Grand Forks - East Grand Forks
METROPOLITAN
PLANNING ORGANIZATION

MPO Staff Report

Technical Advisory Committee:

March 13, 2024

MPO Executive Board:

STAFF RECOMMENDED ACTION: Update from the University of North Dakota on the intern conducting a Traffic Speed Study.

TAC RECOMMENDED ACTION:

Matter of an update from the University of North Dakota (UND) on the intern conducting a Traffic Speed Study.

Background:

This discussion started over a year ago as a great partnership opportunity with the University of North Dakota (UND) and Grand Forks/East Grand Forks Metropolitan Planning Organization. The main objectives of the study include:

- Analyze traffic safety and speeding tickets data for South Grand Forks and determine locations that need more detailed speed studies.
- Determine the effects of traffic calming techniques on driver behavior and pedestrian safety.
- Recommend approaches to address traffic safety concerns.

Findings and Analysis:

- Effect of traffic calming techniques on traffic speed and pedestrian safety

Support Materials:

- Presentation
- Progress report

Traffic Speed, Traffic Calming Techniques, and Safety Implications for Pedestrians and Bicyclists

Wednesday, Feb 14, 2024

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Outline

- Introduction
- Objectives
- PART I - Traffic Data Analysis
- PART II - Effect of In-crosswalk traffic signs
- Conclusions and Future Works

Introduction

- Traffic safety
  - Traffic speed
  - Traffic speed calming techniques

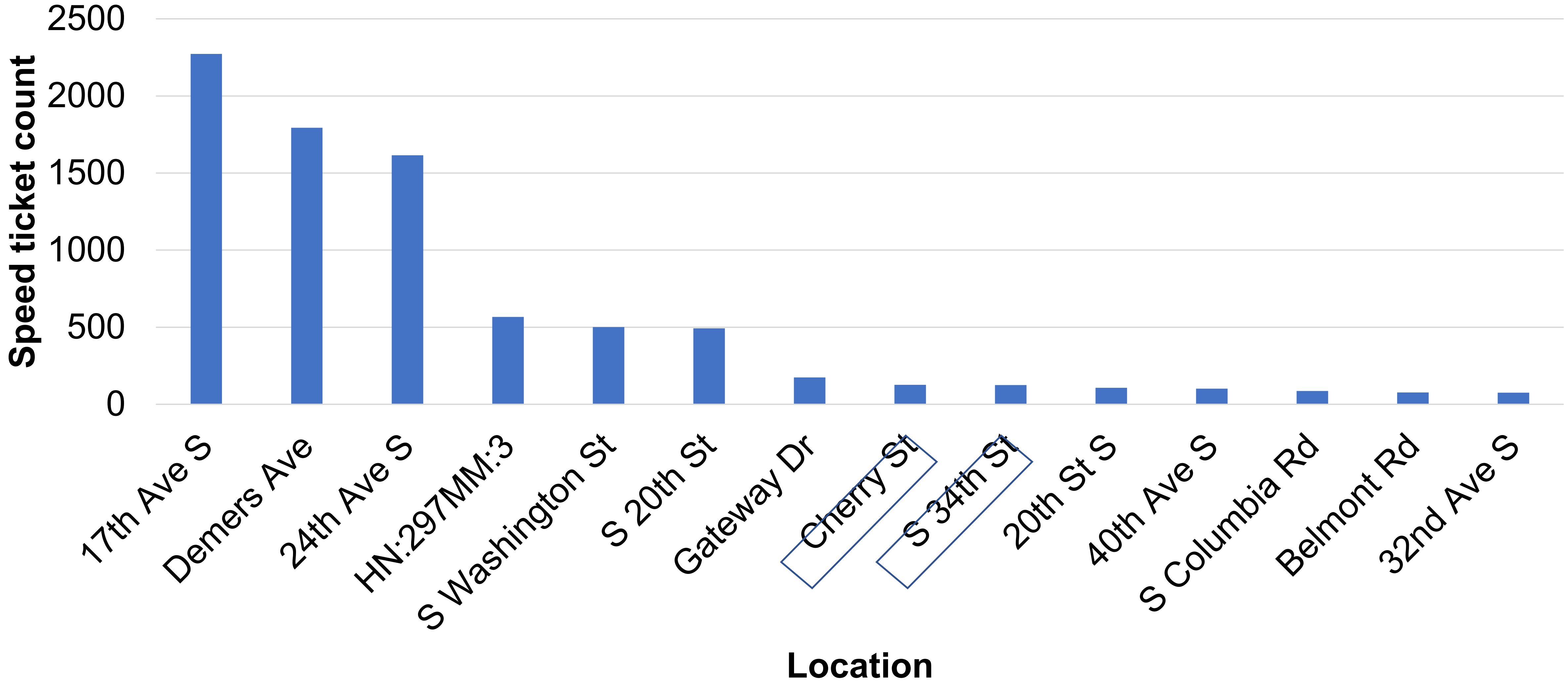
Objectives

- Evaluate the impact of traffic calming methods,
- Analyze traffic crash and speeding citation data of Grand Forks,
- Analyze the effect of YIELD and STOP signs in-crosswalk signs, and
- Recommend approaches to address traffic safety concerns.

Part I - Traffic Data Analysis

- Speeding ticket data analysis
  - Speeding ticket summary
  - Speeding ticket and crash data mapping

Speeding Ticket Data



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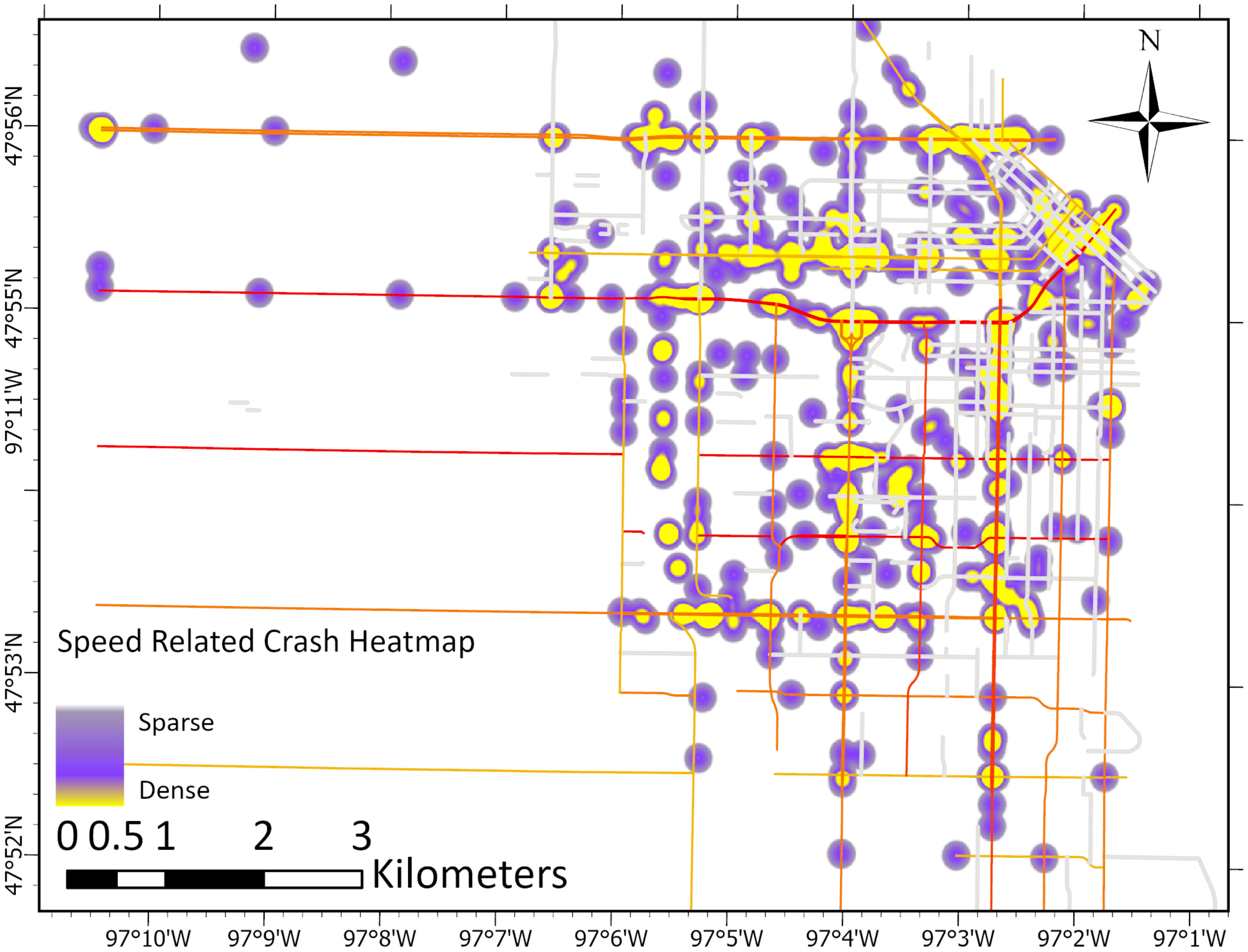
Speed-Related Crash Heatmap



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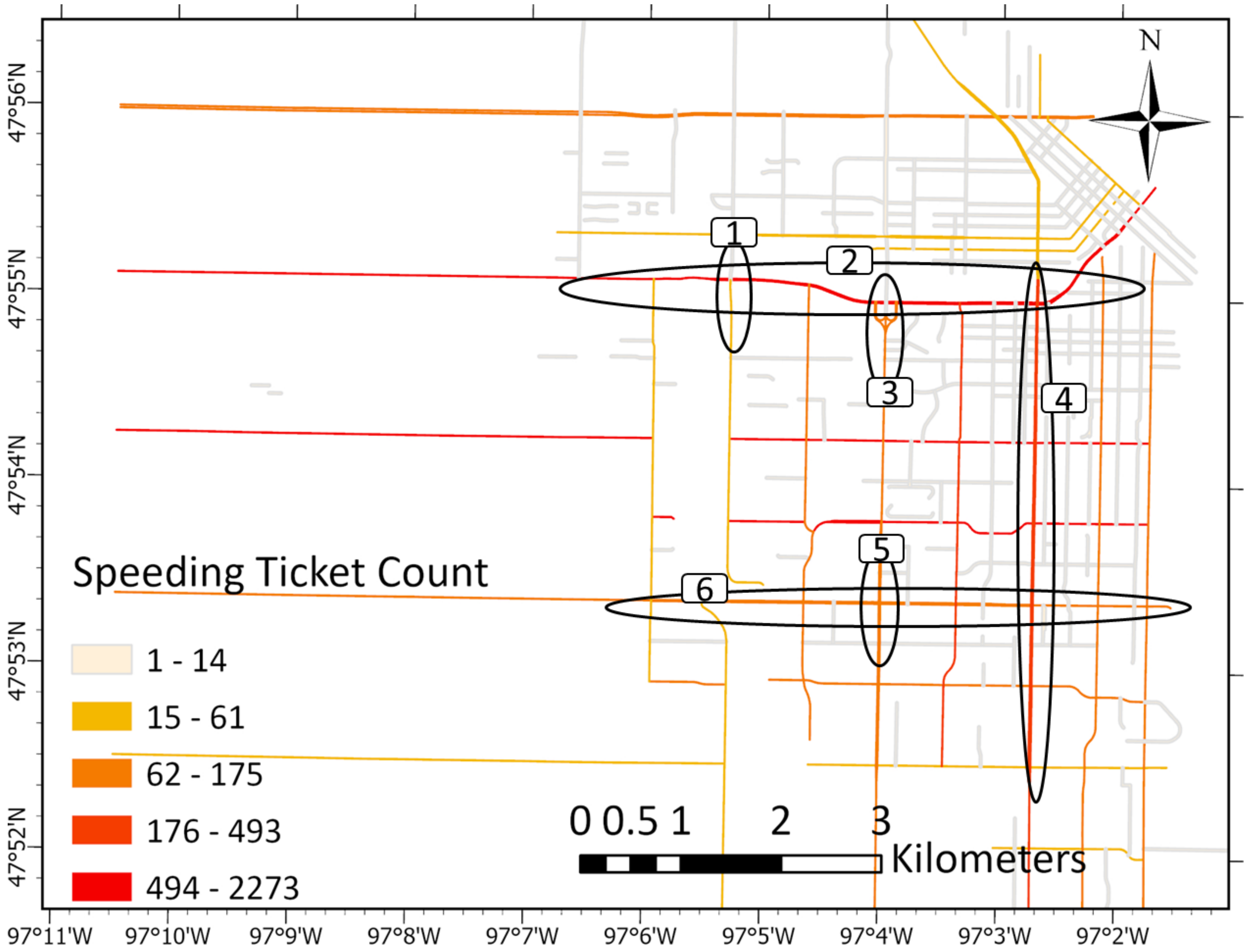
Hotspot Areas



Id.	Location Name
1	Demers Ave and S 42ND ST Intersn.
2	Demers Ave
3	Demers Ave and S Columbia Rd Intersn.
4	S Washington St
5	32^{nd} Ave S
6	32^{nd} Ave S and S Columbia Rd Intersn.

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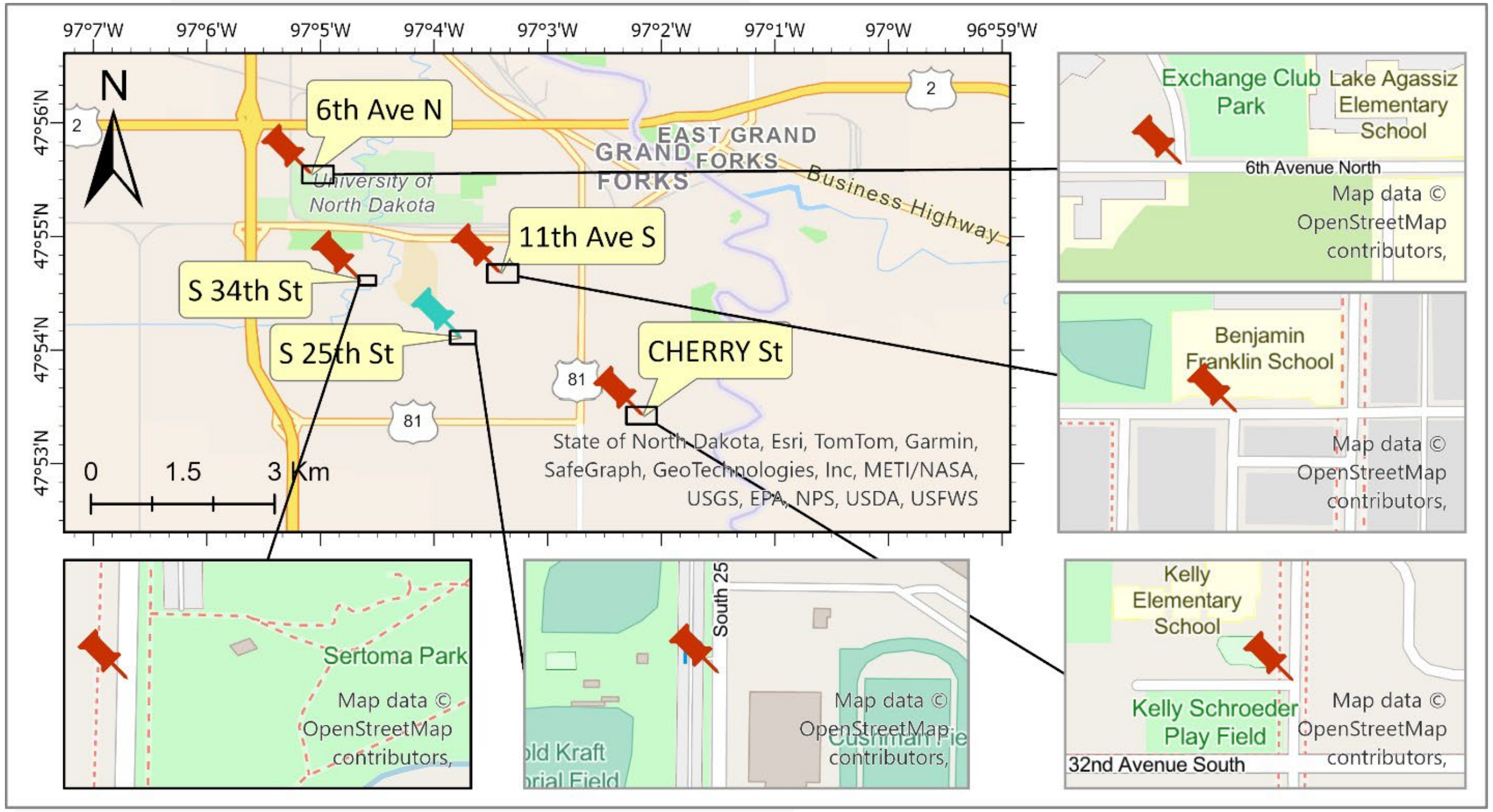
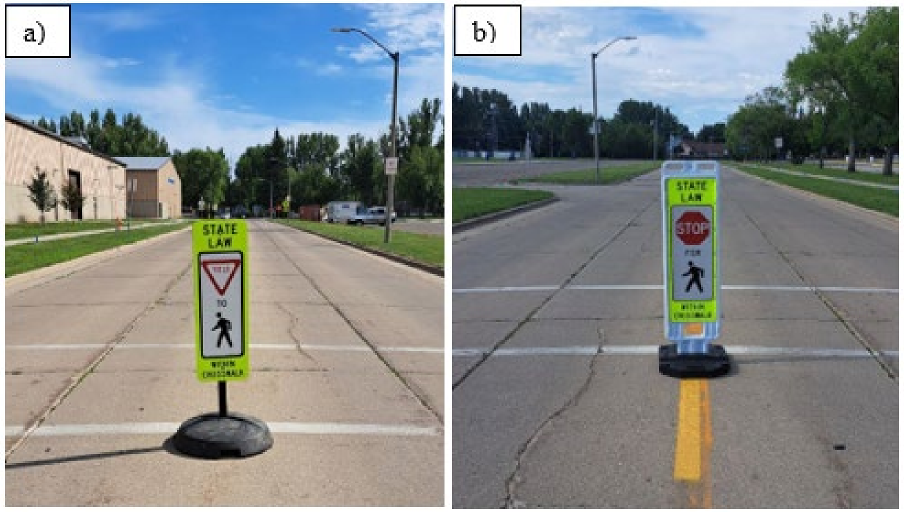
Part II - Effect of In-crosswalk Traffic Signs



