

Identifying the Causes and Types of Accidents Associated with the Spatial Distribution of Black Spots in the Region of Dammam Metropolitan Area, Saudi Arabia

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Abstract

Black spot distribution is a major indicator of urban traffic safety. Identifying the spatial distribution of black spots at urban centers is fundamental to understanding the causes, types, and severity of accidents. Many studies have investigated the spatial distribution of black spots worldwide. However, few studies have investigated the causes, types, and severity of accidents associated with population size, land use patterns, and prevailing traffic conditions in black spots. This study attempts to explore these associations in the black spots in the Dammam Metropolitan Area (DMA). The data was collected between 2015 and 2019 from the Traffic Police Department and the Department of Transportation of the Saudi American Oil Company. The data was analyzed using several spatial analytical techniques, including statistical and GIS-based techniques. It was found that accidents involving pedestrians caused by vehicles turning suddenly and driver distraction were the leading causes of accidents in the black spots of DMA. The study found no relationship between population size, land use pattern, and the spatial distribution of black spots. However, the prevailing traffic conditions were found to be related to the spatial distribution of black spots. The spatial distribution of black spots in DMA was related to the un-prohibition of turning right during the red light at the signalized intersections.

History

Received: 03 Mar 2021
 Revised: 18 Jul 2021
 Accepted: 30 Aug 2021
 e-Available: 21 Dec 2022

Keywords

Black spots, Fatality rates, Causes, Types, Severity, Population size, Land use pattern, Environmental and traffic prevailing conditions, Dammam Metropolitan Area Region

Citation

Alshabibi, N., Gharaibeh, E., and Elhadi, E., "Identifying the Causes and Types of Accidents Associated with the Spatial Distribution of Black Spots in the Region of Dammam Metropolitan Area, Saudi Arabia," *SAE Int. J. Trans. Safety* 11(1):11-24, 2023, doi:10.4271/09-11-01-0002.

ISSN: 2327-5626
 e-ISSN: 2324-5634

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Introduction and Background

The transportation sector has expanded rapidly in the last four decades and has had significant positive impacts on mobility, accessibility, lifestyle, socioeconomic demographic characteristics, and urban activities [1]. Nowadays, transportation of freight and passengers has become a necessity for human life. To enable transportation, modern roadway networks have been expanded and the number of vehicles has grown, which is favorable for human urban society [2]. These factors increase human domination over the environment, which harnesses it to serve better and contribute to humanity's progress and well-being, especially in developing economies.

The increasing rate of road accidents is a serious and complex issue with grave consequences, such as damages, injuries, and fatalities. Thus, traffic engineers have been trying to find a balance between roadway network capacity and traffic safety over the years. Traffic accidents are among the top ten causes of mortality worldwide, and they will become the fifth leading cause of mortality by 2030 [3, 4]. The number of fatal accidents is rapidly increasing, reaching up to 1.2 million deaths worldwide [5]. Globally, approximately 49% of roadway traffic accidents were classified as fatal accidents among pedestrians in 2015 [1]. Thus, traffic accidents have received attention at the local, regional, and global levels. Studies have focused on investigating locations with a high occurrence of traffic accidents, called black spots. Black spot distribution is a major indication of traffic safety levels in urban centers. The problem with black spots is that their numbers are continually increasing. Their severity is also increasing daily, thereby necessitating investigation of their spatial distribution, associated with the causes, types, and severity level of the accidents. Traffic safety studies helped reduce and mitigate the consequences of black spots by speed reduction and traffic calming strategies, which decreased fatal accidents by 30% in 2004 [1].

There is no unified definition of black spots; some studies have defined them as highly ranked locations based on the frequency of accidents. Other studies have described them as locations with a high probability of accident occurrence, or high-risk accident locations [6]. This study used these definitions to identify black spot locations in the DMA region. The types of accidents included in counting the frequency to identify black spot are three types of accidents:

1. Minor roadway traffic accidents with no injuries or fatalities (only damages).
2. Roadway traffic accidents with injuries.
3. Roadway traffic accidents with fatalities.

Many studies have investigated the spatial distribution of black spots [7, 8, 9]. In 2003, a study investigated the leading causes of death between diseases and injuries globally [10].

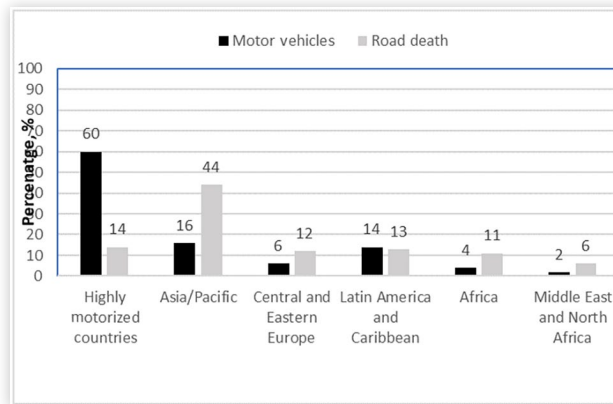
It concluded that traffic accidents were the ninth major cause of death in 1998 and predicted that they will be the third leading cause of death in 2020. However, these studies did not investigate the spatial distribution of black spots, their associated accident causes that are related to population size, socioeconomic demographic characteristics, land use patterns, and environmental and prevailing traffic conditions.

Some studies have investigated the spatial distribution of black spots and the association to differences in socioeconomic demographic characteristics, driving behavior, land use patterns, activity distribution, and prevailing traffic conditions in different urban centers. Between 2009 and 2016, a study collected data on black spots in Dammam City [11]. The study referred to black spots as hot spots and defined them as the locations with high accident concentrations. The study aimed to investigate the relationship between the distribution of black spots, population density, and land use patterns. The study found a correlation between the distribution of population densities and the spatial distribution of black spots. However, the study did not include the prevailing and environmental traffic conditions. The prevailing and environmental traffic conditions include number of pedestrians, number of buses, number of bicycles, lane width, right turners, left turners, lane utilization, weather, work zones, and other factors [12]. Investigating the spatial distribution of black spots associated with broader factors, such as population size, land use pattern, and prevailing traffic conditions, helps mitigate the number and severity of traffic accidents.

