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The temporal and spatial relationships between professional sport events and reported vehicular crashes: an analysis of Cleveland, Ohio

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ABSTRACT

Road safety is one of the world's greatest public health challenges, with more than 3,500 deaths on the roads each day and estimated 50 million injuries annually (World Health Organization, 2021). This study explores the relationship between professional sporting events and vehicular crashes by examining crash data, game times, and venues using longitudinal data from Cleveland, Ohio (2017–2019). We employ two multivariate modeling analyses and spatial statistical techniques to examine the extent to which sporting events are related to car crashes before, during, and after events and the spatial relationship between where the venues are located and the number of crashes. The temporal analyses (n = 28,260) show that crashes with damage reported a significant increase, particularly after the more attended NFL games. Meanwhile, a spatial analysis (n=741) shows that the location of the sports venue also demonstrates associations with the number of crashes, while the significance varies across spatial distances. From a scholarly perspective, our study identifies the relationship between sports events and car crashes nearby sports venues, which adds to the broader literature on vehicular crashes and society. Practically, addressing this relationship can provide a concise strategy for both the public and private sectors to reduce car crashes.

KEYWORDS
Car crashes; sport events; venues; spatial analysis

1. Introduction

Road safety is one of the world's greatest public health challenges. More than 3,500 people die on the roads each day globally, in addition to estimated 50 million injuries annually (World Health Organization, 2021). As the eighth leading cause of death worldwide (Tumwesigye et al., 2016), vehicular crashes have evolved to become an expected by-product of modern life (Vardi, 2014). This study examines the relationship between sports venues, events, and vehicular crashes from the perspective of negative externalities related to sports. Motivated by Cleveland's decision to join the Vision Zero initiative, our analyses examine extensive publicly recorded crash data in Cleveland prior to when the city officially launched the initiative in 2021. A few studies have examined the relationship

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between sporting events and vehicular crashes. Closing this gap in the literature is particularly important amid the increased attention to social issues in sports management studies. The present study explores the relationship between elite professional sporting events and vehicular crashes.

To examine the relationship between sporting events, venues, and vehicular crashes, we employ two multivariate modeling analyses to answer these two separate but related research questions. First, we examine the extent to which sporting events are related to an increase in car crash crashes before, during, and after events. Second, we examine the spatial relationship between where the venues are located and the number of crashes. The results of this study have three key outcomes. The first is to provide the city of Cleveland, and many other American cities, with relevant evidence to make informed policy decisions to achieve the goals of Vision Zero and other initiatives. The second outcome is to build upon a niche, yet important, line of scholarship examining the relationship between sports events and vehicular crashes from a negative externalities framework, while the third outcome of this study is the incremental addition to the broader literature on vehicular crashes and society.

We begin with a brief review of research examining the negative externalities associated with sports venues and the narrow scholarship regarding sporting events and vehicular traffic, as well as the broader scholarship of vehicular crashes. Next, we discuss the city of Cleveland, OH, regarding its crash data and its recently adopted commitment to Vision Zero. Then, we analyze the data through temporal and spatial analyses and present the results. In conclusion, we examine our findings relative to the literature and provide final insights on sport management and vehicular crash intervention.

2. Literature review

2.1 Sport events, negative externalities, and vehicular crashes

Sports venues, and the events occurring in them, incur direct societal and economic measurable impacts. These direct impacts are vital, particularly for the organizations involved. Externalities, which are the indirect impact of events and venues that are felt by other parties, though, can have a greater positive or negative societal impact, such as an increase in happiness and physical activity or, alternatively, an increase in traffic congestion (Humphreys & Pyun, 2018; Orlowski & Wicker, 2019; Storm & Jakobsen, 2021). Within the sports scholarly work, externalities have typically been used to measure the economic impact of new sports venues and the justification for public expenditure (Hyun, 2022; Johnson & Whitehead, 2000; Matheson, 2019). Recent studies have emphasized the importance of environmental and social externalities related to sports events, such as the air pollution associated with fan travel (e.g., McCullough et al., 2019) and criminal activity that can be related to sports events (e.g., Jakar & Gordon, 2022; Pyun et al., 2020). Scholars have examined vehicular traffic in a variety of ways outlined in the following examples.

Humphreys et al. (1983) conducted an exploratory study to examine various “nuisances” that equated to negative externalities associated with a British football venue, with a particular focus on heavy traffic and congestion. They found how the general nuisance field of the grounds was limited in geographical extent and was not continuous.

While the general nuisance field declined in intensity with distance, the decline was not constant. Vehicular traffic, though, was the most spatially extensive negative externality, declining only gradually with distance from the venue. Traffic, interestingly, was not as great in the venue's immediate vicinity – within 500 m – as in 500 to 1,000 m from the grounds. Mills and Rosentraub (2014) examined border crossing data to assess Canadian residents' practice of attending games for the NHL's Buffalo Sabres and how the price and quality of Toronto Maple Leafs games, whose home venue is 99 miles away from the Sabres arena, impacted these travel decisions. Notably, their analysis suggested how Sabres games resulted in an increase of about 1,150 passenger cars crossing the border when the Sabres played a US-based opponent, more than 1,750 cars when they played a Canadian team other than the Maple Leafs and over 2,700 passenger cars when the Sabres hosted the Maple Leafs.

Zagidullin (2017) used a variety of simulations to model road traffic during major sporting events to facilitate more efficient transportation. The mathematical model used in this study led to the conclusion that an increase in travel time of transportation flow can be explained generally by the growth of intensity of the background road traffic to a greater degree than by the intensity of public transportation and the specific transportation for the major sporting event. Finally, Humphreys and Pyun (2018) studied the relationship between MLB games and vehicular traffic by examining urban mobility data from 25 metropolitan statistical areas with teams from 1990 to 2014. The authors found that MLB-related travel accounts for, at most, 0.5% of annual metro area vehicle-miles traveled (VMT) in MLB host cities. MLB's average annual attendance of 2.8 million people caused an increase of about 5 million VMT, which is about 28,000 additional hours of traffic delay annually, and traffic congestion was also worse in metro areas with MLB teams. Humphreys and Pyun (2018) noted that cities hosting other professional sports franchises ought to be examined.