Study area



In Crosswalk signs a) YIELD to Pedestrians and b) STOP to Pedestrians at S 25th St (0 ft)

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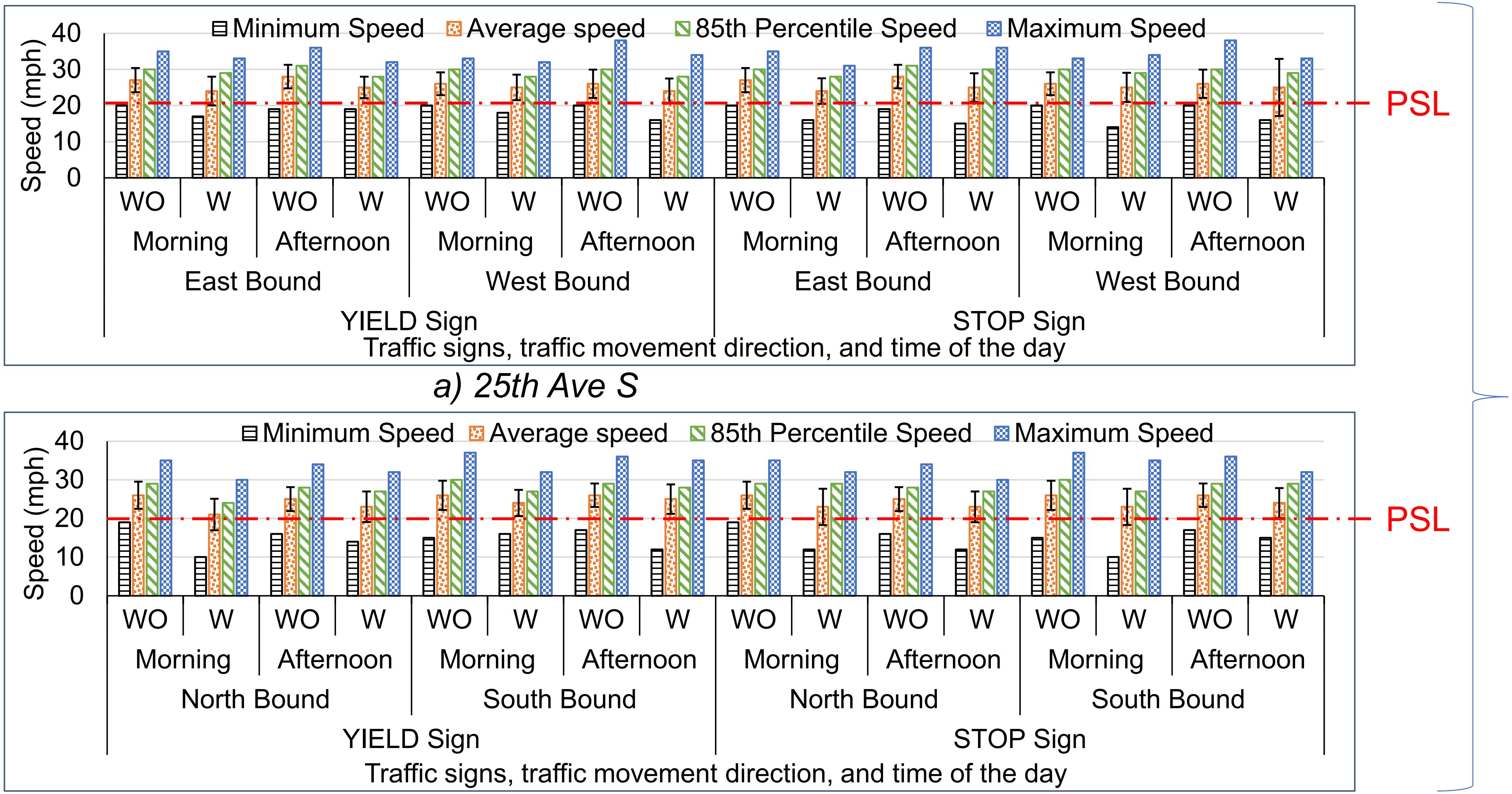
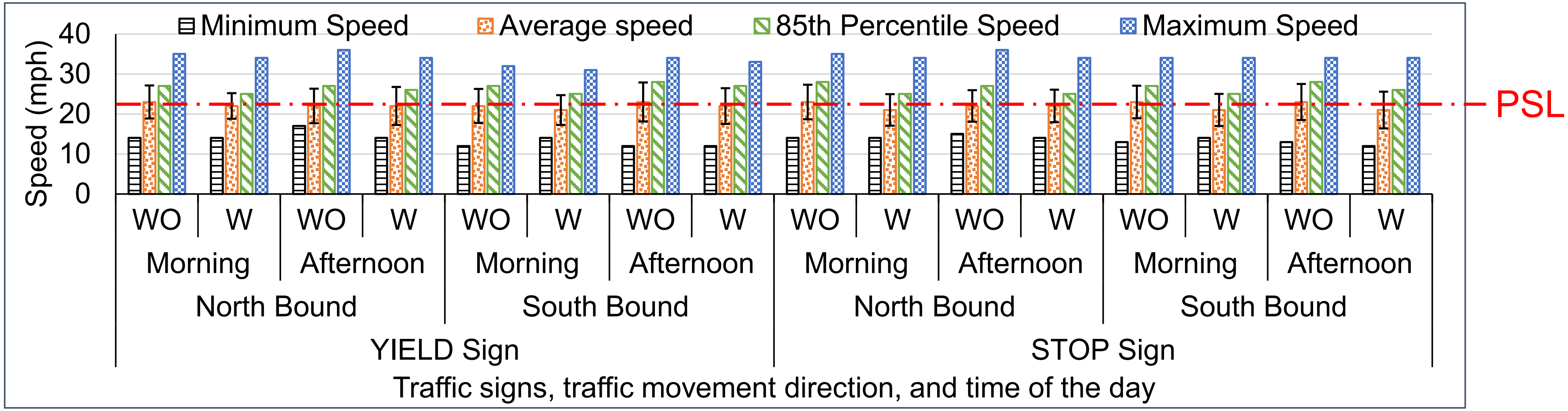
Effect of Signs on Speed When School is not in Session



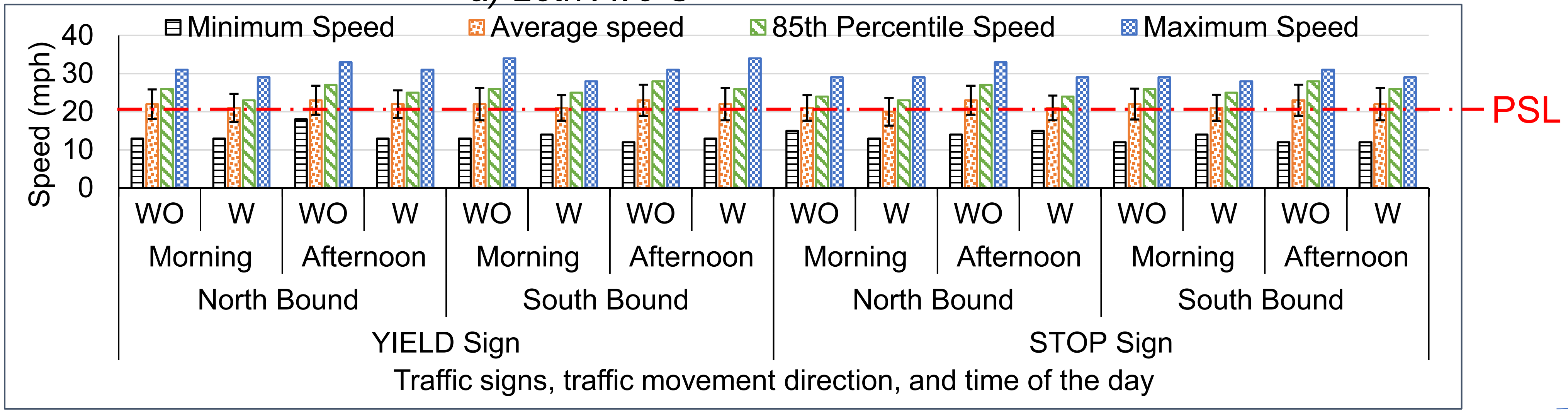
a) 25th Ave S

b) Cherry St

Effect of Signs on Speed During School Sessions



a) 25th Ave S



b) Cherry St

Effect of Signs on Yielding for Pedestrians

Street name	Direction	Time of the day	Yielding data (Proportion)		Significance test		Combined
			WO	W	χ2 (p-value)	z-score, (p-value)	
YIELD Sign							
Cherry St	North	M	90 (68.9)	84 (83.8)	4.951 (0.026) S	-2.225 (0.026) S	-2.950 (0.0032) S
		A	83 (71.1)	81 (77.8)	0.964 (0.326) N	-0.982 (0.327) N	
	South	M	80 (68.8)	84 (81.0)	3.254 (0.071) N	-1.804 (0.072) N	
		A	70 (82.9)	76 (86.8)	0.452 (0.501) N	-0.672 (0.503) N	
S 25th St	North	M	73 (74.0)	78 (92.3)	9.176 (0.002) S	-3.029 (0.002) S	-4.804 (<0.00001) S
		A	75 (76.0)	73 (86.3)	2.559 (0.109) N	-1.599 (0.109) N	
	South	M	83 (75.9)	87 (92.0)	8.191 (0.004) S	-2.862 (0.004) S	
		A	80 (73.8)	85 (87.1)	4.669 (0.031) S	-2.161 (0.031) S	
STOP Sign							
Cherry St	North	M	81 (69.1)	78 (89.7)	10.26 (0.001) S	-3.203 (0.001) S	-4.273 (<0.00001) S
		A	74 (73.0)	77 (84.4)	2.958 (0.085) N	-1.720 (0.085) N	
	South	M	70 (72.9)	73 (83.6)	2.412 (0.120) N	-1.553 (0.121) N	
		A	73 (76.7)	75 (89.3)	4.198 (0.041) S	-2.049 (0.040) S	
S 25th St	North	M	79 (74.7)	82 (90.2)	6.781 (0.009) S	-2.604 (0.009) S	-4.761 (<0.00001) S
		A	88 (73.9)	75 (88.0)	5.128 (0.024) S	-2.265 (0.024) S	
	South	M	76 (68.4)	79 (83.5)	4.875 (0.027) S	-2.208 (0.027) S	
		A	79 (69.6)	74 (86.5)	6.289 (0.012) S	-2.508 (0.012) S	

S Significant at a 0.05 significance level, N Not significant at a 0.05 significance level.

Comparison of the Effects of Signs on Traffic Speed

Location	No-school Session				Sig. Diff (95% CI)	In-School Session				Sig. Diff (95% CI)
	YIELD sign		STOP sign			YIELD sign		STOP sign		
	Avg Speed	n	Avg Speed	n		Avg Speed	n	Avg Speed	n	
6th Ave N	24.1	606	23.5	416	0.0017 S	24.2	312	24.1	356	0.6599 N
11th Ave S	24.8	291	24.9	283	0.7064 N	23.0	247	23.2	229	0.5866 N
Cherry St	23.2	331	23.4	287	0.5447 N	21.3	288	21.0	290	0.3122 N
S 25th St	23.1	243	23	216	0.7359 N	21.2	248	21.3	267	0.8949 N
Overall	23.9	1471	23.7	1202	0.3410 N	22.5	1095	22.5	1142	0.8144 N

S Significant at a 0.05 significance level, N Not significant at a 0.05 significance level.

Comparison of the Effect of Signs on Yielding

Location	YIELD	STOP	z-score (p-value)	Combined z-score (p-value)
6th Ave N	255 (85.9)	279 (87.5)	-0.535 (0.596) N	-0.497 (0.617) N
11th Ave S	227 (92.5)	204 (91.2)	0.506 (0.610) N	
Cherry St	325 (82.2)	303 (86.8)	-1.603 (0.110) N	
S 25th St	323 (89.5)	310 (87.1)	1.036 (0.298) N	

S Significant at a 0.05 significance level, N Not significant at a 0.05 significance level.

Conclusions

❖ 17th Ave S, Demers Ave, and 24th Ave S have more speed citation record.

❖ Most of the speed-related crashes occurred near intersections.

❖ Demers Ave, S Washington St, S Columbia Rd, 32nd Ave S, and the intersections of these roads have more frequent speed violations and crashes.

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Conclusions *(Continued)*

- The presence of in-crosswalk STOP and YIELD signs led to a decrease in both average and 85th percentile speeds.

- The presence of the traffic signs significantly improved yielding behavior toward pedestrians.

- There was no significant difference between the impact of the two types of traffic signs on speeding and yielding behaviors.
  - Transportation planners have the flexibility to use either sign.

Future Works

- ❖Review work and cross-sectional analysis for the application of traffic calming techniques will be done.

- ❖Analysis for signal warrants at intersections will be done. The hot spot analysis result will be used as an initial criterion.

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Thank you

Questions and Comments?

