Vehicle Theft: Intervention Weeks

Table 6 shows the average level of vehicle theft, as defined by 911 calls and UCR reports, for the LPR and manual check groups during three successive periods: the two weeks prior to the intervention, the two intervention weeks, and the two weeks following the intervention. To provide a comparator for the treated hot zones, control zones were also randomly assigned a "treatment" bi-weekly period (from among the nine bi-weekly periods during which the interventions were implemented). Thus, we compare changes in vehicle theft in the treated zones during their intervention and post-intervention weeks (which were selected randomly) to changes in the control zones during randomly selected weeks.

No statistically significant differences were observed (see Table 6) across the control, LPR and manual groups based on CFS (control= 0.94, LPR= 1.72, and manual= 1.33; F= 1.00, df=2, 51; p= 0.374, n= 54) or UCR crime reports (control= 0.67, LPR= 0.72, and manual= 0.67; F= 0.02, df=2, 51; p= 0.983, n= 54) for vehicle theft during the intervention weeks.

6.2.3. Effects of LPR on Levels of Vehicle Theft: Post-Intervention Weeks

In addition to vehicle thefts during the treatment period, we also examined vehicle thefts based on CFS (see Table 6) during the two week post-intervention period. The LPR zones had somewhat fewer calls on average during this period (1.28) compared to the manual check zones (1.89) and the control group zones (1.50), but this difference was not statistically significant (F= 0.47, df=2, 51; p= .626, n= 54). We also observed a similar non-significant difference (see Table 6) across the control, LPR and manual groups based on UCR crime reports (control= 0.72, LPR= 0.39, and manual= 0.78; F= 0.61, df=2, 51; p < .549, n= 53) for vehicle theft during the two weeks post-intervention period. Although the LPR group had a lower number of UCR vehicle theft reports in the two week period post intervention compared to the manual plate checking group and the control group, this result was non-significant.

6.3. Multivariate Models

To follow is an examination of the effectiveness of the LPR equipment in reducing vehicle theft (UCR) incidents and CFS for vehicle theft using a count model approach (in one case Poisson regression and the other case negative binomial regression based on the distribution of the data). Using the same general approach as for our Phase 1 models, we created a panel database pooling data from all zones over the nine bi-weekly intervention periods, the two weeks before the experiment, and the two weeks after the experiment.[31] This yielded a total of 54 * 9 = 486 data points.

6.3.1. Impact of LPR on Vehicle Theft (UCR) Incidents Based on Count Modeling

In Table 8 we present the results of the impact of the randomly assigned treatment on UCR vehicle thefts within a Random Effects Poisson count model, controlling for time trends, treatment of adjacent hot

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[31] As explained in Phase 1, for Phase 2 we also included data points for the weeks before and after the experiment in order to examine pre-post changes and lagged effects for routes that were treated during the first and last periods of the experiment.

zones, the presence of a freeway(s) in the zone, the size of the zone, and levels of vehicle theft in the zone during the same two-week period of the prior year. Statistically significant predictors of vehicle thefts were freeway coverage and the biweekly time trend. Hot zones that had freeways/highways had lower rates of vehicle theft (IRR= 0.55, $p < .05$) relative to areas that had no freeways/highways. The biweekly time trend indicates that as the experiment progressed the incidence rates of auto thefts increased (IRR= 1.05, $p < .05$). Impacts of the LPR and manual check treatments were statistically non-significant during both the treatment weeks and the post-intervention weeks.[32]

TABLE 8

Phase 2: Poisson (Count Model) Regression for UCR Vehicle thefts Incidents

	Incidence Rate Ratio	Std. Err.	Z	P>|z|
Lag UCR Auto theft	1.01	0.04	0.28	0.782
Biweekly Time Trend	1.05	0.02	2.13	0.033
LPR Treat Period	1.05	0.31	0.16	0.873
Manual Treat Period	0.92	0.28	-0.28	0.777
LPR Post 2 Weeks	0.62	0.24	-1.21	0.225
Manual Post 2 Weeks	1.08	0.31	0.26	0.793
Adjacent Treated	0.97	0.11	-0.22	0.825
Freeways in hot zone	0.55	0.15	-2.15	0.032
Area of Hot Zone (in sq. miles)	0.61	0.22	-1.37	0.170
/lnalpha	-0.15	0.28		
alpha	0.85	0.25		

Likelihood-ratio vs. pooled: chibar2(01) = 71.43 Prob>=chibar2 = 0.000
N. observations= 486; N. groups=54, Per group observations= 9;
Wald $X^2(9)$= 13.42; Log likelihood= -515.044; Prob > X^2= 0.14

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[32] Although there were no statistically significant changes in the intervention areas, it is notable that auto theft reports dropped by 38% in the LPR zones during the two-weeks following intervention. With a larger sample size, this change may have proved statistically significant. However, this pattern was not mirrored in the calls-for-service data (see below).

