Effectiveness of the Data-Driven Approach to Crime and Traffic Safety (DDACTS): A Cross-National Study

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Abstract

Data-Driven Approaches to Crime and Traffic Safety (DDACTS) integrate traffic crash and crime data to design more efficient patrol routes for high visibility traffic enforcement. These new methods allow police to more effectively allocate their limited resources. Although the DDACTS program or model seems to reduce crime and crash rates significantly in the United States, it is necessary to thoroughly study its effects before applying it in other parts of the world. The factors that influence crime, crashes, and police patrol systems in the United States may differ significantly from those in Asia. Taiwan was chosen as our first area of study because of its open data policy and good quality of data.

This study focused on two key differences between the United States and Taiwan: (1) the cluster distributions of crash and crime events, and (2) the possible effectiveness of DDACTS in these two regions. ArcGIS was used to calculate point cluster patterns and identify hotspots.

Although the point patterns for crimes and crashes varied greatly between Texas and Taiwan, all pairs of crash and crime hotspots were still in close proximity to each other. Also, DDACTS may be effective for improving patrol efficiency in Taiwan, despite its significant socioeconomic differences than in the US. These results show that DDACTS may be effective in regions with different socioeconomic structures compared to the United States, such as in Asia. In the future, researchers in other countries may be able to use these results to revise and adjust their current DDACTS patrol plans.

Keywords: DDACTS, Hotspots, Traffic Enforcement, Police Patrol Route, Crash and Crime

1 INTRODUCTION

From the social harm perspective, crimes and traffic crashes are major threats to public safety. According to WHO statistics, approximately 1.25 million people die each year because of traffic crashes, and an additional 20 to 50 million are injured as a result of a crash (WHO, 2009). Crime is also a universal social safety issue. For example, violent
crime is responsible for 1.6 million deaths worldwide (WHO, 2002). Together, traffic crashes and crime are the leading causes of death among young people (i.e., less than 24 years old). Hence, it is crucial for the authorities (i.e., police) to develop an effective method for reducing these hazards. Previous studies have shown that the Data-Driven Approaches to Crime and Traffic Safety (DDACTS) method could simultaneously reduce both crash and crime rates if police officers integrated highly visible traffic enforcement and hotspot policing into their patrol plans. As a result, law enforcement departments, as the only authority that can patrol and be a visible deterrent to both crashes and crimes, would be better able to allocate their limited resources so that officers could be at the right place at the right time. Even though many jurisdictions have different police units to attend crimes and crashes, it is the visibility of the police as a whole that can deter or reduce these events. Furthermore, previous studies have shown that crime and crash event hotspots often overlap, making patrol improvements applicable to the department as a whole. Additionally, the police department is the first authority to directly deal with both crime and crash events in most countries. Hence, more efficiently allocating its resources when visiting hotspots, rather than spending human power and long dispatch times to shuttle back and forth between the crime/crash hotspots and police stations, can save staffing budgets while simultaneously decreasing crash and crime events (Weiss, 2013).

Although the DDACTS model has yielded positive results in the United States, it is necessary to verify its effectiveness before applying this approach in other countries (Hardy, 2010). The characteristics of crimes, crashes, and police patrol systems in the United States may differ significantly from those in other countries, especially in Asia. For example, the traffic in most Asian countries is not primarily made of passenger cars but rather a mix of motorcycles, passenger cars, taxis, buses, bicycles, and pedestrians. Hence, the types of transportation modes involved in crashes, ratios of motor vehicle theft types, and corresponding crime and crash prevention policies may vary substantially (Tiwari, 2000). Taiwan was chosen as our test region due to its open data policy; it was ranked number one in the Global Open Data Index by the Open Knowledge Foundation in 2016 (OKF, 2016). Scholars are able to access anonymized crash and crime datasets via an application; other Asian countries are more conservative about the data they release and related privacy issues (Hogge, 2015). The present study looks at the effectiveness of
DDACTS in Taiwan, comparing it to DDACTS studies in Texas, U.S. Other Asian countries may be able to use the results documented in this research as a reference before they promote DDACTS in their own countries, because the study areas resemble more closely their socioeconomic distribution than do existing studies conducted in western countries. Also, in the future, if other Asia countries open their crime and crash data to academia or the public, the study methods and frameworks will be useful in analyzing that data.

This study illustrates the difference between using the DDACTS program in the United States and in Taiwan. The hypothesis is that although the cluster patterns of crime and crashes are different between the two regions, DDACTS may still be useful for improving patrol effectiveness and reducing police dispatch times in both. There were three main goals of this study: 1) Use local crash and crime data to examine the spatial distributions of these types of incidents in Taiwan; 2) determine if the relationship between crashes and crimes is similar (positively related) in Taiwan to what it is in the U.S.; and, 3) determine if the DDACTS program would be as effective in Taiwan as it has been in the U.S.

2 LITERATURE REVIEW

2.1 DDACTS and Related Programs

DDACTS is a relatively new traffic law enforcement model used in America. This innovative system utilizes a combination of crime and crash data with a focus on high risk areas to help officers design corresponding patrol routes for deterrence-based high visibility enforcement (Hardy, 2010). This program was developed by the National Highway Traffic Safety Administration (NHTSA) first, and then NHTSA cooperated with the National Institute of Justice (NIJ) and Bureau of Justice Assistance (BJA) to support and promote the DDACTS program nationwide.