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Traffic Speed, Traffic Calming Techniques, and Safety Implications for Pedestrians and Bicyclists

Report submitted by: Mulugeta Amare and Daba Gedafa

Principal Investigator: **Daba S. Gedafa, Ph.D., P.E., ENV SP, F. ASCE**

Chair and Michael & Sitney Lodoen Endowed Professor

UND Civil Engineering

Proposed Budget: $**30,000.00**

Proposed Time Period: **November 16, 2022-July 15, 2024**

UNIVERSITY OF NORTH DAKOTA

Civil Engineering Department

January 2024

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ABSTRACT
Transportation involves the movement of road users on a given corridor, and the safety aspect is the primary concern for the transportation system. Previous reports have documented that traffic speeding is a safety concern for pedestrians and bicyclists, contributing to 29 percent of fatalities and 13 percent of injuries. Pedestrian fatalities have increased by 77% over the past decade, constituting a 5% increase in pedestrian fatalities per the overall number of traffic-related fatalities. Identifying hotspot crash locations is the critical parameter for creating an informed safety measure; however, previous studies on traffic safety have primarily focused on using crash frequency as a fundamental parameter. Moreover, studies have investigated the application of different regulatory traffic signs but did not make a significant comparison between different sign types in different areas and time settings. This study presents a review of the safety implications of traffic speed for pedestrians and bicyclists and the traffic speed calming techniques on non-interstate highways. Moreover, the study evaluates the spatiotemporal clustering of traffic crashes using Geographic Information System tools. In addition, a comparative analysis was conducted to evaluate the effectiveness of in-crosswalk traffic signs, such as "YIELD TO PEDESTRIAN" and "STOP FOR PEDESTRIAN," as a potential solution for improving pedestrian safety. The findings from the spatiotemporal analysis revealed that more crashes occurred during winter, and the hotspot identification results from the Getis-Ord (Gi*) and Anselin Local Moran's (I) statistics were compelling. Furthermore, the results from the traffic sign data analysis show that the change in vehicle speed due to both traffic signs was significant in mornings and afternoons, as well as whether or not schools were in session. The yielding to pedestrians was improved in the presence of the traffic signs. However, the difference between the impacts of the two traffic signs on speed and yielding was not significant. Hence, the signs can be used interchangeably.

1. INTRODUCTION

Agencies work closely with law enforcement entities, state traffic safety offices, and the National Highway Traffic Safety Administration (NHTSA) to plan and implement policies that can help reduce the number of crashes to combat high costs, injuries, and deaths. One approach is through the Four Es of traffic safety: Enforcement, Engineering, Education, and Emergency Medical Services. The Four Es play an important role in road safety. Each component is essential and, when taken together as a unified approach, has achieved the lowest crash rates in decades. There were 5.5 million police-reported traffic crashes in 2009. Law enforcement officers work diligently to prevent crashes by enforcing traffic safety laws such as seat belt use, child passenger protection, traveling over the speed limit, impaired driving, and distracted driving. Studies have indicated that increased enforcement and educational campaigns can yield significant changes in driver behavior.

A national awareness campaign called "Click It or Ticket" has increased seatbelt use by as much as 85 percent between 2005 and 2009, saving an estimated 72,000 lives. The NHTSA, state DOTs, law enforcement, and traffic safety offices can prevent crashes by holistically addressing the four components. Technology can also improve how traffic safety advocates, engineers, and other vital stakeholders use the Four Es. The Four Es approach has contributed to a steady decline in fatality and injury rates over the past few years. The ultimate safety goal is Toward Zero Deaths (TZD) on all highways, a data-driven highway safety strategy focusing on changing driver culture. The TZD initiative relies on data from crashes and police stops, in concert with the four Es, to determine priority areas and make policy and program changes that will reduce the current fatality rate per million vehicle miles traveled (VMT) from 1.14 to zero.

Data used in analysis includes vehicle speed, traffic volume, law-enforcement crash investigation information, emergency medical response information, road sensors, design data, and the effectiveness of public education campaigns. This data can be analyzed holistically to assist decision-makers in creating strategies for comprehensive traffic safety improvement plans. Local, state, and federal agencies host this data in various databases, formats, and types of hardware, creating a challenge when integrating this information to create the holistic view of traffic safety needed to coordinate an approach that prevents crashes. Data analysis enables road designers, law enforcement officers, emergency medical responders, and those designing public education campaigns to identify trends and develop highway safety plans and interventions with the best return on investment.

2. PROBLEM STATEMENT

Safety and traffic concerns arise from increased vehicle traffic, excessive speed, and a disregard for stop signs. The speed of the vehicles is a function of the roadway quality, driver behavior, time of the day, and other roadway elements like traffic signals. United States traffic safety ranks lowest among developed countries (WHO 2021). Speed and careless driving contributed to 34% of North Dakota's fatal crashes in 2021 (NDDOT 2021a). Crashes involving speeding occurred every two and a half hours, and fatalities occurred once, approximately every ten days.

The 2022 North Dakota Department of Transportation (NDDOT) report (NDDOT 2022) reveals that Grand Forks County is ranked second and third in crash rate per million vehicle miles traveled (MVMT) and the number of crashes, respectively. Speeding is a perceived issue in general near the Intersection of Belmont Rd and 55th Ave S in particular. A pedestrian struck by a speeding vehicle in a residential neighborhood with low posted speed limits will have a much higher mortality rate. Suppose a driver increases a speed from 20 mph to 30 mph. In that case, the pedestrian fatality rate may increase by 40%, especially since the driver's ability to stop quickly decreases as their speed increases. That ten mph increase in speed affects a driver's stopping distance by about 85 feet, significantly impacting their ability to stop suddenly, especially under wet, snowy, and icy conditions prevalent in Grand Forks.

Despite all the efforts and measures, crashes still occur at a considerable rate. Identifying the specific locations where a significant number of traffic crashes occur and understanding the underlying causes of these crashes are crucial factors that play a pivotal role in making informed decisions regarding safety measures (Herbel et al. 2009; Varhelyi 2016). The crash frequency has been used as a hotspot screening by agencies. However, crash hotspot analysis should include the effect of traffic volume and crash severity.

Some methods that can increase a driver's adherence to yielding for pedestrians and reduce their traffic speed are the installation of "Stop for Pedestrian" and "Yield to Pedestrians" within crosswalk signs. The Manual on Uniform Traffic Control Devices (MUTCD) by the Federal Highway Administration (FHWA) includes in-roadway "Yield to Pedestrians within Crosswalks" signs that can be placed at uncontrolled marked crosswalks (FHWA 2009). Past studies have also documented the significance of within-crosswalk traffic signs in reducing traffic speed and increasing the drivers' yielding behavior (Ellis et al. 2007; Gedafa et al. 2014; Huang et al. 2000; Pulugurtha et al. 2012). In-roadway signs may be effective since they are directly in the motorist's field of view.

A study on the impacts of alternative yield sign placement on pedestrian safety (Gedafa et al. 2014) determined that placing a yield sign at a crosswalk was the most effective way of increasing the likelihood of a vehicle yielding for pedestrians; however, the authors recommended research on the repeatability of their results at other sites to increase the robustness of their findings. The impact of traffic signs on speeding and yielding may differ based on the type of within-crosswalk sign. A comparison of signage impacts in various time circumstances, as well as during school and non-school sessions, was not investigated.

Therefore, Part 1 of this paper reviews the safety concerns regarding traffic speed and engineering traffic speed-calming techniques, preferred locations, and their effect on pedestrians and bicyclists by reducing traffic speed. Part 2 entails an analysis of traffic crash data along with speed citation data, employing ArcGIS geospatial analysis tools to pinpoint critical areas. Part 3 illustrates the effect of YIELD and STOP in crosswalk signs on vehicle speed and yield to pedestrians.

3. OBJECTIVES OF THE PROJECT

The main objectives of this study include the following:

- Evaluate the impact of traffic calming methods on the reduction of vehicle speed and enhancement of pedestrian and bicyclist safety,
- Analyze traffic crash and speeding citation data of Grand Forks and determine locations that need more detailed studies,
- Analyze the effect of yield and STOP in crosswalk signs on drivers' yielding and speeding behavior and the associated safety implications on pedestrians and bicyclists, and
- Recommend approaches to address traffic safety concerns.

4. LITERATURE REVIEW

Road crashes are a significant global issue, leading to thousands of human fatalities and injuries and incurring substantial resource loss. The growing concern for public safety and transportation network optimization has recently highlighted the need for accurate traffic crash analysis and assessing traffic safety in cold regions, which poses a critical challenge for developing sustainable and resilient infrastructure. The complex interplay of factors, including weather conditions, road maintenance, and driver behavior, significantly impacts transportation system safety (Maze et al.

2006). This section covers a review of traffic hotspot areas analysis, crash factors analysis techniques, and traffic calming techniques.

4.1. Traffic Speed and Safety

Increasing vehicle traffic, excessive speed, and disregard for stop signs pose safety and traffic concerns. According to the World Health Organization's report (WHO 2021), the United States is way behind other developed countries regarding traffic safety concerns. The Road Traffic Death Rate per 100,000 population in the USA is 12.7, more than twice the rate in Canada, which is second place on the list. The 2020 traffic safety fact report from NHTSA shows that 29% of the total 38,824 fatalities and 13% of the total 1,974,002 injuries across the nation were due to speeding. Moreover, speeding-related fatalities have increased by 17% from 2019 to 2020 (NHTSA 2022). Speed and aggressive driving were a factor in 34% of fatal crashes in North Dakota in 2021. In addition, a speed driving-related crash occurred every two and half hours, and fatality occurred once in nearly ten days (NDDOT 2022).

Figure 1 presents the percent contribution of speeding towards fatalities and injuries. For the ten years of data in the USA, the average contribution of speeding is 28% and 15% for fatality and injuries, respectively. Other factors like belt non-use, helmet non-use, distraction, alcohol involvement and causation, and absence of traffic signs and signals account for the remaining percentage.

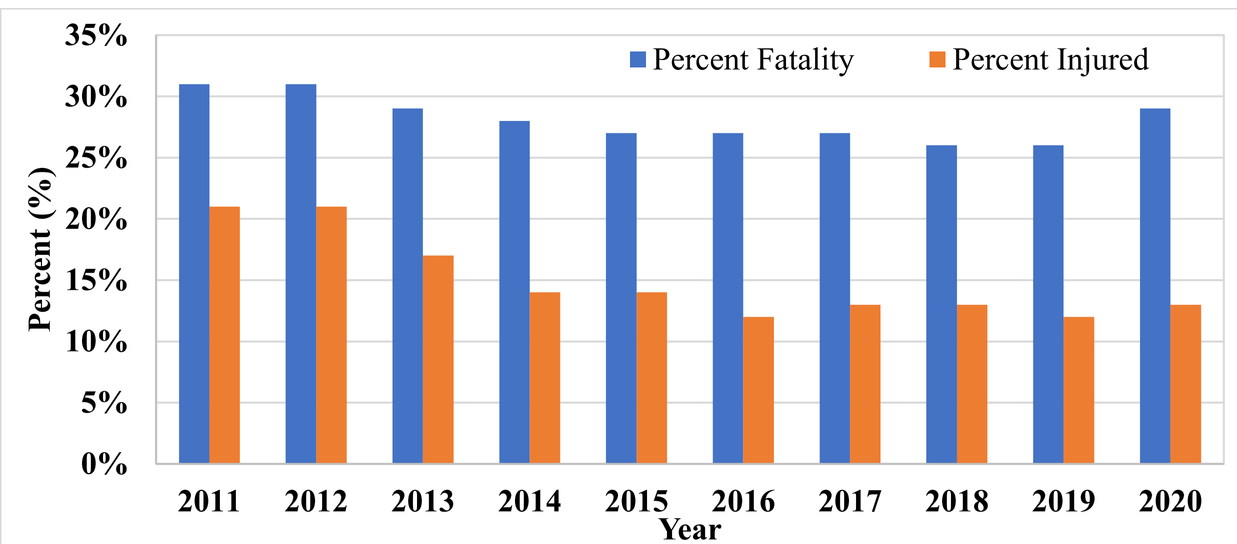


Figure 1 Percent fatality and injury due to traffic speeding, 2020 USA (NHTSA 2022)

In a Crash Summary Report by the North Dakota Department of Transportation (NDDOT), more than 50% of the traffic citations for five consecutive years, 2011-2016, reports were due to speeding. Moreover, in 2021, 27% of the fatalities were due to speeding. Among all the counties in North Dakota, Grand Forks is ranked second and third in crash rate per million vehicle miles traveled (MVMT) and the number of crashes, respectively. In 2021, nearly every six and three days, one bicyclist and one pedestrian were involved in a crash (NDDOT 2022).

The NHTSA fact sheet data (NHTSA 2022) for ten consecutive years, 2011-2020, documented the fatality exposures experienced by five groups of road users. The passenger car occupants are the most affected, followed by light trucks and non-occupants. Figure 2 summarizes the percentage fatality of each passenger type in the USA in 2020. From this, it is evident that at least one out of five persons killed is non-occupant, mainly pedestrians and bicyclists.

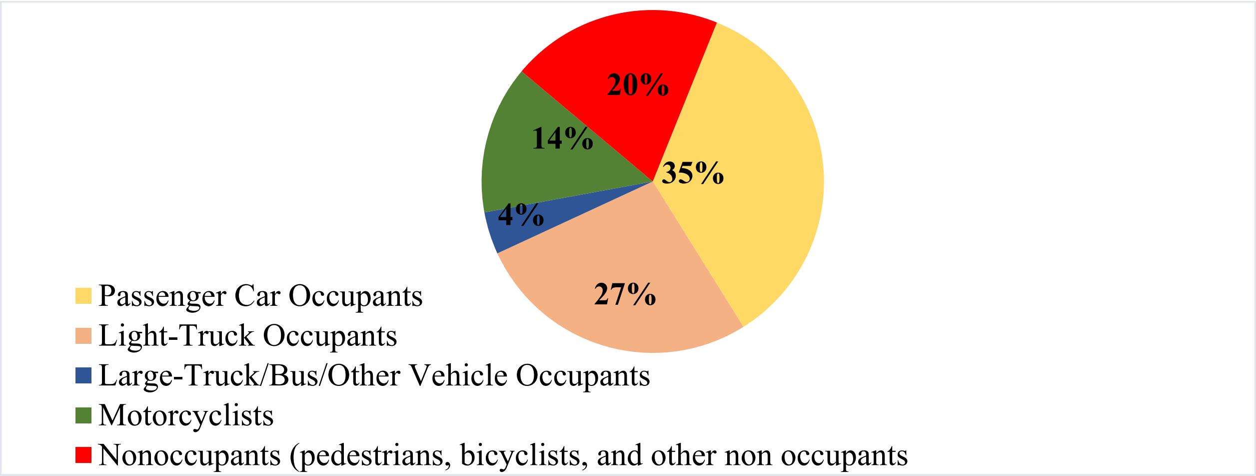


Figure 2 Percentage of traffic fatality per occupant type, 2020 USA (NHTSA 2022)

The relationship between the risk of fatality of a given passenger hit by a vehicle and the speed of the vehicle during collision or impact is calculated using a single logistic regression model, and it is called risk factor (Kong and Yang 2010; Li et al. 2015; Nie et al. 2014; Nie et al. 2010; Tefft 2013). The trend of the fatality curve is similar for all curves, and the risk of pedestrian death looks inevitable for speed values greater than 40mph. Figure 3 summarizes the results of regression models developed by researchers for different countries (considering other parameters like age, impact location, and pedestrian height are constant).

By reducing vehicle speeds and enhancing safety for non-motorized street users, traffic calming can enhance the quality of life for locals living along affected roadways. By improving the safety, mobility, and comfort of non-motorists, traffic calming supports the livability and vitality of residential and commercial districts. These goals are often met by lowering vehicle speeds or densities on a single route or a network of streets. Road-side, vertical, lane-narrowing, and other elements that use self-enforcing physical or psycho-perception mechanisms to achieve desired results are included in traffic-calming measures (FHWA 2017).