Saudi Arabia (KSA) has a severe road accident problem, similar to many Middle Eastern countries. In KSA, accidents with a high fatality rate continue to increase annually compared to those in other countries around the world. The fatality rate in KSA per capita in 2013 was 27.4 fatalities per 100,000 of the total population, exceeding the international average rate of 17.4 deaths per 100,000 [1, 13]. Traffic accidents in KSA have been a persistent problem hampering development efforts nationwide. Accident records from the Ministry of Interior (MOI) in KSA identified different causes of accidents, such as entering signalized intersections during red light, speeding, joyriding, drifting, improper stopping/turning/passing, traffic rules violation, and other reasons [14]. The MOI study reported that 90% of traffic accidents are related to human behavior and the misconduct of road users, whether drivers, passengers, or pedestrians. Figure 1 shows that in Middle East and North Africa the percentages of road deaths are high than the percentages of vehicles ownerships in 2000.

Figure 2 shows that in the KSA, from 1971 to 1990, the number of road accidents increased from 4,147 to 35,799. Road crash-related fatalities increased from 570 to 2,697 during the same period, and injuries increased from 5,483 to 22,526 [16]. By 2013, according to the Saudi Traffic Police Department, the total number of accidents increased to 526,429, and crashes involving injuries totaled 37,530. Furthermore, there were 7,600 fatalities associated with road accidents, nearly three

FIGURE 1 Distribution of road deaths with vehicle ownership by region.



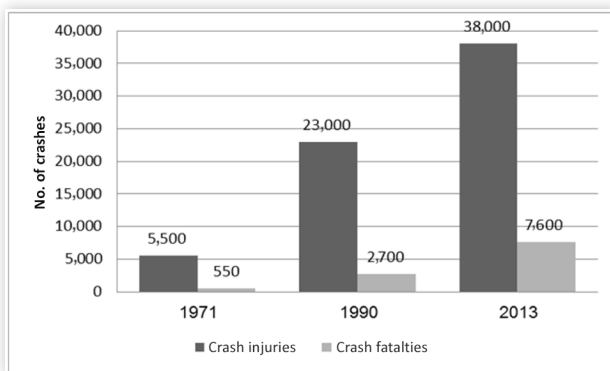
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times higher than the number in 1990 [17, 18]. Figure 2 shows the growth in crash-related injuries and fatalities from 1971 to 2013.

Despite the efforts, and technological enhancements conducted to the KSA traffic system, the strategies to make the roads safer need to be improved, as is apparent in Figure 2. It shows that the number of road accidents from 1971 to 1990 jumped by over 800%, fatalities in the same period increased by over 450%, while injuries increased by over 400%. Comparing fatalities between 1971 and 2013, the number of deaths increased by over 1200% [19].

The contributing factor analysis shown in Figure 3 include weather, timestamps, road works, and radar approximation. The analysis associated with accurate collection and reporting of crash data, which are highly beneficial for fatality reduction. Usually, these data have been used to study the causes, types, and severity of accidents, and to propose measures to mitigate crashes' severity.

FIGURE 2 Traffic crash-related injuries and fatalities by year.



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Figure 4 shows the contributing factor analysis including the probability distribution of accidents caused by either a single factor or multiple factors, without considering traffic calming measures that prevent accidents, such as speed humps, which prevent speeding. As illustrated in Figure 3, a single factor rarely causes road accidents.

Traffic safety studies assist in reducing traffic accidents and raising the awareness of road users. The Dammam Metropolitan Area (DMA) has a severe road accident problem. Fatal accidents are high and yearly increasing compared with other regions in KSA. This study investigates the spatial distribution of roadway traffic accidents and black spots in the DMA and the associated causes and types of roadway traffic accidents. Also, the study investigates the relationship of black spot distribution with population size, land use pattern, and prevailing traffic conditions, using statistical and GIS-based analysis techniques. The study helps decision-makers and local traffic authorities to provide traffic calming, changing configuration, signal optimization, and other traffic solutions, such as smart transportation and deployment of information technologies (ITS).

Method

Data Collection and Analysis

This study was conducted by collecting the traffic accident distribution data in the DMA from 2015 to 2019. The data of roadway traffic accidents in Dammam, Khobar, Dhahran, and Qatif were collected and analyzed as follows:

STEP 1: Data collection

A comprehensive roadway traffic accident data of the DMA were obtained from the Eastern Province Traffic Department and The Traffic Department of the Saudi American Oil Company (ARAMCO). The acquired data included the following:

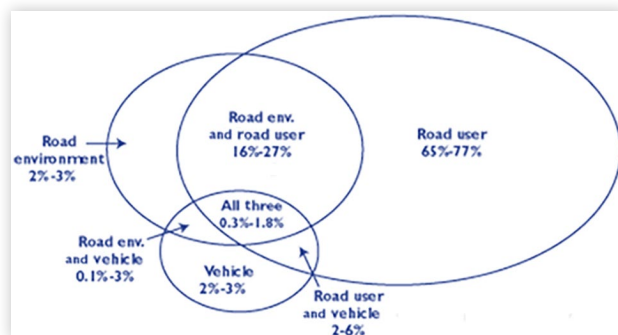
1. A complete traffic accident database and generated maps of the DMA region. The traffic accident database included a data collected by traffic department and maps prepared to represent the spatial distribution of accidents in DMA on GIS. The data included the X-Y coordinates registered for each accident by the traffic department at the location of the accident. The data of the X-Y coordinates have used to prepare the attribute table of accidents spatial distribution in GIS. The GIS layers have prepared to include the DMA region, the roadway networks, and the accidents' locations. Also, GIS layers of different types and sets of information, including road centerlines, road pavement edges, land use, neighborhood, and block distribution.
2. Data of socioeconomic demographic characteristics and geospatial data of urban centers in the DMA, including population size, land use patterns, prevailing traffic conditions, roadway, and infrastructure data.