Compared to traditional enforcement methods, DDACTS is more effective because it offers three key advantages: proactive prevention, location-focused patrolling, and diverse approaches to multiple operations systems (Weisburd & Eck, 2004). In traditional enforcement systems, police officers must react when they receive a service call. They rely on their forensic skills to collect evidence that is then used to solve crimes. However, this passive and event-reactive means of enforcement is both inefficient and cumbersome. The
more advanced enforcement model, such as DDACTS or the Computer Statistics (Compstat), focuses on allocating limited enforcement resources to crime hotspots, which are determined via an analysis of crime data from recent years. In addition to focusing on hotspots, Weisburd and Eck (2004) also claim that if law enforcement officials embrace such a model, it will allow them to be more proactive and comprehensive; they will be able to cooperate directly with multiple authorities such as prisons, social welfare institutions, and departments regulating transportation.

DDACTS has already been used in several cities in the United States. Hardy’s study shows 41% reduction in crime and 31% reduction in crashes by applying DDACTS programs under optimal conditions (Hardy, 2010). Over 250 police agencies across the U.S. have participated in DDACTS training (NIJ, 2012). However, most DDACTS-related studies have been conducted by local law enforcement officers themselves; these practitioners have primarily focused on the implementation of detailed enforcement plans. In other words, their studies had a practical, results-oriented emphasis and were not focused on the generation of academic theories (NHTSA, 2014). For example, their crime and crash data are secondary data that are collected by existing resources (by the census unit instead of patrol ranges). By failing to define the affected area may have biased estimations of the benefit of DDACTS because the treatment may have no effect outside of the area to which it was applied (Kuo et al., 2013). There is no substantive meaning in choosing this study unit, and in fact, a poor choice of this parameter may produce data with an ecological fallacy. For example, a spatial pattern that appears using an aerial unit of one scale may disappear at a smaller or larger scale, so this may prevent DDACTS results from being generalized outside of the conditions. A well-chosen scale, however, can avoid this problem.

Many DDACTS scholars have addressed the benefit of reduced traffic crash and crime rates after adding new patrol routes; however, few have discussed the potential benefits of this system or conducted more advanced statistical analyses. Only Fell (2013) estimated the effects of increasing traffic enforcement on other types of crimes; his results showed a 17% reduction in drunk-driving, 32% reduction in burglary, and 29% reduction in car theft. Kuo et al. (2013) compared police dispatch times in two different scenarios: (1) when police officers patrol around hotspots, and (2) when they patrol randomly. The results show that
hotspot policing focusing on the top ten hotspots could reduce police dispatch times up to 17%.

Although relatively few DDACTS studies have been published, a large body of work has been devoted to crime hotspot monitoring programs. The Compstat model, which originated in New York in 1993, is one of the most famous crime reduction programs in use. The idea came from a subway policeman who used pins to denote crimes on an office map, which he then analyzed to predict future crime locations and determine his daily patrol route. The New York Police Department improved this targeted enforcement plan and promoted it statewide. Compstat went on to be adopted in more than 60 stations throughout the U.S. (Weisburd et al., 2003). A similar monitoring program in Memphis also had very positive results. By cooperating with the University of Memphis and IBM, the Memphis police developed the Criminal Reduction Utilizing Statistical History system (or Blue CRUSH) to analyze and predict crimes. In January of 2010, the Memphis police declared that Blue CRUSH had helped them arrest more than 50 drug dealers, reducing the local crime rate by 36.8% (IBM, 2011).

In the traffic safety field, the Crash Analysis Reduction Strategy (CARS), which originated in Cincinnati, Ohio in 2006, is another excellent example of problem-oriented patrol. CARS was developed based on the crime prevention theory of Problem-Oriented Policing (POP) and intelligence-led patrolling (Gerard et al., 2012). Thanks to a highly visible patrol pattern and consistent enforcement, fatal traffic crashes were reduced by 47% (as compared to 2005).

Although the above location-based patrol programs only focus on the hotspots of one specific problem (crime or crash) instead of both problems as in DDACTS, their positive results are still valuable for use as references to evaluate DDACTS program performance.

### 2.2 Place-Based Learning and Routine Activity Theorems

Hotspot patrols and DDACTS programs are based on environmental criminology theories (Wilson, 2010), because police officers also treat crashes as unintentional crimes caused by human factors, such as various dangerous driving behaviors (speeding, running a red light, drunk driving, etc.). The key concepts of environmental criminology theories include place-based learning theorems and activity theory. The first concept of environmental
Criminology theories is that if police officers adequately maintain and monitor a specific place, such as a community, further serious crimes can be prevented there. The “broken windows” analogy provides a useful example. When a car is parked along a roadside, people tend not to damage it. However, if this same car’s window is broken, people tend to believe that the car is abandoned, and thus they can do whatever they want to it (such as spray paint graffiti all over it, steal the tires, or otherwise cause damage). In other words, people test the commitment of the police force according to perceived levels of enforcement and patrol frequency. Researchers have utilized a learning theorem to explain this behavior. People learn from their own experiences and reactions from others. The above theorem is supported by real-world cases such as the rapid increase in crime after Detroit declared bankruptcy and upswings in crime after natural and man-made disasters. As discussed in Kuo et al. (2012), crime hotspots and traffic crash hotspots are often spatially clustered. Based on the Deterrence Theorem, the DDACTS program can simultaneously reduce crimes and crashes. More specifically, the targeted traffic enforcement discourages unsafe driving behaviors, such as speeding, red-light-running, and DWI. Hence, crashes caused by behavior factors instead of environmental factors could be reduced, and potential criminals are likely to avoid illegal activity within such heavily patrolled zones.