6.3.2. Impact of LPR on Vehicle Theft Calls-for-Service (CFS) Based on Count Model

The impact of assigned treatment on vehicle theft CFS is presented in Table 9. As in Table 8, treatment impact is assessed through two variables, one for the period of treatment delivery and the other corresponding to the two-week period post-treatment. Hot zones that contained freeways/highways had lower rates of vehicle theft (IRR= 0.49, p< .05) relative to areas that had no freeways/highways. The biweekly time trend indicates that as the experiment progressed the incidence rates of auto thefts generally increased (IRR= 1.06, p< .05). The assigned treatment (either manual or LPR) does not have a statistically significant impact on auto theft calls relative to controls during the treatment period or two-weeks post-treatment.

TABLE 9

Phase 2: Negative Binomial (Count Model) Regression for Vehicle theft Calls-For-Service (CFS)

	Incidence Rate Ratio	Std. Err.	Z	P>|z|
LAG CFS Vehicle theft	0.97	0.02	-1.31	0.191
Biweekly Time Trend	1.06	0.02	3.44	0.001
LPR Treat Period	1.36	0.29	1.43	0.152
Manual Treat Period	0.89	0.22	-0.47	0.640
LPR Post 2 Weeks	0.98	0.24	-0.07	0.941
Manual Post 2 Weeks	1.14	0.26	0.59	0.558
Adjacent Treated	1.05	0.10	0.51	0.610
Freeway	0.51	0.14	-2.40	0.016
HZ Area (in sq. miles)	0.55	0.21	-1.54	0.123
/ln_r	2.04	0.41		
/ln_s	0.18	0.25		
r	7.68	3.15		
s	1.19	0.30		

Likelihood-ratio vs. pooled: chibar2(01) = 86.92, Prob>=chibar2 = 0.000
N. observations= 486; N. groups=54, Per group observations= 9;
Wald $X^2(9)$= 24.31; Log likelihood= -697.65; Prob > X^2= 0.004

6.4. Assessment of Potential Displacement and Diffusion of Benefits

For the Phase 2 analysis, we assess potential crime displacement and diffusion of crime control benefits based only on the indicator for effects from treatment in an adjacent zone(s).[33] This variable

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[33] As noted earlier, this indicator shows, for each zone (i) and time period (t), whether officers were intervening in an adjacent zone(s) with either LPR or manual patrols

provides a gauge of possible displacement and diffusion to surrounding areas of comparable size and type, as is common in studies of interventions in areas such as patrol beats or neighborhoods.[34] The adjacent route treatment indicator was statistically non-significant in both the UCR and CFS models. This pattern and the lack of direct effects in the target areas leads us to conclude that neither the LPR nor the manual check patrols produced displacement or a diffusion of benefits into surrounding areas.

7. DISCUSSION

Our paper focuses on a relatively new innovation for use by law enforcement in addressing vehicle theft. In general, the police have struggled addressing vehicle theft with only about 10% of vehicle thefts resulting in an arrest nationwide (FBI, 2010). LPR technology has been advanced as an innovation which could serve as a useful tool for law enforcement in addressing this serious problem. While it is a promising technology, that seems to be growing in use (Koper et al., 2009), other than a study by Lum and colleagues (2010) there has not been much research on the effectiveness of LPR systems in addressing vehicle theft. Beyond basic descriptive/pilot research with LPR systems in the United Kingdom and United States, none of these or other auto related evaluations (other than Lum et al., 2011) applied randomized experimental designs or at least rigorous quasi-experimental methods. Our study was designed to advance the field of policing research through a large-scale randomized experiment in Mesa, AZ, grounded in a hot spot policing framework and the “journey-after-crime” literature. More broadly, our study also adds to the rather limited evaluation literature on technology and policing (see Koper et al., 2009).