Propheter (2020) analyzed the impact of an NBA team's migration from a home venue in the suburbs to the urban core on the negative externality of police response time. His study compared daily police incident data in Sacramento, California. Police response time to incidents within one-fourth mile of the new venue's location in the downtown area during event periods was on average 7.4% longer, or about 33 seconds, during event periods after the downtown arena was built compared to incidents further away. Propheter (2020) noted that social costs attributed to sports facilities may vary depending on the built environment in which they are located and how emergency response times are a frequently used performance metric for local government, which suggests locating elite venues in the urban core may "entail political costs of unknown magnitude" (p. 279).

While a small number of studies have examined vehicular traffic impacted by sporting events, there appear to be just two studies examining vehicular crashes associated with sporting event-related traffic. Redelmeier and Stewart (2003) demonstrated a 41% relative increase in the average number of traffic fatalities across 27 Super Bowl Sundays after the respective game telecasts. In another study of sporting events and vehicular crashes, Wood et al. (2011) examined the potential correlation between spectators' alcohol consumption, vehicular crashes, and "good," elite, basketball and football games, which were determined by the closeness of their scores. Game day fatalities for a given event were positively associated with the closeness of the game's outcome at the game location; games with closer scores led to more traffic fatalities than "blowout" games. They noted that, "[I]t may be fair to say on any given day, the danger of a close game is as detrimental as the absence of seat belt laws" (Wood et al., 2011, p. 614).

2.2 Vehicular crashes and society

Scholarship involving vehicular crashes is robust and exists across six different themes, some of which overlap: geographic, crash causes, medical, financial impact, vehicular type, and technology and have been studied in different geographic areas and scales (e.g., Getahun, 2021; Hamzeh et al., 2016; Otero & Rau, 2017). Notably, the urban built environment and land-use patterns have been widely recognized for their impact on people's travel and driving behavior, including vehicular crashes (Berkovitz, 2001; Kim et al., 2006; Rahman et al., 2020).

Kim et al. (2006), for example, found a higher degree of activities around parks, commercial areas, and schools were positively and significantly associated with vehicle crashes based on data from Hawaii. Another study demonstrated that commercial areas are positively related to greater traffic collisions in general and to the degree of injury severity within crashes in Hong Kong using Bayes analysis (Yang & Loo, 2016). Other empirical methods have included a generalized structural equation model (Xie et al., 2019) and geographically weighted regressions (Rahman et al., 2020). A positive statistically significant relationship was noted in both studies between crashes and geographical and land-use attributes.

Studies analyzing the cause of vehicular crashes hold different approaches, ranging from the engineering design of road systems (Berkovitz, 2001) to the analysis of driving behavior that leads to the increased risk of vehicular crashes (e.g., Hong et al., 2015; Noh et al., 2017; Taylor & Bramoweth, 2010). In the latter, the focus is often on the examination of internal factors, such as alcohol consumption, drug use, and digital device distractions, and some research investigating the relationship between driver demographics (e.g., age) and psychographics (e.g., risk tolerance) on the likelihood of collisions. The impact of vehicular crashes was examined from different perspectives including the extent of physical harm (e.g., Fakharian et al., 2017; Petit et al., 2018), the economic impacts on individuals and industries (e.g., Dimitriou & Poufinas, 2016), and the impact on industries such as the insurance industry (e.g., Blows et al., 2003; Yakovlev & Orr-Magulick, 2018). Some research has examined the influence of specific vehicle types (e.g., autonomous vehicles, motorcycles, and light trucks/sport utility vehicles) and/or shapes on both the quantity and quality of collisions (e.g., Bonnefon et al., 2016; Guibing et al., 2017; Oikawa et al., 2021; Yuen et al., 2020).

Several key points regarding the relationship between vehicular crashes and broader society emerged from the literature. Goniewicz et al. (2017), for example, noted that the first collision of two cars occurred in 1893, while today fatal car crashes occur every 50 s and injuries occur every 2 s. Vardi (2014, pp. 352–353) asserted how vehicular crashes "have long constituted a widespread troubling condition in the United States" as more than 3 million Americans have been killed on roads since the first recorded fatality occurred on September 13, 1899. Vehicular crashes are now the eighth leading cause of death around the world (Tumwesigye et al., 2016). Verbavatz and Barthelemy (2019) found that a city's area size is positively associated with an increase in car crashes and the density of public transport associated with a decrease in crashes were the most relevant variables that influence urban traffic congestion. While urban factors are significant indicators, car types are also indicative of the increase and decrease in accidents, as well the personal economic severity of the accident (Anderson, 2008; Li, 2012; White, 2004).

Vardi's (2014) ethnographic content analysis of the historical discourse surrounding vehicular crashes provides an interesting examination of the ways in which American society has evolved to view them as an acceptable outcome of modern life. The automobile industry's co-optation of the railroad industry's notion of "passenger mile" since the 1920s has enabled the use of "fatality rate per mile" as the dominant metric for assessing "the traffic accident problem" in the US. The metric has continuously been the "central statistical means by which to demonstrate progress in safety or counterbalance alarmist claims about accidents" (2014, pp. 352–353) for over a hundred years, which has shifted the perspective of vehicular crashes from a "moral wrong" to a "necessary evil." Correspondingly, Vardi (2014) asserted that numerical claims-making has historically enabled policymakers and automobile manufacturers to place responsibility onto individual drivers and largely ignore the structural causes of crashes, which include the influence of spatial factors, such as the built environment and demographic factors, such as drivers' socio-economic status (Males, 2009). Thus, while the relationship between sporting events and vehicular crashes has been largely unexamined, the broader literature regarding vehicular crashes and society is robust yet thematically diverse. The impact of professional sports venues, the events held within them, and the urban environments in which they take place on vehicular crashes, though is important and needs to be examined more fully.