FIGURE 3 Contributing factor analysis of roadway traffic accidents.

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Step 2: GIS and Statistical Analysis to Quantify Traffic Safety

The data of the study including current traffic accident data and highway safety levels have been analyzed to identify black spots in the DMA using several analytical techniques and procedures. The analytical techniques and procedures included statistical analysis in Excel Spreadsheets (to tabulate data and report the black spots) and geographic information system (GIS) analysis in ESRI's ArcGIS software (to visualize the black spot distribution from the collected data). Different maps have been generated in GIS to represent the spatial distribution of locations with high frequency of accidents. The locations with high frequency of accidents on GIS maps have been identified as black spots. Black spot locations have been counted manually on GIS maps in association with the data of the GIS attribute table.

FIGURE 4 Probability associated to contributing factor analysis of roadway traffic accidents.

Data taken from Ref. [19]. © Imam Abdulrahman Bin Faisal University - Nawaf Alshabibi

Study Area

The data of the study have been collected in the DMA region in The Eastern Province of The Kingdom of Saudi Arabia (KSA). The region is located 380 km from the capital city of Riyadh. It includes four major cities: Dammam, Khobar, Dhahran, and Qatif. It has a population of 1.66 million people with an annual population increase rate of 2.8%. The DMA covers 204,896.6 square meters, including the four major urban centers. Figure 5 shows the locations of urban centers such as Dammam, Qatif, Khobar, and Dhahran in the DMA region.

The roadway network in the DMA region includes three major highways, eight major arterial roads, 33 collectors, and local roads providing the accessibility to residential neighborhoods in urban centers. The traffic roadway network covers 312.5 million urban roadway paths and the right of ways. Figure 6 represents the roadway networks in the DMA region including the four major cities Dammam, Qatif, Khobar, and Dhahran.

Study Result

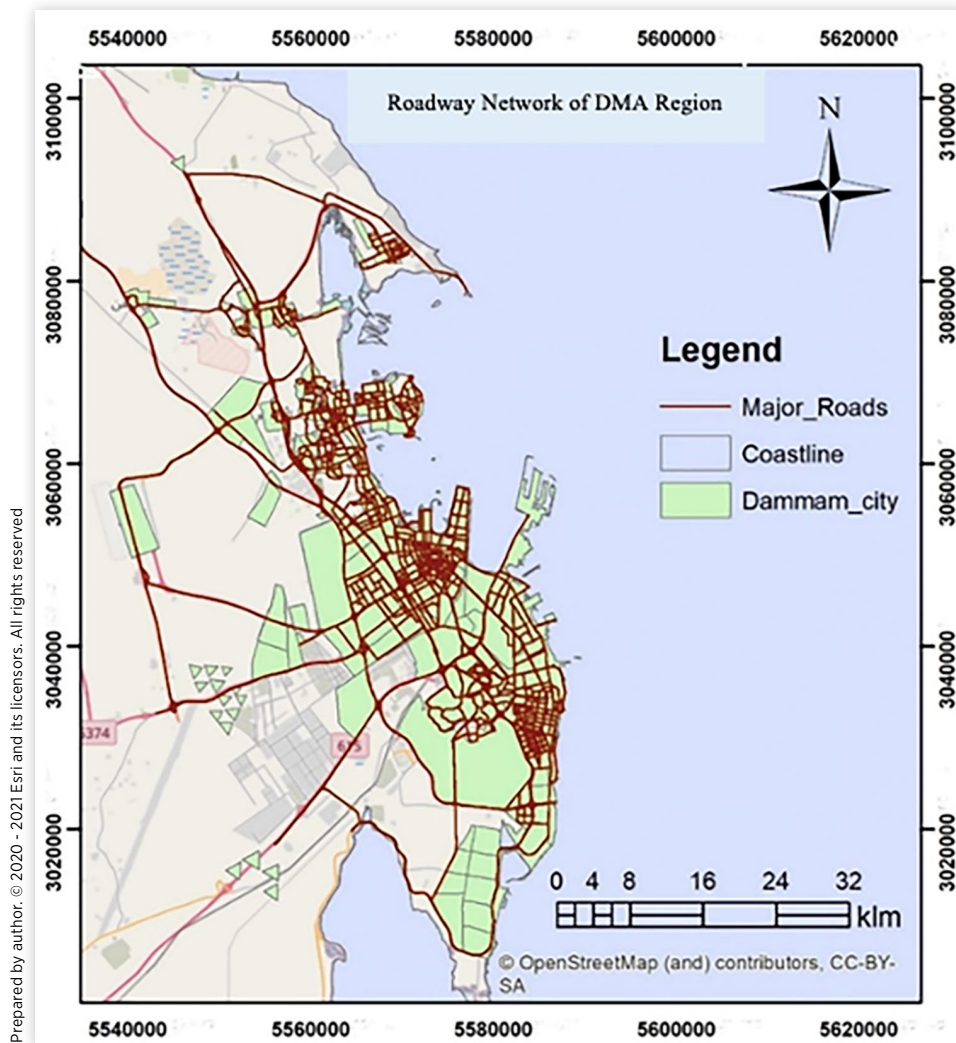
Urban, Demographic, and Traffic Characteristics

The population size in the DMA is 1.66 million people, 1,024,409 people are living in Dammam, 524,182 in Qatif, 457,748 in Khobar, and 138,135 in Dhahran [20]. The population and land use of urban centers in the DMA region have similar socioeconomic demographic characteristics, such as average income, educational levels, gender distribution, age classes, activities, and services distribution. The average income per household among urban centers in the DMA is 4,000 USD, which is 15,000 SR. The average

FIGURE 5 Locations of urban centers in the DMA region.



FIGURE 6 Location and roadway network of the DMA region.



household size is from six to eight people per household. The average vehicle ownership per household is three vehicles per family.

