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Using GIS to interpret automated speed enforcement guidelines and guide deployment decisions in mobile photo enforcement programs

Yang Li[1], Amy Kim*[1], Karim El-Basyouny[1], Ran Li[2]

[1] Department of Civil and Environmental Engineering, University of Alberta
[2] Office of Traffic Safety, City of Edmonton

* Corresponding author. Address: 6-269 Donadeo Innovation Centre for Engineering, University of Alberta, Edmonton, AB, T6H 1G9, Canada. Tel.: +17804929203.

E-mail addresses: li18@ualberta.ca (Y. Li), amy.kim@ualberta.ca (A. Kim), karim.el-basyouny@ualberta.ca (K. El-Basyouny), ran.li@edmonton.ca (R. Li)

ABSTRACT

Automated speed enforcement (ASE) guidelines are designed to guide enforcement agencies in operating ASE programs that are effective in improving traffic safety. Given that appropriate deployment decisions are essential to a program's effectiveness, a number of deployment priorities are generally included in most ASE guidelines. However, when implementing the guidelines, most descriptions of deployment goals are so qualitative that they might have multiple quantitative interpretations, and thus affecting the identification of specific deployment considerations. In addition, limited research has been done to improve the process by which guidelines are implemented. Therefore, this paper proposes quantitative measures for an ASE program, in order to facilitate interpretation of the main ASE principles and improve deployment decisions. To illustrate the various types of high-priority deployment considerations, a case study in the city of Edmonton in the province of Alberta, Canada is presented. It explores the deployment outcomes of the mobile photo enforcement (MPE) program in Edmonton, in relation to six priorities identified in the provincial enforcement guidelines. Two performance measures, spatial coverage and enforcement intensity, are assessed for priority sites and non-priority sites. Moreover, the distance halo effects of MPE are considered in the review of spatial coverage. All findings are visualized using Geographic Information Systems, such that high priority sites and coverage of these sites in the historical deployment can be visually assessed. A better understanding of the governing ASE guidelines and how to implement them can help enforcement agencies to improve decision-making and resource allocation, thereby increasing program effectiveness and efficiency.

Keywords Automated speed enforcement (ASE) guidelines, Quantitative measures, Mobile photo enforcement (MPE) program, Resource allocation, Geographic Information System (GIS)

1. INTRODUCTION

Speeding undermines road traffic safety around the world. Each year, more than one million people die in traffic collisions worldwide(WHO, 2006; WHO, 2008; WHO, 2013); 30% of these fatalities are due to speeding (OECD/ECMT, 2006). In order to protect citizens against the risks of collisions caused by speeding, the implementation of speed management programs has become a high priority for many governments around the world. Automated speed enforcement (ASE) is one countermeasure that has been widely adopted throughout the world to manage speeding. Automated speed camera systems are used to assist police in enforcing speed limits. Specifically, the speed camera is mounted on the roadside or in an enforcement patrol vehicle to detect vehicle speeds and photograph vehicles violating speed limits. This technology has been shown to significantly improve traffic safety. According to a review of studies from the late 1990s and early 2000s, adopting an ASE program may lead to a 2-15% speed reduction and 9-50% decline in collisions(Rodier, Shaheen, & Cavanagh, 2007).

In some jurisdictions, the design and operation of ASE programs are governed by specific rules, which are set out in official guidelines. ASE program guidelines outline basic principles for how ASE programs should operate, providing a tool to assist local enforcement agencies in developing a successful ASE program with positive safety outcomes. ASE guidelines emphasize controlling the deployment of enforcement cameras, in order to ensure deployment at the right locations, thus improving the program's effectiveness in improving safety. However, when implementing guidelines, most descriptions of deployment goals are too qualitative to interpret, impacting the successful identification of specific deployment considerations. Guidelines provide general descriptions of where ASE should be deployed to achieve objectives of reducing speed and collisions, but they do not specifically define how site identification and ASE deployment should be conducted. Local enforcement agencies must rely only on their own interpretations during the design and implementation phase. Consequently, the potential benefits of using the guidelines are not entirely realized.

Research tackling this inadequacy of ASE guidelines is very limited. Therefore, this paper proposes quantitative measures based on the main guiding principles of ASE to facilitate interpretation of the guidelines and deployment decisions that well reflect these guiding principles. In order to illustrate the outcomes of adopting quantitative measurements, a case study of the mobile photo enforcement (MPE) program in the city of Edmonton (COE), in the province of Alberta, Canada, is presented. MPE is a subset of ASE technology, and therefore should adhere to ASE program guidelines. In particular, the case study explores the relationship between ASE principles and the interpretation and application of guidelines by a local enforcement agency. The results are visualized using Geographic Information System (GIS) plots, through which this paper provides insight into the geographic distribution of enforcement throughout the city, in terms of where enforcement should take place and where it is actually conducted. Two MPE program indicators – spatial coverage and intensity – are used to investigate the interpretation and application of the provincial ASE guidelines. Given that MPE activities have distance halo effects, which are safety effects that extend upstream and downstream of the camera site(Vaa, 1997), this paper also considers these effects. Coverage of the MPE program is also considered using a measure of the distance halo effect. The results of this paper can help enforcement agencies gain greater clarity on how to improve program performance with the help of ASE guidelines, in order to achieve increased efficiency and effectiveness.

2. MAIN GUIDING PRINCIPLES OF THE ASE PROGRAM

A number of ASE guidelines were published by local, provincial or national governments in the U.S., Canada, Australia and the U.K. during the early 2000s. All of these guidelines have similar principles that primarily focus on outlining an efficient way to deploy enforcement cameras. They recognize that making good decisions regarding ASE deployment during program design and operation is essential to a program's effectiveness(NHTSA, 2008; Victoria Police Traffic Camera Office, 2006). Specifically, six considerations for enforcement attention are most commonly addressed in deployment guidelines; these include 1) high collision sites; 2) high speed violation sites; 3) school zones; 4) construction zones; 5) high pedestrian volume sites; and 6) sites with community speeding complaints. Local enforcement agencies should identify and prioritize these sites accordingly, in order to efficiently manage their resources and safety outcomes.

2.1 High Collision Sites

Traffic collisions are responsible for over 1.2 million fatalities and 20 million injuries every year worldwide(WHO, 2006). 90 people are killed on U.S. roads and five on Canadian roads nearly every day(NHTSA, 2015; Transport Canada, 2015).

However, these figures are decreasing gradually with government interventions(NHTSA, 2015; Transport Canada, 2015). Automated speed enforcement (ASE) programs are one type of intervention shown to significantly reduce the frequency and severity of collisions. Previous studies indicate that ASE reduced collisions by 8.9% to 51%, and collision-related injuries and fatalities by 12% to 50%(Coleman & Paniati, 1995; Elvik, 1997; Berkuti & Osburn, 1998; Chen, Wilson, Meckle, & Cooper, 2000; Christie, Lyons, Dunstan, & Jones, 2003; Hess, 2004; Goldenbeld & Schagen, 2005; OECD/ECMT, 2006). Given that the primary objective of ASE programs is to reduce traffic collisions and in turn improve traffic safety, prioritizing high collision and collision risk sites for ASE attention in ASE guidelines is critical.

Although all ASE guidelines indicate the need for deploying enforcement cameras to high collision sites, the level of detail provided on how to identify these sites vary among different jurisdictions. Guidelines from the Province of Alberta (Canada) and the State of Victoria (Australia) identify high collision sites as a major deployment focus (Alberta Justice and Solicitor General, 2014; Victoria Police Traffic Camera Office, 2006), but present little further detail. In contrast, the U.S. Department of Transportation, the State of Queensland in Australia and the County of Humberside in the U.K. propose criteria for evaluating high collision sites in their guidelines. Four key elements – collision frequency, collision severity, exposure measure of collision risks and data analysis period – are most commonly included in the evaluation procedures(NHTSA, 2008; Queensland Government, 2014; Humberside Police, 2008). One high collision site identification criteria proposed is the equivalent-property-damage-only (EPDO) collision frequency per kilometer (km) over three years(Humberside Police, 2008). The EPDO method converts all collisions, including fatalities, injuries and property damage only, into property damage only collisions by assigning weighting factors to different collision severities(AASHTO, 2010). Therefore, it can effectively combine both the collision frequencies and collision severities into one factor that assigns higher weights to collisions with higher severity. In addition, the road length is employed as an exposure measure in relation to EPDO collision frequency by the County of Humberside(Humberside Police, 2008), in order to measure and compare the risk of collisions to the exposed population over a certain distance traveled(ETSC, 1999). Road length data can be collected relatively easily since a large number of cities has a well-maintained database.

2.2 High Speed Violation Sites

Although the ASE program's ultimate goal is to reduce traffic collisions, the mechanism through which this goal is achieved is the reduction of speeding vehicles. Speeding has been recognized as the leading cause of collisions, as it increases the likelihood and severity of collisions (OECD/ECMT, 2006). ASE programs are able to achieve significant deterrent effects in reducing speeding. An ASE program has been shown to reduce the total number of speeding vehicles by 15% to 88%(Lamm & Kloeckner, 1984; Coleman & Paniati, 1995; Davis, 2001; Retting & Farmer, 2002; Cities of Beaverton and Portland, Oregon, 1997).