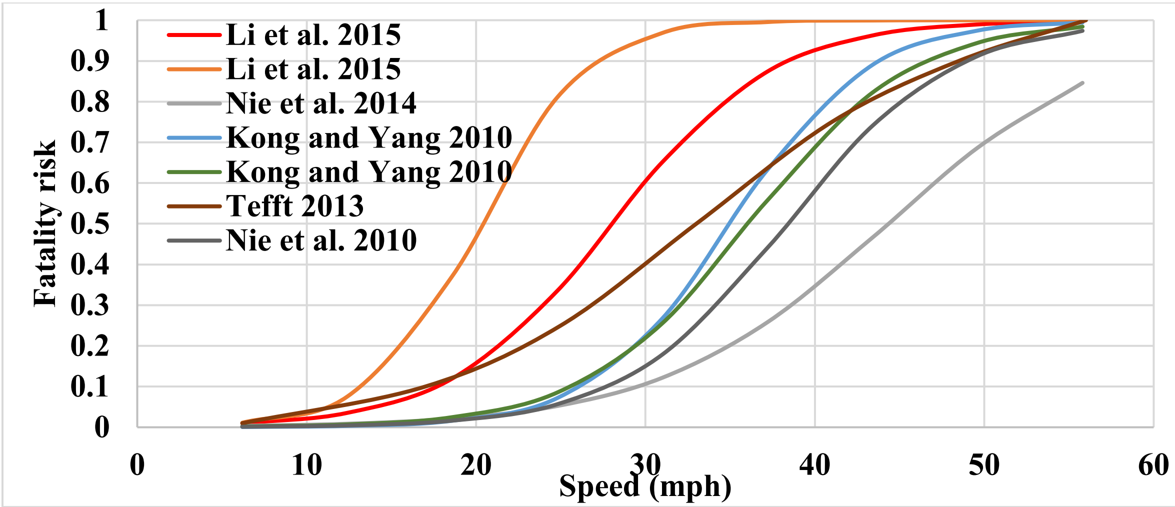


Figure 3 Vehicle speed vs. Fatality risk for pedestrians

4.2. Traffic Hotspot Area and Crash Contributing Factors Analysis

Identifying the specific locations where a significant number of traffic crashes occur and understanding the underlying causes of these crashes are crucial factors that play a pivotal role in making informed decisions regarding safety measures (Herbel et al. 2009; Varhelyi 2016). State-of-the-art Geographic Information System (GIS) tools are instrumental in effectively pinpointing frequently occurring traffic crash locations (Amiri et al. 2021; Audu et al. 2021; Ivajnsic et al. 2021; Lee and Khattak 2019). Additionally, employing advanced Association Rule Mining (ARM) methods can yield valuable perspectives into the multitude of factors and situations statistically associated with these crashes (Das et al. 2019; Yang et al. 2022).

Previous research has investigated the use of GIS-based techniques, including Hotspot Analysis using Getis Ord Gi*, Global Moran's I, Mean Center, Emerging Hotspot Analysis, and Kernel Density Estimation-KDE to discern spatial and temporal crash distribution patterns (Amiri et al. 2021; Le et al. 2020; Mesquitela et al. 2022). These tools can be integrated with road network screening methods, such as Crash Rate (CR) and Equivalent Property Damage Only (EPDO), and increase result accuracy (Le et al. 2020). Researchers have compared GIS tool performance as it relates to identifying hotspot areas (Le et al. 2020; Lee and Khattak 2019; Mafi et al. 2019; Mesquitela et al. 2022). A study comparing five cluster mapping techniques (Amiri et al. 2021) revealed that Moran's I method was the most accurate and precise tool for hotspot identification and clustering pattern identification. Alternative tools, such as KDE and Gi*, are also effective in pinpointing hotspot areas. Integrating weighted crash parameters, such as severity index, using these GIS tools enhances the rationality of hotspot identification (Le et al. 2020).

Creating associations between crashes and contributing factors significantly affects traffic safety analysis. These associations can be revealed using state-of-the-art data analysis approaches such as Association Rule Mining (ARM) (Hossain et al. 2022; Lan et al. 2023; Rahman et al. 2021). Previous studies have explored traffic incident data; however, they could not often establish clear causal relationships between contributing factors; therefore, identifying root causes remains elusive (Basheer Ahmed et al. 2023; Li et al. 2018; Zaitouny et al. 2022). Previous research has not fully utilized advanced data mining techniques, such as Association Rule Mining (ARM), for comprehensive incident data analysis.

4.3. Effect of Traffic Calming Techniques on Traffic Safety

The Institute of Transportation Engineers defines traffic calming as the combination of measures that reduce the adverse effects of motor vehicle use, alter driver behavior, and improve conditions for non-motorized street users. Traffic calming consists of physical design and other measures put in place on existing roads to reduce vehicle speeds and improve safety for pedestrians and cyclists. For example, vertical deflections (speed humps, speed tables, and raised intersections), horizontal shifts, and roadway narrowing are intended to reduce speed and enhance the street environment for non-motorists. Closures that obstruct traffic movements in one or more directions, such as median barriers, are intended to reduce cut-through traffic. Traffic calming measures can be implemented at an intersection, street, neighborhood, or area-wide level (USDOT 2021). Table 1 summarizes traffic calming techniques and case study areas registered by FHWA.

Table 1 Summary of traffic-calming countermeasures (FHWA 2017; Johnson 2005; Zegeer et al. 2013)

Calming measures	Purpose	Main Considerations	Case study area
Temporary Installations for Traffic Calming	Change the entire look of a street to send a message to drivers that the road is not for fast driving.	Check for the cost of measures and use them for specific and emergency cases.	Fifth Street Traffic Calming, Tempe, Arizona
Chokers	Designed to slow vehicles at a mid-point along the street through	Ensure that bicyclist safety and mobility are not diminished	Fifth Street Traffic Calming, Tempe, Arizona
Chicanes	Reduce vehicle speeds on local streets and add greener (landscaping).	Reduce on-street parking	Berkshire Street Traffic Calming, Cambridge, Massachusetts
Mini-circles	Reduce speed and manage traffic at intersections where volumes do not warrant a stop sign or a signal.	Use yield, not stop, controls, and do not make generous allowances for motor vehicles.	Seventh Avenue Traffic Calming, Naples, Florida
Speed Humps and Speed Tables	Enhance the pedestrian environment at pedestrian crossings.	It is not recommended in a sharp curve.	Corridor Traffic Calming, Albemarle, Virginia
Gateways	Create an expectation for motorists to drive more slowly and watch for pedestrians entering a commercial, business, or residential district from a higher-speed roadway. They can also create a unique image for an area.	Traffic-slowing effects will depend upon the chosen device and the area's overall traffic-calming plan.	Leland Street Redesign Bethesda, Montgomery County, Maryland
Specific Paving Treatments	Send a visual to motorists about the function of a street and create an aesthetic enhancement of a street. It can be used to delineate separate spaces for pedestrians or bicyclists.	Slippery and bumpy surfaces should be treated.	Downtown Revitalization Partnerships, Clemson, South Carolina
Serpentine Design	Change the entire look of a street to send a message to motorists to drive slowly on this street.	Most cost-effective to build as a new street or where a street will soon undergo significant reconstruction	Old Town Improvements, Eureka, California
Curb Ramps	Provide access to street crossings and improve sidewalk accessibility for people with mobility restrictions.	Consideration of disabled pedestrians	
Speed Cushion	preferred alternative primary emergency response route or on a transit route with frequent service	Cutouts width design	

"Road diets" are one approach to traffic calming. Road diets reduce the width or number of vehicular travel lanes and reallocate that space for other uses such as bicycle lanes, pedestrian crossing islands, left turn lanes, or parking. Safety and operational benefits for vehicles and pedestrians include (USDOT 2021):

- decreasing vehicle travel lanes for pedestrians to cross,
- providing room for a pedestrian crossing median,
- improving safety for bicyclists when bicycle lanes are added,
- providing an opportunity for on-street parking (which also serves as a buffer between pedestrians and vehicles),
- reducing rear-end and side-swipe crashes,
- improving speed limit compliance and
- decreasing crash severity when crashes do occur.

Implementing traffic calming measures can reduce traffic speed, reduce motor-vehicle collisions, and improve safety for pedestrians and cyclists. These measures can also increase pedestrian and bicycling activity (USDOT 2021).

Table 2 summarizes the effect of traffic calming techniques on 85th percentile vehicle speed in different states of Canada and the US. The traffic calming techniques, in most cases, were effective in terms of reducing vehicle speed.

Table 2 Summary traffic calming techniques effect on 85th percentile vehicle speed (FHWA 2014; FHWA 2017)

Traffic Calming Technique	85th %tile Speed (mph)			Study area	No. of site	Location
	Before	After	Change			
Speed Hump	35	27	-8	Various	178	Straight section and pedestrian crossing
	36	31	-5	WA	8	Excessive speeds and cut-through traffic
	37	29	-8	FL	1	In rural residential streets
	28	22	-6	IA	3	At a pedestrian crossing of a rural community street
Speed Table	37	31	-6	Various	72	In straight sections of featured community streets
	38	29	-9	GA	19	At continuous intervals on residential streets
	33	29	-4	IA	1	At a pedestrian crossing of a rural community street
	28	22	-6	IA	3	At a pedestrian crossing of a rural community street
Raised Intersection	37	38	1	Various	2	At entire sections of intersections and junctions
	30	30	0	NY	1	At medium-traffic street intersections
Chicanes	31	22	-9	WA	4	At the community road-side straight section
Center Island	35	33	-2	IA	3	At the intersection and straight section center of main streets
	36	35	-1	IA	2	
Transverse Rumble Strips	55	54	-1	TX	11	Edge of rural roads and at straight sections near intersections and curves
	49	52	3	KY	3	Horizontally curved rural roads
Converging Chevrons	53	52	-1	TX	-	At the freeway-to-freeway connector ramp
	53	53	0	TX	-	
	37	33	-4	OH	1	At intersection and curve approaches
Speed Activated Speed Limit Sign	36	30	-6	CO	1	In streets near schools and restricted speed zones
	39	34	-5	CO	2	
	37	33	-4	CO	3	
	37	32	-4	CO	1	
Speed Feedback Sign with Action Message	65	63	-2	TX	1	At curved road sections
	59	52	-7	IA	1	
	34	32	-4	WA	9	
	33	31	-5	WA	3	
	36	31	1	WA	1	

With a significant contribution from the SRC, West Fargo's project team developed a list of traffic-calming solutions that can be implemented (METROCOG 2021). Some criteria used to come up with the list were feasibility, effectiveness, maintenance, and other measures such as emergency services or vehicular impacts. The list includes lane narrowing, curb extension, pinch-point, chicane, median island, mini roundabout, speed hump, pavement material, diverter, and landscaping.

4.4. Effects of YIELD and STOP Signs on Pedestrian Safety and Traffic Speed

Engineers have traditionally marked crosswalks for three reasons: to increase pedestrian safety by identifying the safest location to cross the street, to alert drivers to the possibility of pedestrians crossing at that location, and to increase a pedestrian's level of service and safety (Van Houten et al. 2002). Crosswalk markings and their correlation to increased pedestrian safety have been the subject of much debate. A study on the safety effects of marked versus unmarked crosswalks at uncontrolled locations (Zegeer et al. 2001) compared 1,000 marked and 1,000 unmarked crosswalks in 30 USS cities. Their study indicated only one instance where there was a significant difference in the number of crashes between marked and unmarked crosswalks: crosswalks on multilane roads with an uncontrolled approach had significantly more crashes than unmarked crosswalks if the road had average annual daily traffic (AADT) above 12,000. The study also indicated that more than 70% of pedestrians cross at marked locations, most notably those younger than 12 and more than 64 years old. Research indicates that marked crosswalks can lead to a false sense of security; however, behavioral data collected from multiple sites before and after crosswalks were installed contradicted this hypothesis. This data indicated that marked crosswalks were associated with higher pedestrian-observing behavior and lower driver speeds (Knoblauch et al. 1999).

Several studies have demonstrated that "YIELD to Pedestrian" signs placed in roadways can increase the percentage of motorists yielding for pedestrians (Ellis et al. 2007; FHWA 2009; Huang et al. 2000; Kannel et al. 2003; Strong and Ye 2010). In-roadway signs were also evaluated in other studies (Turner et al. 2006). The research team collected data on motorist yielding behavior at 42 crosswalks in different regions of the United States. The results indicated that the in-roadway signs were associated with yielding rates of 87% for two-lane roads and were highly cost-effective in increasing yielding behavior. Gedafa et al. (2014) also determined that yield signs installed at any location result in vehicles yielding to pedestrians. The placement of the sign at a crosswalk is the most effective method for increased yielding, and the presence of a yield sign results in a lower average traffic speed. These findings imply that the risk to pedestrians and bicyclists is lower in the presence of the sign. These studies need to be validated with additional studies at different locations.

Research conducted in Iowa analyzed the effects before and after implementing the State Law – Yield to Pedestrians at three locations and concluded that the sign positively affected driver behavior (Kannel et al. 2003). An observational study focused on the spillover effects of within-crosswalk signs reported that the signs positively impact and enhance motorist and pedestrian behaviors (Strong and Ye 2010). Another study comparing the single and gateway configurations of in-crosswalk signs discovered that all setups effectively increased the yielding percentage (Bennett et al. 2014).

Pedestrian's right of way in crosswalk includes driver and pedestrian responsibilities according to North Dakota Century code: when traffic-control signals are not in place or not in operation, the driver of a vehicle shall yield the right of way, slow down or stop if need be to yield so, to a pedestrian crossing the roadway within a crosswalk when the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger; and no pedestrian may suddenly leave a curb or other place of safety and walk or run into the path of a vehicle which is so close as to constitute an immediate hazard.

5. MATERIALS AND METHODS

5.1. Study Area and Materials

The Grand Forks city, which had an estimated population of 58,692 in 2022, is located in the Great Plains region; therefore, there are notable climate variations between the summer and winter seasons, with the lowest temperatures typically recorded in winter months, such as January, February, and December, and occasional snowfall extending into April (Bangsund et al. 2022; NOAA 2022).

I) Traffic Hotspot Area and Crash Contributing Factors Analysis

The hotspot analysis focused on traffic crashes in the city of Grand Forks, North Dakota, USA, from 2017 to 2022. Crash hotspot analysis requires a minimum of three to five years of data (Cheng and Washington 2005; FHWA 2011). This study used six years of data from the Grand Forks City Police Department, including 2,048 police-reported crashes. All traffic crashes were used for the crash hotspot analysis. The study used street centerline data and AADT generated from the Grand Forks Data Hub website. Figure 4 illustrates the study area and crash data map. All crash points were geocoded on the road networks using ArcGIS Pro version 3.1.2.

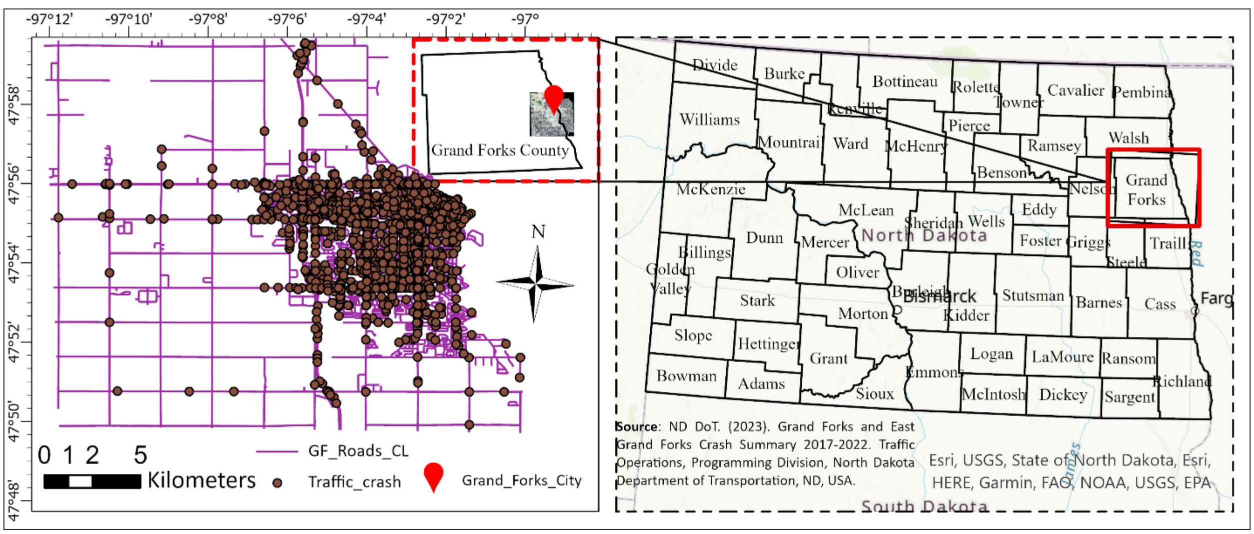


Figure 4 Crash map of Grand Forks city

II) Effect of In-Crosswalk Traffic Signs on Pedestrian Safety

The traffic speed and yield data were collected at five locations in Grand Forks, North Dakota, USA. The main facilities in the city include business areas, residence areas, schools, and recreational parks. The city streets that are close to the recreational parks and schools experience more pedestrians and bicyclists; therefore, those regions were selected for data collection. The streets selected for the study were 6th Ave N, S 25th St, Cherry St, 11 Ave S, and S 34th St. Figure 5 indicates the location of the study areas selected for speed and yield data collection.