The hypothesized benefits of the LPR system are expected to be realized by law enforcement because of the large number of plates that the system is supposed to be able scan. Therefore, the first test

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[34] Otherwise, the selection of a smaller displacement area around each zone would have been highly uncertain and arbitrary. For the Phase 1 hot route analysis, in contrast, the considerations were somewhat different; using the adjacent route indicator and looking at other small displacement/diffusion areas enabled us to look for displacement/diffusion in other surrounding micro areas.

we conducted was to see if this first premise was true. We compared LPR scanning to manual plate checking, controlling for the use of a special vehicle theft unit in both Phase 1 and Phase 2. We found that the LPR achieves its most basic purpose of increasing the number of plates scanned compared to manual plate checking in both phases, about 8 times more plates scanned with the LPR in Phase 1 and about 10 times more in Phase 2. The tests that followed examined whether the police could achieve a variety of benefits associated with this additional plate scanning.

Our Phase 1 results suggest that the routes with the LPR had more total “hits” for vehicle theft crimes (stealing of vehicles and/or plates) than the manual checked routes, more “hits” for stolen plates, more arrests for stolen cars, and more recoveries involving occupied stolen vehicles. In Phase 2, the zones with the LPR had statistically more total hits for stolen cars and license plates than the manual zones. While the LPR was associated with more arrests for stolen cars in Phase 1, no differences existed on arrests for stolen cars in Phase 2. As in Phase 1, the zones with the LPR in Phase 2 had significantly more recoveries for stolen vehicles compared to the manual zones. However, instead of the difference emerging for occupied stolen vehicles, the difference emerged for unoccupied stolen vehicles in Phase 2. Thus, by most of our measures the productivity of the vehicle theft unit was several times higher when using the LPR devices in both phases.[35,36]

Our next set of results explored whether the LPR was associated with reductions in vehicle theft crime, as measured by CFS and UCR crime reports. Also, for these tests, we were able to collect data for our additional control group of standard patrol. When examining the weeks of the interventions and a two-week period immediately after the interventions, we first observed only one bivariate statistically significant

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[35] It is also worth emphasizing that these analyses compare LPR use to the use of extensive manual license plate checks conducted by a specialized unit. In comparison to normal patrol operations (with sporadic license plate checks), the productivity gains from LPR use would almost certainly be greater.

[36] The small number of vehicles recovered during the experiment precluded us from doing a rigorous analysis of whether LPR use leads to faster recoveries of stolen vehicles. However, based on our small number of cases, we did not find indications that vehicles detected by LPR were recovered more quickly than other vehicles.

difference across the control, LPR and manual groups based on CFS or UCR crime reports (and only in Phase 1). That is, we observed that the LPR group had a slightly higher (but statistically significant) number of vehicle thefts (based on UCR data) in the two week period post intervention compared to the manual plate checking group or control group. To improve the precision of the treatment comparisons for our vehicle theft outcome measures, we examined these results through multivariate modeling. In our later multivariate models, where we control for pre-intervention levels of vehicle theft and other route characteristics, we no longer observe a difference between the LPR route and the control group on this measure in Phase 1. However, the manual group does emerge as having lower two-week post intervention vehicle theft levels (based on UCR data) than the control group in Phase 1. No treatment effects were observable in Phase 2 based on the UCR or the CFS data.

Also, using the Phase 1 data, the multivariate test of the randomly assigned treatment revealed a significant decline in CFS for vehicle theft in the two weeks after treatment in manually treated hot routes compared to the control group. Also, we found no vehicle theft crime displacement or diffusion of benefits from our targeted routes and zones to areas adjacent or near these locations related to any of our analyses in either Phase 1 or 2. Our results, at least based on Phase 1, suggest that a specialized vehicle theft unit can have an effect on reducing vehicle theft compared to the control group, but only when this group does manual checking of plates as opposed to using the LPR equipment. This would appear to be an illustration of "residual deterrence" associated with short-term "crackdowns" at hot spots (Sherman, 1990).[37] Why this occurred in the manual check routes but not in the LPR routes is not entirely clear, nor is it clear why this was not replicated in Phase 2. Based on our discussions with the officers in this specialized unit, we believe the vehicle theft unit possibly had a more visible presence when they were doing manual checking as opposed to when they were operating the LPR equipment. The vehicle theft unit spent more time