As the allocation of ASE to high speed violation sites plays a key role in addressing traffic safety concerns, nearly all guidelines stipulate that higher priority be placed on high speed violation sites. However, most guidelines' treatment of high speed violation sites is similar to that of high collision sites; although the importance of deploying cameras to these sites is identified, information on how to identify high speed violation sites is limited. For instance, the Province of Alberta and the State of Queensland discuss the criticality of enforcing these sites, but do not provide further information on how to identify and assign enforcement resources to these sites(Alberta Justice and Solicitor General, 2014; Queensland Police, 2015). The State of Victoria uses reports of speeding problems from governments, authorities and police officers to identify high speed violation sites(Victoria Police Traffic Camera Office, 2006). However, these reports are subjective and difficult to verify or quantify, and the guidelines do not demonstrate how to go from a report to a clearly identified problem location.

In contrast, the U.S. Department of Transportation and the County of Humberside propose using data on travel speeds or the percentage of vehicles violating the speed limit to screen high speed violation sites. The U.S. guidelines highlight several data to be used for identifying high speed violation sites, including average speed, 85^{th} percentile of speed, speed range and dispersion, percentage of speeding vehicles and number of citations (NHTSA, 2008). The County of Humberside guidelines use the 85^{th} percentile of free flow speed to identify high speed violation sites(Humberside Police, 2008).

2.3 School Zones

Children are the most vulnerable road users and require the greatest protection. About one third of child deaths worldwide were caused by traffic collisions(WHO, 2008), and children of school age (from 5 to 19 years of age) are the main victims of road collisions(Warsh, Rothman, Slater, Steverango, & Howard, 2009). Furthermore, they are more likely to be struck by a vehicle when walking to school, especially within 300 meters of the school(Warsh, Rothman, Slater, Steverango, & Howard, 2009).

Hence, ASE initiatives for school zones have been included in many jurisdictions' ASE program guidelines. For instance, the Province of Alberta, the U.S. Department of Transportation and the State of Victoria all address school zones as priorities for deployment. In addition, conducting ASE at school zones acts as a demonstration to the public of law enforcement attention, which promotes overall public buy-in for a program(NHTSA, 2008). Again, however, no guidelines provide details on identifying school zones for enforcement. Because the number of collisions involving school children decreases as the distance from the school increases(Warsh, Rothman, Slater, Steverango, & Howard, 2009), there is a need to identify specific regions around schools where children are at significant vehicle collision risk.

2.4 Construction Zones

Workers in construction zones are exposed to the risks of injuries and fatalities from passing vehicles. According to the Federal Highway Administration (FHWA), 1.6% of total road collisions in the U.S. in 2010 occurred at construction zones. More than 2,000 U.S. workers were hit in construction zones every year from 2003 to 2008(FHWA, 2015). In these collisions, speeding is the primary risk to the safety of construction workers on the road, accounting for 31% of work zone fatalities in 2008 in the U.S.(FHWA, 2015). Therefore, speed enforcement cameras are needed at construction zones to protect workers in construction zones. In addition, enforcement at construction zones is also an effective method of promoting ASE programs to the public(NHTSA, 2008). ASE attention at construction zones is addressed in the guidelines of the U.S. Department of Transportation, the Province of Alberta, the State of Victoria and the State of Queensland. However, these guidelines only mention this enforcement priority, and lack detailed instructions on how to deploy enforcement resources. The State of Victoria provides one identification instruction, calling for an assessment of construction locations, construction time periods and the traffic at construction zones to inform deployment decisions(Victoria Police Traffic Camera Office, 2006). However, the guidelines are still difficult to implement based on the rather general information provided.

2.5 High Pedestrian Volume Sites

In addition to school children and construction workers, other pedestrians also need protection from speeding vehicles. According to the National Highway Traffic Safety Administration (NHTSA), in 2003 about 12 pedestrians died and 180 pedestrians were injured each day on roads in the U.S.(NHTSA, 2013). Moreover, in a collision, the vehicle's speed determines the pedestrian's likelihood of survival. A pedestrian has a 20% chance of surviving when hit by a vehicle traveling at 50km/h; however, the likelihood of survival increases to 90% if the vehicle speed decreases to 30km/h (Interdisciplinary Working Group for Accident Mechanics, 1986; Waiz, Hoefliger, & Fehlmann, 1983; OECD/ECMT, 2006). Urban areas often have high pedestrian volumes, and subsequently, a high number of pedestrian collisions. For instance, in the city of Edmonton (COE), districts with shopping, restaurants, and nightlife historically have experienced high numbers of pedestrian collisions(Office of Traffic Safety, 2013). The Province of Alberta guidelines require local enforcement agencies to identify high pedestrian volume sites and prioritize enforcement efforts for those sites (Alberta Justice and Solicitor General, 2014). However, the guidelines do not provide quantitative measurements for identifying high pedestrian volume sites. In addition, pedestrian volume is expensive and almost impossible to collect citywide.

2.6 Sites with Community Speeding Complaints

Complaints about speeding in residential areas are one of the most common citizen complaints to police(Scott, 2003; Weisel, 2004). Although fewer crashes occur on local roads than on arterial and collector roads, assigning ASE priority to a residential area can mitigate community concerns, and is yet another way by which an ASE program's profile can be raised to gain citizen support for enforcement programs. The guidelines from the Province of Alberta, the State of Victoria, the State of Queensland and the U.S. dictate that enforcement efforts should address community complaints. But, similarly, these guidelines only mention dedicating enforcement attention to sites with community complaints about speeding, without further describing how to evaluate these sites.

2.7 Summary

Many ASE guidelines identify six key priorities for ASE programs. These include enforcement resource attention to roadways exhibiting high numbers of collisions and speed violations, roadways in school zones, construction zones, and high-pedestrian areas, and those with community speeding complaints. However, a large majority of guidelines provide only qualitative guidance on identifying the sites. This leads to difficulties when conducting data analysis for measuring and comparing sites for enforcement attention. When local enforcement agencies make decisions on deploying cameras, precise instruction on how enforcement resources should be allocated to different sites is unclear. Therefore, translation of these qualitative descriptions to precise quantitative measures can help agencies identify specific deployment priorities, and improve deployment decisions.

3. QUANTITATIVE INTERPRETATION OF ASE GUIDELINES AND GIS VISUALIZATION OF GUIDELINE APPLICATIONS

In this section, quantitative measures are proposed and used to identify each of the six deployment priorities described in Section 2, for the road network of the city of Edmonton (COE). Then, each criteria is visualized on a GIS map of the city. The COE has a mobile photo enforcement (MPE) program that involves dispatching mounted photo radar cameras in unmarked/marked patrol vehicles to sites, to photograph the license plates of those that violate speed limits by a predetermined threshold. The operation of MPE in the COE must adhere to the ASE guidelines released by the Province of Alberta, which dictate the deployment goals for the six deployment priorities. To illustrate the interpretation and application of the Alberta ASE guidelines by the COE enforcement agency, the deployment information of the MPE program, including spatial coverage and intensity, is visually presented for each deployment priority.

Five years of citywide geocoded data, from January 2010 to December 2014, have been gathered and assessed for this case study. These data serve two purposes. The first is to identify the six deployment priorities, using data from traffic collisions statistics, travel speed surveys, schools, construction projects, neighborhoods and road networks. The second is to investigate the operation of the MPE program using data from the deployment sites and enforcement time.

Because a much higher number of collisions occurs on arterial roads and collector roads than on local roads, and collisions are the primary motivation for enforcement, this paper focuses on identifying arterial and collector roads exhibiting need for enforcement attention according to the priorities discussed. Local roads are considered only in regards to community complaints on residential roads. The arterial and collector road network in the COE is segmented into 2,691 sites, with each site representing a segment for enforcement. Specifically, an arterial site refers to an arterial road segment between two adjacent signalized intersections. Whereas, a collector site is determined to be a collector road segment that intersects any arterial or collector roads. On the other hand, when considering local sites with community complaints, the potential local sites are aggregated on the neighborhood level. As a result, 388 neighborhoods were identified after aggregation. Grouping the data from local sites by neighborhood allows this paper to investigate the implications of enforcement on each community.

3.1 High Collision Sites

Although the Alberta guidelines for ASE address enforcement goals for high collision sites, they provide limited instructions on how to identify these sites. Based on the review of ASE guidelines in identifying high collision sites in other jurisdictions, this paper attempts to do so by assessing four characteristics: collision frequency, severity, exposure measure of collision risks and the data analysis period. In particular, this paper employs the EPDO frequency of collisions to account for both frequency and severity, using COE data on collisions resulting in fatality, injury and property damage over 2000 CAD. Moreover, the length of the road segment is used to evaluate the exposure to the risk of collisions, given that this information is available in the COE database. The final measure for evaluating high collision sites is EPDO per kilometer (km) traveled on a road segment over five years.