Second, the routine activity theory can also be used to explain why some lifestyle and environmental factors (such as the presence of nightclubs, casinos, and bars) are associated with high crime and crash rates. In other words, daily routine activities and crime/crash rates coincide with one another. This theory assumes that when potential offenders and victims meet in the same place, the risk of criminal events increases if there is also the absence of a capable guardian. However, DDACTS provides capable guardians at the right times and in the right places. In other words, this method is a community-focused and place-based law enforcement mechanism used to help officers address current issues of social harm and the safety concerns of citizens in a manner that is more efficient than traditional policing strategies.

2.3 Differences in Crashes and Crimes Between Taiwan and the United States

Current DDACTS researchers have viewed the DDACTS method in a positive light; however, a major restriction to promote this method here is that the characteristics of
crashes and crimes are different in Taiwan than in the United States, especially in terms of offender characteristics, event probabilities, and the distribution of occurrence points. There are two main perspectives on this problem. Land-use laws in the U.S. are simpler than in Taiwan: business and residential areas are usually separated in the U.S., while land uses in Taiwan are usually mixed. It is worth considering if the different land-use patterns might affect the efficiency of DDACTS, if event probabilities are tied to land usage. Also, other important factors such as lifestyle, culture, or even economic conditions might have an impact on this method’s effectiveness. For example, it is known that drunk driving and street crimes cluster around alcohol retailers and bar areas on Friday nights in the U.S (Gorman et al., 2013; Levine, 2017). However, alcohol-related crashes and crimes might be clustered in different locations (e.g., homes or workplaces) and at different time periods in Taiwan because laws controlling the sale of alcohol and the toleration of drinking are different.

The DDACTS method tends to be more effective for specific crimes such as street crime, and it is unknown if these types of crimes are as common and clustered in Taiwan as in the U.S. Table 1 shows that the rates of various types of crimes in Taiwan and the U.S. are very different. First, the overall crime rate of the United States is approximately two times higher than that of Taiwan (2.09=4123.97/1976.69). The most common offense in Taiwan is burglary and larceny. The rates of other types of offenses, especially hate crimes, are much higher in the U.S. The ratio of crime rates in the United States to those in Taiwan for murder, rape, assault, robbery, and burglary are approximately 6, 4, 8, 12, and 2 to 1, respectively. The robbery ratio differs the most, while the vehicle theft rate is much closer. One possible reason for the difference in crime rates is that there is more restricted access to guns in Taiwan. Another contributing factor between the two countries can be attributed to the differences in reporting rates to authorities. The values for crash, fatality, and injury rates, as well as crash frequency, are much higher in Taiwan than in the U.S. The reason is that the mixed traffic flow in Taiwan results in more conflict points, higher speed variance, and an overall higher crash risk in Taiwan. The overall crash rate in Taiwan is higher than that in the United States, which suggests that DDACTS could have an even greater effect on crash prevention in Taiwan than in the United States. Furthermore, the most common offense in both countries is theft, and DDACTS can reduce most crimes of this type through
visible deterrence. In addition, property crimes, such as burglary can more consistently be predicted than other types of crime (Chainey et al., 2008).

Table 1 Crime and Crash Rate per 100,000 inhabitants in Taiwan and the U.S. (National Police Agency (NPA), 2002)

<table>
<thead>
<tr>
<th>Type</th>
<th>Rate in Taiwan (R_T)</th>
<th>Percentage (%)</th>
<th>Rate in U.S. (R_USA)</th>
<th>Percentage (%)</th>
<th>Rate Ratio (R_USA./R_T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Murder</td>
<td>0.9</td>
<td>0.05%</td>
<td>5.51</td>
<td>0.13%</td>
<td>6.12</td>
</tr>
<tr>
<td>Rape</td>
<td>7.79</td>
<td>0.39%</td>
<td>32.05</td>
<td>0.78%</td>
<td>4.11</td>
</tr>
<tr>
<td>Assault</td>
<td>40.33</td>
<td>2.04%</td>
<td>323.62</td>
<td>7.85%</td>
<td>8.02</td>
</tr>
<tr>
<td>Robbery</td>
<td>11.64</td>
<td>0.59%</td>
<td>144.92</td>
<td>3.51%</td>
<td>12.45</td>
</tr>
<tr>
<td>Burglary &amp; Larceny</td>
<td>1,604.15</td>
<td>81%</td>
<td>3,205.72</td>
<td>78%</td>
<td>2.00</td>
</tr>
<tr>
<td>Vehicle Theft</td>
<td>215.24</td>
<td>10.89%</td>
<td>414.17</td>
<td>10.04%</td>
<td>1.92</td>
</tr>
<tr>
<td>All</td>
<td>1,976.69</td>
<td>100.00%</td>
<td>4,123.97</td>
<td>100.00%</td>
<td>2.09</td>
</tr>
<tr>
<td>Fatality rate</td>
<td>8.25(24 hrs.)</td>
<td></td>
<td>10.30 (30 days)</td>
<td></td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>13.23(30 days)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury rate</td>
<td>1598.25</td>
<td></td>
<td>727.88</td>
<td></td>
<td>0.46</td>
</tr>
<tr>
<td>Crash rate</td>
<td>1191.04</td>
<td></td>
<td>510.11</td>
<td></td>
<td>0.43</td>
</tr>
</tbody>
</table>

2.4 Hotspot Identification Methods

The main purpose of the DDACTS method is to improve the efficiency of traffic enforcement patrols and reduce crimes and crashes by determining the shortest and most effective patrol routes using crime and crash data simultaneously. Scholars have traditionally separated their analyses of hotspots for crimes from those of hotspots for crashes, and making the combination of crime and crash data for interdisciplinary study is relatively new.