3. Cleveland's car crash statistics, distribution, and initiatives

Motor vehicle crashes, and the consequential physical, mental, and financial implications related to them, are strongly correlated with the increase in the use of private transportation and related technological advancements. According to the U.S. Department of Transportation Bureau of Transportation Statistics, while the number of overall crashes in 2019 was estimated at around 6,756,000 compared to 6,323,000 in 2001, the number of fatalities was 36,096 in 2019 compared to 42,196 in 2001. Despite this decrease in fatalities, vehicular crashes remain a troublesome issue concerning personal, physical, and property harm that cities and countries have attempted to address by introducing new laws, policies, and initiatives. One of those initiatives is the Vision Zero Network, which is a collaborative campaign between cities throughout the world involving the pursuit of policy changes and local initiatives aimed at reducing the number of collisions to create safer environments. Cleveland officially joined the Vision Zero initiative in 2021 following the City's resolution to join the initiative passed by the Council in August 2018. In line with Vision Zero's emphasis on preventing fatal traffic-related incidents and serious injuries, the objective of the current study is to identify potential risk factors associated with the temporal and spatial factors around sports venues and events through advanced data analysis and contribute to evidence-based policies toward achieving the goal of "Vision Zero".

In 2019, there were 1,039 fatal crashes in Ohio, 79 of those were in Cuyahoga County, where Cleveland is located. There were also 722 crashes involving potentially serious injuries and a total of 33,955 crashes in the county. Cleveland's agenda is a response to these car crash statistics and, as the city's Vision Zero website states (https://www.visionzerocle.org/), "Vision Zero Cleveland will eliminate serious injuries and deaths from crashes on Cleveland roads through clear, measurable strategies to provide safe, healthy, and equitable mobility for all".

Cleveland is home to professional sports franchises competing in three of the four major professional sports leagues in the U.S.: NFL, MLB, and NBA. Only the National Hockey League (NHL) is not represented by a franchise in Cleveland. This study, while contributing to the scholarly research on the analysis of negative externalities associated with sports venues and events, will contribute to the estimation of unintentional contributors, such as sporting events, that may be related to the increase in the number of crashes or shifts in the spatial and temporal distributions of collisions. Hence, it is important to identify the spatial distribution of vehicular crashes depicted in Figure 1 and then provide a more extensive analysis of crashes using both temporal and spatial analyses described in the next section.

Cleveland's geographical features, particularly its transportation pattern, are primarily shaped by its location along Lake Erie, which is the fourth largest of the five Great Lakes in North America. The city's main roads follow this pattern, connecting east and west and north and south and stretching along the city's outskirts. There is a clear downtown area in the city's center and near the waterfront where all three major professional sports venues are also located. Figure 1 depicts the distribution of car crashes between 2017 and 2019, the major highways and roads in and around the city, and the city's borders. A clear cluster of collisions was recorded near downtown, as were three other clusters that are near the main highway intersections (Figure 1 – bottom right corner). We have two hypotheses. The first is temporal; events are associated with an increase in the number of crashes before and after the events. The second is spatial; the areas near the venues are associated with an increase in the number of vehicular crashes, which therefore emphasizes the relevance of accounting for an increase or decrease in crashes when and where events take place.

4. Methods and data

In this study, we investigate both the temporal and spatial relationships between reported vehicular crashes and sports events. We first examine the hourly aggregated data and when sporting contests (including pre-season and post-season ones) take place to test the null hypothesis where the number of car crashes is not positively or negatively associated with sporting events throughout 2017–2019. Our second analysis focuses on the spatial distribution of motor vehicle collisions using equally sized cells capturing the environmental characteristics of Cleveland. We describe each of the models in the following paragraphs. Limitations in each of the models are that they do not include certain physical conditions, such as road works, possibly related to the volume of car traffic. Despite these limitations, the models still provide insightful data relevant to the relationship between sports venues, events, and the number of vehicular crashes. Our primary source for the 2017–2019 accident data is from the Ohio Department of Public Safety, which includes substantial data included in this study. Game time data was collected from the baseball-reference, pro-football-reference, and basketball-reference

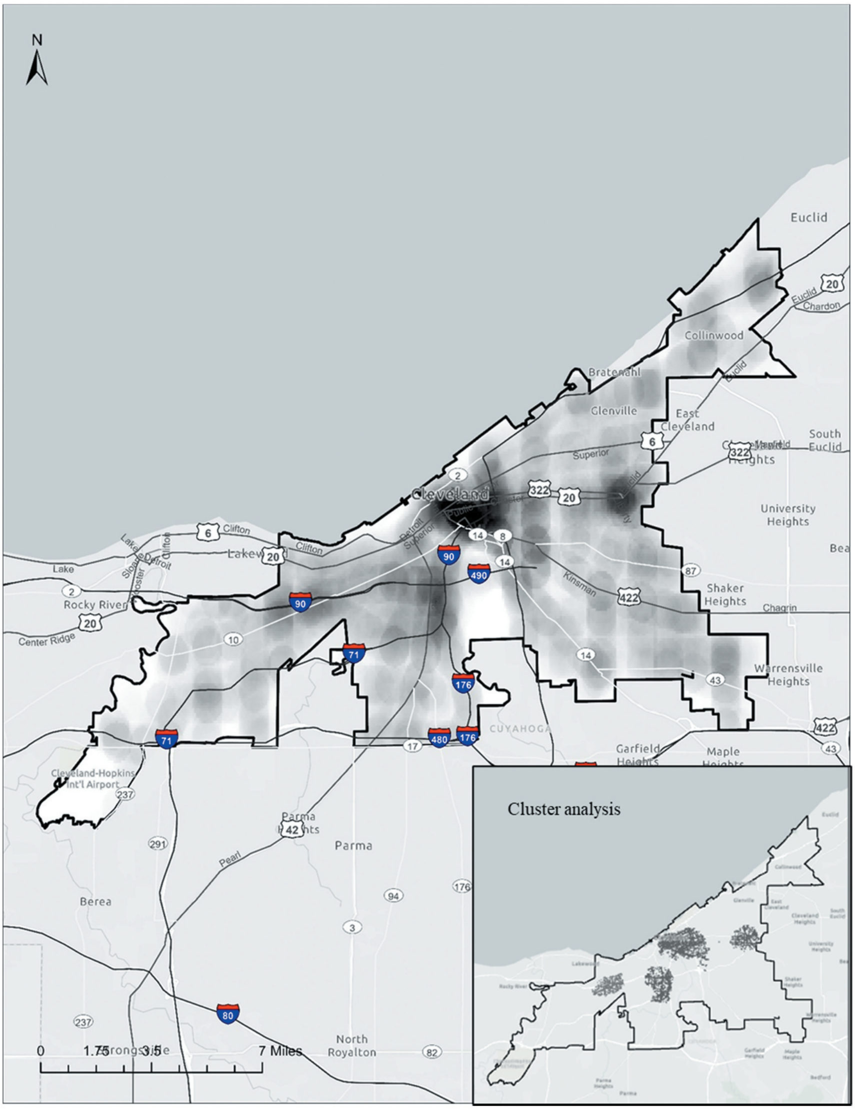

Figure 1. Spatial distribution and cluster analysis of Cleveland's car crashes (2017-2019).

websites for the game times. Sunrise and sunset data were collected from https://sunrise.maplogs.com/. Data specifically for the spatial analysis, including land use and roads, were collected from the Cuyahoga County Open Data website.