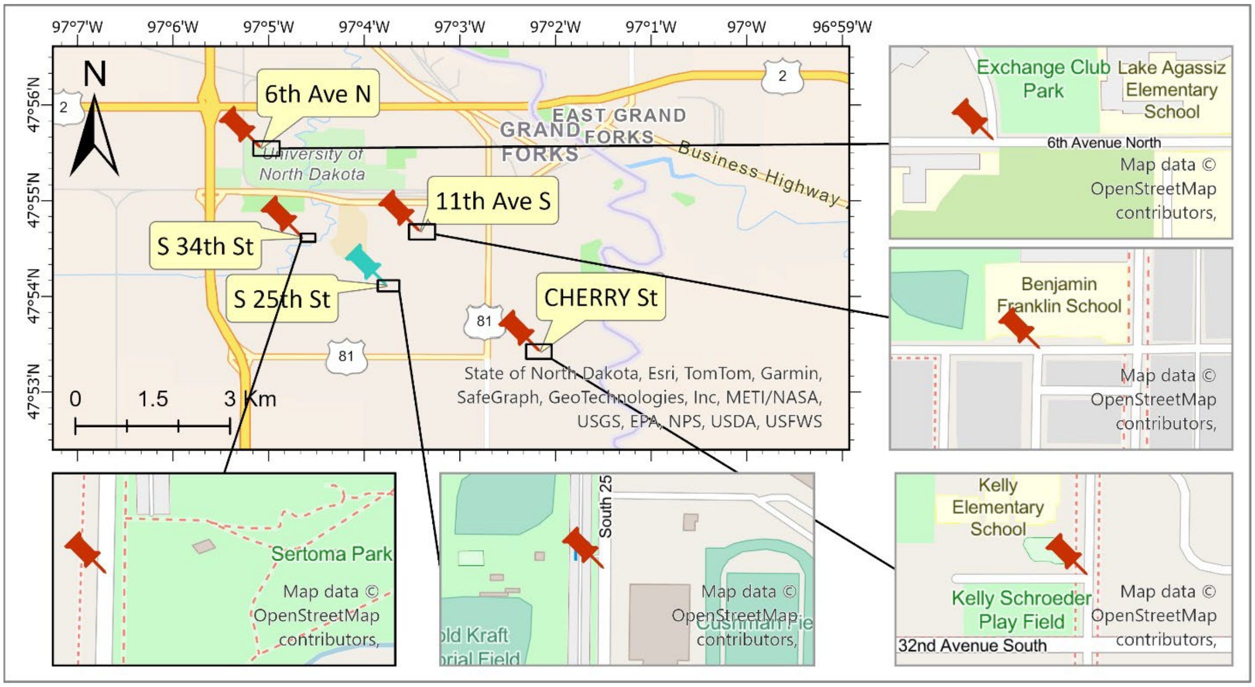


Figure 5 Study area for in-crosswalk signs

The speed data were collected during in-school hours and times when schools were not in session at all locations; however, the yield data were collected at all locations for the in-school sessions only. Table 3 summarizes the main features and collected data types at each location.

Table 3 Study location features (NDDOT 2021)

Location	Number of Lanes	AADT (2020)	Posted Speed Limit (mph)	Collected Data			
				Speed		Yield	
				School	No-School	School	No-School
6th Ave N	Two-lane with turning-lane	3908	25	*	*	*	
11th Ave S	Two lane	2320	20	*	*	*	
Cherry St	Two lane	3065	20	*	*	*	
S 25th St	Two lane	1550	20	*	*	*	
S 34th St	Two lane	3160	30		*		

5.2. Methods

This study used various GIS analysis tools to analyze traffic crash hotspot locations and their temporal patterns. The analysis consisted of two parts: a) a spatiotemporal analysis using Emerging Hotspot Analysis and b) a hotspot spatial analysis using Anselin Local Moran's I and Getis-Ord Gi*.

Crash frequency has been used in the past to identify areas with significant safety concerns (Abdulhafedh 2016; Lord and Mannering 2010); however, safety analyses using crash frequencies are biased toward higher traffic volume areas and do not take the effect of traffic volume and crash severity into account. Equivalent Property Damage Only (EPDO) and Crash Rate (CR) values were calculated to factor in the effect of severity and traffic volume, respectively.

The EPDO technique applies a weighting factor and converts the fatality and injury severity levels to an equivalent Property Damage Only-PDO level (Bonneson 2010; Wemple et al. 2014). The weighting factors related to the societal costs for each severity level could be variable for different regions. The study used the NDDOT's KABCO injury classification and weighting factors of 100, 55, 17, 11, and 1 for fatal, incapacitating, non-incapacitating, possible, and PDO injury levels, respectively (NDDOT 2021b). Equation 1 is used to calculate the EPDO Weighted total.

$$EPDO\ Weighted\ Total\ = 100K\ +\ 55A\ +\ 17B\ +\ 11C\ +\ O \quad (1)$$

Where K, A, B, C, and O represent fatal, incapacitating, non-incapacitating, possible, and PDO injury, respectively.

Crash rate (Equation 2) was used to identify hotspot areas and consider the effects of traffic volume and vehicle miles traveled. The CR considers traffic and road network parameters, such as Million Vehicle Miles Travelled (MVMT), road length, and AADT (NDDOT 2021b; Wemple et al. 2014).

$$Crash\ Rate, CR\ = \frac{n\ *\ 1{,}000{,}000}{AADT\ *\ 365\ *\ t\ *l} \quad (2)$$

Where n is the number of crashes per street, AADT is the average annual daily traffic, t is years, and l is road length in miles.

Hotspot Spatial Analysis

Crash hotspot analysis can be performed using either the original crash point data or data that has been integrated into the road network (Le et al. 2020; Mafi et al. 2019; Mesquitela et al. 2022). It is advisable to assess the data's global spatial pattern before conducting any local spatial analysis (Mesquitela et al. 2022). The Global Moran's I-statistic was used to determine if the crashes exhibited clustering, dispersion, or random distribution. This statistic ranges from -1 to 1, where values near -1, 0, and 1 indicate random dispersion, complete geographic randomness, and clustered patterns, respectively. The I statistic calculates a Z-score, which is a standard deviation that measures statistical significance and checks spatial relation (ESRI 2019). An 800-meter bandwidth was selected after several trials since it yielded the highest Z-score.

The Gi* tool calculates a statistic that yields high and low spatial point clusters (ESRI 2019). This study calculated Gi * statistics for the road network. The areas with statistically high and low feature attributes were identified. Each feature's Z-score is the dataset's Gi* statistic. The hotspot intensity, a cluster of high values, is proportional to the Z-score value for positively significant statistical data. A near-zero Z-score implies no spatial clustering. A significance level of α=0.05 was considered. The Gi* statistic is computed as:

$$G_i^* = \frac{\left(\sum_{j=1}^{n} W_{i,j}X_j - \left(\frac{\sum_{j=1}^{n} X_j}{n}\right)\sum_{j=1}^{n} W_{i,j}\right)}{\sqrt{\frac{\sum_{j=1}^{n} X_j^2}{n} - (\bar{X})^2} * \sqrt{\left(\frac{n * \sum_{j=1}^{n} W_{i,j}^2 - \left(\sum_{j=1}^{n} W_{i,j}\right)^2}{n-1}\right)}} \tag{3}$$

Where Xj is the attribute value for feature j, Wi,j is the spatial weight between i and j, and n is the number of features.

The I-statistic (Equation 4) identifies clustered and outlier data points at a confidence level of 95%. The Anselin Local Moran's I tool was used to identify high and low clusters and outliers. The outliers are locations of statistically significant points with high values surrounded by low-value segments, or vice versa (Anselin 1995; ESRI 2019). A positive I value implies a clustered feature with similarly high or low neighboring attribute values; however, a negative I value indicates an outlier. The results could be clusters of high values - HH, low values - LL, outliers of high values surrounded by low values – HL, or low values surrounded by high values - LH (ESRI 2019).

$$I_i = \frac{(x_i - \bar{X}) * \sum_{j=1, j\neq i}^{n} w_{i,j}(x_i - \bar{X})}{\sum_{j=1, j\neq i}^{n} \frac{(x_i - \bar{X})^2}{n-1}} \tag{4}$$

Where x_i is a feature of the i attribute, $\bar{X}$ is the corresponding attribute mean, $w_{i,j}$ is the spatial weight between i and j, and n is the total feature number.

Spatiotemporal Analysis

The Emerging Hotspot Analysis is a location and time pattern tool used to identify the space-time clustering of points using other tools, such as the Create Space Time Cube By Aggregating Points from Defined Locations and Multidimensional Raster Layer tools (ESRI 2019). This study used the Aggregating Points tool as a preliminary step before conducting the Emerging Hotspot Analysis. The crash data was incorporated, and the study area, situated in the northern hemisphere, was subdivided into the four primary seasons: winter, spring, summer, and autumn (Trenberth 1983).

Association Rule Mining (ARM)

Association rule mining is a powerful method used to uncover interesting relationships between variables within extensive datasets. Association Rule Mining (ARM) facilitates the extraction of insights regarding the causes, consequences, and likelihood of various outcomes. This technique is distinctive due to its simplicity, making it straightforward to implement and understand; however, it has a significant disadvantage when managing complex datasets with many variables since it can generate irrelevant rules. This study extracted patterns with high frequency and confidence values to address this issue.

Apriori Algorithm

There are several ARM algorithms, such as Apriori, LP-growth, eclat, and FP-Growth (Chee et al. 2019); however, this study used the Apriori algorithm due to its advantages of shorter mining times and lower memory consumption when mining frequent item sets. The algorithm uses three key metrics, support, confidence, and lift, to select interesting rules from many potential rule sets. Support is the number of times that item sets co-exist (Equation 5).

$$Support\ (A \rightarrow B) = P(A \cap B) = \frac{N(A \cap B)}{N(ALL)} \tag{5}$$

Where A is a factor, B represents a consequence, $N(A \cap B)$ represents the frequency of occurrence of A and B together, and N(ALL) is the total frequency of all incidents.

Confidence is a conditional probability, which refers to the probability of B occurring if B has already occurred (Equation 6).

$$Confidence\ (A \rightarrow B) = P\left(\frac{B}{A}\right) = \frac{P(A \cap B)}{P(A)} \tag{6}$$

Where $P(B/A)$ is the probability of effect B occurring given that factors A have occurred, P(A∩B) is the probability of two events co-occurring, and P(A) is the probability of A occurring.

Lift quantifies how much more likely it is for the items to occur together than if they were independent (Equation 7).

$$Lift\ (A \rightarrow B) = \frac{Support(A \rightarrow B)}{\big(Support(A) * Support(B)\big)} \tag{7}$$

Where Support(A→B) is the support of the rule A → B (the co-occurrence of items A and B), and Support(A) and Support(B) are the individual supports of items A and B, respectively.

Figure 6 illustrates the approach used to extract association patterns between cause factors and their impacts from crash data through association rule mining. Crash reports were initially gathered, and variables were categorized into distinct subgroups. Association rules were then applied to identify the relationships between these factors and their effects. Strong association rules were subsequently extracted and subject to discussion.

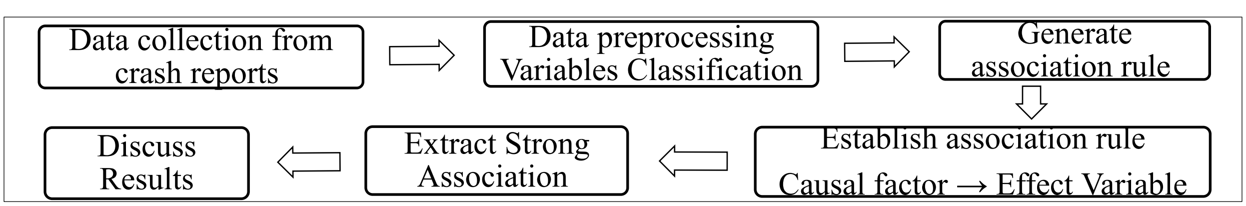


Figure 6 Framework for extracting the cause and effect of a traffic crash

Speed and Yield Data Analysis

The regulatory in-street traffic signs described in Section 2B.12 of the FHWA Manual on Uniform Traffic Control Devices (FHWA 2009) were used. Figure 7 presents the two traffic signs placed at the edge of the crosswalk lines at 25th Ave S. Vehicle speed data were collected using a Scout Wireless Handheld Traffic Radar Gun by Decatur.

The speed and yield data were collected at the test streets with (W) and without (WO), the two within-crosswalk traffic signs. The data were collected twice a day from May 2023 to October 2023, during the morning (M) and afternoon (A) hours at 20-minute intervals. The speed and yield data were collected at free-flow traffic conditions and peak-hour conditions, respectively. These free-flow conditions are usually observed during off-peak hours (Manual 2000). The traffic signs were placed at the most effective location: the intersection of the road center line and crosswalk line (Ellis et al. 2007; Gedafa et al. 2014).

The minimum, average, 85th percentile, and maximum speeds were calculated. The 85th percentile speed is a fundamental element in setting speed limits (Forbes et al. 2012). The speed for turning vehicles was excluded from the analysis since the drivers reduced speed even without the presence of the traffic signs. The yield data were collected at peak hours and only during school sessions. The drivers were scored according to how they interacted with the pedestrians.

The leading vehicle's speed and yield score were considered when vehicles traveled closely. The stopping sight distance (SSD) determined vehicle proximity, and roads were marked at this distance from the pedestrian crossing line. The SSD was calculated based on posted speed limits at each site and consisted of brake reaction distance and braking distance (AASHTO 2011). Vehicles following another within a distance shorter than the SSD were excluded from the analysis. Drivers received a yielding score if they stopped or yielded for pedestrians. Drivers also received a yielding score if pedestrians appeared after drivers passed the SSD mark. A driver was marked as not yielding if the pedestrian reached the road crossing before the driver reached the SSD mark and did not yield. Any conflict between a driver and a pedestrian was considered as not yielding.

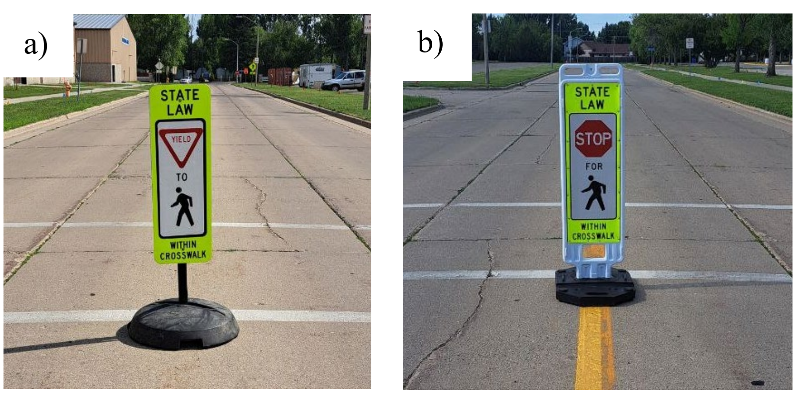


Figure 7 Within-crosswalk traffic signs at S 25th St: a) YIELD to Pedestrians: R1-6 and b) STOP to Pedestrians: R1-6a

Significance Difference Tests

Statistical tests were used to check the significant difference between the with and without traffic sign yield and speed data. A 95% confidence level was used for all statistical tests. An independent t-test was used to test for the significant difference between the average speeds with and without traffic signs. This test can be used to make inferences about two independent means (Ott and Longnecker 2015). The null hypothesis for the t-test stated that the means of the two samples were not significantly different and could be rejected when the p-value was less than the selected significance level (Mendenhall et al. 2012).