Also, the geospatial characteristics and the land use patterns in the urban centers of the DMA region are similar. Because determination of activities distribution and land uses have prepared under similar land use, land subdivision, spatial regulations in the master and structure plan. Land use classification in the structure plan of the DMA region includes a similar distribution of zones and activities because it was prepared under similar conditions and regulations. Thus, the urban form and pattern of land use and activities distribution in urban centers in the KSA do not differ significantly. Accordingly, the characteristics of socioeconomic demographics, geospatial, and land use patterns do not vary much spatially among urban centers in the DMA region.

The population of the urban centers of the DMA have similar driving behaviors and the roadway network classifications and characteristics were prepared by the Ministry of Municipal and Rural Affairs (MOMRA), including local roads, collectors, majors, arterials, and highways. The prevailing traffic conditions, such as pedestrians, buses, cycling, lane width, lane utilization behavior, signalized intersection configurations, and operation are similar.

Pre-timed signalized intersections operation, with a 240 s cycle length, are deployed based on updated rush-hour demand in the urban centers of the DMA. Signalized intersection operation were conducted to allow one approach with four-lane group movements during a single phase with unprohibited right turning during red light. There are 108 signalized intersections in Dammam, 76 in Khobar, 37 in Qatif, and 25 in Dhahran [21]. The spatial distribution of signalized intersections in the urban centers of the DMA has a relatively similar distribution of black spots. Accordingly, transportation infrastructure, and prevailing traffic conditions in the four urban centers in the DMA region, are similar.

Black Spot Distribution The accidents data have been grouped based on the frequency at the location through the spatial distribution on the maps. Mapping accidents data (location, type, circumstances, and road users) is essential to reach a clear conclusion concerning crash countermeasures and the spatial distribution of black spots. From crash data, the evaluation focused on crash density over geographic space, identified as a black spot in the urban centers of the DMA roadway network [6]. Accordingly, frequency of accidents at a particular location is the major determination parameter of black spot. [Figure 7](#) shows the spatial distribution of the black spots in the urban centers of the DMA. [Figure 7\(a\)](#) is the black

spot distribution in Qatif, [7\(b\)](#) is in Khobar, [7\(c\)](#) is in Dammam, and [7\(d\)](#) is in Dhahran.

From the maps, there are 223 black spots in Dammam City, 193 in Qatif City, 154 in Dhahran, and 126 in Khobar City.

[Figure 8](#) shows the X-Y coordinates of the spatial distribution of black spots, which represent that Dammam has the highest number of accidents in the region. Khobar, Qatif, and Dhahran have relatively similar numbers of black spots. [Figures 9](#) and [10](#) show the heat map of black spots in the DMA region.

As per [Figures 9](#) and [10](#), Dammam and Qatif have the highest number of black spots in the region. These locations are the most populated in the DMA, where Khobar and Dhahran come next. [Figure 10](#) shows the spatial distribution of the accident in the urban centers of the DMA. The heat map in [Figures 9](#) and [10](#) represented a high concentration of black spots on the highway between Dammam and Qatif heading to Jubail. This highway is the second highest number of roadway traffic accidents in KSA in 2000.

[Figure 11](#) illustrates the distribution of 5,123 accidents in the urban centers of the DMA for the period 2015-2019. It shows that the highest number of accidents are in Dammam, Dhahran, Khobar, and Qatif, respectively.

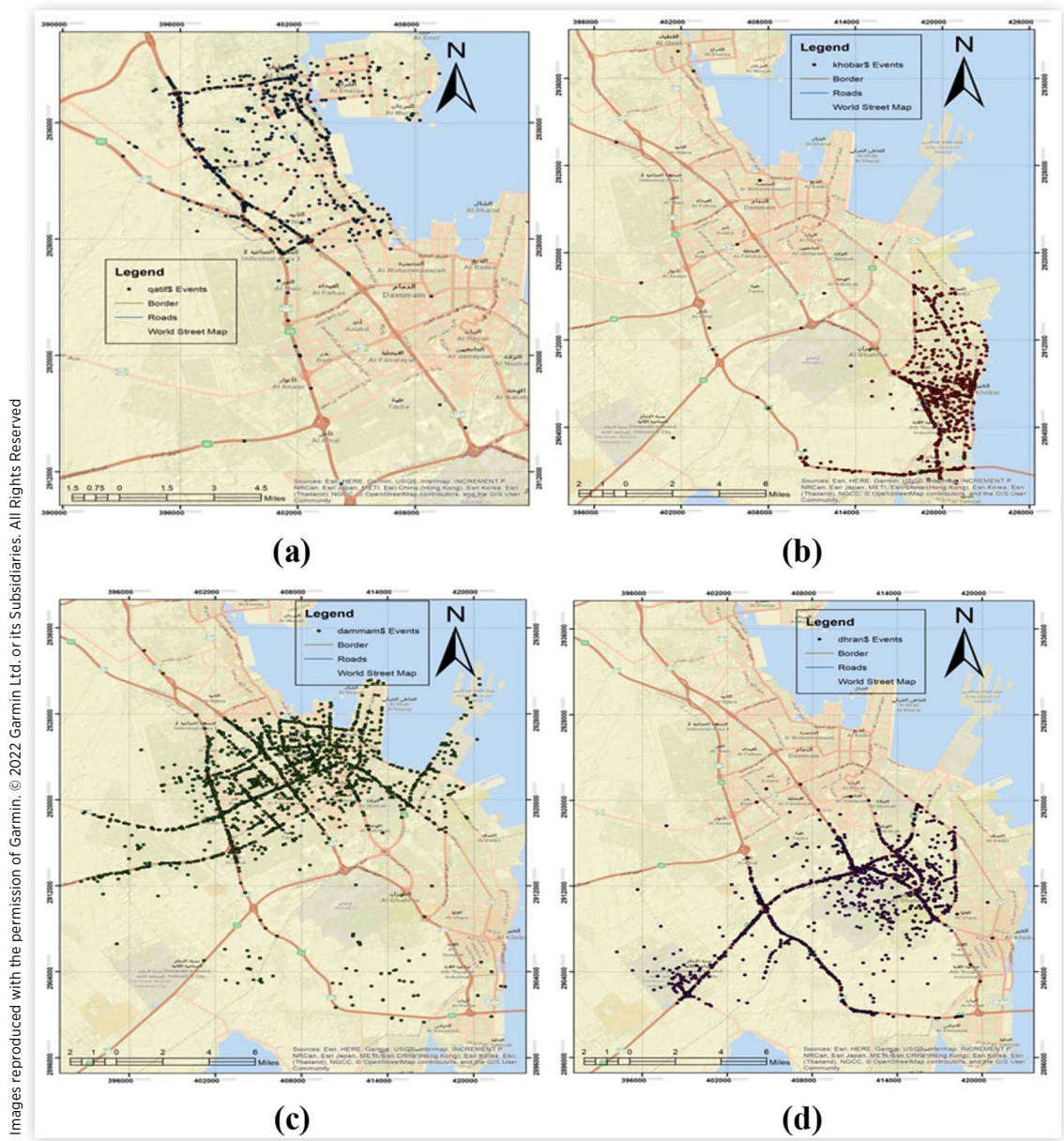
[Figure 12](#) shows the frequency distribution of accidents in the urban centers of the DMA based on the types of accidents. It shows that hitting a pedestrian is the most frequent type of accident in the DMA region.