The theorem to define crime hotspot is more complex than that which deals strictly with traffic issues; however, certain analysis software applications can be useful for both aspects, such as ArcGIS, which provides various hotspot identification tools (i.e., kernel map and network kernel). Readers are referred to several crime hotspot studies for other common software and packages, such as CrimeStat and SpaceStat (Eck et al., 2005; Levine,
Also, Bernasco and Elffers’s (2010) study includes reviews of historical research on how criminologists have used GIS techniques to analyze data, as well as a discussion of the types of crimes suitable for spatial analyses and a comparison between the most common analytical methods.

Methods such as Ripley’s K function, Morans’ I, Local Indicators of Spatial Associations (LISA), and Gi* have all been used to calculate point cluster patterns. Point mapping, spatial ellipses, grid thematics, and KDE maps can also be used to identify hotspots on maps (Kuo et al., 2013; Erdogan et al., 2008). Chainey et al. (2008) compared these common hotspot mapping techniques and systematically listed their advantages and limitations. Unlike previous studies that only considered ease of use when evaluating hotspot mapping techniques, Chainey et al. (2008) used accuracy as the main criterion. A new index, PAI, which combines hit rate and target area, has also been used to assess the performances of hotspot identification methods. The results showed that KDE was more accurate in crime prediction than the other methods. Although numerous researchers have attempted to individuallly define the hotspots related to crashes and crimes, few have combined these two types of data together (Kuo et al, 2013). So, there is a study gap and we can define multiple event (crash and crime) hotspots and then use it to design a police patrol route.

2.5 Patrol Systems in Taiwan

From a traffic enforcement perspective, DDACTS should be adjusted according to current local patrol plans. For example, the detailed settings of hotspot maps (such as cell size and bandwidth of kernel density function) are primarily based on the size of the patrol block or beat. Using U.S. settings as the default values would have biased results of this study and rendered ineffective any patrol plans that were generated. It is also needed to consider how the responsibilities of officers and expectations of police departments differ between the U.S. and Taiwan. In Taiwan, it is common for the same police officers to be in charge of investigating both crimes and traffic collisions. Only a very few large-scale departments with a wealth of manpower can afford to handle crimes and crashes separately.

It must be noted that Japan has a strong influence on Taiwan’s police patrol system, which can be seen in its use of the “koban” system for determining current police patrol
areas (Alarid & Wang, 2000). In Taiwan, many communities have their own neighborhood police station, and the officers can give directions, fill out crime reports, manage the lost and found, and perform other community policing services. The police officers usually keep a good relationship with local residences/citizens. Also, police officers are in uniform when they patrol their fixed routes, which have several stops and checkpoints that officers visit in the same order, at the same time or on a regular schedule every week. Only investigation teams from the criminal investigation division and juvenile affairs officers wear street clothes. Police officers spend most of their working hours at the police station or patrolling their precinct. They may patrol by foot, motorcycle or automobile, adapt their patrol routes, or change the above rules if they feel it is necessary to do so. According to the NPA statistics, patrol duty usually occupies 50% to 70% of an officer’s shift.

The time spent on patrol continues to increase for two key reasons. The first is that people tend to call 110 (emergency call for police, similar to 911 in the United States) for all kinds of requests, not only emergencies. During off hours, many people call 110 simply because they cannot contact other government authorities. Unrelated service calls and extra workload occupy much of the already limited police resources and leave less time for their primary tasks. The second reason is that people tend to evaluate the performance of their local police department based on increased patrols and police visibility. In other words, when the public sees police officers out on patrol, their satisfaction with public safety increases and their fear of crime is reduced. Consequently, the current police work schedule is actually a rotation system that encompasses all hours of the day. Together, these two elements have created a vicious circle for police departments. Resources allocated to law enforcement activities are frequently insufficient for responding to service calls, dealing with threats to public safety, and staffing the rotation system (Kao et al., 2013). Due to these and other issues, it is necessary to verify the transferability of the DDACTS program to Taiwan and then modify its implementation plan. Local data was used to determine if DDACTS would be more effective, have a similar level of effectiveness, or be less effective in Taiwan than in the United States.

3 Study Data and Methodology

3.1 Research Framework and Methodology
The project research framework includes six steps: (1) mapping the DDACTS data, (2) identifying the hotspots, (3) examining the coincidence of the hotspots, (4) estimating possible spatial correlations between crashes and crimes, (5) designing the shortest patrol routes, and (6) evaluating the effectiveness of the DDACTS program.

3.2 Data Sources

In our two study regions, both crashes and crimes posed serious safety problems on the national level. In the United States, there are over 32,000 traffic crash fatalities, 2.2 million crash-related injuries, and 1.31 million violent crimes annually (Naumann et al., 2010; FBI, 2012). In Taiwan, according to statistics obtained from the Ministry of the Interior, there were 278,387 vehicle crashes in 2013, which caused approximately 2,500 fatalities and 380,000 injuries, and there were 298,967 crime events in 2013 (NPA, 2014). Undoubtedly, the corresponding costs to society are substantial for both countries.