4.1 Temporal analysis

Temporal analysis of the data is based on a Negative Binominal Regression (NBR) following previous studies that examined count data related to vehicular crashes and other events such as crime (Chang, 2005; Garnowski & Manner, 2011). Negative Binomial Regression for the count data is used in this study because the mean value (μ) does not equal the standard deviation (σ) in the dependent variable in our dataset, which does not fit the analytical assumption of Poisson Regression (Wooldridge, 2012),

Weather conditions during a specific day were included, noting if at some point during the day there was some form of precipitation and other bad weather conditions potentially impacting other hours in the day. Weather and daylight capture the environmental factors affecting the probable increase in car crashes (Razi-Ardakani et al., 2018). Variables including time, day, month, and year capture seasonal effects and weekends versus weekdays. Finally, we include 2 hours before and after games, and hours during games, to account for the potential changes associated with the games. The selections of 2 hours before and after are somewhat arbitrary but were selected to account for the potential activities before games near the venues and arrival time to the game and departure time from the game and the likelihood that other factors are likelier related to incidents before the two-hour marks (Copus & Laqueur, 2019).

This study's focus is on the relationship between sporting events and crashes at the venues; therefore, we do not include the few, other, large cultural events delivered in the venues. We assess the temporal relationships and their association with sporting events and venues using three different datasets: crashes within three and five miles of the venues and city-wide crashes. These three models were set up to identify if the association between sporting events and crashes is greater near the venues compared to the entire region. During the model construction process, we examined the relationship between car crash incidents and game attendance, by incorporating the interaction terms of attendance data with the game hours. As a result, the robustness of the model decreased overall. Based on the caution regarding the relatively small variance within the attendance data, we decided not to include the attendance variables within our final modeling approach.

$$Accidents_i^j = \alpha_i + Weather_i * \beta_1 + Light_i * \beta_2 + \sum_{h=3}^{h=26} Hour_{i_i} * \beta_h + \sum_{d=27}^{d=33} Day_i * \beta_d + \sum_{m=34}^{m=45} Day_i * \beta_m + Year_i * \beta_{46} + Holiday_i * \beta_{47} \; PreGame_i * \beta_{48} + Game_i * \beta_{49} + PostGame_i * \beta_{50} + \varepsilon \quad (1)$$

Where *i*, is the count of accidents, cars involved, and property damage accidents in each hour, *j* represents the three distance-based models and if the model includes all games or each league separately, α is the intercept, $\in$ is the error term, and β represent the different coefficients. Weather (*Weather*) variables are categorized as dry or wet. Daylight or dark (*Light)* is categorized as daytime (0) or nighttime (1). Time variables include the hour in the day (*Hour*), the day of the week that also accounts for weekends (*day*), the month of the year (*Month*) and the year (*Year*) to account for any potential yearly changes. Our final variables include whether there was a home game at a given hour in one of the three venues (*Hgame*), an away game at a given hour (*Agame*), 2 hours before the home game (*PreHome*), 2 hours before the away game (*PreAway*), 2 hours after the home game (*PostHome*) and 2 hours after the away games (*PostAway*). MLB games and NBA games are listed as 3 hours and the NFL games are 4 hours based on average game times. Table 1 displays the summary statistics for the hourly data included in the analysis

Table 1. Summary statistics for the temporal analyses (n = 26,280).

	All				5 Miles			3 Miles			
Variable	Mean	Std.dev.	Min	Max	Mean	Std.dev.	Max	Mean	Std.dev.	Max	Description
Crashes	3.859703	3.515794	0	56	1.128387	1.330456	10	0.562633	0.864919	7	Number of crashes at given hour
Night	0.488432	0.499876	0	1	0.488432	0.499876	1	0.488432	0.499876	1	Dark at given hour
Weather	0.490373	0.499917	0	1	0.490373	0.499917	1	0.490373	0.499917	1	Weather condition not good on given day
Hour	12.5	6.922318	1	24	12.5	6.922318	24	12.5	6.922318	24	Hour of the day
Day	4	1.999125	1	7	4	1.999125	7	4	1.999125	7	Day of the week
Month	6.509589	3.448796	1	12	6.509589	3.448796	12	6.509589	3.448796	12	Month
Year	2018	0.816512	2017	2019	2018	0.816512	2019	2018	0.816512	2019	Year
Christmas	0.00548	0.073822	0	1	0.00548	0.073822	1	0.00548	0.073822	1	Christmas eve and day
July 4th	0.00274	0.052272	0	1	0.00274	0.052272	1	0.00274	0.052272	1	July 4th
Thanksgiving	0.00274	0.052272	0	1	0.00274	0.052272	1	0.00274	0.052272	1	Thanksgiving Day
Game	0.092922	0.290329	0	1	0.092922	0.290329	1	0.092922	0.290329	1	Game at given hour
BGame	0.061225	0.239748	0	1	0.061225	0.239748	1	0.061225	0.239748	1	Two hours before a game
AGame	0.061301	0.239887	0	1	0.061301	0.239887	1	0.061301	0.239887	1	Two hours after a game
GameH	0.047222	0.212118	0	1	0.047222	0.212118	1	0.047222	0.212118	1	Home game at given hour
BGameH	0.030974	0.173251	0	1	0.030974	0.173251	1	0.030974	0.173251	1	Two hours before a home game
AGameH	0.031012	0.173354	0	1	0.031012	0.173354	1	0.031012	0.173354	1	Two hours after a home game

for the entire city, accidents within five miles of the pro-sport venues, and accidents within three miles of the pro-sport venues.