In the COE, the total number of speed-related midblock collisions from January 2010 to December 2014 is 29,573, consisting of 40 fatal collisions, 2,881 injury collisions and 26,652 property-damage-only collisions. All these collisions are converted into corresponding EPDO frequencies, based on the report released by the Capital Region of Alberta in 2010, which specifies that the direct cost of one fatal collision is equivalent to that of 16.6 PDO collisions and the direct cost of one injury collision is equivalent to that of 3.6 PDO collisions (de Leur, Thue, & Ladd, 2010).

Figure 1 identifies the ranking of high collision sites within the top 10% of EPDO collisions per kilometer (km) over the five-year study period, and shows them marked in red. The average EPDO/km of all road segments is 13.8, but surges to 53.1 EPDO/km in this figure due to the narrowing of the scope to high collision sites only. The density map of high collision sites highlights areas in greatest need of enforcement. As shown in Figure 1, high collision sites are clustered in the central neighborhoods of the COE, on two major freeways (Yellowhead Trail and Whitemud Drive), as well as some northern, western and southeastern neighborhoods.

When the geographic allocation of MPE for the five-year study period is plotted, it is observed that 1,087 MPE sites are widely dispersed throughout the COE's major urban road network. The MPE sites are represented as circles in Figure 1, and the intensity of MPE at each site is represented by the size of the circles. The larger the circle, the longer the enforcement time spent at that site during the five-year period. As seen from Figure 1, 85 MPE sites (marked in green) cover high collision sites, and the other 1,002 MPE sites (marked in black) do not precisely overlap with high collision sites.

MPE Program Coverage on High Collision Sites

	High Collision	Others	Total
Number of Sites	269	2,422	2,691
Number of Sites Covered by MPE	47	529	576
5-year Average Deployment Hours Per Site	305.1	314.3	313.5

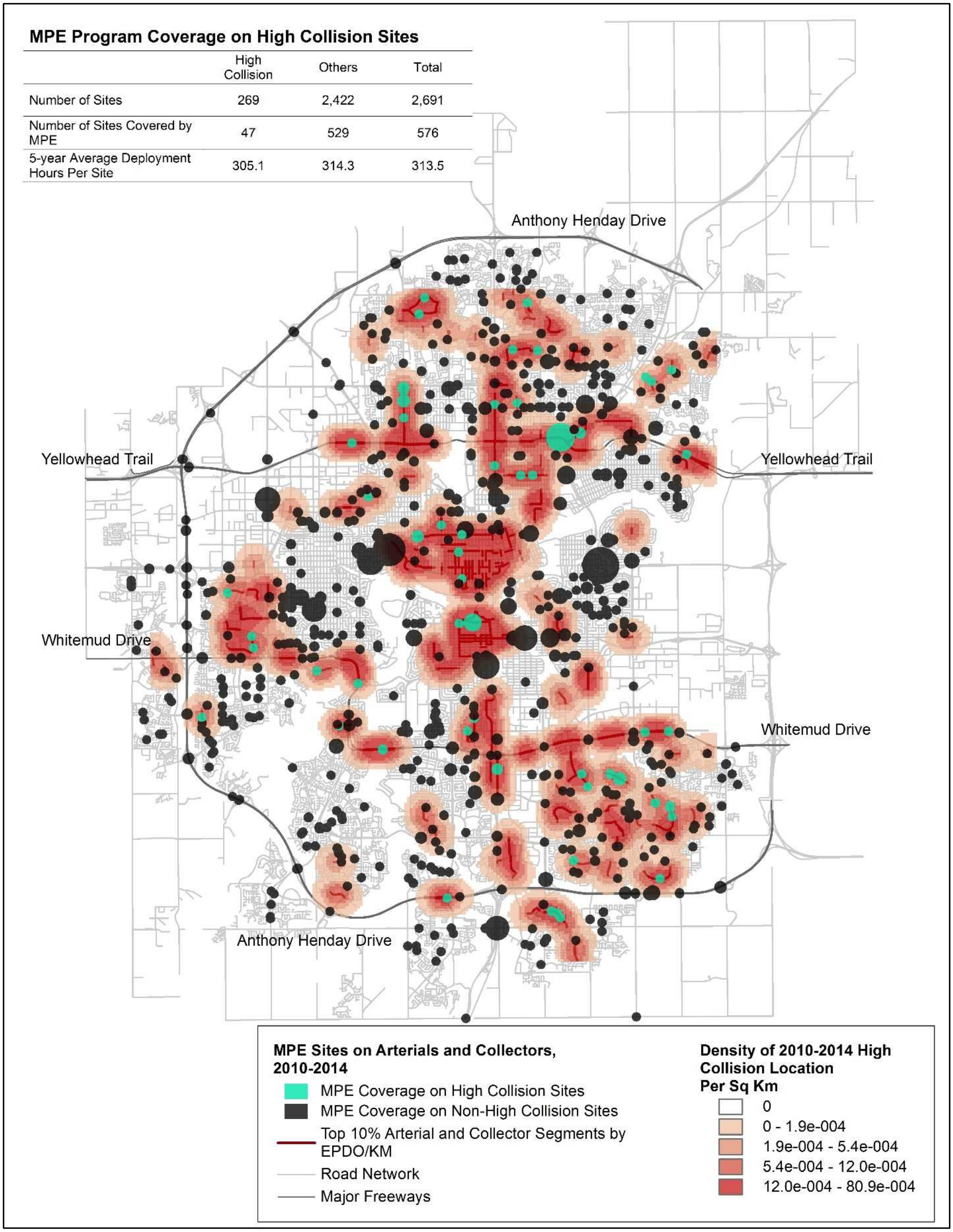


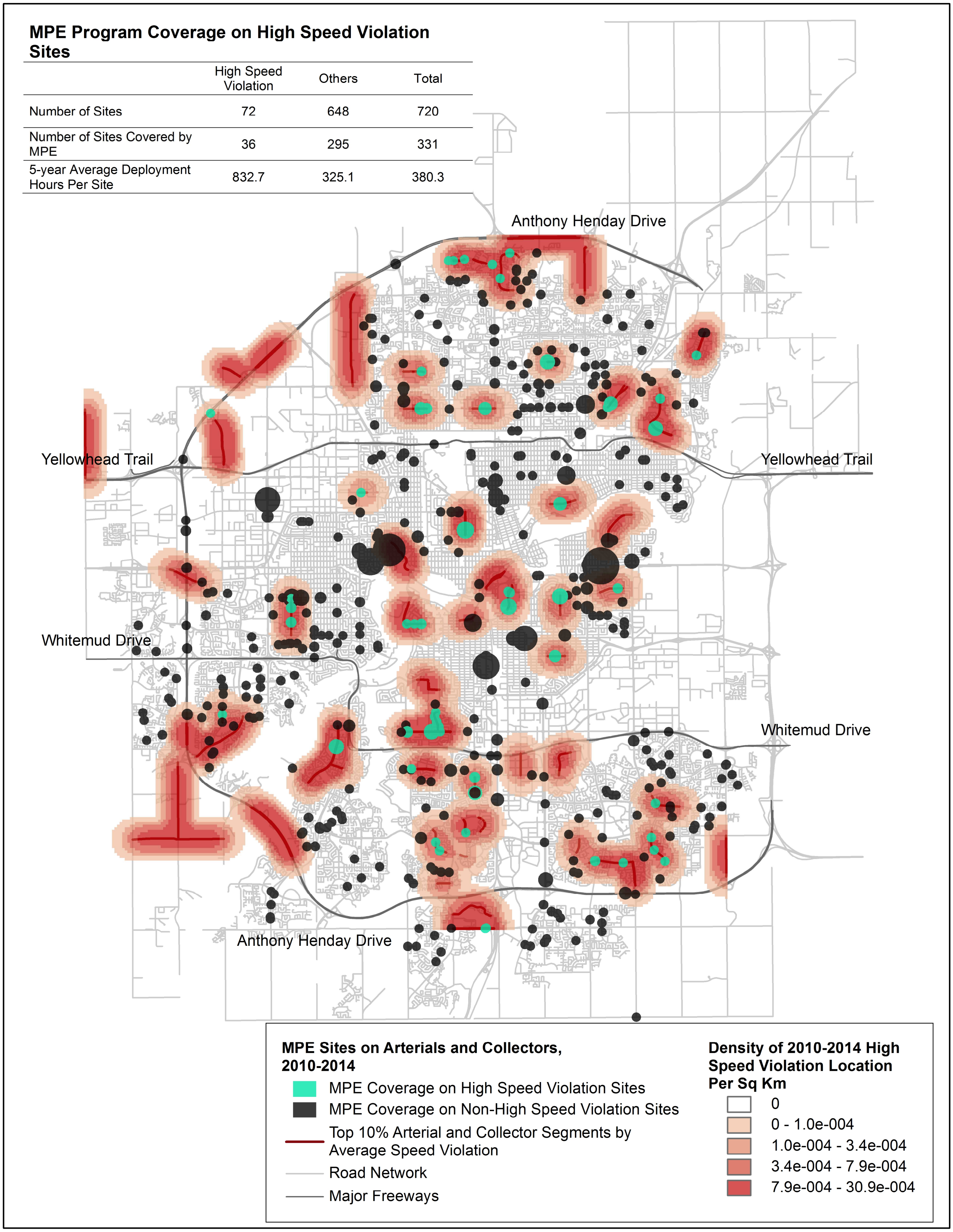
Figure 1 2010-2014 MPE program coverage on high collision sites.