Chi-squared and two-proportion tests were used to check the yielding proportion difference between the with and without conditions. The tests were used to test the significant difference between two categorical variable proportions, and the null hypothesis for these tests stated that there was no significant difference between the two sample proportions (Mendenhall et al. 2012; Ott and Longnecker 2015). Figure 8 summarizes the main steps followed while conducting this study.

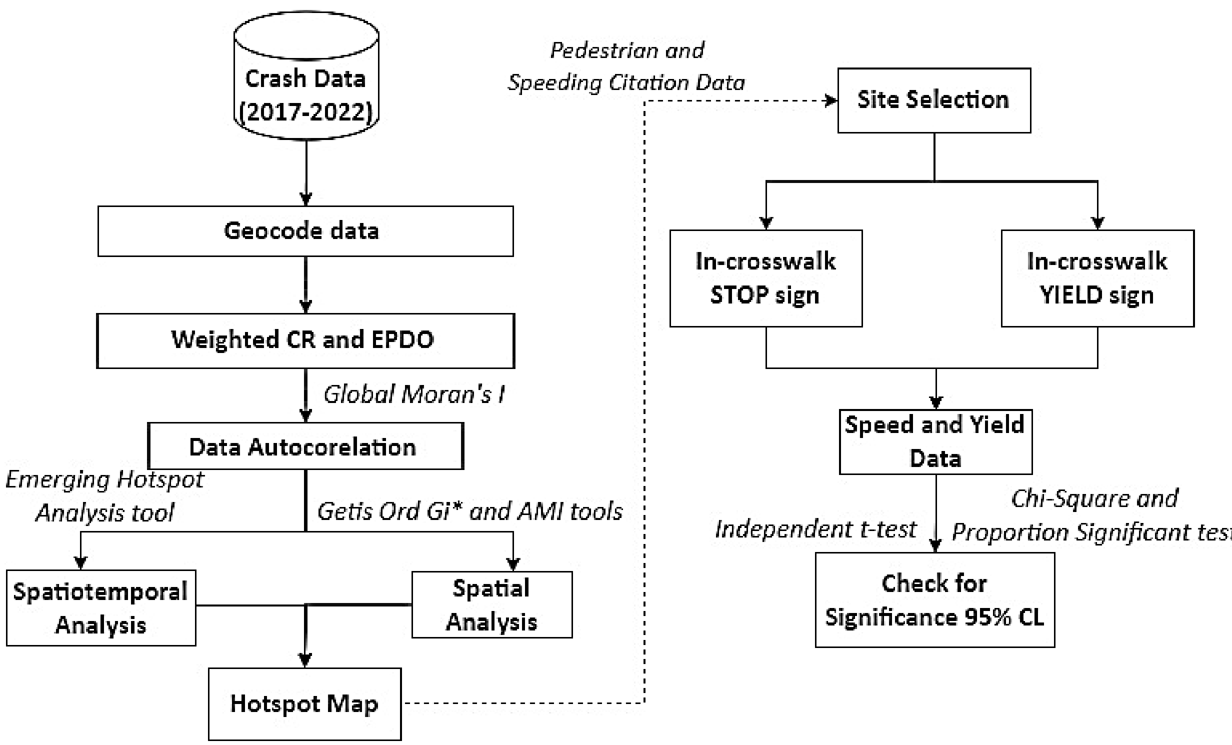


Figure 8 Study flowchart

6. RESULTS AND DISCUSSIONS

6.1.Preliminary Analysis

Different crash pattern summaries were done before the hotspot area analysis. There were more than 22 factors reported as a cause for each crash. Figure 9 presents the total number of crashes caused by each contributing factor except the unknown factors. The reasons for 797 crashes were reported as unknown. The major contributing factors for the crashes were Failure to Yield (16%), Too Fast for Conditions (16%), Following Too Close (15%), Careless Driving (12%), and Weather (11%). The crashes due to animals in the roadway and disregarding road markings were one. According to the NDDOT vision zero initiative definition, speeding includes driving too fast for the conditions, following too close, and recklessly operating a vehicle. Hence, speed-related factors accounted for 45% of the crashes with known causes and 28% of the total reported crashes with known and unknown reasons.

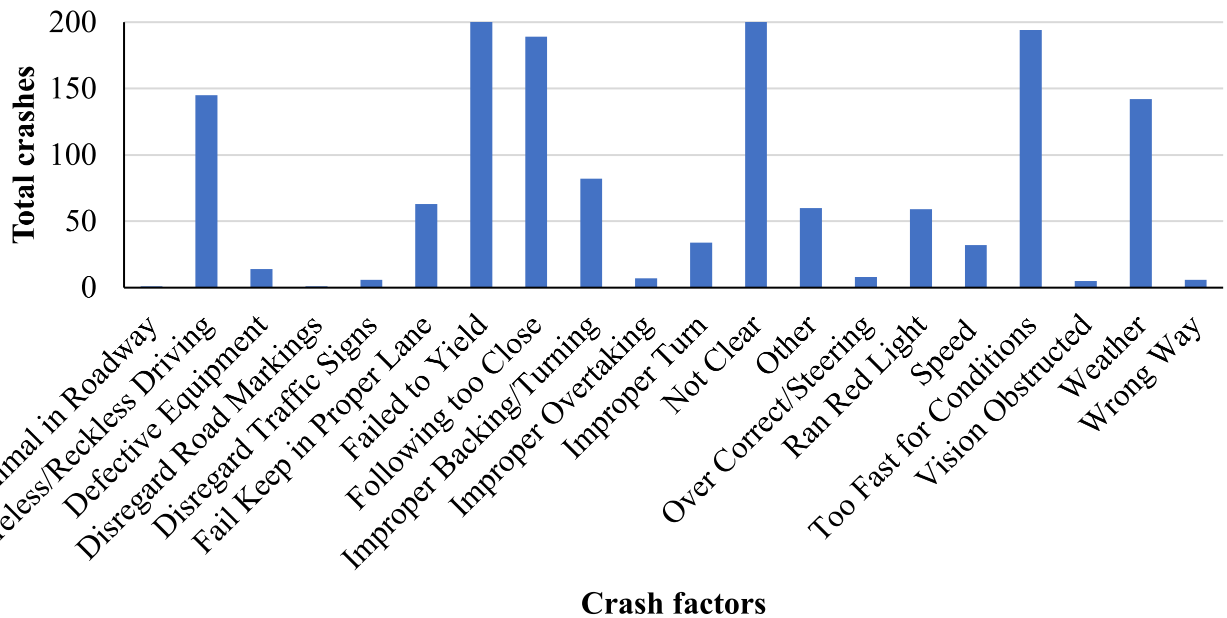


Figure 9 Crash contributing factors and percent total crash

Alcohol use increases the possibility of a crash and severity (Beaulieu et al. 2022). Figure 10 presents the number of crashes for the corresponding alcohol use and severity level conditions. Only 5% of the total crashes involved alcohol. The severity level data shows 81% of the crashes were property damage only (PDO), 10% were non-incapacitating injuries, 8% were possible injuries, and 2% were fatal and incapacitating injuries. Most of the fatal crashes involve drivers with no alcohol use. For all severity cases, the number of crashes due to alcohol use is less than no alcohol use. The higher alcohol use rate was seen for incapacitating injuries, where crashes due to alcohol use accounted for 19% of the total incapacitating injuries.

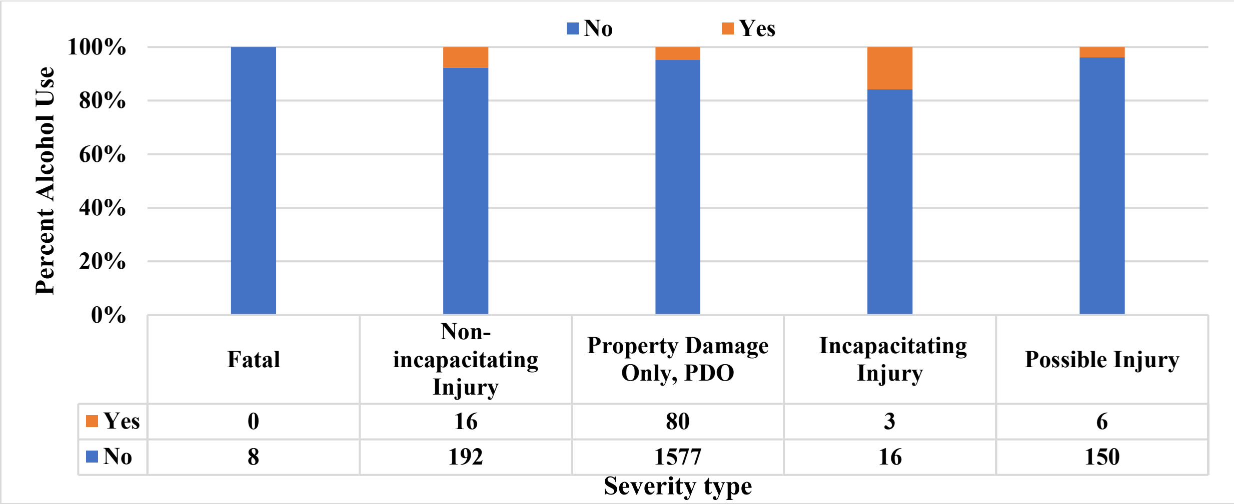


Figure 10 Percent crash severity levels due to alcohol use

The safety equipment (seat belts and helmets) that the drivers or passengers used during the crashes could significantly affect the severity level (Egly and Ricca 2023). The safety equipment should be appropriately used to minimize the extent of the injury (Kashani et al. 2022). Table 4 shows the total number of crashes under each safety equipment. The data showed that crashes 63% of drivers involved in crashes use lap and shoulder belts.

Table 4 Safety equipment use data

Safety equipment type	Number of crashes
Restraint use unknown	1118
Not in use	43
Lap and shoulder	2191
Shoulder belt	27
Helmet worn	3
Lap belt only	40
Not applicable	32
Child safety seat (prop)	1

Figure 11 depicts the total number of male and female drivers involved in the crash for each age category. The number of male drivers involved was higher in 87% of the age categories. However, the number of female drivers involved in crashes was higher than male drivers for the age category of 19 years and younger. The male and female driver crash exposure was equal for those between 80 and 84 years. There were 3169 drivers involved in traffic crashes.

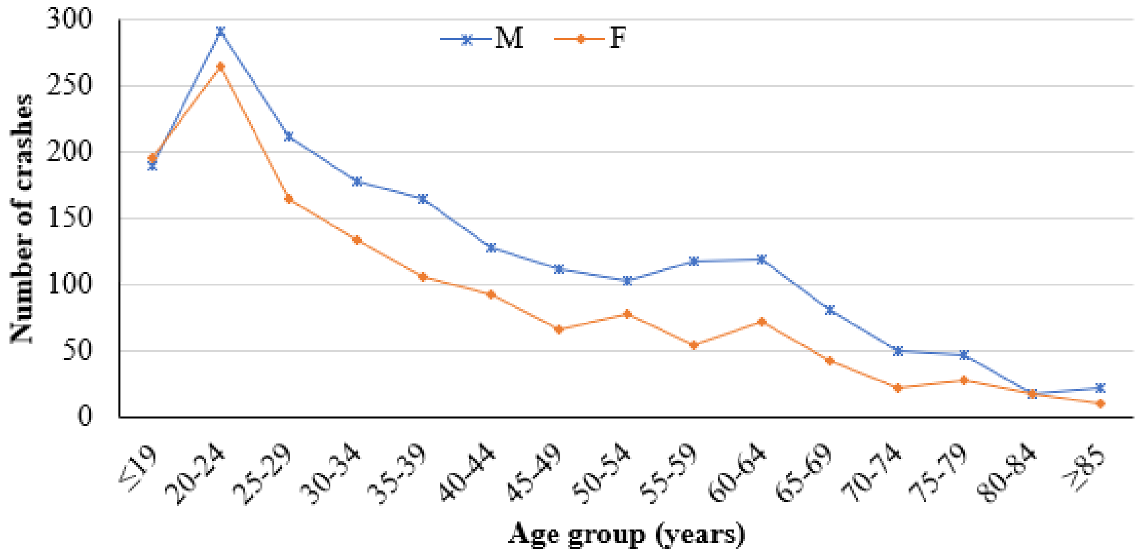


Figure 11 Age group and sex of drivers

The prevailing weather and road surface conditions affect the severity and probability of crash occurrence (Hammad et al. 2019; Malin et al. 2019; Zhai et al. 2019). Table 5 shows the crash scenes under each surface and weather conditions. Unfavorable weather and surface conditions can increase crashes. Of the total crashes, 41% occurred on dry pavement and clear sky conditions, while 17% occurred on icy roads and clear sky conditions.

Table 5 Road surface and weather conditions during the crash scene

Weather Condition	Surface Condition					
	Dry	Snow	Ice / Compacted Snow	Mud Dirt Gravel	Wet	Slush
Unknown	46	6	11	1	0	0
Clear	841	170	350	0	42	17
Cloudy	110	79	89	0	48	7
Rain	0	0	7	0	46	0
Snow	0	78	26	0	3	7
Blowing Snow	1	14	12	0	0	1
Sleet/Hail/Freezing Rain	0	6	18	0	2	1
Fog / Smoke / Dust	2	0	1	0	3	0
Severe Wind	1	0	1	0	1	0

Speed Violation Data Analysis

The speed data that spans from 2015 to 2022 was analyzed. The results show that roads such as 17th Ave S, Demers Ave, 24th Ave S, S Washington St, HN:297mm:3, S 20th St, Gateway Dr, 32nd

Ave S, Cherry St, Belmont Rd, And University Ave have higher rates of driver speed violation records. Most of the top-ranked roads have relatively higher traffic volume than the others. Table 6 summarizes the top 16 streets with the highest number of citations.

Table 6 Speeding Ticket Summary

Location	No. of ticketed drivers	Location	No. of speed violation
17th Ave S	2270	40th Ave S	159
Demers Ave	1861	Cherry St	158
24th Ave S	1681	S 34th St	150
Hn:297mm:3	567	S Columbia Rd	141
S 20th St	531	20th Ave S	129
S Washington St	501	32nd Ave S	107
Gateway Dr	414	N Washington St	97
Belmont Rd	179	S 48th St	80

6.2. Road Network Hotspot Analysis

The total number of hotspots for each analysis case, Gi* from EPDO, Gi* from CR, I_i from EPDO, *and* I_i from CR, were compared. Figure 12 a) and b) present the Gi* output using the EPDO and CR input parameters, respectively. The Central-East and Central-West parts of the Grand Forks city streets were identified as hotspots. The red graduated colors on the map depict the hotspot areas at confidence intervals of 90%, 95%, and 99%. Most hotspots were observed at intersections where streets with high traffic volumes intersect. The CR input only yielded hotspot areas at a CI of 95% and 99%. The CR input at p=0.05 established that only 1% of the road networks were hotspots, while 7% were statistically significant at p=0.01. The EPDO technique revealed that there were 17% and 4% statistically significant hotspots at 0.01 and 0.05 p-values, respectively. Table 7 summarizes the Gi* statistic outputs for EPDO and CR input parameters under each p-value. There were more hotspot road segments for the hotspot analysis using EPDO than CR.