[Figures 13](#) and [14](#) show the highest causes of accidents in the urban centers of the DMA, based on 97% of the total accidents. The first highest number of causes of accidents in the DMA region is the sudden turning. This is related to the non-prohibition of turning right during the red light while pedestrians are crossing on the crosswalk at the adjacent approach at signalized intersections [[14](#), [18](#)].

[Figures 13](#) and [14](#) also show that driver distraction is the second highest cause of accidents in the DMA region. Globally, many studies have found that driver distraction by cellphone usage is a major cause of accidents in urban roadway networks, especially at the signalized intersections [[22](#), [23](#), [24](#), [25](#), [26](#), [27](#), [28](#), [29](#), [30](#), [31](#), [32](#), [33](#)]. Also, other studies have found that driver distraction by cellphone usage reduces urban roadway network capacity [[27](#), [34](#), [35](#)]. [Figure 15](#) shows the trends of significant accident types between the years 2015 and 2019.

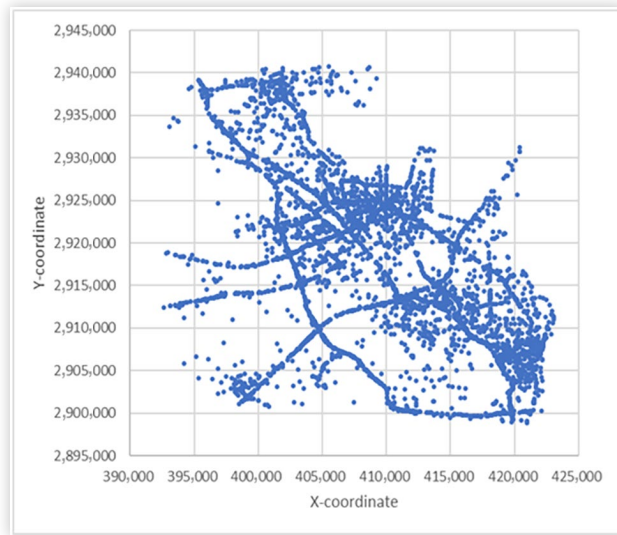
[Figure 15](#) shows that accidents have a relatively similar variation pattern over the years from 2015 to 2019 except falling off bridges, because there is one bridge in the DMA region, which is King Fahad Causeway heading to The

FIGURE 7 Black spots distribution by urban centers in the DMA region: (a) Qatif, (b) Khobar, (c) Dammam, and (d) Dhahran.



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FIGURE 8 X-Y coordinated spatial distribution of accidents in the DMA.



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Kingdom of Bahrain. Figure 16 shows the variation pattern of accidents over weekdays and weekends between 2015 and 2019.

The figure shows no variation in the number of accidents over the weekdays and weekends between 2015 and 2019 in the DMA region. However, the total number of accidents in 2015 Wednesday showed a relatively significant increase in the number of accidents compared to other weekdays. This is related to the unique location of the DMA region between gulf countries and the beginning of the weekend, which allows many visitors from the gulf countries to visit the region for recreation and shopping.

Comparison Analysis A comparison analysis t-test has conducted on the data to test the significance of the difference between the causes and types of accidents and the black spots among the urban centers of the DMA. Table 1 lists the frequency distribution of the causes of accidents and their severity in the region.

Table 2 included a statistical comparison between types and severity of accidents in the DMA region. The results of the t-test in Table 2 shows no significant difference between the frequency of accidents with no injuries, and accidents with injuries. However, there is a substantial significant difference between the frequencies of fatal accidents and other accidents' severity and types. The results were deemed significant if $p < 0.05$. Accordingly, fatal accidents in black spots are significantly different than minor accidents with only damages and injuries accidents.

Table 3 illustrates that sudden turning and distracted drivers caused the highest number of accidents and black spots

in the urban centers of the DMA. Dammam has the highest number of accidents associated with sudden turning, followed by Khobar, Qatif, and Dhahran. Insufficient stopping distance and speeding is the third and fourth causes of accidents in Dhahran, respectively. Khobar has the highest number of accidents associated with distracted driving. Also crossing without a crosswalk (mid-block) is a major cause of accidents in Dammam.

As shown in Table 4, there is no significant difference ($p < 0.05$) between the causes of accidents and the black spots among the urban centers of the DMA. Accordingly, sudden turning and distracted driving are the highest causes of frequency of accidents and black spots in the urban centers of the DMA region.