4.2 Spatial analysis

We first examine the overall spatial distribution of vehicular crashes in ArcGIS using a machine-learning based algorithm that identifies clusters within the city shown in section three of this study. The second step of the spatial analysis was to divide the city into equally (0.11 square miles) sized cells using ArcGIS, which was also used to aggregate data for each of the 741 cells created for the regression analysis. By analyzing the data spatially, we include variables in the dataset that are spatial rather than temporal. Our hot-spot analysis was done on ArcGIS and is based on the statistical analysis of differences in each of the cells, identifying statistically significant hot-spots and cold-spots. In the regression model, we include land use data, which entails the percentage of residential land use, the percentage of commercial and retail, and the percentage of parks and recreational space, highway road intersection, and distance to the sports venues. We also include a variable to control for the spatial autocorrelation. The dependent variable is the number of vehicular accidents within each cell within our time scope.

$$Accidents_i = \alpha_i + \%Residential_i * \beta_1 + \%Commercial_i * \beta_2 + +\%Green_i * \beta_3 + Junctions_i * \beta_4 + Sport\ Buffer_i * \beta_5 + w * \gamma_i + \in \quad (2)$$

Where for each cell we test the association between the dependent variable, i.e., the number of accidents in each *I*'th cell, and the independent variables, while controlling for the spatial autocorrelation term. Our independent variables include both the land use characteristics, transportation access, and the adjacency to major sports venues. Specifically, the land use characteristics are measured by the percentage of land use, the percentage of residential land use (*residential*), the percentage of commercial land use (*commercial*), and the percentage of parks and green spaces (*green*). Transportation access is measured by the number of major intersections (*Junctions*). To account for the location of the venues, we include a series of spatial dummy variables, based on buffers from each major sports venue ranging from half mile, one mile, three miles, to five miles.

The spatial autocorrelation is taken into consideration because some cells can potentially be cut-off near intersections that can still be dependent on the nearby cell. We conducted Moran's I test in ArcGIS to detect the spatial autocorrelation between each built environmental variables, using inverse distance as the conceptualization of spatial relationships: highway, junction, residential land-use, commercial land-use, industrial land-use, green space, as well as utility. According to the results, Sig: commercial (Moran's I index: 0.35, $p < 0.01$), green space (Moran's I index: 0.087, $p < 0.01$), industrial (Moran's I: 0.331, $p < 0.01$), residential (MI: 0.506, $p < 0.01$), junction (MI: 0.23, $p < 0.01$). We use Geoda to create the spatial weight and calculate the spatial lagged variables using the Queen contiguity and the first order. Descriptive statistics for the data included in the spatial analysis are summarized in Table 2.

Table 2. Descriptive analysis for variables used in the geographically weighted negative binomial regression (n = 741).

Variable	Mean	Std. Dev.	Min	Max	Description
Log(number of crashes)	3.4816	1.1862	0	6.0707	Number of crashes in cell i
% Commercial	10.8051	17.1669	0	100	% of the cell that is commercial
% Commercial (sp. Lag)	10.9431	10.0885	0	66.7934	Spatial lag of the % of the cell that is commercial
% Green space	5.5085	15.3200	0	100	% of the cell that is green space
% Green space (sp. Lag)	5.4637	7.0575	0	70.9580	Spatial lag of the % of the cell that is green space
% Residential	46.5885	35.6925	0	100	% of the cell that is residential
% Residential (sp. Lag)	47.0141	25.1147	0	97.2511	Spatial lag of the % of the cell that is residential
Highway Intersection	0.3792	1.0895	0	10	Number of intersections
Highway Intersection (sp. Lag)	0.3713	0.5404	0	3.2	Spatial lag Number of intersections
Sport Venue _ half mile buffer	0.0310	0.1735	0	1	Cell within half mile from venues
Sport Venue _ 1 mile buffer	0.0689	0.2533	0	1	Cell within a mile from venues
Sport Venue _ 3 mile buffer	0.2740	0.4463	0	1	Cell within three miles from venues
Sport Venue _ 5 mile buffer	0.6019	0.4898	0	1	Cell within five miles from venues

5. Results

5.1 Temporal analysis

Analyses of the temporal data examined the relationship between the number of crashes in each of the hours between 2017 and 2019 and based on the different iterations of distance, all games and only home games, and for each league separately resulted in 108 iterations. We report the results for the control variables including the holiday variables only from the models including all the games, but other results are available upon request (Table 3).

The results indicate the positive relationship between darker hours (Night) and an increase in the percentage of vehicular crashes, with the results statistically different than zero in all six models. Results related to darker hours are important given NBA games are

Table 3. Control variable results for the models including all the games.

	All games			Home games		
VARIABLES	All	5 miles	3 miles	All	5 miles	3 miles
Night	0.177***	0.179***	0.0965***	0.0970***	0.119***	0.126***
	(0.02)	(0.02)	(0.03)	(0.03)	(0.04)	(0.04)
Weather	0.0747***	0.0750***	0.0404*	0.0409*	0.0413	0.0423
	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
2018	0.00818	0.00819	0.00563	0.0056	0.0152	0.0151
	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
2019	0.0211*	0.0209*	0.114**	0.114**	0.109**	0.108**
	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
New Year	0.0489	0.0512	0.0937	0.096	0.0604	0.0669
	(0.06)	(0.06)	(0.09)	(0.09	(0.12)	(0.12)
Christmas	−0.479***	−0.477***	−0.562***	−0.560***	−0.612***	−0.606***
	(0.07)	(0.07)	(0.11)	(0.11)	(0.16)	(0.16)
July 4th	−0.423***	−0.424***	−0.388***	−0.387***	−0.451*	−0.448*
	(0.09)	(0.09)	(0.14)	(0.14)	(0.2)	(0.2)
Thanksgiving	−0.666***	−0.664***	−0.535***	−0.534***	−0.673***	−0.671***
	(0.1)	(0.1)	(0.15)	(0.15)	(0.21)	(0.21)
lnalpha	−2.068***	−2.068***	−2.150***	−2.150***	−2.046***	−2.049***
	(0.03)	(0.03)	(0.07)	(0.07)	(0.12)	(0.12)
Constant	0.186***	0.185***	−0.843***	−0.843***	−1.577***	−1.581***
	(0.04)	(0.04)	(0.06)	(0.06)	(0.09)	(0.09)
Observations (Hours)	26,280	26,280	26,280	26,280	26,280	26,280