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[37] The lack of effect during the treatment period itself may suggest that it took several days of repeated treatment to change potential offenders' perceptions of risk at these locations.

roaming the streets and parking lots (both residential and commercial) of their respective routes—often at slow speeds and with frequent pauses—when they were doing manual checks. This was especially evident in Phase 1 when the study areas were smaller, but perhaps less the case in the Phase 2 zones (which might have been too large to create this same effect). When using the LPR in Phase 1, in contrast, they were more likely to make quick passes through side streets and parking lots and then remain at fixed positions. The additional roaming with manual checks may have created more of a preventative effect on vehicle theft by being more noticeable and unpredictable and by making it more obvious to onlookers that the officers were checking cars. The greater use of fixed surveillance points with the LPR equipment may have been less threatening to vehicle thieves because it was easier to avoid.

7.1. Limitations

Like other randomized control trials, our study has a number of strengths related to the strong counterfactual we created. We have good evidence that our random assignment process worked as planned (we detected no pre-treatment differences and experienced no misassignments connected with the random assignment process) and created comparable intervention/control conditions. We have a high degree of confidence in our ability to describe what would have happened to the treatment group if it had not been exposed to the treatment. However, the downside of our experimental assignment process was the creation of somewhat artificial conditions under which we asked the Mesa Police Department to operate. While the officers in our study carefully followed the assignment pattern dictated by the experiment, the resulting “hit” rate appears to have been constrained by the fact that the officers had to confine their efforts to pre-assigned places and times rather than target their operations based on current crime analysis and daily traffic patterns.[38] Despite their expressed strong dedication to the project, the officers did not seem to like being confined to our designated locations, particularly during the Phase I hot route operations. While our approach is not very different from other hot spot policing strategies used by the MPD and other agencies, the officers would have preferred to move more naturally through the city's high crime areas (e.g., work many more hot areas in a given shift and move away from hot areas that happen to be very slow on a given night).

After the Phase 1 study was completed, MPD wanted to assess how the same unit could perform on any given shift without the constraints of confining the officers to specific routes or zones on the shift. During an 8-day period (spread over 2 weeks) between Phase 1 and Phase 2, the unit conducted "freestyle" operations guided by recent auto theft and traffic patterns. During this time, the unit was able to recover 6 cars, or 0.75 per shift, based on using the LPR in any area throughout the whole city. The unit conducted another such freestyle operation for 6 weeks after Phase 2 and recovered 15 cars for 0.63 recoveries per shift. In contrast, the auto theft unit recovered a total of 14 vehicles when using the LPRs across Phases 1 and 2 combined. Considering that the unit used the LPRs half-time during the 48 weeks of Phases 1 and 2, this amounts to a recovery rate of approximately 0.15 per shift. This does not invalidate our findings, for all of the hot routes (LPR and manual) were similarly constrained; hence, our study provides valid estimates of the extent to which LPRs improved the officers' productivity. However, it does provide some evidence that more vehicle recoveries and other "hits" could potentially be achieved by law enforcement agencies not constrained by following research protocols (i.e., under normal operating conditions).

In this regard, Phase 2 of the experiment, which allowed officers to roam throughout larger hot zones, provided a test of the LPR equipment in a more typical operational context than did Phase 1, though

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[38] As we note below, results obtained with LPRs will also be affected by the volume of crime in a jurisdiction, the general difficulty of catching auto thieves in possession of stolen vehicles (e.g., due to delays in reporting of thefts), and the types of data fed into the LPR system.

still through the framework of a randomized experiment that required the officers to work the zones according to a predetermined schedule. However, it is worth noting that the productivity gains from using the LPRs were no greater in Phase 2 than in Phase 1. Consistent with research on hot spots policing more generally, this supports the merits of focusing LPRs on well defined micro places (in this case, high-risk road segments).