According to Figure 1, 47 of 269 high collision sites were covered by the MPE program, which indicates about 17.5% citywide spatial coverage. The five-year MPE program invested about 305 hours at each high collision site, which indicates that each site was enforced for more than five hours every month. This indicates that the COE enforcement agency took into account high collision sites when making deployment decisions. However, it was observed that the MPE program spent an average of 314.3 hours at sites not identified as high collision sites over the five-year period – about nine hours more than the average time spent at high collision sites. This demonstrates that there were other considerations (such as the other five priorities discussed) for MPE deployment in the COE that resulted in greater enforcement intensity at these sites.

3.2 High Speed Violation Sites

According to the Alberta guidelines, enforcement should be conducted at locations with high speed violation rates. This paper identifies high speed violation sites by the percentage of vehicles that exceed the speed limit. More specifically, the top 10% of sites with the highest average percentage of vehicles violating speed limits during the five-year study period is employed as the threshold for screening high speed violation sites.

Speed surveys in the COE were conducted on 720 out of 2,691 sites, from January 2010 to December 2014. Therefore, as shown in Figure 2, 72 high speed violation sites have been identified and marked in red. As with high collision sites, a density map is also used to illustrate how the high speed violation sites are clustered throughout the city. Figure 2 shows that the high speed violation sites are located mainly on the city's ring road (Anthony Henday Drive), as well as the central, northeastern and southern portions of the city. According to the five-year speed surveys, approximately 45.6% of surveyed vehicles on the total 720 sites exceeded the speed limit. This high value could be due to a selection bias – speed detectors tend to be placed on roadways that are known to have a high number of speed violations. The average percentage of speeding vehicles surges to 81.9% on the 72 identified high speed violation sites which is almost double that of all 720 sites.



MPE Program Coverage on High Speed Violation Sites

	High Speed Violation	Others	Total
Number of Sites	72	648	720
Number of Sites Covered by MPE	36	295	331
5-year Average Deployment Hours Per Site	832.7	325.1	380.3

Figure 2 2010-2014 MPE program coverage on high speed violation sites.

After overlapping the MPE deployment information with the high speed violation sites, only 720 of 1,087 MPE sites are selected for investigation because the other MPE sites do not have speed survey data. Figure 2 shows that about half of the high speed violation sites are covered by 97 of the 720 selected MPE sites during the five-year study period. The average deployment time at each high speed violation site is 832.7 hours, which is more than 2.5 times that of other sites. Furthermore, the average number of deployment hours spent on high speed violation sites is 2.7 times higher than that spent on high collision sites.

Despite the limited scope of the data, it can be seen that the resources of the five-year MPE program, in terms of the spatial and time coverage, were more invested in locations with speeding problems than those with collision problems. The green circles of Figure 2 show how the amount of time spent on high speed violation sites is evenly spread geographically. However, the green circles of Figure 1 indicate that MPE deployment is concentrated along specific corridors and areas with high collision rates – along Yellowhead Trail and central areas.

3.3 School Zones

The locations of primary schools, middle schools and high schools and the size of each school zone in the COE are the basis for assessing their enforcement priority. Given that data on the individual size of each school zone were not available for this case study, this paper demarcates a circular area around each school as an enforcement measure. The risk of collisions involving school children is significantly higher within 150 meters of the school building, but then decreases substantially beyond distances of 300 meters(Warsh, Rothman, Slater, Steverango, & Howard, 2009). This paper chooses a 250-meter school zone radius for enforcement, which accounts for the school property size as well as the traffic areas beyond school boundaries with different road designs and speed limits(Alberta Ministry of Transportation, 2007).

Figure 3 presents the spatial distribution of 296 schools in the COE, which includes primary schools, middle schools and high schools. As seen from Figure 3, school zones received much enforcement attention during the five-years assessed, with 84% of school zones covered by MPE. Of the 1,087 MPE sites, 508 overlap with school zones. The average number of deployment hours spent on school zones is about 300 hours per zone over the five-year study period, which is of similar average intensity to that of high collision sites. This result indicates that deployment at school zones has been a focus of the COE MPE program.

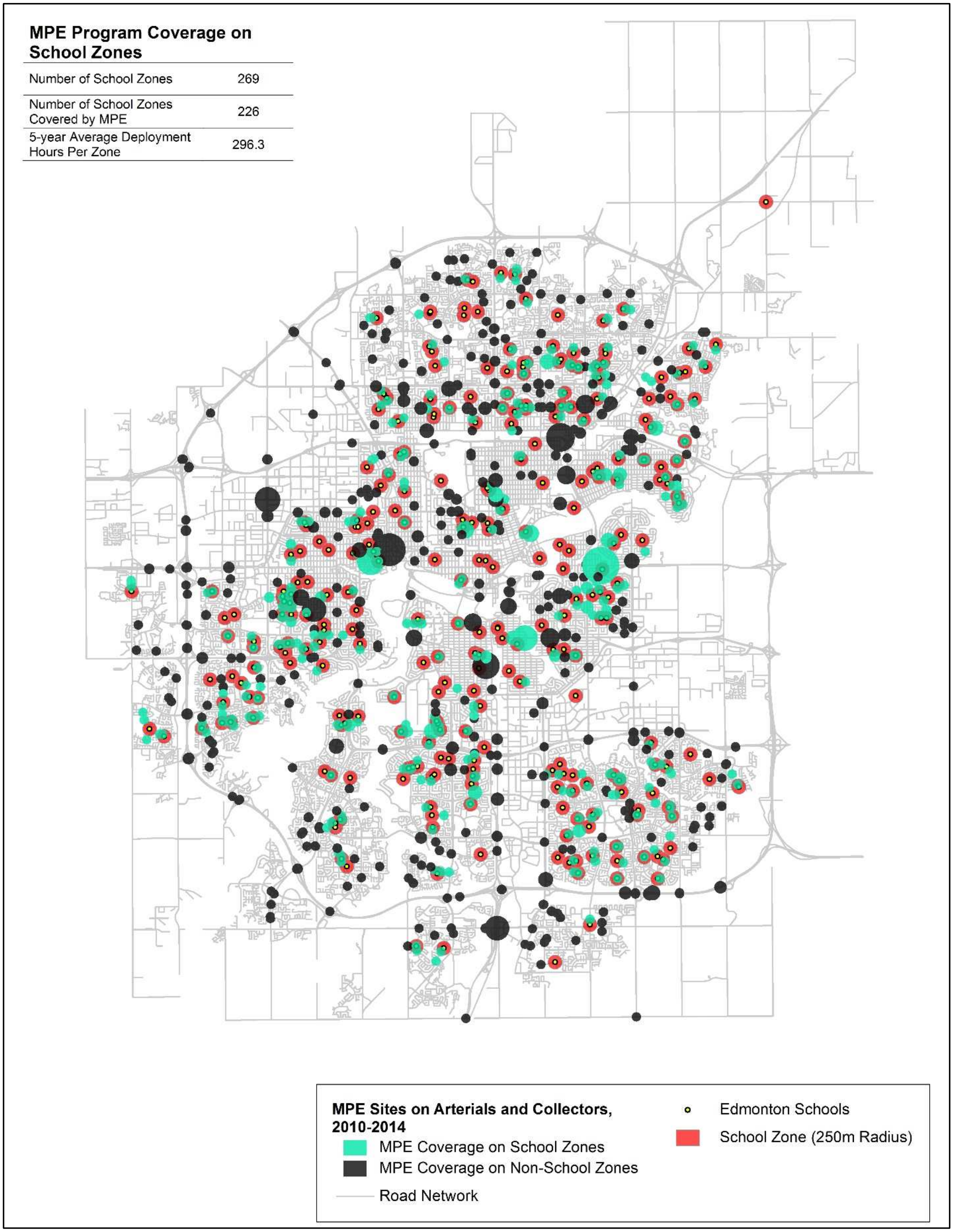
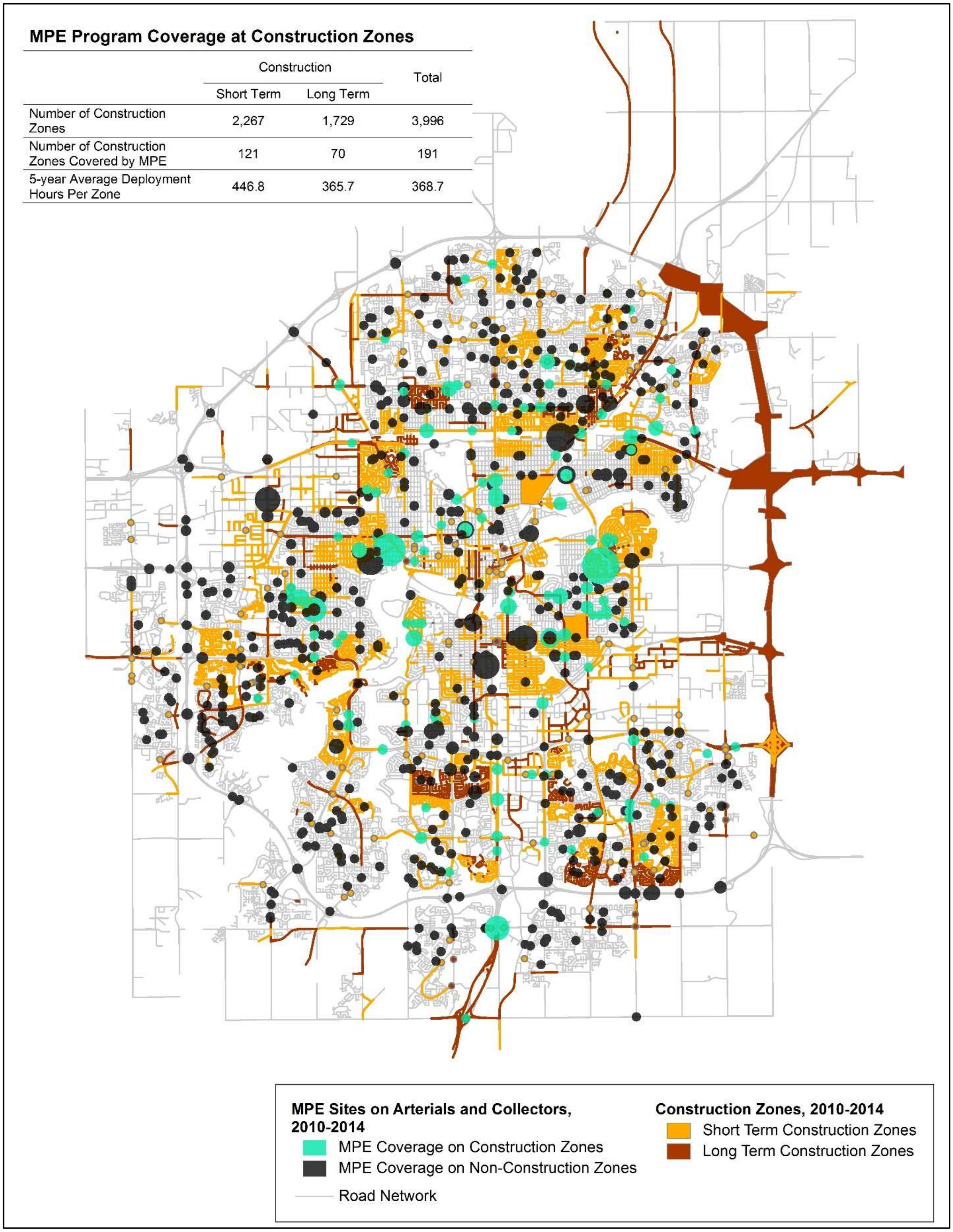