However, because the population and area of the United States are much larger than in Taiwan, these two regions are not comparable at the national level. For this reason, the researchers were forced to limit the data to the city and district level in order to review our treatment and control sites.

In this study, a crash and crime dataset from a city in the United States was used as a baseline to compare the levels of effectiveness of the DDACTS models for Taiwan and the United States, as well as the distributions of hotspot crime scenes, including coincidental hotspots. For convenience purposes, the same datasets from a 2013 research study conducted by the lead author, using College Station, Texas was used as our control group (Kuo et al., 2013), but re-ran the analyses to adapt it for this work. Then, the Zhong-shan district of Taipei City was chosen as the study area because it has a similar population density, land use, and area size to that of College Station, Texas. For example, Zhong-shan district and College Station both have a large shopping center, a university campus, and areas with high concentrations with alcohol-serving establishments. In additional, Zhong-shan district being in the middle of Taipei city minimizes the boundary condition issues. Based on the literature review, two to three years of crash and crime data (2012–2014) was used to establish accurate hotspot maps; this was done to retain data consistency and remove high variance effects (NHTSA, 2014; Hauer, 1997).
3.3 Hotspot Identification and Coincidence Estimation Framework

The ArcGIS software (ESRI, 2012) was utilized to map the crash and crime data. It should be noted that before we could locate any hotspots, it was required to estimate the overall cluster pattern; otherwise, the so-called “hotspots” or “cold-spots” could simply have been random occurrences. The section below includes a brief discussion of each cluster pattern and hotspot identification method:

- **Average Nearest Neighbor (ANN)** is an index to define the general cluster pattern of our observed points using Eq. (1), below,

\[
ANN = \frac{\bar{d}}{\bar{\delta}} = \frac{\bar{d}}{0.5 \times \sqrt{A/n}}
\]  

(1)

where \( \bar{d} \) is the mean distance between each incident point and its nearest neighbour, \( \bar{\delta} \) is the mean distance of points distributed randomly, \( A \) is our study area, and \( n \) corresponds to the number of points (incident locations). When the ANN value is less than 1 and its Z-score is significant, our dataset contains clustered points. If the ANN value is larger than 1 and its Z-score is significant, our dataset points are dispersed. Otherwise, the observed points are randomly distributed.

- **Ripley's K-Function** is also called Multi-Distance Spatial Cluster Analysis in ArcGIS. This method can define the spatial patterns of data points (clustered or feature-dispersed) over a range of distances. The observed Ripley's K value is calculated using Eq. (2). If the observed \( K \) value is larger than its expected \( K \) value for a particular distance \( d \), then the point pattern is clustered instead of randomly distributed. When the observed \( K \) value is outside the 95% CI, the distribution of the data points is significantly different from a random distribution at distance \( d \) (see Figure 1 as an example).
\[ K(d) = \sqrt{\frac{A(\sum_i \sum_j (K_{ij})/ (\pi \times n(n-1))}{\tau^2}} \] (2)

where \(d\) is the distance between the points \(i\) and \(j\), \(n\) is the total number of points, \(A\) is the area of the region containing all points, and \(K_{ij}\) is the weight. For example, the value of \(K_{ij}\) would be 1 for the adjusted area; otherwise, \(K_{ij}\) would be zero.

- Kernel Density Estimation (KDE) map is a common hotspot mapping methods because of its accuracy and consistency in prediction as well as its superior visual component (Chainey et al., 2005; 2008). The main purpose of the KDE is to calculate the risk surrounding each point. The risk density of an event is highest when the distance is zero; the kernel density value decreases with increased distance. The detailed calculation of the quartic kernel density function is shown below in Eq. (3):

\[ K(u) = \sum_{d<s} \frac{3}{\pi \tau^2} \left(1 - \frac{d^2}{\tau^2}\right)^2 \] (3)

where \(K\) is the kernel density value, \(d\) is the distance from the incident, and \(s\) is the search bandwidth (Silverman, 1986).
3.4 Organizing Patrol Routes to Estimate Their Effectiveness

The application of highly visible traffic enforcement is a proven and effective countermeasure to address both crashes and crimes, whether they occur simultaneously or independently in terms of time and/or location. Providing solutions and estimating their corresponding effectiveness are both important. With help from GIS, establishing the most effective patrol route is easier than ever before because ArcGIS can locate hotspots and determine the shortest distances among them based on built-in network information. If speed and turn information is also available, GIS can help establish another effective patrol route based on the shortest driving times. In order to compare the effectiveness of the DDACTS model in Taiwan to its use in the United States, the same estimation formula of effectiveness ($\theta$) was used for determining the difference adjustment as was used in Kuo et al. (2013). The effectiveness is calculated using Eq. (4). The treatment’s effectiveness is higher if a new patrol route can reduce more dispatch time.

$$\theta \ (\%) = \frac{\sum_{i=1}^{m} T_{i, \text{after}} - \sum_{i=1}^{n} T_{i, \text{before}}}{\sum_{i=1}^{m} T_{i, \text{before}}} = \frac{n \times \bar{T}_{i, \text{after}} - m \times \bar{T}_{i, \text{before}}}{m \times \bar{T}_{i, \text{before}}} = \frac{n-m}{m} \left( \bar{T}_{i, \text{after}} - \bar{T}_{i, \text{before}} \right) (4)$$

In equation (4), the effectiveness of a hotspot patrol plan ($\theta$) is the percentage of the dispatch time reduced in the after period compared to the period before the implementation of the route. In other words, $T_{i, \text{before}}$ and $T_{i, \text{after}}$ are the required time to dispatch police officer to incident $i$ in the before and after periods, respectively. It should be noted that it was assumed that the average dispatch time to point $i$ in the before and after period are the same, and that the number of incidents in the before period ($m$) and the number of incidents in the after period ($n$) are equal.