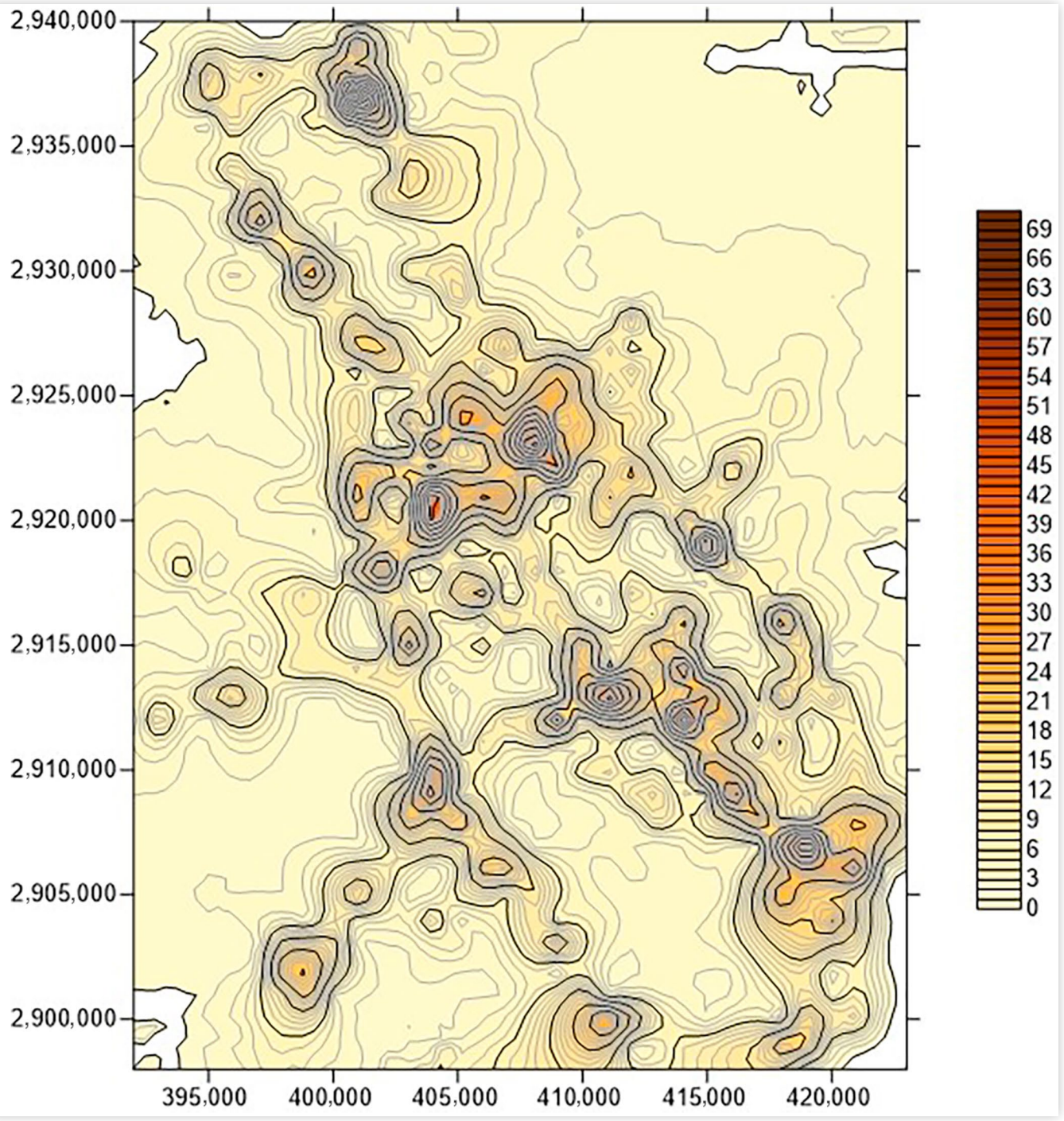
Discussion

Many studies have dealt with accidents and black spots by solutions associated with accident locations [36]. Traffic departments (DOTs) help deploy several solutions at these locations associated with traffic control, changing intersections configuration, traffic calming, and technologies to reduce the frequency and severity of accidents at the location.

However, few studies have investigated broader factors such as population and land use distribution. The frequency of accidents at a location on the roadway network has characteristics similar to the frequency of crimes at a location. Recurring urban crimes at the same location are investigated and solved using local locational solutions including urban design solutions such as lighting and widening sidewalks [37]. Local and locational solutions to black spots include changing the configuration of roadway links and signalized intersections, deployment of information technology systems (ITS), and smart transportation technologies such as cameras and sensors. Also locational solution include calming traffic solutions such as installing fences, pedestrian overbridges, raised intersections, and other calming solutions. Traffic control devices, signs, markings, and segregation of paths should be enhanced at locations with high frequency and severity of accidents. Those studies suggested individual specific solutions to accidents and black spots for a particular location.

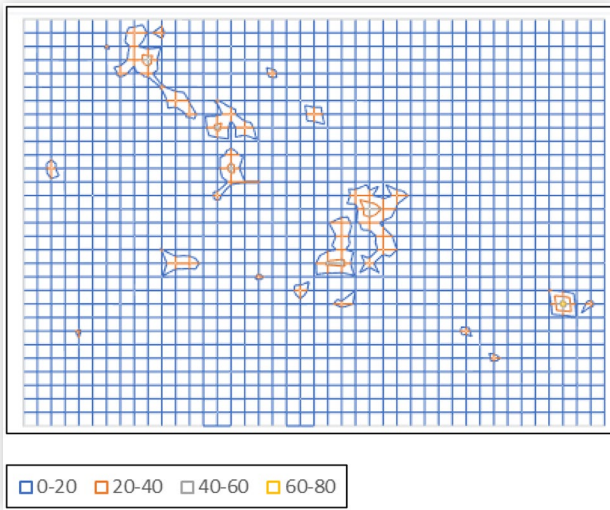
This study presents the current spatial distribution of types, severity, and causes of accidents and black spots in the DMA region of KSA. The study has shown that the frequency and severity of accidents in black spots have no relationship with population or land use patterns. The study found that the primary cause of fatal accidents and black spots is the unprohibited right turn during the red light at the signalized intersections. Comprehensive and locational solutions must be deployed and adopted in the cities of the region.

FIGURE 9 Spatial distribution of black spots in urban centers of the DMA.