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

played more often in the evenings, hence the results for the relationship between NBA games and an increase in the percentage of crashes are indicative of an increase in the percentage of car collisions in addition to the increase related to darker hours. Similarly, interpretation of the results for NFL and MLB games will take into consideration the different game times, as well as the considerable number of NFL games played on Sundays. A slight increase in crashes is also recorded on days with precipitation at some point during the day, though the results were not always statistically significant. Of the holiday variables, New Year's Day is the only variable with non-statistically significant coefficients, whereas the other holidays are associated with a decrease in the percentage of accidents overall and are statistically significant throughout the models. This can be explained because there is substantially less work-related travel and commercial activity. Time-related variables indicate that relative to Monday, there is a substantial decrease in the percentage of car accidents during the weekend and a slight increase in the midweek. The results in all six models were statistically different than zero (Figure 2 – top). Hourly coefficients were statistically significant in all six models and indicate the peaks in the evening hours (Figure 2 – bottom).

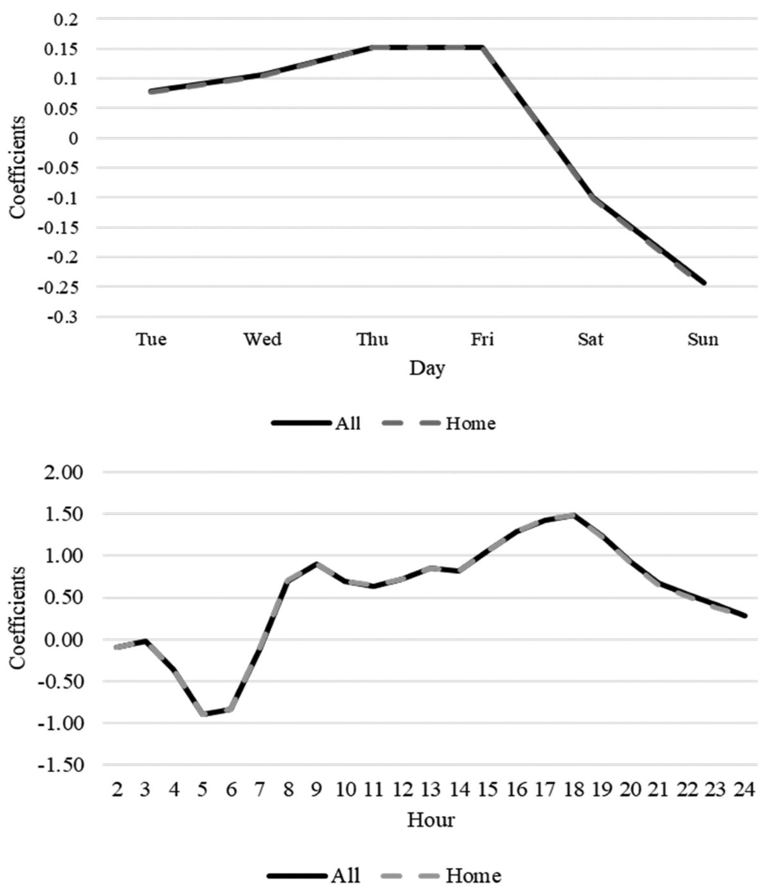

Figure 2. Day of the week and hourly coefficients in the models including all games and all home games.

Table 4 outlines the results from the 72 regressions examining the relationship between the percentage increase in crashes and the hours before the game, during the game, and after the game. The models include results from the models examining each of the three dependent variables including all crashes, number of cars involved in crashes, and number of crashes that specifically involved damage and not injuries. Coefficients in Table 4 indicate if they were statistically significant and if the relationship between the hours before, during, and after the game was positive or negative.

When including all the games and data in the model, the only statistically significant coefficient is the positive relationship between the number of crashes involving only damage during home games. This result is likely due to the results in the MLB specific model that in each of the home-game models indicate a positive relationship between accidents overall, number of cars, and damage-related accidents during game-time. Given the spatial context of the model covering the entire region, these data may be related to other factors. Models including data for the entire region focused on NFL games point to an overall decrease during games and the hours after the game, which may have a similar indication to the reduction in crime during football games in Chicago (Copus & Laqueur, 2019). In both the five- and three-mile models, including all games, there is a statistically significant and positive relationship between the number of overall crashes and the number of cars involved and the hours after games. There is what appears to be an approximate 20% increase in vehicular crashes in the hours after the games within three miles of the venues. This increase in the number of crashes is particularly noticeable when NFL and NBA home games are played, which can be related to as much as a 33% increase in the number of crashes during the hours after the games.

5.2 Spatial analysis

In addition to the temporal analysis conducted above, we constructed a set of spatial analyses using the Geographically Weighted Negative Binomial Regression (GWNB). The rationale for choosing GWNB is because it allows us to control for spatial spillover effect (He & Li, 2022; Miranda-Moreno et al., 2005; Wooldridge, 2012). Table 5 presents the robust coefficient based on the model output.

Based on the GWNB model, we find how the percentage of commercial land use is positively related to the number of reported vehicular crashes ($p < 0.01$) while controlling for other factors. The spatial lag variable for commercial land use is also positively related to the number of car collisions ($p < 0.01$), meaning a higher percentage of commercial land use is also positively associated with more collisions in adjacent neighborhood cells, holding all else constant. We also find that the percentage of residential land use is positively associated with more car crashes in adjacent neighborhoods but not its own neighborhood cell ($p < 0.01$).

(1) Consistent with our hypothesis and existing studies, we find that the number of highway intersections within a neighborhood cell is positively associated with higher numbers of vehicular crashes ($p < 0.01$). The location of sport venue also demonstrated association with the number of crashes, while the significance varies across spatial distances. Interestingly, neighborhood cells immediately adjacent to sports venues, i.e., within a half-mile buffer, show a negative association with car

Table 4. Model output for game-related crash analysis.