4 RESULTS

The first step in this analysis was to define the point patterns for the crime and crash data using ANN. As mentioned above, before defining any hotspots on maps, it was needed to estimate the overall cluster ratio to ensure that the identified hotspots were significant and not just random occurrences. Eq. (1) was used to estimate the ANN values and Z scores of the 2012 to 2014 crash and crime data (see Table 1). As expected, the results showed that
both types of data (crime and crash) were clustered, with their ANN value significantly less than one. However, the crash data were more concentrated than the crime data in Zhongshan. This result was contrary to the results in the College Station, where the crime data were more concentrated than for the crash data. There are several possible reasons for this outcome. First, as mentioned earlier, the crash frequency was much higher than the crime frequency in the current study area. In the Zhong-shan district of Taipei, the number of crashes (29,576) far exceeded the number of crimes (7,021), to a ratio of 4:1. However, in College Station, Texas, the number of crashes was 14,712 and the number of crimes was 65,461 (a ratio of 1:4). Their ratio is about 16 times different. Second, there are significant differences between Western and Asian countries in terms of ratios of vehicle types (e.g., the number of motorcycles and types of public transportation). For example, the motorcycle, which has a much higher risk of involvement in severe crashes than other types of vehicles, is a major mode of transportation in Taiwan.

The order of the ANN (cluster ratios) of the four types of crimes in Zhong-shan was burglary, motorcycle/scooter theft, vehicle theft, and robbery. These data are summarized in Table 2. These results aligned with our expectations. The crime of burglary is most concentrated in Zhong-shan district because of overcrowding, high land cost, and many tall, modern buildings. Also, the public roads and arcades near homes have a high density of moving and parked motorcycles, causing the cluster pattern of motorcycle theft to be similar to that of burglary. Interestingly, the point pattern for vehicle theft showed fewer clusters because the Taiwanese tend to park their cars in public parking lots, which lack security systems and are usually located far from their homes. The ANN value for robbery was the lowest of the four types of crime, because robberies occurred much less often than other crimes. In addition, robberies seldom occurred more than once in the same location. It should be noted that the average size of a city block is shorter in Taiwan than in the West. In other words, traffic density in Taiwan tends to be higher than in the United States.
Table 2  *ANN Values for Crashes and Crimes*

<table>
<thead>
<tr>
<th>Events</th>
<th>Number</th>
<th>ANN</th>
<th>Z</th>
<th>Number</th>
<th>ANN</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zhong-Shan District, Taiwan</td>
<td>College Station, Texas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crashes</td>
<td>29,576</td>
<td>0.002</td>
<td>-328.47</td>
<td>5,554</td>
<td>0.129</td>
<td>-124.19</td>
</tr>
<tr>
<td>Crimes - all</td>
<td>7,021</td>
<td>0.476</td>
<td>-40.13</td>
<td>27,416</td>
<td>0.062</td>
<td>-297.02</td>
</tr>
<tr>
<td>Burglary</td>
<td>4,093</td>
<td>0.395</td>
<td>-73.99</td>
<td>3,275</td>
<td>0.180</td>
<td>-89.75</td>
</tr>
<tr>
<td>Moto. theft</td>
<td>2,451</td>
<td>0.405</td>
<td>-56.38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car theft</td>
<td>319</td>
<td>0.564</td>
<td>-14.64</td>
<td>2,852</td>
<td>0.194</td>
<td>-82.40</td>
</tr>
<tr>
<td>Robbery</td>
<td>158</td>
<td>0.730</td>
<td>-6.48</td>
<td>50</td>
<td>0.612</td>
<td>-5.25</td>
</tr>
</tbody>
</table>

The second method, Ripley’s K function, provides a means of summarizing spatial patterns for different distances. The results can also be used to compare the cluster patterns of various events (such as the crashes and crimes in our study). Figures 2(a) and 1(b) show that the observed data (indicated by the red line) is significantly different from the expected data (the blue line) and is outside of the 95% CI (the dashed line). Because our sample size is large, the 95% CI is very narrow (very close to blue line). In other words, the crash and crime points are both clustered. However, it is difficult to distinguish the difference between the cluster patterns when the Ripley’s K function values are compared in Figures 2(a) and 1(b). This function was also utilized to measure the occurrences of different crime types (such as burglary and vehicle theft), and found that the results were very similar to those above. Hence, it was decided not to include all of the K function figures here.
As for the last method, a kernel density map was employed to define the hotspots of crashes and crimes. There are two common methods for achieving this. The first is to set the threshold of crash or crime risk to over 95% (or higher than the mean plus two standard deviations in the normal distribution). This location would be counted as a hotspot. The second method is to define the classes by natural breaks that maximize the differences between the groups and minimize the differences within groups. For example, when the risk distribution is significantly skewed, using the equal interval class method will cause the researcher to place too many observations in the same subgroup and too few in the groups with higher values. Here, since the data distribution was right-skewed, the latter method was used to define these areas. In order to keep the color consistent, nine groups and same symbology were used as categories here for the whole paper.