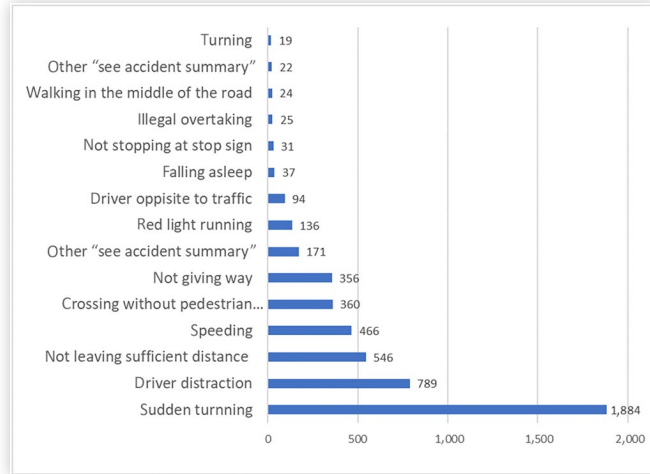
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FIGURE 10 The black spots in the DMA showing the frequency of accidents.



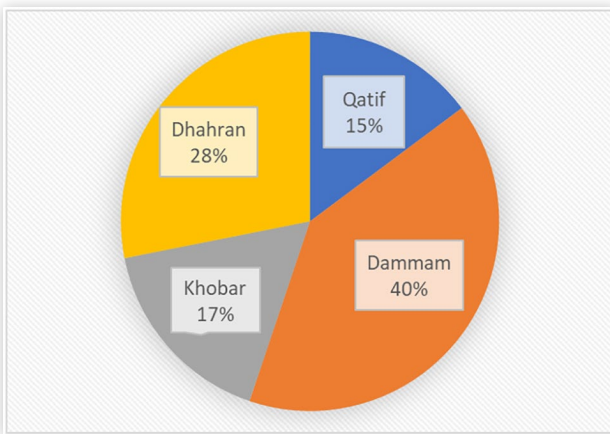
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FIGURE 13 The frequency of the most common causes of accidents (97% of total accidents).



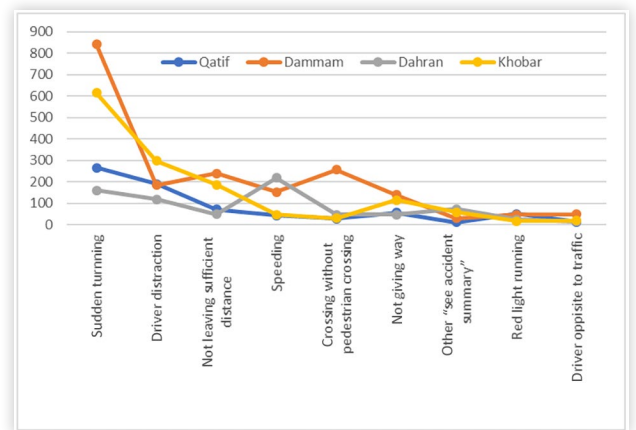
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FIGURE 11 The accidents distribution among cities of the DMA region



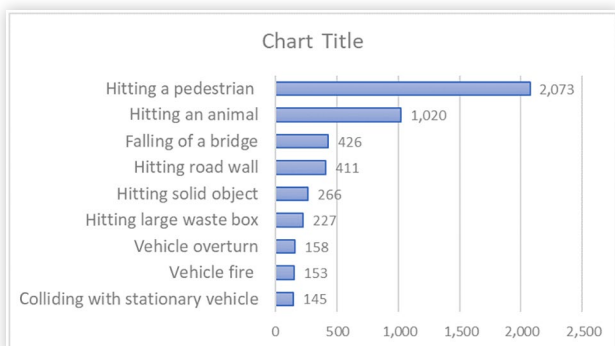
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FIGURE 14 The frequency of the most common accident causes in the four main cities (97% of total accidents).



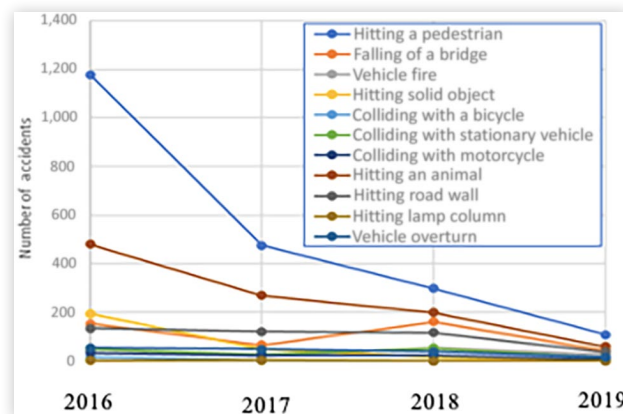
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FIGURE 12 The frequency distribution of the type of accident reported in the DMA (98% of total accidents).

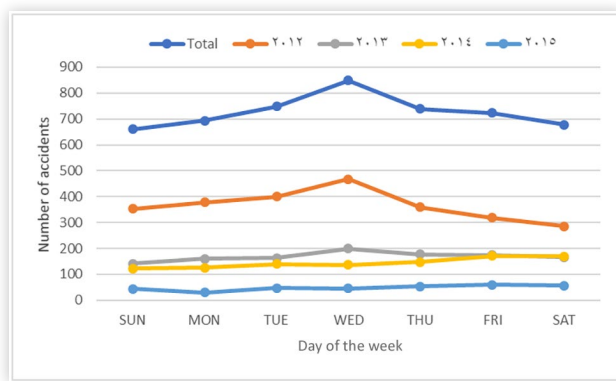


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FIGURE 15 Variation in major accident types, counts for 2015-2019.



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FIGURE 16 Number of accidents vs. day of the week.