Another potential limitation of our study is the number of routes included in our research. Even in a city such as Mesa, AZ that has a fairly high vehicle theft rate (within the top 10 in the U.S.), we struggled to identify 117 hot routes for vehicle theft in Phase 1 and only 54 hot zones in Phase 2. While a sample size of 117 for Phase 1 is not a small study, especially in this context, it does provide some limitations in statistical power. For example, while this study had a sample size comparable to or larger than that of many prior "hot spot" experiments (Braga & Bond, 2008; Braga, Weisburd, Waring, Green-Mazerolle, Spelman, & Gajewski, 1999; Mazerolle, Price, & Roehl, 2000; Sherman & Weisburd, 1995; Weisburd & Green, 1995), it is not very large (especially Phase 2) compared to other experiments in criminal justice, which can have hundreds of cases (e.g., see Davis & Taylor, 1999, for a review of batterer treatment experiments). With only 117 or 54 cases and relatively low base rates, our statistical power was limited to finding medium (not small) effect sizes. In future research of this type, researchers may need to consider using multiple cities.

The intensity of our intervention was also fairly modest. In both Phase 1 and 2, each LPR and manual hot route received eight days of "treatment" for each route for one-hour per day for a total of eight hours of intervention. With the level of resources available for this project, a greater amount of intensity was not an option. However, it is possible that if the "treatment" dosage were higher that greater crime prevention effects might have been uncovered.

Another point worth considering is that we conducted our study (both Phase 1 and 2) during a 10-year low in vehicle theft in Mesa. In 1999 there were 2,851 vehicle thefts in Mesa, which increased for three successive years until reaching a high of 5,089 in 2002 and these numbers ended up dropping to 2,047 in year 2008 (the time frame of our study). While both the experimental and control routes were subject to the same general conditions that led to this drop in vehicle thefts and this does not impact the comparability of our groups (i.e., internal validity of our study), this may affect the generalizability of our findings. To date, there have been no explanations for this drop (e.g., demographic shift in population, waning of drug problem or introduction of new policing program). However, Mesa has had a general reduction in crime over recent years across most of their crime categories. At this point, it is an open question what results we would have seen during times of greater criminal activity. As pointed out to our team by an anonymous reviewer, the historically low auto theft rates might have also led to a plateau effect. That is, while LPR was associated with vastly more plate checking than the manual mode of checking, the identification and recovery rates for the LPR areas were only a few times greater which might have been due to the fact that the recovery rates were suppressed by the generally fewer number of auto thefts in Mesa.

Another issue is the relatively recent introduction of LPR equipment to policing. Over time, as law enforcement grows in its experience with the LPR, new strategies may emerge that will improve the "hit" rate of the LPR equipment. Also, this might also help with officer morale. Given the relatively infrequent level of "hits" associated with vehicle theft surveillance work, the officers can get bored or lose their focus.

Finally, there are still technological advances that are needed to make sure that the most current data on vehicle thefts are being sent to the LPR equipment. In addition to the traditional delays associated with vehicle theft reporting (e.g., victims may be unaware for many hours that their vehicle is missing and/or delay reporting their car stolen because they think someone may have legitimately borrowed the vehicle), there may be further delays in the entry of reports into the LPR system if it does not have wireless connectivity to receive reports in real-time (this was a limitation to the LPR system used in this study). The value of LPR will also be affected by the types and volume of data fed into the system (e.g., incorporation of warrants, inclusion of data from other jurisdictions, etc.). There are also other technological issues that still need to be resolved. For example, false positives can still be a problem (e.g., out of state plates that are similar to a plate stolen in another city), and misreads of dirty license plates or misreads from scanning plates across multiple lanes of traffic can present difficulties. There are also technical failures associated with the LPR equipment (e.g., due to extreme heat).

7.2. Policy Implications for Policing

Despite some of the issues outlined in our limitations section, we believe our results demonstrate that LPR technology holds a limited amount of promise for law enforcement. Some of the benefits include increasing the number of plates that the police can scan, increasing the number of "hits" for vehicle theft and "hits" for stolen plates, increasing the number of arrests for stolen cars, and increasing the number of recoveries involving occupied stolen vehicles. However, we did not find evidence that the LPR reduced actual vehicle theft rates for our targeted areas. Instead, we found that the same special vehicle theft unit conducting manual plate checks was able to reduce vehicle theft rates, but only in Phase 1. The fact that we did not lower vehicle theft rates with the use of the LPR equipment is in some ways not too surprising. First, our results are similar to Lum and colleagues' experimental study (2010) that recently demonstrated that LPR equipment was not associated with reductions in auto theft. Also, in our study the specialized vehicle theft unit operating the LPR equipment consisted of only four officers and a supervisor and each LPR route received only a modest "dosage" (8 hours, in the afternoon or evening, of intense surveillance by four officers over a two week period). Given that level of intensity (the Lum et al., 2010, study was also implemented at a modest intensity rate), and the newness of the LPR system (both in terms of officer familiarity with the technology and some technological limitations with the technology itself), we believe that the positive findings that did emerge (i.e., more plates scanned, "hits," arrests and recoveries) are notable, especially in a field where so little research-tested interventions exist. We now have evidence that at least one strategy, LPR use, can achieve some demonstrable benefits in addressing vehicle theft.