Figure 3 2010-2014 MPE program coverage on school zones.

3.4 Construction Zones

A total of 3,996 construction projects were carried out from 2010 to 2014 in the COE. The lengths of these construction projects ranged from a few hours to several years. Therefore, deployment priorities should be based on the length of construction projects, as longer construction projects are expected to experience more collisions. As a result, this paper has categorized construction projects into long-term projects (duration of one year or longer) and short-term projects (less than a year), and overlapped MPE information with that of construction zones to see what zones were enforced during the five-year study period.

Figure 4 illustrates 2,267 short-term projects, highlighted in yellow, and 1,729 long-term projects, marked in brown. Of these, 121 short-term projects and 70 long-term projects are covered by the five-year MPE program. The percentage of construction projects covered is only about 5%. Accordingly, 138 MPE sites and 69 MPE sites precisely cover short-term projects and long-term projects respectively. When calculating the MPE coverage, apart from spatial coverage, only the MPE conducted within the time period when the construction projects were ongoing is considered as coverage.



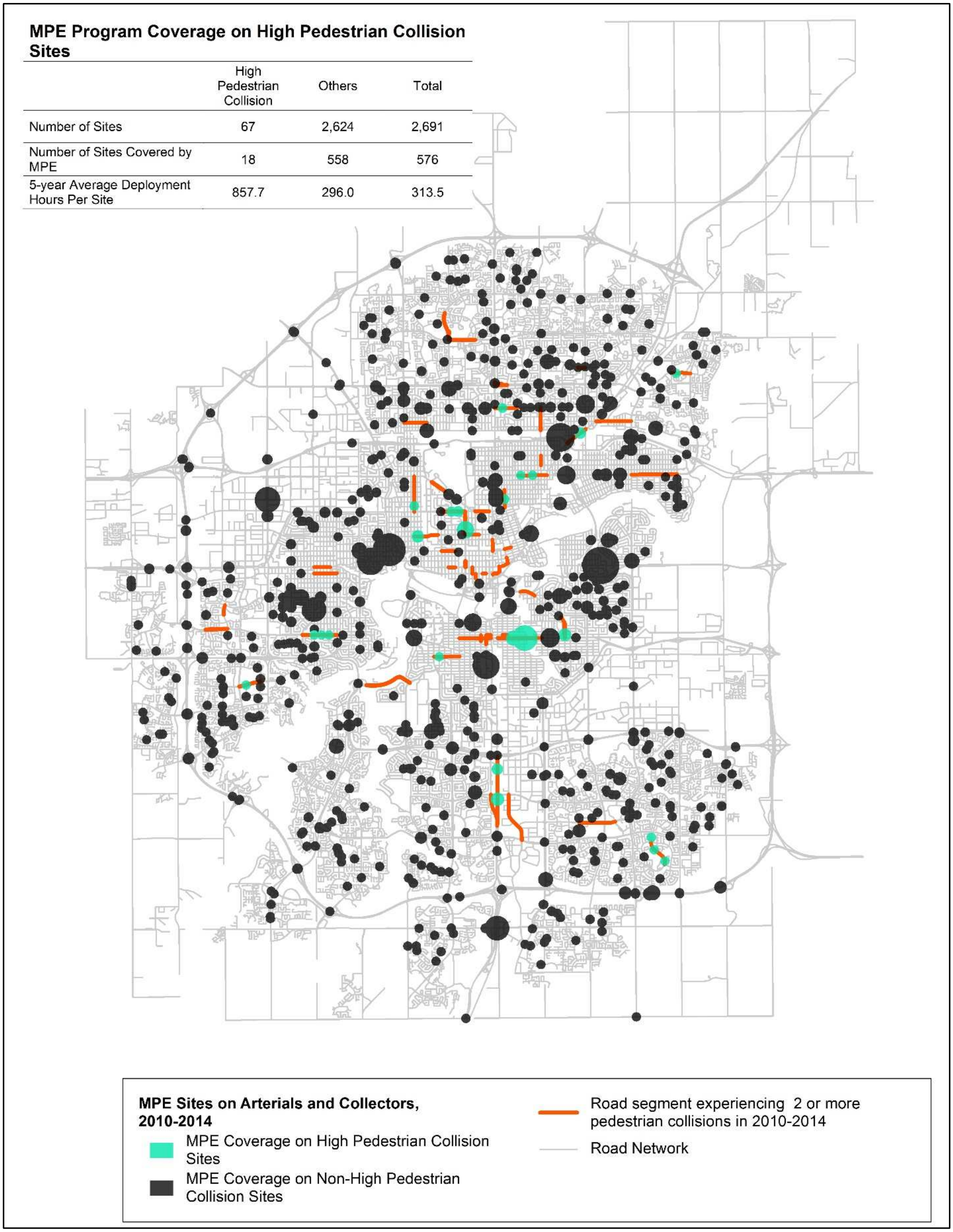
	Construction		Total
	Short Term	Long Term	
Number of Construction Zones	2,267	1,729	3,996
Number of Construction Zones Covered by MPE	121	70	191
5-year Average Deployment Hours Per Zone	446.8	365.7	368.7

Figure 4 2010-2014 MPE program coverage on construction zones.

Although spatial MPE coverage on construction zones is relatively low, the coverage time intensity is high in that the average deployment hours per zone is 368.7 hours for the five-year period. The duration of the enforcement at short-term construction zones is somewhat higher than for long-term construction zones, 446.8 and 365.7 hours respectively. It is noted that the MPE program did not distinguish between projects of different lengths for the amount of enforcement allocated. However, Figure 4 shows that short-term construction projects are mainly distributed within inner city areas, whereas long-term projects are primarily located along the city boundary or on highways. Long-term construction projects may have had lower enforcement intensity because traffic was diverted from these facilities during the construction. However, owing to the fact that further information on construction zones was not available for this analysis, further investigation is needed to reach a concise conclusion.