Fig. 3 shows the KDE maps for the burglary, motorcycle/scooter theft, vehicle theft, and robbery crime types. Based on these maps, it was easy to identify the hotspots and differentiate them by color. The cold colors (i.e., blue) in the KDE maps represent cold spots, while the warm colors (i.e., red) represent hot spots. The KDE hotspots corresponding to the four crime types were all close to one another, except for those representing vehicle thefts. The major hotspots were located on Linsen North Road (the circle in Figures 3(a), 2(b), and 2(d)), which is an area famous for its many bars, pubs, and other nightlife entertainment. Also, the buildings in this area tend to be old, have fewer than five floors, and do not have security personnel or alarm systems. The major hotspot for vehicle theft was close to a parking lot, ramp, and large public park/garden (the circle in Figure 3(c)). Many vehicles park here because of the convenience and low cost, but there
are very few pedestrians because it is not well lit at night. Another hotspot was near a local shopping center in the northern part of the Zhong-shan district. There are several large department stores, hotels, and one university in this area. This result was consistent with the findings from the United States, where crime hotspots tend to occur in areas close to shopping centers and bars, and crash hotspots are usually located on major roads with high levels of traffic flow (Kuo et al., 2013). Based on this information, the routine activity theorem was borrowed from the field of criminology to explain why this area in Taiwan (with specific crime-attracting business types) tends to attract more crime than other places.

(a) Burglary

(b) Motorcycle theft
As mentioned above, the hotspots for crimes and crashes appeared close to one another in previous studies conducted in the United States, even when the offenders were not the same, which is consistent with the environmental criminology theorem. Taiwan’s local crash and crime data were used to test the above hypothesis. Table 3 shows the distances between the crash and adjusted crime hotspots in both Zhong-shan and College Station. The distances here were measured by ArcGIS from the center point of crash hotspot (A) to its adjusted crime hotspots (A’). See Figure 5 for more details.

Table 3 Distances Between the Centers of Crash and Crime Hotspots' Center

<table>
<thead>
<tr>
<th>Hotspot Center Distance</th>
<th>Zhong-shan, Taipei</th>
<th>College Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash #A to Crime #A’</td>
<td>108.91</td>
<td>75.01</td>
</tr>
<tr>
<td>Crash #B to Crime #B’</td>
<td>284.55</td>
<td>291.75</td>
</tr>
</tbody>
</table>
According to the data in Fig. 4, the Zhong-shan crash hotspots were close to highways with heavy traffic flow and ramps with high speed limits, while the College Station crash hot zones were clustered along all types of roads. It is believed that this is due to spatial distribution of urban traffic flows in Taipei and high under-reporting rates in Taiwan (only several and fatal crashes in major roads were reported to the police).

The researchers found that in all cases hotspots of crashes and crime are relatively close together. The distance between the hotspots in College Station ranged from 75.01 to 291.75 meters, while the average distances between hotspots in Zhong-shan ranged from 108.91 meters to 284.55 meters. The distances between crash and crime hotspots were relatively close, especially considering that the recorded distance bias was approximately 100 meters in our dataset. Another interesting finding is that the distances between crash and crime hotspots in Zhong-shan were slightly longer than in the United States. A possible reason is that in College Station, business and residential areas are separated, and only two crime attractors exist (bars and shopping malls), which means adjusted hotspots tend to be close by.
Figure 4. Hotspots for crash (c) (d) and crime events (a) (b) in two areas
Setting the KDE parameters (such as bandwidth and cell size) carefully is very important, as they may significantly affect the KDE results. Originally, the search bandwidth for the kernel maps was set to 500 meters, based on the findings of our previous studies and local police officer suggestions (Kuo et al., 2013). However, since the study site was different from those of earlier study (e.g., Ratcliff et al., 2011), 250 and 1,000 meters were used as search bandwidths to test the KDE outputs and their visual performances (see Figure 5). Once it was determined that the maps would remain balanced and retain the local and global point patterns, the final parameter was set to 500 meters. However, police departments could easily change the parameter setting (instead of using the default value in the ArcGIS software), based on their specific needs. For example, defining hotspots for police officers on foot patrol would require a greater level of specificity and accuracy. The primary and secondary hotspots were found to remain in the same places for all the different search bandwidths examined. Only a few new hotspots appeared in the area (circled in red). The kernel maps in Fig. 5 use different colors to symbolize the different hotspot climates.

This finding was consistent with the findings of previous studies. Figs. 4(c) and 4(d) show the KDE maps for the crime and traffic crashes. Again, the hotspots for all crimes are located in the same place as the hotspots of crashes. In other words, the crash generators and crime generators seem clustered together and we may apply DDACS in these hot spots to improve it.
Figure 5. Hotspots resulting from different search bandwidths. 
Last, the effectiveness of applying DDACTS patrol routes was examined in Zhong-Shan (Taipei). Data for all crime and crash types were used to design police patrol routes. Then, the same weight to all crash and crime events were used and how much dispatch time could be reduced was calculated by applying the new patrol routes. For the sake of consistency, the same procedures and hotspot maps used in previous studies were employed here (Kuo et al., 2013). After redrawing the kernel density maps, a frequency layer was added. The researchers found that the hotspots with higher event frequencies (aggregated for each community) and those from the kernel density maps were almost identical. These points (marked with numbers) were chosen as hotspots. The above weights could be changed based on the specific study objectives. If the traffic enforcement is found to be effective for deterring certain types of incidents (such as DWIs), it is suggested that police give higher weights to these points and design their patrol routes accordingly.