However, given the cost of each device (about $20,000) and our use of four LPRs that is an investment of nearly $80,000. Regardless of potential impact, cost alone is likely prohibitive in the current economic climate, where many police departments (especially in Arizona) are under such budgetary pressure that layoffs of personnel are being considered. And the other side of the cost question is return on investment. If a police chief asks, “what do I get in return for my $80,000 investment?;” the response from this study (based on Phase 1 data) is a hit rate of 24 hits divided by 457,368 plates scanned or a hit rate of .00005 (or in terms of hours: 45 LPR routes * 8 hours each= 360 hours and this produced 24 hits; or 1 hit every 15 hours of use of the device). This is even less compelling given the outcomes produced by the special unit manual condition (8 hits in Phase 1), and the evidence of a deterrent effect with this condition. It could be reasonable for a police chief to conclude that his or her agency might be able to achieve a reasonably high hit rate and greater deterrence of auto theft simply by re-assigning a small number of officers to the auto unit and increasing the rate of manual checking or perhaps by requiring patrol officers to do extensive manual checking in designated hot routes (thereby saving $80,000).

We also learned that another strategy, a specialized vehicle theft unit (even under modest dosage levels) can achieve actual reductions in vehicle theft, at least on smaller hot routes (as opposed to the Phase 2 hot zones). That is, in Phase 1 the specialized vehicle theft unit conducting manual plate checking (on as many plates as possible in a shift) was associated with lower vehicle theft compared to standard patrol that typically only conducts a limited amount of plate checking (and usually only when there is some evidence that warrants a check). Our work, at a minimum, demonstrates that focusing law enforcement resources on vehicle theft reduction at hot routes can potentially achieve quantifiable positive results. That is, broad based license plate checking, as opposed to the approach used by standard patrol of situational checking (e.g., a rear window of a car is down indicating a possible break-in), is associated with a number of benefits if done through LPR scanning (i.e., more plates scanned, “hits,” arrests and recoveries) or manual checking (lower vehicle theft rates).

The implications for future law enforcement applications is to figure out a strategy that maintains the documented benefits of LPR use by a specialized unit in both phases of our study (i.e., more plates scanned, “hits,” arrests [phase 1 only] and recoveries), but also achieves the benefits associated with manual checking by a specialized unit (i.e., lower vehicle theft rates) on smaller hot routes. More research will be needed to determine the best strategies to be used by officers operating the LPR equipment, including which elements present in the manual checking approach can and should be adopted by officers using the LPR. For example, by necessity officers doing manual checking need to use more roaming strategies (as opposed to fixed point scanning) to be able to view the license plates of fast moving cars. They also need to move slowly through parking lots and apartment complexes and make frequent stops to scan plates. This stands in contrast to the LPR approach used by the MPD in our study, and by other law enforcement agencies, which involves more fixed point scanning on roadways and quick sweeps through parking lots and apartment complexes. The fixed point scanning approach was adopted to maximize the number of plates scanned with the LPR equipment. However, by sacrificing some of the number of plates scanned with the LPR, in favor of more roaming surveillance and other strategies to increase the officers’ presence, perhaps more vehicle theft reduction may occur. One strategy to consider is to have less expensive non-sworn officers operate the LPR equipment and have sworn officers do the more intensive and more visible manual plate checking, which seems to reduce vehicle thefts. Under this scenario, when non-sworn officers get a “hit” for stolen vehicles they could then call it in to nearby patrol officers. Another possibility is that sworn officers using LPRs could adopt some of the methods used for manual check strategies—i.e., more slow roaming through parking lots, apartment complexes and side streets and fixed surveillance at prominent intersections where it is easier to view plates and be seen. These adjustments might both improve scans and generate greater deterrent effects.