3.5 High Pedestrian Volume Sites

Shopping areas, transit stations, colleges, universities, and other such places often have a large number of pedestrians, but the enforcement sites in or close to these areas cannot be identified when pedestrian volumes are not available (and pedestrian volumes in these areas are not typically collected as part of on-going regular traffic data collection programs). Instead, speed-related collision data involving pedestrians can be used as an alternative to evaluate MPE deployment priority, as the motivation of enforcement at high pedestrian volume sites is to protect the safety of pedestrians. Therefore, locations experiencing a high number of speed-related collisions involving pedestrians in the COE are assessed. A high pedestrian collision site is identified as having two or more speed-related pedestrian crashes from 2010 to 2014.



	High Pedestrian Collision	Others	Total
Number of Sites	67	2,624	2,691
Number of Sites Covered by MPE	18	558	576
5-year Average Deployment Hours Per Site	857.7	296.0	313.5

Figure 5 2010-2014 MPE program coverage on high pedestrian collision sites.

The screening results are shown in Figure 5. A total of 67 sites were found to be high pedestrian collision sites. Of the 1,087 MPE sites, 39 cover 18 high pedestrian collision sites, resulting in about 27% of high pedestrian collision sites being covered, which is 1.5 times higher than the spatial coverage of high collision sites. Moreover, the deployment intensity at high pedestrian collision sites is the highest among the six enforcement priorities, with 857.7 hours per site during the five-year period. When pedestrians are struck by a speeding vehicle, there is a high likelihood of severe injury(OECD/ECMT, 2006). Therefore, these high pedestrian collision sites merit significant attention by the COE enforcement agency.

3.6 Sites with Community Speeding Complaints

The frequency of collisions, severity level of collisions and percentage of speeding vehicles on local roads in residential areas are much lower than for arterial and collector roads. Specifically, the five-year average EPDO frequency of local sites is 5.5 EPDO/km, which is only about 40% of the average EPDO frequency for arterial and collector sites. In addition, the percentage of vehicles violating the speed limit is 21.1% at local sites, which is less than half of the average figure for arterial and collector sites. For optimal resource allocation, more enforcement efforts should be exerted to other critical sites experiencing a higher risk of collisions. However, given that enforcement at local sites can mitigate community concerns and improve the enforcement program’s profile, this type of site could still be a consideration when evaluating deployment decisions, with a low number of visits and enforcement times being appropriate.

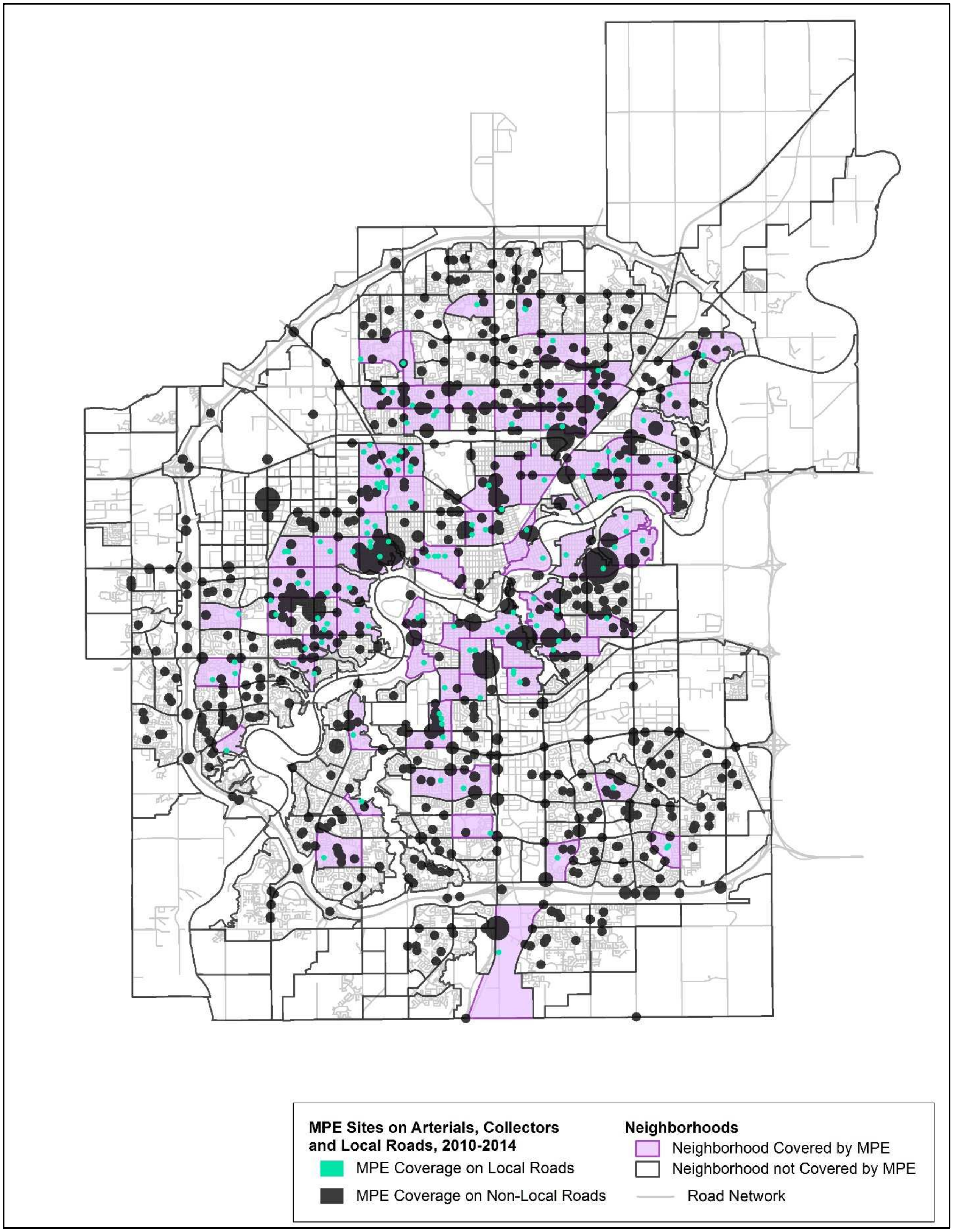


Figure 6 2010-2014 MPE program coverage on local roads in neighborhoods.

Since speeding complaints records were not available for this case study, this paper only reviewed the MPE program resources devoted to these neighborhood sites. As shown in Figure 6, the COE is divided into 388 clearly defined neighborhoods. Apart from 1,087 MPE sites enforced on arterial and collector sites, MPE was deployed to another 230 local sites (marked in green), which were in neighborhoods adjacent to central areas of the city. This number indicates that enforcement in residential areas was a priority of the COE enforcement agency. The 230 local MPE sites cover 83 neighborhoods (colored in purple). The average deployment time spent on each neighborhood is 31.3 hours over the five-year period, which is more than 10 times less the intensity spent on other deployment priorities. This paper presents only an idea of how to review this type of site. Further work on measuring the risk of neighborhoods using data on community complaints can be carried out, so that deployment decisions for these sites can be made based on a more thorough evaluation.

3.7 MPE Program Coverage Overview

Based on the analysis of MPE program coverage for the six deployment priorities, Figure 7 illustrates an overview of MPE program deployment from 2010 to 2014. A total of 1,317 MPE sites are divided into three groups: 732 sites covering one priority only, 190 sites covering two or more priorities simultaneously, and 395 sites with none of the high-priority deployment considerations identified by the Alberta ASE guidelines.