The optimum police patrol route was constructed by linking together the top five and top ten hotspots as New Patrol Route #1 and New Patrol Route #2, respectively. The road
GIS file was provided by the Transportation Research Center. Since the algorithm for generating the optimal route is not the focus here, an existing tool, Network Analyst (an ArcGIS package), was utilized to design the shortest patrol route. Future researchers may build optimal patrol routes with the optimized travel times if detailed traffic data such as speed limits, traffic turn, and possible traffic delays is available. The total length of the new patrol route was 3,845.62 meters. There were 3,982 crimes and crashes located within 50 meters of our patrol route area, 5,553 within 100 meters, and 8,331 within 200 meters.

According to Eq. (3), Patrol Route 1 could reduce the total dispatch time by 8.9% under neutral condition. Under more favorable conditions (i.e., the highest level of effectiveness and the widest effective area), Route 1 could reduce the total dispatch time by as much as 26.7%. Under less favorable conditions (i.e., the lowest level of effectiveness and narrowest area), the route could still reduce the total dispatch time by 3.2%. These estimates are summarized in Table 4. By comparing this level of effectiveness (under neutral conditions) with the routes in College Station, it was determined that DDAC TS was slightly less effective in Zhong-shan. However, if the effect area was extended to 200 meters, the effectiveness of the new police patrol route in Zhong-shan was slightly higher than in College Station. One possible reason is that there were more crash and crime hotspots near the patrol route (major roads within 200 meters) in Zhong-shan.

Table 4 Sensitivity Analysis of Dispatch Time-Reducing Ratio

<table>
<thead>
<tr>
<th>Effectiveness (Zhong-shan)</th>
<th>Effectiveness (College Station)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>50%</td>
</tr>
<tr>
<td>50 m</td>
<td>3.2%</td>
</tr>
<tr>
<td>100 m</td>
<td>4.5%</td>
</tr>
<tr>
<td>200 m</td>
<td>6.7%</td>
</tr>
</tbody>
</table>
5. CONCLUSIONS

Though a great deal of attention has been paid to deploying DDACTS programs in Western countries, in this study, the possibility of applying this approach in an area of Taiwan was examined in order to determine if DDACTS would be useful outside the United States. The results may also be applicable to other Asian countries, such as China, Japan, and Singapore because their land uses, population distributions, crash and crime patterns, and lifestyles tend to be similar to the region that was studied here (Kenworthy & Laube, 1996).

The results showed that crashes and crimes in Zhong-shan (Taipei, Taiwan) tended to be clustered based on both our calculated ANN values and Ripley’s K test. The KDE maps were compared and the straight-line distance between every pair of crash and crime hotspots was calculated. As expected, these hotspots were in close proximity to one another (Hardy, 2010; Kuo et al., 2013). Also, hotspot locations located near shopping centers and bars were found to be consistent between Zhong-shan and College Station. And the same was found with crash data on major roads with high levels of traffic. However, some interesting differences in the cluster order of crimes and crashes, as well as between various types of crimes, were found. For example, crashes were more clustered than crimes in Zhong-shan. The above results may reflect that the main social safety problems in the United States are more crime related, and the main challenges for the Taiwan police officers are more crash related. Also, the results showed that the hotspots for burglary and motorcycle theft in Zhong-shan were closely co-located because Taiwanese people tend to park their motorcycle close to their house. However, the hotspots for vehicle theft were located in large parking lots in rural areas because of this is where most cars are parked in Taipei due to high parking fees in the city downtown.

The practical contribution made by this work is it provides an evaluation procedure for Taipei and other Asian local police departments to use to determine if they should apply DDACTS in their beat/management district. Based on the sensitivity analysis, applying new police patrol routes by incorporating the top five hotspots would add 21 minutes to patrol but could reduce police dispatch times by 8.9% (as calculated by Google maps). The results under the best and worst conditions were also estimated in this study, in order to
provide our readers with a performance reference. Based on the results, it suggested that DDACTS is still useful and then can be applied in the Zhong-shan district. Also, according to Fell (2013), DDACTS’s actual effectiveness could be even higher than expected, because traffic enforcement can reduce other traffic violation crimes such as drunk-driving and illegal drug use. In additional, real crime data should be higher than study data used here, because of few types of crime data were unreleased (removed by the Taipei City Police Station) due to the Personal Data Protection Law. However, verifying this would require information about other types of crime (such as DWIs and assault), as well as suitable enforcement methods.

There are a few limitations associated with this study. In this study, 100 and 500 meter bandwidths were utilized and cell sizes for the KDE maps with best visual results. However, reasonable bandwidths may vary for different events (crime versus crash events, different types of crimes, etc.). Future research should verify the effectiveness of the KDE maps by employing various search bandwidths for different crimes, and overlap these maps in the final product. Also, the cell size has been shown to affect the accuracy of hotspot repeats, and different types of patrols may require different cell sizes. Foot and bicycle patrol need more accurate hotspots. Future researchers will need to determine the best default values for these key parameters. Also, in order to test the accuracy of hotspot maps documented in this research in the future, extra data should be collected over an extended study time to further validate the proposed model. In addition, future research can combine these crash and crime hotspots information with other socioeconomic datasets by overlaying the various map files, and then build the spatial model to explain the possible impacts caused by the related factors. It is believed that the GIS technique and spatial analysis will become more useful in the future because most of crash and crime data now comes with location information, and as showed here, calculating routes incorporating DDACTS methods can provide reductions in crashes, crimes, and patrol times in cities in both the United States and Taiwan.
References


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