		All			5 Miles			3 Miles		
Event	Type	Before	During	After	Before	During	After	Before	During	After
All	Crashes	0.0118	−0.00325	−0.0303	0.00669	−0.000742	−0.000387	0.0482	−0.0172	0.0296
	Crashes (Home)	0.0149	0.0188	0.0249	0.00665	0.00761	0.0700	0.0383	0.0202	0.191***
	Cars	0.0126	−0.00963	−0.0321	−0.00033	−0.01	−0.00557	0.0352	−0.0219	0.0297
	Cars (Home)	0.0193	0.013	0.036	0.0125	0.00227	0.0841	0.0312	0.0187	0.221***
	Damage	0.00492	0.00836	−0.0297	0.00395	0.0289	−0.0125	0.0717	−0.00673	0.0419
	Damage (Home)	0.00423	0.0388	0.0187	−0.0201	0.0542	0.0546	0.0271	0.0499	0.196***
NFL	Crashes	0.00291	−0.0867	−0.120*	−0.204	−0.0547	−0.0846	0.0883	−0.00657	0.083
	Crashes (Home)	0.133	−0.102	−0.0874	0.104	−0.115	0.0734	0.362	0.0778	0.328*
	Cars	−0.0275	−0.118*	−0.168*	−0.263*	−0.118	−0.0923	−0.0372	−0.0709	0.0651
	Cars (Home)	0.0853	−0.134	−0.131	0.0298	−0.172	0.0629	0.193	0.0341	0.307
	Damage	0.0306	−0.0661	−0.133	−0.247	−0.044	−0.117	0.172	0.0567	0.111
	Damage (Home)	0.173	−0.101	−0.101	0.0377	−0.0809	0.0315	0.401	0.113	0.350*
MLB	Crashes	0.0450*	0.0411*	−0.00772	0.0436	0.0604*	0.0357	0.0993*	0.0244	0.00315
	Crashes (Home)	0.0354	0.0533*	0.0515	0.0211	0.0567	0.0611	0.0942	0.0449	0.0702
	Cars	0.0413	0.033	−0.00538	0.035	0.0497	0.0263	0.077	0.0157	−0.0159
	Cars (Home)	0.0371	0.0455	0.0635	0.0245	0.0506	0.0832	0.0748	0.0449	0.102
	Damage	0.0351	0.0526*	−0.0132	0.0161	0.0888*	0.0182	0.0876	0.034	−0.0231
	Damage (Home)	0.0259	0.0755***	0.0326	−0.026	0.101*	0.0303	0.0586	0.0672	0.0389
NBA	Crashes	−0.0323	−0.0348	−0.0259	−0.0286	−0.0434	−0.0123	−0.0767	−0.0381	0.0994
	Crashes (Home)	−0.0354	−0.00805	0.00665	−0.0308	−0.0377	0.0815	−0.116	−0.0362	0.304***
	Cars	−0.0179	−0.0253	−0.0261	−0.0138	−0.0311	−0.0112	−0.0548	−0.0217	0.119
	Cars (Home)	−0.0229	0.00007	0.0206	−0.0144	−0.017	0.0825	−0.0873	−0.0243	0.328***
	Damage	−0.0409	−0.0272	−0.000105	0.00418	−0.0258	0.00495	−0.0246	−0.0493	0.180*
	Damage (Home)	−0.0519	0.0103	0.0346	−0.00553	0.00839	0.111	−0.0739	0.000964	0.361***

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

Table 5. Model output from geographically weighted negative binomial regression.

Log(number of accidents)	Coef.	Robust SE	p > z	[95% Confidence Interval]	
% Commercial	0.0047	0.0011	0.000***	0.0026	0.0069
% Commercial (sp. Lag)	0.0059	0.0018	0.001**	0.0024	0.0095
% Green space	−0.0015	0.0011	0.180	−0.0037	0.0007
% Green space (sp. Lag)	0.0016	0.0019	0.397	−0.0021	0.0053
% Residential	0.0007	0.0005	0.173	−0.0003	0.0017
% Residential (sp. Lag)	0.0037	0.0009	0.000***	0.0020	0.0055
Highway Intersection	0.0722	0.0089	0.000***	0.0548	0.0897
Highway Intersection (sp. Lag)	0.0235	0.0222	0.290	−0.0200	0.0669
Sport Venue _ half mile buffer	−0.2219	0.1058	0.036*	−0.4293	−0.0145
Sport Venue _ 1 mile buffer	0.0752	0.0672	0.263	−0.0565	0.2070
Sport Venue _ 3 mile buffer	0.0454	0.0299	0.129	−0.0132	0.1040
Sport Venue _ 5 mile buffer	0.0989	0.0262	0.000***	0.0476	0.1503
Constant	0.7910	0.0615	0.000***	0.6705	0.9115

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

crashes ($p < 0.05$). In contrast, the over-neighborhood cells within a five-mile buffer demonstrate a positive association with crashes overall ($p < 0.01$), which demonstrates the impacts of sport venue locations on the geography of car crashes on a relatively greater spatial scale.

7. Discussion

Vehicular crashes incur physical costs, personal financial costs, and collective financial costs (Reynolds, 1956). There are several factors related to the spatial and temporal distributions of crashes, which include environmental factors such as weather and road conditions (Rahman et al., 2020), human factors, such as alcohol consumption (Strayer et al., 2006; Summala & Mikkola, 1994), and urban factors, such as land use (Berkovitz, 2001; Kim et al., 2006; Xie et al., 2019; Zhang et al., 2018). The economic impact of crashes on both the overall economy and personal level has proven to be substantial (Alemany et al., 2013; Ayuso et al., 2010; Shults et al., 2004). These costs are substantially increased but less quantifiable when considering the psychological and personal impacts that vehicular crashes have on people's lives. Considering the impact of crashes on lives and the economy (Kim et al., 2006), the public sector's objective is to reduce them. Achieving such a goal, though, requires a comprehensive understanding regarding the different factors associated with vehicular crashes. This study addresses one potential factor associated with the negative externalities of sporting events and the location of corresponding venues, thus considering vehicular crashes in specific geographic areas and certain periods of time (e.g., Getahun, 2021; Hamzeh et al., 2016; Otero & Rau, 2017).