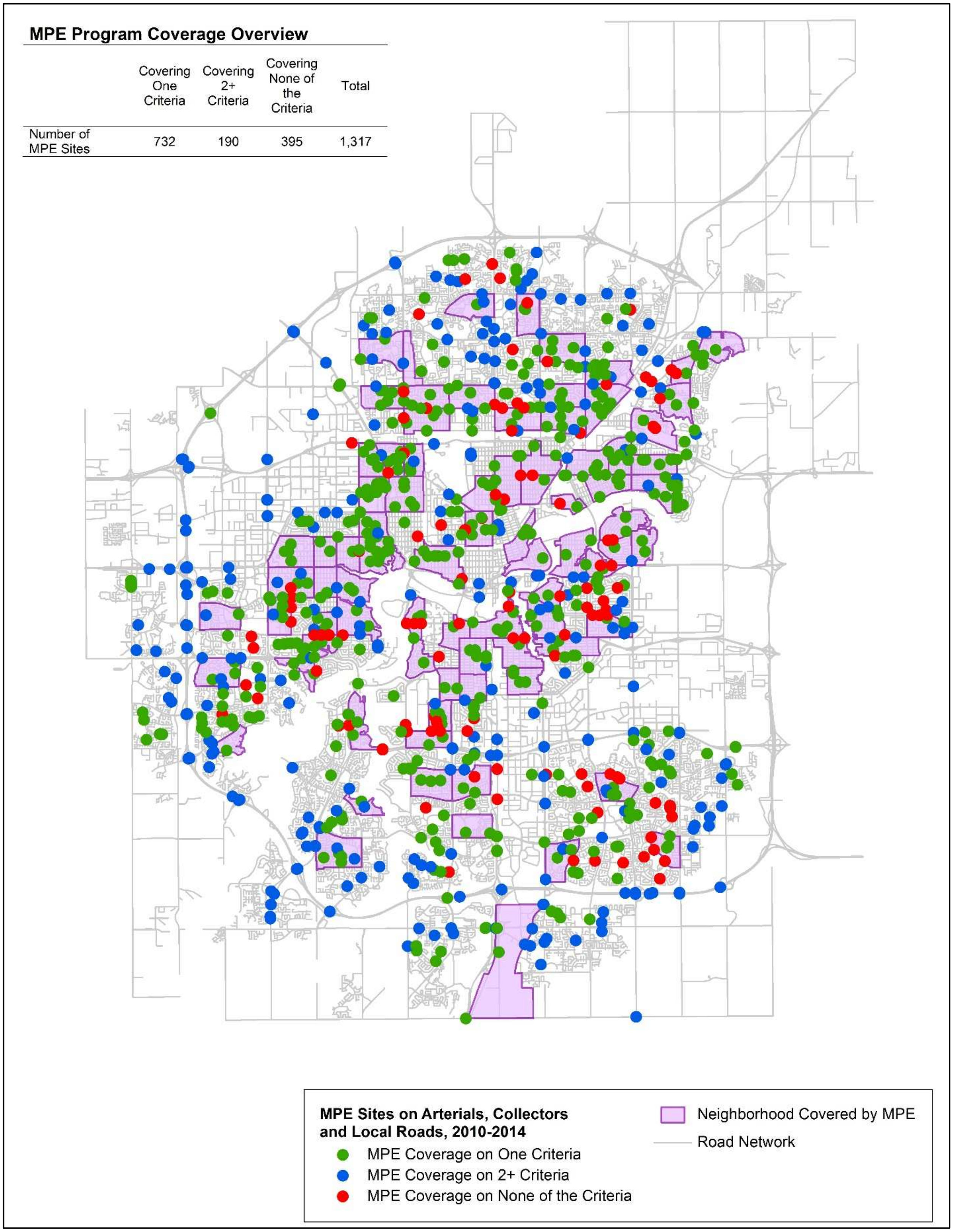


Figure 7 2010-2014 MPE program coverage overview.

The greatest benefit gained from visualizing the overview of MPE program coverage is that enforcement agencies can observe which sites identified as non-priority sites still received enforcement attention. Figure 7 shows that 30% of MPE sites were allocated to non-priority locations. This indicates that the enforcement program may be able to achieve greater safety outcomes by reallocating resources from non-priority to priority locations.

4. COVERAGE ACCOUNTING FOR DISTANCE HALO EFFECT

Achieving maximum citywide coverage may be very difficult for local enforcement agencies, owing to the fact that there are a number of deployment goals but limited resources. However, sites that have been enforced by ASE may experience distance halo effects, which are safety effects that extend upstream and downstream of the camera site(Vaa, 1997). In the review of MPE spatial coverage, this section investigates the geospatial relationship between high-priority deployment considerations and historical deployment priorities, taking distance halo effects into consideration. The distance range of this effect varies across studies. Nilsson (1992) states that the distance halo effect for MPE in urban areas can reach up to 500 meters upstream and 500 meters downstream. In contrast, Champness et al. (2005) conclude that the distance halo effect of a mobile overt speed camera program extends 1000 meters downstream, but is insignificant for upstream traffic. Elvik (2011) concludes that the level of enforcement intensity significantly affects the scope of the enforcement safety effects. Therefore, this paper has established a function to estimate the range of the distance halo effect based on deployment intensity.

The function of the estimated radius of the MPE distance halo effect is shown in Equation (1):

$$R_i = R_0 * [0.5 + 0.124 * ln\ (y_i/Y)] \tag{1}$$

Where:

i *= deployment site* i

R_i *= expected radius of enforcement distance halo effect at site i in meters*

R_0 *= baseline radius of distance halo effect in meters*

y_i*: = total enforcement level at site* i *in hours*

Y*: = average citywide level of enforcement in hours*

Equation (1) is based on the logarithmic formulation constructed by Elvik (2011). The relative level of enforcement is calculated by dividing the total enforcement hours of each deployment site by the average total deployment hours of all the sites. In this paper, the average deployment hours of the 1,317 MPE sites operating during the five-year study period is 139.1 hours. Considering that the maximum distance halo effect of the MPE program in urban areas is 500 meters (Nilsson, 1992), the radius constraints are such that the minimum distance halo should not be less than zero meters and the maximum should not be greater than 500 meters. Furthermore, a 250-meter baseline radius is adopted; when the deployment hours at a site are less than the average citywide deployment intensity, the distance halo is estimated less than the baseline. Therefore, the fewer the deployment resources that are allocated, the smaller the distance halo effect predicted, and vice versa.

As in the review of spatial coverage, the GIS layer of MPE sites accounting for distance halo effects is overlapped with the locations of high-priority deployment considerations. Because reducing collisions and speed is the ultimate objective of enforcement, this section investigates only high collision and high speed violation sites to illustrate the distance halo effect. The MPE coverage accounting for the distance halo effects is visually compared with these two priorities respectively, and the findings are discussed below.

4.1 High Collision Sites

The distance halo effects of the five-year MPE program are mapped for high collision sites in Figure 8. The sizes of the blue circles on the maps are calculated based on Equation (1), which considers the degree of enforcement of each site, and reflects the estimated distance halo effect to surrounding areas. In summary, 19% of 1,087 enforcement sites generated distance halo effects within a radius of 250 to 500 meters; whereas, the other 81% of enforcement sites generated effects covering less than a 250-meter radius.

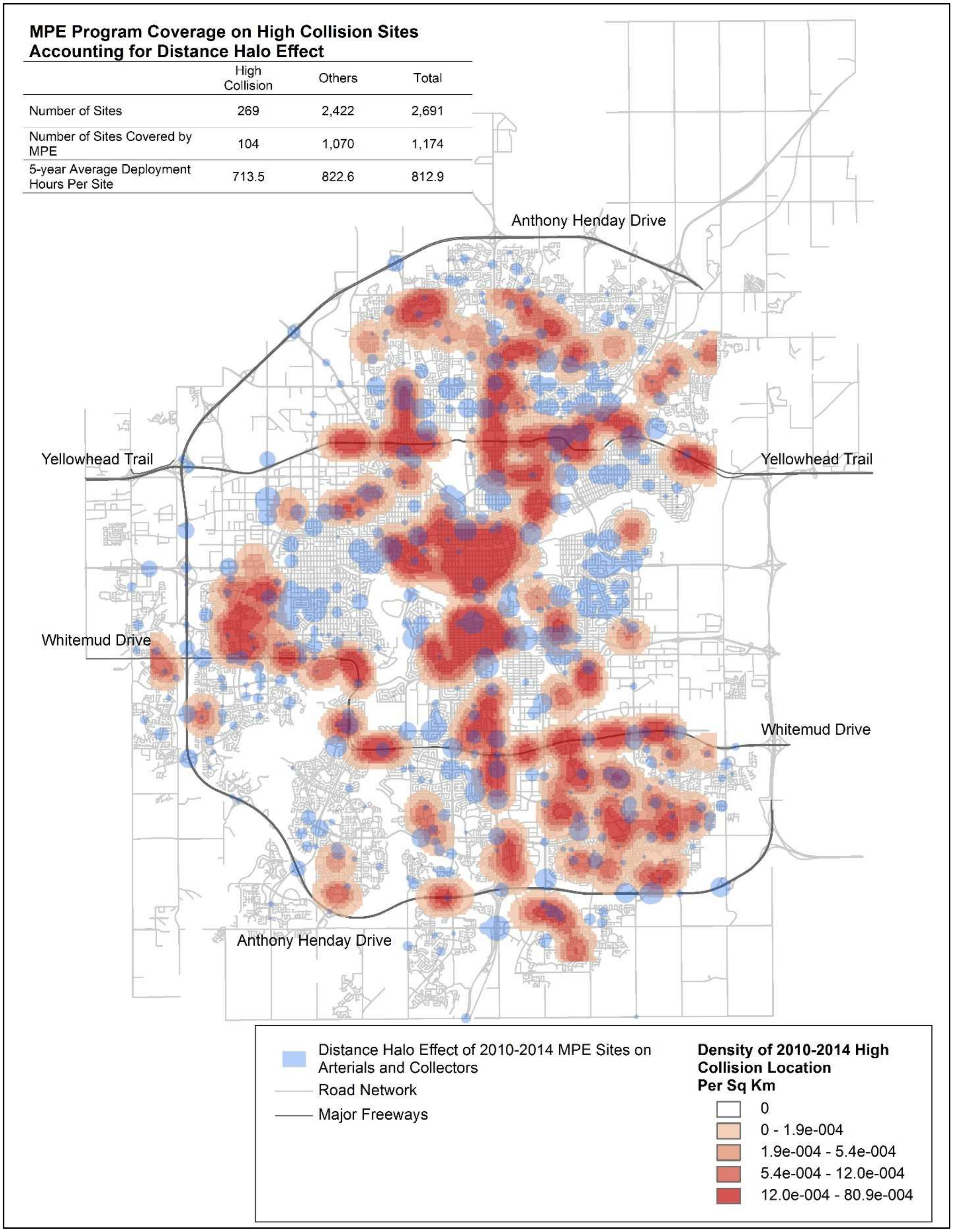


Figure 8 2010-2014 MPE program coverage on high collision sites accounting for distance halo effect.