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Comprehensive solutions in management and control include shared mobility, ridesharing, alternative transportation services, and real-time information sharing [38]. Providing real-time information through dynamic message signs to road users about congestion levels reduce accidents and then black spots. Also, management and control solutions like improving the services on existing roadway networks such as traffic incident management, traffic signal timing optimization and management, arterial road management, access road management, freeways management, traffic operation control, and road weather management. Also, management and control solutions include work zone management, travel demand management, events traffic planning, and management. These solutions can help reduce congestion, provide better control and management on traffic, reduce accidents and black spot, and enhance roadway traffic safety levels. Locational solution is the prohibition of turning right during the red light at signalized intersections in urban centers of DMA region. Deployment of these solutions by providing and preparing centers for traffic control and management around the DMA, which are not available recently. The Department and Centers of Transportation (DOTs) enhance roadway traffic surveillance, optimize the usage of the current capacity of the roadway network, and improve safety levels through day and night surveillance, supervision, management, and control. It contributes to transportation officials and traffic agencies by offering comprehensive and locational solutions to accidents and black spots in the DMA. The study is presenting the quantitative distribution of accidents and black spots and assists decision-making in deploying single or multiple solutions to transportation and traffic operations in the DMA [39]. Investigating spatial distributions of accidents and black spots help decision-makers and local authorities in traffic control and management to identify solutions associated with traffic calming or changing roadway network configurations, if needed. Other solutions related to ITS and smart transportation can be considered.

The finding of this study leads to a substantial question in roadway traffic safety, which is what is the acceptable number of pedestrians to allow turning right during red light.

TABLE 1 The frequency of accident causes in the black spots, classified according to their severity.

Description	Number of		
	Accidents	Injuries	Deaths
Sudden turning	1884	2596	307
Driver distraction	789	952	116
Not leaving sufficient distance	546	783	57
Speeding	466	562	109
Not giving way	356	532	36
Crossing without pedestrian crossing	360	305	82
Red light running	136	222	15
Driver opposite to traffic	94	135	16
Other "see accident summary"	50	50	9
Falling asleep	37	42	6
Not stopping at a stop sign	31	39	6
Illegal overtaking	25	38	3
Turning	19	27	3
Walking in the middle of the road	24	24	6
Faulty tires	17	24	6
Drifting	16	21	7
Other "see accident summary"	22	20	7
Downhill	13	14	2
Drink driving	8	12	2
Not obeying traffic signs	6	11	1
Exhaustion	6	9	0
Skidding	3	9	1
Violating pedestrian sign	8	8	1
No-warning signs	4	7	1
Unsafe road works	4	7	0
Other "see accident summary"	5	5	0
Overloading	2	5	0
Getting out of a vehicle before stopping	5	4	1
Hanging on the outside of a vehicle	4	3	1
Illegal parking	2	2	0
Sitting on top of a vehicle	2	2	0
Sitting on the trunk of a vehicle	2	2	0
Playing on the road	2	2	0
Faulty breaks	2	2	2
Larger loads (exceeding vehicle dimensions)	1	2	0
No traffic signal	1	1	1

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For example, in New York City, turning right during red light at signalized intersections is prohibited. The prohibition of turning right during red light at signalized intersection in New York City related to the high number of crossing pedestrians. Thus, New York City is the only part in the United States of America where turning right during red is prohibited. Other states in the United States of America allow turning right during red [40].

TABLE 2 P-values of the t-test of the severity of accidents in black spots.

Type and severity of accidents	P-value
Minor Accidents and Injuries Accidents	0.05
Minor Accidents and Fatal Accidents	0.02
Injuries Accidents and Fatal Accidents	0.03

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TABLE 3 Frequency of accident causes classified by the cities in the DMA.

Description	Qatif	Dammam	Dhahran	Khobar
Sudden turning	265	841	159	614
Driver distraction	189	184	118	297
Not leaving sufficient distance	71	239	48	186
Speeding	42	152	218	47
Crossing without pedestrian crossing	28	256	46	30
Not giving way	55	139	47	115
Other "see accident summary"	11	29	73	58
Red light jumping	50	47	23	16
Driver opposite to traffic	12	49	15	18
Falling asleep	0	27	7	3
Not stopping at the stop sign	3	20	5	3
Illegal overtaking	7	1	1	16
Walking in the middle of the road	3	4	16	1
Turning	4	6	4	5
Faulty tires	4	3	5	5
Drifting	3	8	4	1
Downhill	0	13	0	0
Sum	747	2018	789	1415

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TABLE 4 P-values of the t-test of the accident causes in the black spots between the cities of the DMA.

Cities of DMA region	P-value
Between Qatif and Dammam	0.17
Between Dammam and Dhahran	0.18
Between Dhahran and Khobar	0.38
Between Qatif and Dhahran	0.91
Between Qatif and Khobar	0.36
Between Dammam and Khobar	0.57

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Conclusion

This study found that differences in population, land use activities, traffic conditions, regulations, and prevailing traffic conditions are not associated with the spatial distribution of black spots and the accident causes, types, and severity levels. This finding suggests that mitigation solutions to black spots must be conducted locally at the location. The black spots in DMA require urgent locational solutions to reduce the number of injuries and fatal accidents, such as building and providing pedestrian bridges, isolation fences, and other traffic calming solutions. The study also found that there is a significant difference between the severity of accidents associated with its causes.

This study found that the spatial distribution of black spots is similar to the spatial distribution of signalized intersections in the urban centers of the DMA. The collected data in [Tables 1 and 3](#), [Figures 12, 13, and 15](#) of this study showed that the highest cause and type of accidents in black spots in the DMA is hitting pedestrians while suddenly turning [\[41\]](#). The most frequent type and cause of accidents in DMA region proved that the unprohibited right turn during red light is the major cause of frequent occurrence of accident at signalized intersections. The spatial distribution of black spots (frequent occurrence of accident at a location) has supported this finding [\[41\]](#). Accordingly, this study concluded that allowing the right turn during the red light at the signalized intersections in DMA increases the frequency of hitting pedestrians by suddenly turning accidents. Therefore, right turns during red lights must be prohibited at the signalized intersections in the DMA.

Acknowledgment

The author would like to thank traffic department in Dammam Metropolitan Area and The Saudi American Oil Company for supporting this study with the required data. Also the author would like to thank Mohamed alshammari, ayham Ibrahim, and nader Alsyaseb from the tourism authority of DMA for maps preparation in GIS. The author also thanks Editage (www.editage.com) for English language editing.

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