Table 7 Getis Ord Gi* results summary

Input Parameter	Coldspot (%)			Hotspot (%)			Not Significant (%)
	p=0.01	p=0.05	p=0.1	p=0.01	p=0.05	p=0.1	
EPDO	5	10	6	17	4	1	57
CR	0	0	0	7	1	0	92

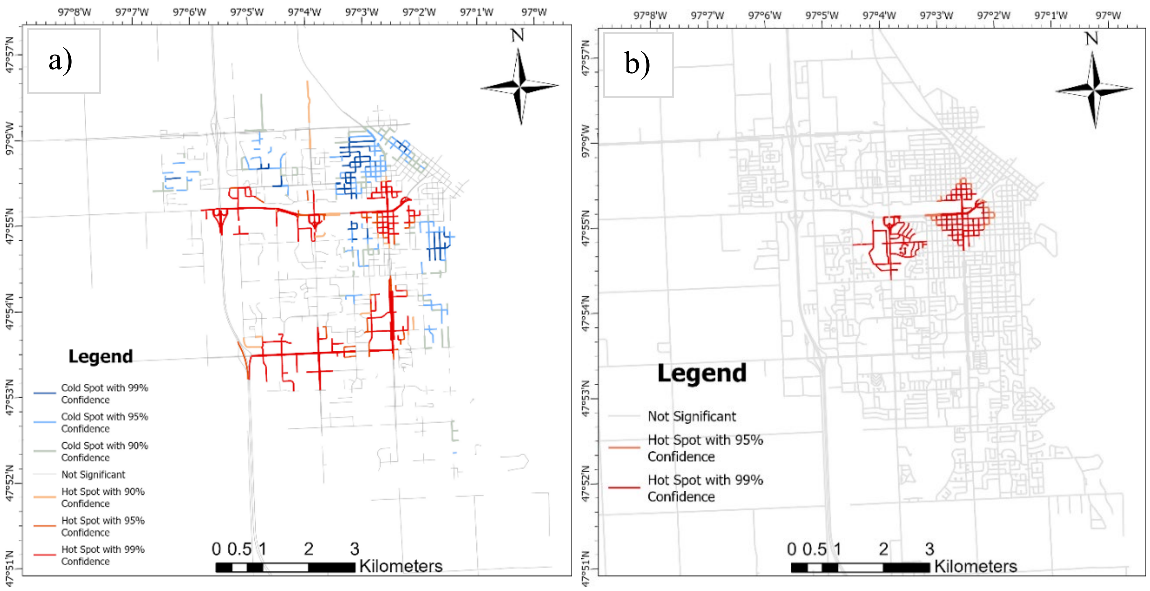


Figure 12 Hotspot results using a) Gi* - EPDO and b) Gi* - CR

The Anselin Local Moran's (AMI) I statistics were also calculated to check the consistency of the output variation for the EPDO and CR input parameters. Figure 13 a) and b) demonstrate the I-statistic cluster and outlier outputs from EPDO and CR, respectively. There were more HH clusters for the EPDO input parameter than the CR. The HL and LH outliers from the EPDO analysis were dispersed. Most road networks were identified as LL clusters for the CR analysis, with a p-value of 0.05. The LL-clustered roads are surrounded by roads with low CR values.

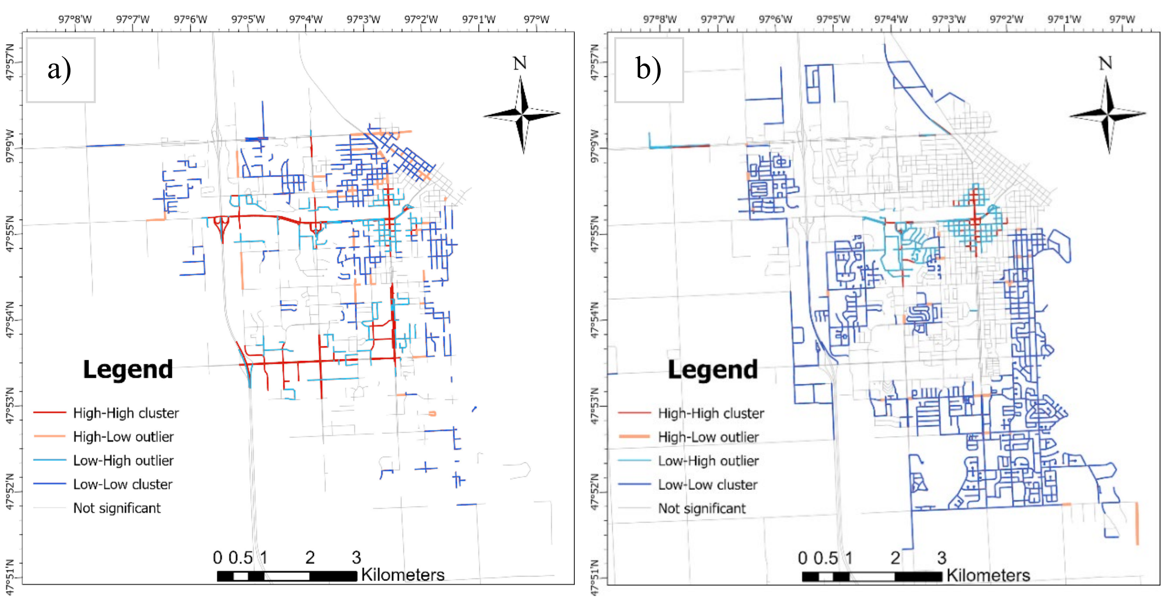


Figure 13 Crash hotspots using a) AMI - EPDO and b) AMI - CR

Table 8 provides road segment percentage summaries for each output cluster and outlier category. The percentage of outliers and clusters for the EPDO was higher than the CR. The I-statistic with a 0.05 p-value revealed that 10% and 3% of the road networks were identified as HH clusters from EPDO and CR, respectively. The non-significant road networks for CR were higher than the EPDO, consistent with the Gi* statistic summary. The p-values for clusters and outliers were less than 0.05 with different Z-scores, negative for outliers, and positive for clusters. The Z-score for the non-significant road segments was between -1 and 1, while the p-values were above 0.05.

Table 8 AMI (I_i) results summary

Input Parameter	HH Cluster (%)	HL Outlier (%)	LH Outlier (%)	LL Cluster (%)	Not significant (%)
EPDO	10	4	13	28	44
CR	3	1	5	31	60

6.3.Spatio-Temporal Analysis

The Emerging Hotspot Analysis results established the spatiotemporal correlation between crashes. Figure 14 a) depicts the crash data temporal summary analyzed from the raw crash data. The crashes occurred predominantly during the winter season, which comprises December, January, and February. Figure 14 b) presents the statistical summary of the hotspot areas. There were no spatiotemporal patterns for the majority of the crashes. Only 16 spatiotemporal patterns were detected out of the total 235 location bins. The detected patterns included Diminishing Hotspots, Sporadic Hotspots, and New Coldspots. There were 13 sporadic hotspots and two diminishing hotspot areas. The sporadic areas were spatial bins under observation and continually switched from being a hotspot to not being a hotspot and to being a hotspot again. The hotspots had a p-value less than 0.05 and a negative Z-score. The percent significance for the diminishing hotspots was 94%, while it ranged from 61% to 88% for the sporadic hot zones. The New Coldspot region had a 5.5% significance and p-value higher than 0.05. A post-comparison of the raw data and the spatiotemporal analysis indicated that the sporadic and diminishing hotspots were primarily due to the crashes that occurred in the winter.

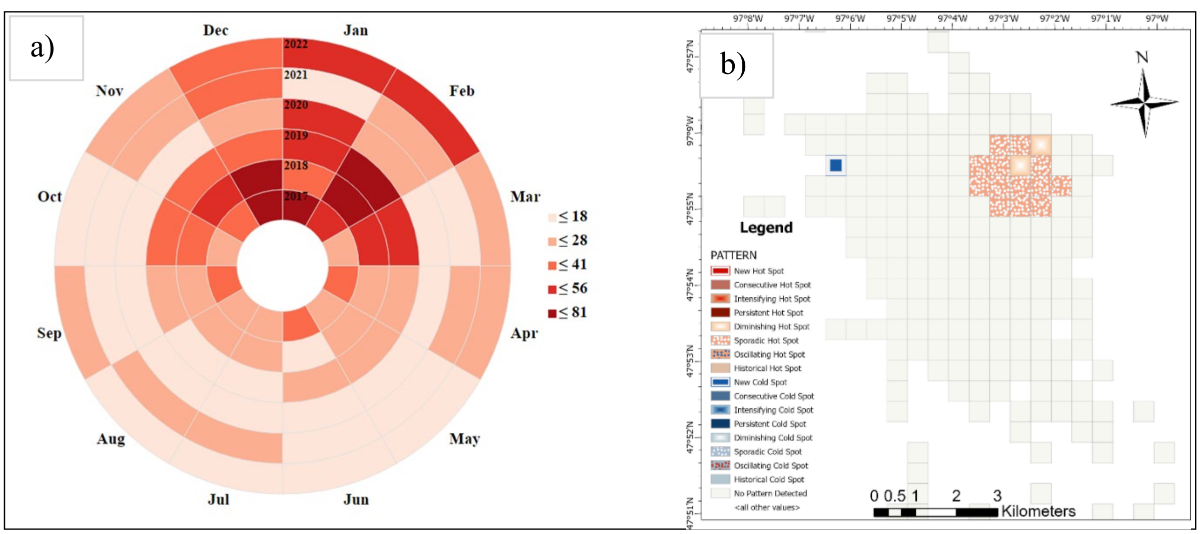


Figure 14 a) Crash Data Clock and b) Emerging Hotspot Spatiotemporal Analysis

Similarity Test

The Hotspot Analysis Comparison tool was used to compare and check the spatial association between the hotspots from the EPDO and CR input parameters. Table 9 presents the percentage of EPDO hotspots within the CR hotspot at each confidence interval. Only 15.79% of the CR hotspots were identified as EPDO hotspots at the given CI. The similarity value-SV, including the non-significant road segments, was 0.72, and the expected similarity value-ESV between the two results was 0.59. The Spatial Fuzzy Kappa, which scales the SV by ESV, was computed as 0.31. The Kappa value between 0.2 and 0.4 revealed that the hotspot results had a fair spatial association.

Table 9 Hotspot results comparison using the significance level

CR-Hotspot Significance Level	EPDO-Hotspot Significance Level						
	Coldspot 99%	Coldspot 95%	Coldspot 90%	Not Significant	Hotspot 90%	Hotspot 95%	Hotspot 99%
Coldspot 99%	0	0	0	0	0	0	0
Coldspot 95%	0	0	0	0	0	0	0
Coldspot 90%	0	0	0	0	0	0	0
Not Significant	5.96	10.72	7.04	62.18	0.95	2.54	10.6
Hotspot 90%	0	0	0	0	0	0	0
Hotspot 95%	0	0	0	31.58	10.53	15.79	42.11
Hotspot 99%	0	0.53	0	13.76	2.12	12.7	70.9

6.4. Association Rule Mining

This study obtained relevant patterns meeting both relatively high frequency and confidence criteria through filtering. Table 10 summarizes the statistical association summary between variables in the dataset.

Table 10 Association between crash variables

Rule	Frequency	Support	Confidence	Lift
First Harmful Event → Manner of Collision				
Collision with an object (Not fixed) → Angle Collision	660	0.32	100.00%	1.17
Intersection Type → Manner of Collision				
Multi-leg intersection → Angle Collision	660	0.20	61.52%	1.86
Intersection Type → Crash Severity Class				
Non-intersection →Fatal Injury	27	0.01	66.67%	1.17
Light Description → Manner of Collision				
Daylight → Angle Collision	651	0.29	84.02%	1.12
Relation to Junction Location → Crash Severity Class				
Non-Junction → Fatal Injury	27	0.01	55.56%	1.13
Relation to Junction Location → Manner of Collision				
Interchange Related → Single Vehicle Crash	42	0.01	57.14%	1.91
Weather Condition → Manner of Collision				
Hazardous → Single Vehicle Crash	169	0.03	40.24%	1.41

The support metric specifies the frequency of the rule in the dataset, while confidence measures how often the rule is true when the antecedent (left side) is true. Lift indicates the strength of the association between the rule's antecedent and consequent (right side), with values greater than 1 indicating a positive association. These rules can be valuable for understanding and potentially mitigating the causes and consequences of traffic incidents. For instance, in incidents involving "Collision with an object (Not fixed)," there is a high likelihood (100% confidence) of an "Angle Collision" as the collision manner. The support of 0.32 indicates that this pattern is relatively common in the dataset. The lift of 1.17 suggests that this association is slightly more likely to occur than if the two events were independent.

6.5. Trafic Crash and Speeding Data Analysis

On the reported data, the exact location for most of the speeding citations was not reported, and the citations were assumed to exist at any point along the reported road section. Figure 15 summerizes the streets with more number of traffic speeding citation. The cited drivers were assumed to travel with the same speed along the street. The streets such as 17th Ave S, Demers Ave, and 24th Ave S had the highest speeding citation records.

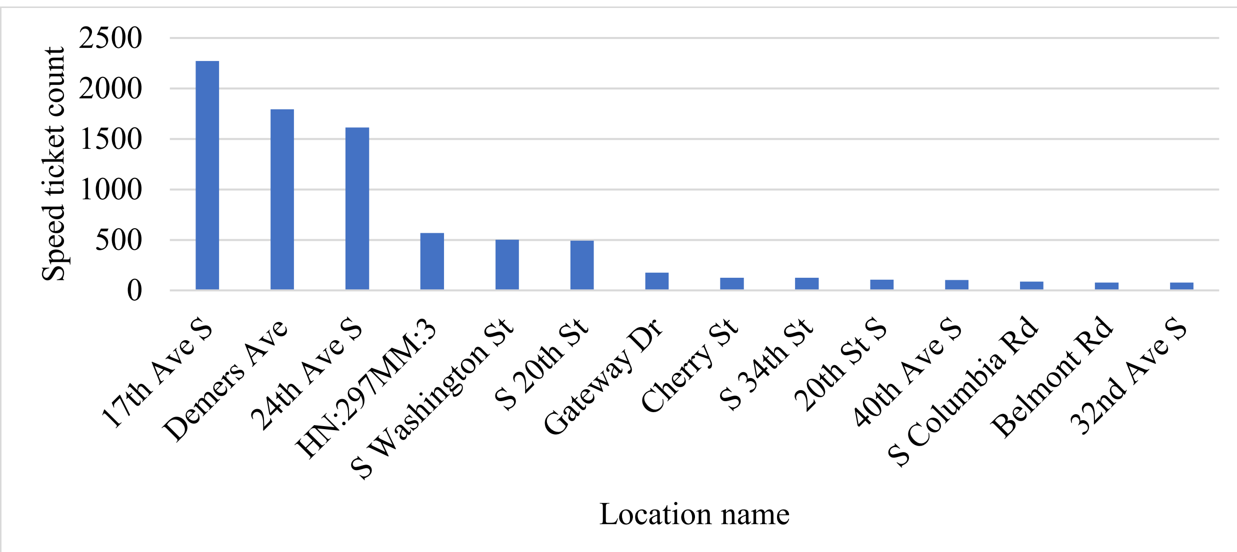


Figure 15 Speed ticket count per street

The speed-related crashes were extracted and the heatmap for those crashes were mapped using ArcGIS Pro software. Figure 16 presents heatmap for speed-related traffic crashes. The regions with a solid yellow color were found to have more dense speed-related traffic crashes, and the purple colors signify areas of sparse crash records. The heatmap shows that the speed-related crashes were mostly found near intersections.