Without considering the distance halo effect, the spatial coverage of the MPE program for high collision sites does not account for high collision sites adjacent to MPE deployment locations. For instance, 18 high collision sites are identified along the Yellowhead Trail and Whitemud Drive freeways. The number of MPE deployment sites on these two freeways is also very high, with a total of 38 MPE sites. However, only one third of these high collision sites is precisely covered by MPE. It is observed that 66% of these enforcement sites are located on an overpass or underpass of interchanges, which may be due to ease of camera placement. In contrast, most high collision sites are located between freeway interchanges, with only three located at interchanges. Although these 38 MPE sites may have deterrence effects on high collision sites nearby, these effects cannot be determined without the distance halo effect.

When evaluating MPE program coverage with the distance halo effect, the coverage of high collision sites increases from 47 to 104, doubling the citywide coverage to 38.7% (Figure 8). In addition, the number of enforcement sites influencing high collision sites expands from 85 to 171 when the spatial deterrent effect of each MPE operation is considered. Furthermore, the average deployment time at each high collision site doubles, adding to 713.5 hours per site for the five-year study period.

4.2 High Speed Violation Sites

As with high collision sites, the five-year MPE program performance for high speed violation sites is improved when the distance halo effect is accounted for. As shown in Figure 9, the coverage increases by 13.9%, reaching 63.9%. In addition, the number of MPE sites influencing high speed violation sites expands to 146, with the average deployment hours rising to 1,373 per site.

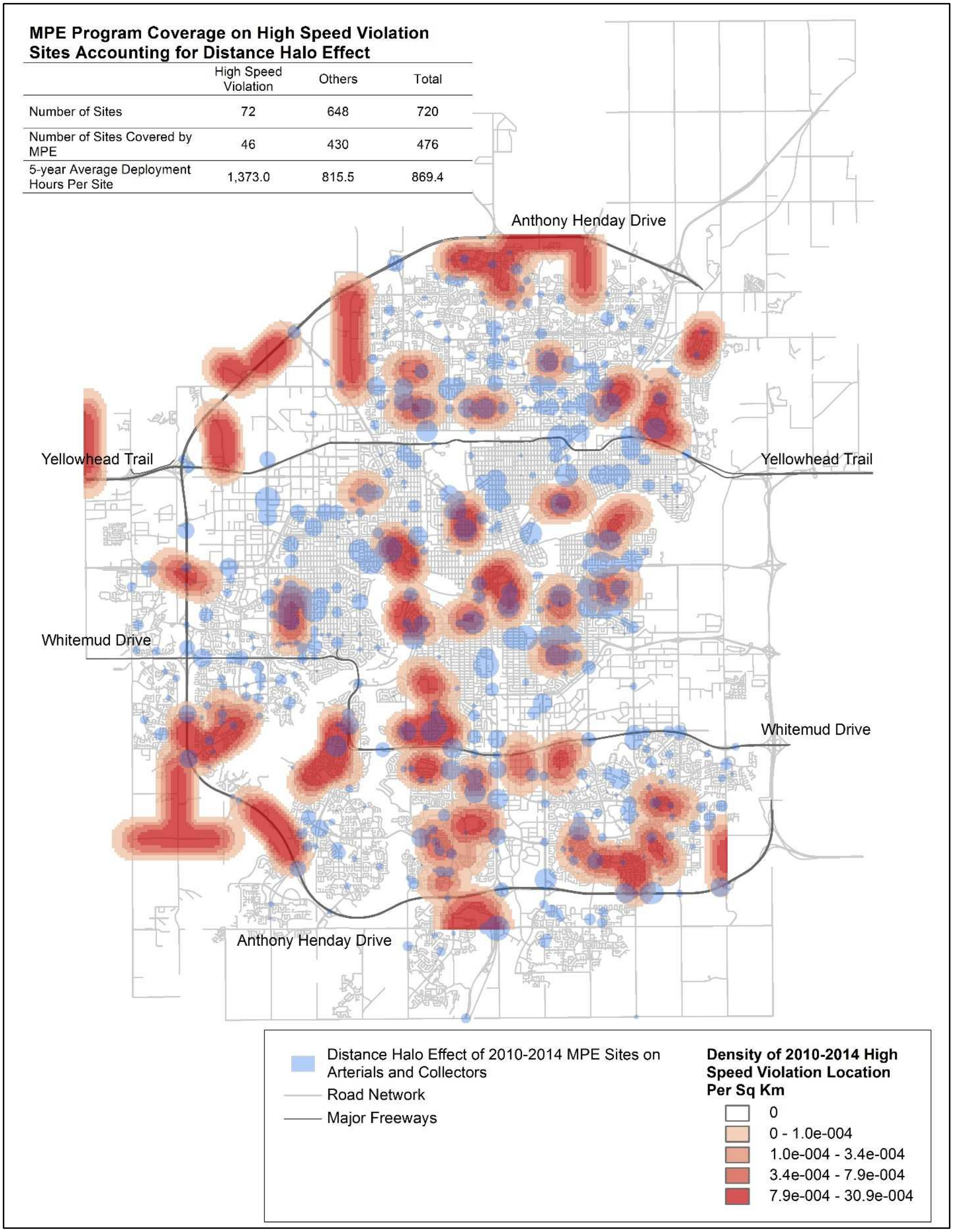


Figure 9 2010-2014 MPE program coverage on high speed violation sites accounting for distance halo effect.

As a result, the performance of the MPE program in terms of spatial coverage and the level of enforcement intensity is improved when accounting for the distance halo effect. This effect is a more reasonable indicator of MPE deployment performance when assessing the spatial coverage and intensity. However, this paper presents only a method to estimate the distance halo effect of the MPE program; further research should be conducted in the future to test this estimation function and method.

5. CONCLUSIONS

This paper proposed quantitative measures to help agencies conducting automated speed enforcement (ASE) programs to identify and evaluate ASE deployment priorities. These priorities are based on six considerations typically identified in ASE guidelines: high collision sites, high speed violation sites, school zones, construction zones, high pedestrian volume sites, and sites with community speeding complaints. A case study from the city of Edmonton (COE), Alberta, Canada, was presented, and five years of data (2010–2014) were used to identify and plot these six priorities using GIS. Maps were also overlaid with deployment data from the COE's mobile photo enforcement (MPE) program, showing enforcement presence at high priority locations.

Sites at high risk of experiencing collisions and speeding – warranting greater enforcement attention – were identified using quantitative criteria. High collision sites were identified as those with an average of 53.1 EPDO/km, while high speed violation sites were identified as those where 81.9% of vehicles violated the speed limit.

Spatial coverage and enforcement intensity were assessed to investigate the interpretation and application of the six Alberta ASE deployment priorities by the COE's MPE program. It was observed that each priority was addressed, but at different levels of attention. High speed violation sites, school zones and high pedestrian collision sites were shown to have had the most attention amongst the six priorities, with comparatively high spatial coverage and intensity. High speed violation sites and high pedestrian collision sites received the greatest enforcement time, with more than 800 deployment hours on average for each site during the five-year study period. In contrast, school zones received more enforcement coverage, at 84%. Additionally, it was found that 30% of MPE resources were not allocated to sites meeting the criteria of any of the six deployment priorities. If the MPE program were to reallocate these resources to sites meeting any of the six priorities, the program may be able to achieve greater safety outcomes.

Furthermore, this paper introduced a function to assess MPE distance halo effects. After mapping MPE distance halo effects with the locations of high collision sites and high speed violation sites, both spatial coverage and intensity increased. The spatial coverage and average deployment hours on high collision sites doubled, and increased by 30% and 60% on high speed violation sites respectively. These increases indicate that enforcement cameras were located very close to some high priority sites.

This paper contributes to the literature and practice by 1) demonstrating spatial visualization of multiple ASE deployment priorities and traffic data sources, and 2) applying quantitative measures to ASE guidelines, using the case study of the MPE program in the COE. The mapping of traffic safety data and enforcement activities was demonstrated to be an impactful method of organizing the spatial information of an ASE program. It can help agencies review their allocation of deployment resources, and help facilitate better deployment decisions to increase program efficiency and effectiveness in terms of safety outcomes. However, there were some limitations in this paper that could be addressed with additional research. Future research that incorporates additional data on construction zones, neighborhood complaints and tests the method estimating the distance halo effect should be conducted.

6. ACKNOWLEDGEMENT

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