As pointed out to our team by an anonymous reviewer, another issue law enforcement will have to attend to are adaptations made by auto thieves in response to their awareness of the existence of LPR equipment. Auto thieves may well develop strategies to counter LPR technology, for example using decoys with stolen plates (a lesser offense) to tie up law enforcement while other confederate thieves steal more expensive vehicles.

7.3. Implications for Future Research

There are some important next steps for researchers and funding agencies. First, our research demonstrates the ability of researchers to implement randomized experiments with law enforcement technology. Aside from being one of two randomized experiments with LPR equipment (the other being Lum et al., 2010), this is one of the few randomized experiments with any law enforcement technology. Our use of a randomized experiment led to rigorous results and was implemented with little disruption to police operations. Especially in the case of a scarce resource (we only had four LPRs for the whole city of Mesa and could not use the technology across the entire city at once), the random assignment element of the experiment can be justified to law enforcement and city officials. That is, large portions of the city are not going to receive the benefits of the technology with or without the experiment. In this case, the experiment simply allocates the resource in a way that all portions of the city in need of the technology have an equal chance of receiving it.

Second, additional replication research is needed. Our study was only of one city. While Mesa, AZ is a relatively large city, among the top 50 in the nation, evaluations should also be undertaken in the very largest urban centers of the U.S. and also in some of very small jurisdictions to confirm our findings in different contexts. Combined with the Lum and colleagues study (2010) (which was implemented in smaller urban communities, Alexandria, VA and Fairfax, VA, outside of Washington, DC), the mid-level cities are fairly well covered with LPR research data. Also, the Mesa, Alexandria and Fairfax police departments are widely considered to be very progressive and innovative agencies. It is not clear how well other agencies not possessing those characteristics would do with the LPR equipment.

Third, additional testing and research should also be undertaken on other methods of deploying LPRs. For example, the LPR equipment could be mounted to a standard patrol car or fixed to a toll booth or city lighting pole. Future researchers should consider studying different methods of deploying LPRs (e.g., comparing fixed vs. mobile LPR). As pointed out by an anonymous reviewer, target selection might also be a worthwhile variable to study, including whether LPRs are most effective when used in traffic, scanning plates of other vehicles in the flow of traffic, or is trolling parking lots and street side parking more effective? While these strategies may not lead to reductions in vehicle theft, they may yield other benefits associated with the LPR equipment. Future work should also extend to assessing the benefits of LPR use beyond recoveries of stolen cars, apprehension of vehicle thieves, and the reduction of vehicle theft. While technology limitations restricted our study to assessing only vehicle theft-related crime, other jurisdictions have the capability to use the LPR equipment to aid in apprehending fugitives, probation and parole violators, and those not paying court fines. These can be potentially important additional benefits associated with the LPR equipment that also need to be tested.

Fourth, more research is needed to understand the why the “hit” rates in our study were so low. Was it solely because of the low dosage (8 days of intervention for one-hour each day by four officers)? Or perhaps there are limitations to the use of LPR with vehicle theft due to the natural delays in reporting vehicle theft to the police. Combining these factors with detection avoidance efforts by thieves (e.g., switching license plates) may suggest that there is a very small window of effectiveness for LPR. Future researchers should consider whether the future deployment of LPRs should be publicized more through a media campaign. If potential vehicle thieves were made aware of the technology and its deployment, perhaps a deterrent effect could be generated.

Fifth, as pointed out by an anonymous reviewer, future research should explore the possibility that the pool of stolen plates and vehicles decreases with time, as the efficiency of recoveries increases. Also, the next line of research will need to assess whether most of those recoveries using the LPR would inevitably occur anyway, without the use of LPR. If LPR only increases the speed with which stolen vehicles are recovered, rather than the volume, the benefit would be reduced.

Finally, over time we might also expect the cost of this technology to lower substantially from the current pricing scheme (in the $20,000 to $25,000 range) and lead to greater adoption of this technology by law enforcement. However, with the greater adoption is also likely to include greater legal scrutiny of the privacy rights of citizens associated with this equipment or charges of the invasion of “big brother.” As with any law enforcement equipment or strategy, the law enforcement community should look for careful empirical research to help provide guidance and insights into the effective and ethical use of this and other technology.[39]

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[39] Lum et al. (2010), for example, surveyed community residents about LPR use and found that attitudes vary depending on the ways in which the data are used.

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