Results identified that the relationships between increased car crashes and sport events are apparent in some instances when one considers the spatial and temporal distributions of motor vehicle crashes, sporting events, and venues. Consequently, the current study appears to be the first to explore the relationship between sporting events across multiple professional sports leagues and vehicular crash patterns. When factoring in distance from the sports venues, the results from our models indicate the association between sporting events and the increase in vehicular crashes attributed to the increase in traffic (Humphreys et al., 1983; Humphreys & Pyun, 2018). Focusing on the relationships between vehicular crashes and events near professional sport franchises' home sports venues, specifically within three miles of the venues, relays the relationship between games and crashes, and, more importantly, the geographical relationship between games, crashes, and time with both research and practical implications. Results covering the entire city are valuable, but they are likely to capture several other factors related to car collisions possibly influencing the results. The randomness of the sporting events is not determined by public officials taking vehicular crashes into consideration, increases the relevancy of these results, strengthening the plausibility of identifying causal effects related to the timing of the games (Copus & Laqueur, 2019; Jakar & Gordon, 2022).

In addition to games, there are other indicators associated with changes in the volume of vehicular crashes. Results from the spatial analysis consider the downtown location of the venues. Once again, our results indicate the relevance of the spatial relationship to scholars who study spatial relationships related to car crashes and practitioners engaged in initiatives to reduce them and their consequences. These findings corroborate previous research demonstrating how the placement of sports venues within the urban core increases social costs, including and especially vehicular traffic (Humphreys et al., 1983; Humphreys & Pyun, 2018; Orlowski & Wicker, 2019; Storm & Jakobsen, 2021) and the resulting consequences therefrom (Propheter, 2020). Cleveland's initiative to join the Vision Zero program acknowledges the need to identify the causes of vehicular crashes to reduce their occurrences and effects by using extensive data analyses, identifying contributing factors, and identifying vulnerable spaces.

Built environmental characteristics form the backcloth upon which people conduct their daily activities. Naturally, the form of land use as well as the locational characteristics of urban space relative to sport venues are important to the traffic pattern and the geography of vehicular collisions. Our findings from the spatial analysis show how the percentage of commercial and retail land use is positively related to vehicular crashes, which is similar to other studies (Yang & Loo, 2016). We also identify how areas with more road conjunctions or intersections are subject to a greater risk of traffic accidents, which echoes the U.S. Department of Transportation's finding that 43% of motor vehicle crashes occur at intersections or are "intersection-related" (Federal Highway Administration, 2022).

While most findings from this study regarding the built environmental factors are consistent with the literature, some results are novel for research on vehicular crashes. Similar to Humphreys et al. (1983), who found a decrease in traffic congestion in the venue's immediate vicinity relative to the traffic just beyond the initial perimeter, we find a non-linear relationship between the distance from sports venues and the number of motor vehicle crashes. Neighborhood areas within a half-mile buffer are likely to have fewer vehicular crashes, even though the overall five-mile range from Cleveland's sport venues are likely to have greater risk for car collisions, holding all else constant. This may be because more police patrol and law enforcement are present within immediately adjacent areas around these sports venues, in addition to the lower speed limits and other physical facilities installed to manage game-related traffic. On the one hand, drivers could become more cautious about their driving behaviors with the presence of police patrol and law enforcement and will follow the speed limit, leading to fewer crashes. Conversely, the physical presence of traffic management facilities could also help alert the drivers and regulate the traffic flow and improve road safety.

8. Conclusions

Car crashes are one of the primary causes of fatalities in the United States and the rest of the world. Many environmental factors, in addition to personal driving factors, have been identified as detrimental to these otherwise avoidable events. The attention and solution to road safety have been reflected in both academic and professional efforts across the disciplines of transportation planning, community development, and urban planning, and recently in the disciplines of sport management. Using temporal and spatial analysis to examine the nexus between sports events and car crashes in Cleveland, OH, this study provides novel insights into how sport event planning could contribute to road safety in urban communities.

Our findings could help the City of Cleveland identify a clearer framework with areas of high risk for achieving its Vision Zero goal of no traffic fatalities or injuries by addressing the impact of sporting events on the frequency of crashes. Similar to Menaker et al. (2019), the results of this study indicate that the relationship between sporting events and negative externalities in Cleveland is associated with an increase in both crime and vehicular crashes. From a scholarly perspective, our study contributes to a less examined but much-needed line of inquiry, especially in the field of sports management. Our study identifies the relationship between multiple sports event types and vehicular crashes and adds to the broader literature on crashes and societal events. Subsequently, Cleveland may be either unique or indicative of a pattern that needs to be addressed in future studies to examine vehicular crashes and events in other cities. We perceive these results and the methods used in this study, including the use of spatial analytics and GIS software, enabling the investigation of both time and space lags, to be an important contribution to the growing body of the literature discussing and analyzing negative externalities, such as crime and car crashes related to large entertainment venues (see, Jakar & Gordon, 2022; Menaker et al., 2021). Future studies can use these methods to analyze other externalities related to sport where both the spatial and temporal factors are an important component.

The practical implications of this study may be more important given the potential contribution to the public sector's efforts to reduce the number and severity of car collisions emphasized in Cleveland's Vision Zero initiatives. If we believe the results to be true and sporting events are associated with an increase in vehicular crashes near the venues and a causal effect may be involved, when addressing this relationship can provide a concise strategy to satisfy the goals of Vision Zero. One of the possible solutions is to partner with the private sectors, such as team ownership and incorporate more aggressive initiatives during games and through media outlets where there is a captive audience. More extreme measures may include the reduction of alcohol consumption at events, the release of sections of game attendees at various time intervals, or "harden" venues through an increase in law enforcement and impose monetary consequences, such as fines, that could impact drivers' decision-making. This study also points to the importance of local roadways' land-use patterns and how they could moderate the impact of professional sports events on road safety. Through appropriate design and management, road traffic interventions around professional sports venues and smart-growth urban policies could ultimately result in safer local road systems and corresponding sports events. More research inquiries, scholarly activism, as well as greater involvement of both public and private sectors are necessary to address road safety, an issue claiming more than 38,000 lives per year in the United States.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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