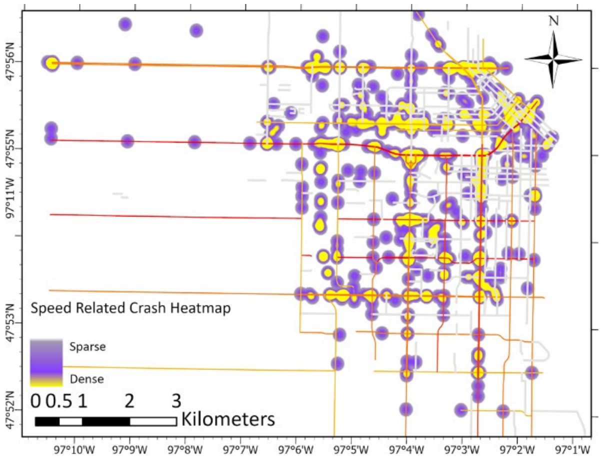
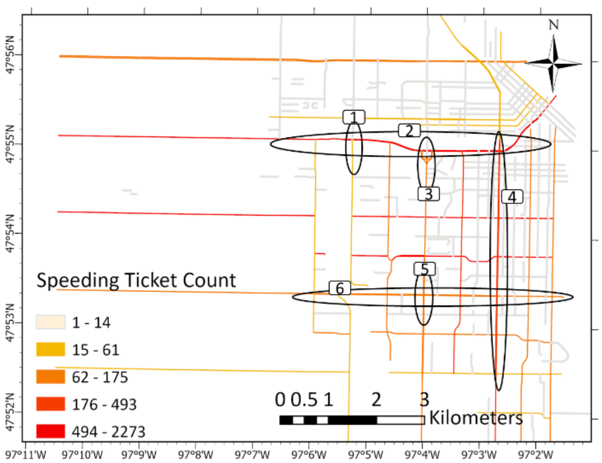


Figure 16 Speed-related traffic crashes heatmap

The areas from identified from the speed-related crashes and speeding ticket data are a major concern. Figure 17 depicts areas of significant traffic crashes, speed-related crashes, and speed violations. The areas highlighted with black oval shapes experience significant traffic crash areas and a higher number of speed violations. The areas along Demers Ave, S Washington St, 32nd Ave, and S Columbia Rd have higher speeding and crash rates during the study period. Though the other roads, such as 17th Ave S, 24th Ave S, and S 20th St, have more speeding violation records, the crashes near these areas were not significant.

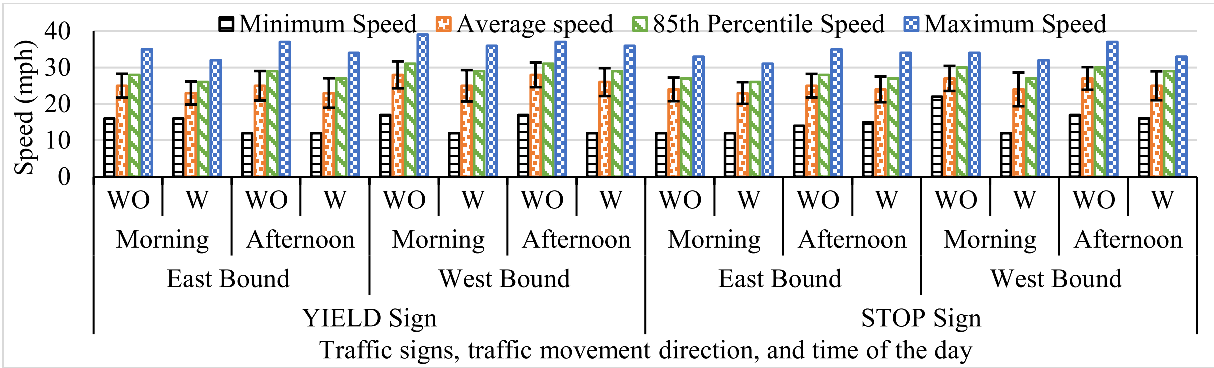


Id	Location Name
1	Demers Ave and S 42ND ST Intersn.
2	Demers Ave
3	Demers Ave and S Columbia Rd Intersn.
4	S Washington St
5	32nd Ave S
6	32nd Ave S and S Columbia Rd Intersn.

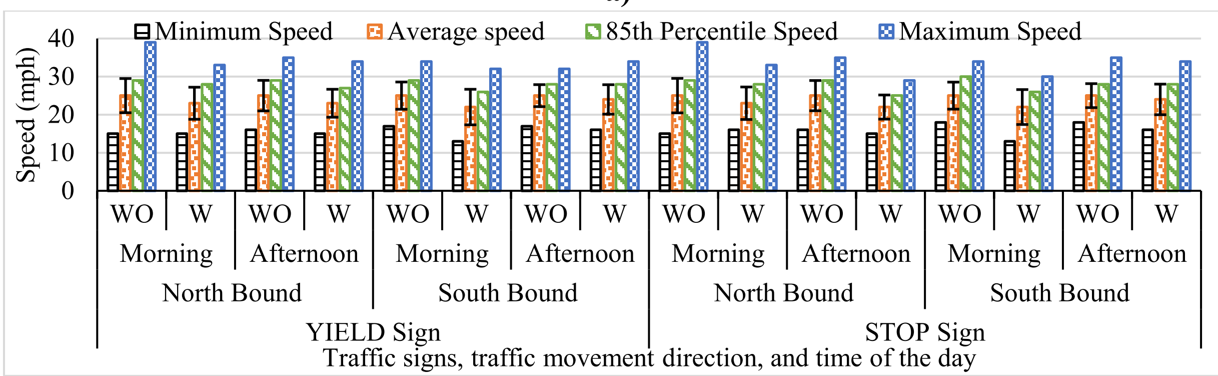
Figure 17 Roads with high speeding citation records and significant crashes

6.6. Effect of Traffic Signs on Speed

The minimum, average, 85th percentile, and maximum speeds at all locations were calculated from the collected data. The presence of the within-crosswalk signs resulted in a lower average speed for both in-school sessions and times when schools were not in session. The 85th percentile speed was also lower when the traffic signs were present on the road crosswalk. The minimum and maximum speeds observed were generally higher for the without conditions, and there were some exceptions where the drivers traveled at a higher speed regardless of the traffic signs. Figure 18 summarizes the speed data and standard deviation when schools were not in session.



a)



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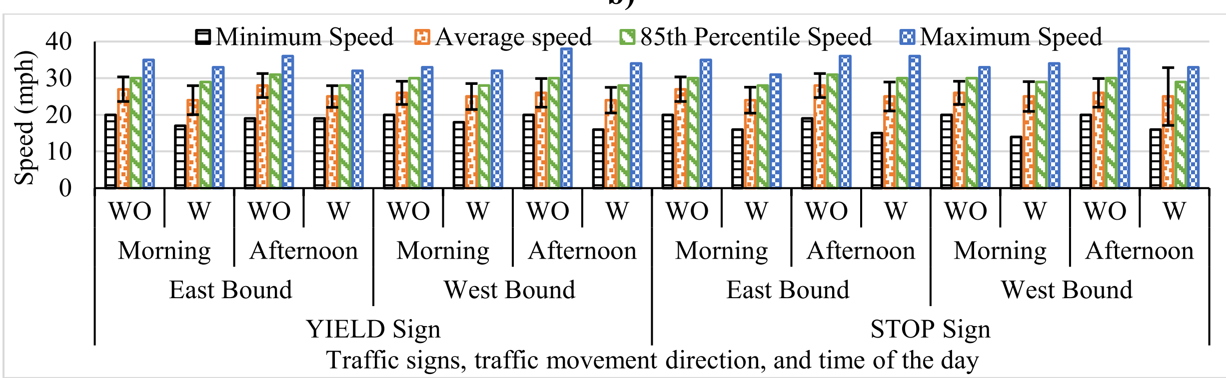
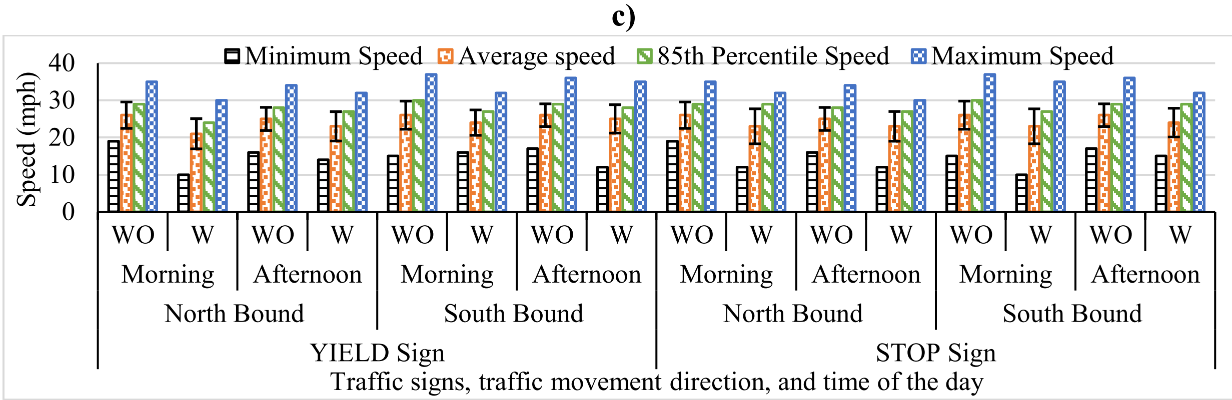


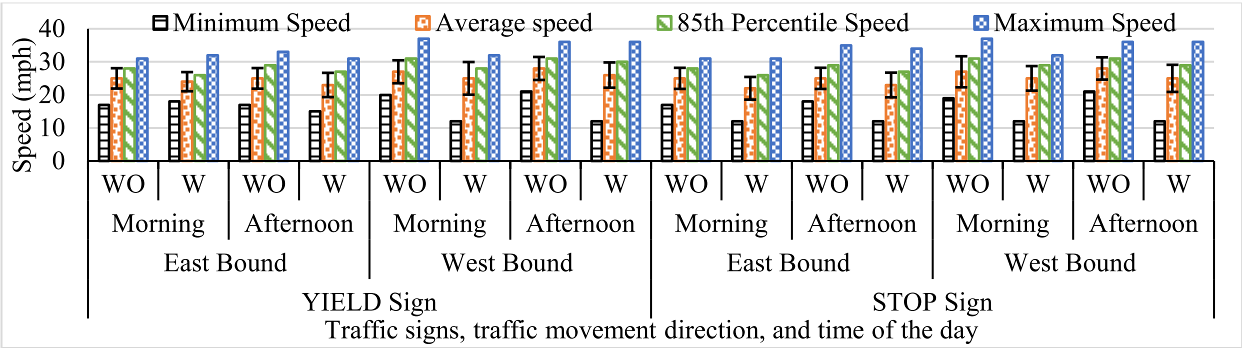
c)



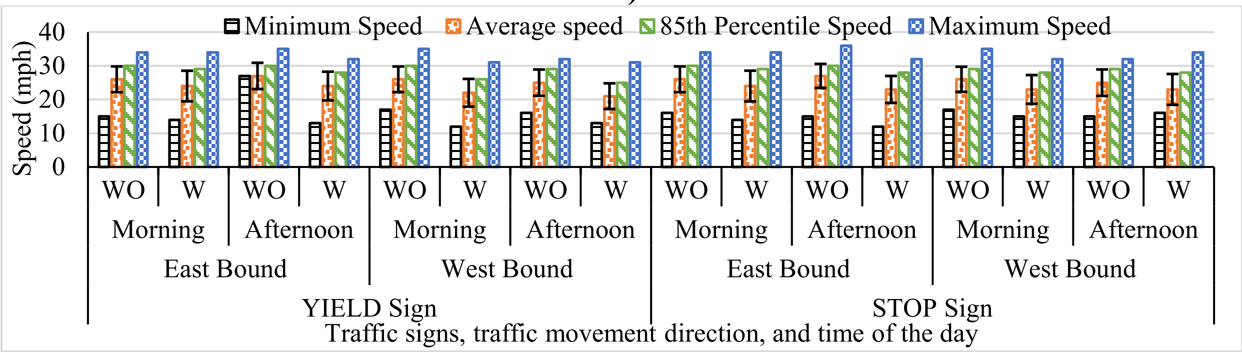
d)

Figure 18 Speed data summary: no-school session a) 6th Ave N, b) 11th Ave S, c) 25th Ave S, and d) Cherry St

The speed reduction pattern was also similar for the in-school session data. Figure 19 summarizes the speed analysis results with standard deviation for the in-school session data.



a)



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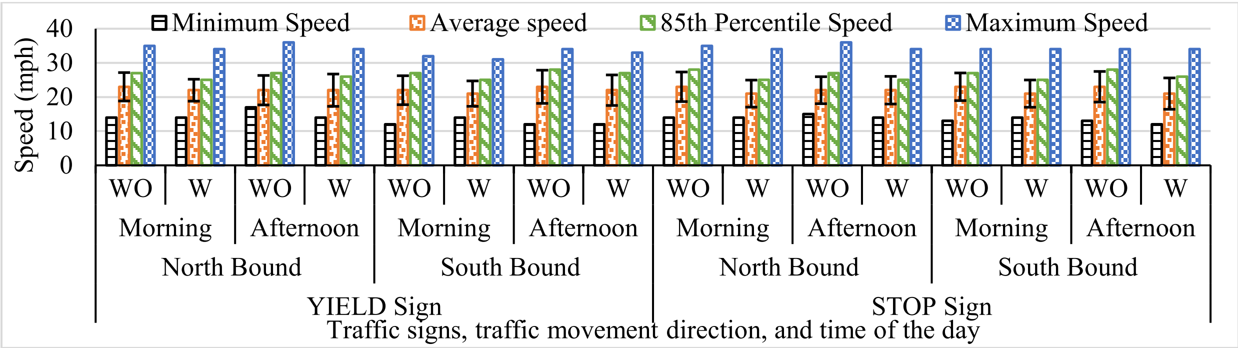
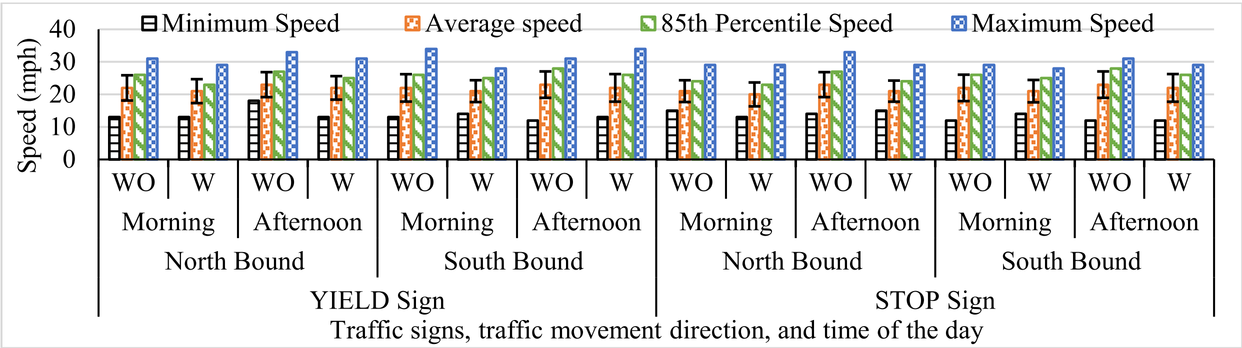


c)



d)

Figure 19 Speed data summary: in-school session a) 6th Ave N, b) 11th Ave S, c) 25th Ave S, and d) Cherry St

An independent t-test with a significance level of 0.05 indicated the presence of significant differences in the average speeds at the two conditions. The study areas have similar features, and the individual values can be added to check the overall significance of the differences (Gedafa et al. 2014). The overall tests revealed that the speed reduction due to the traffic signs significantly reduced the average speed; therefore, the null hypothesis was rejected.

Table 11 presents the statistical test summary for both traffic signs during in-school sessions and times when schools were not in session. The results indicate that the presence of traffic signs resulted in a significant reduction in the average speed of drivers at all locations. A significant average speed reduction was observed in more than 93% and 87% of the total cases for the YIELD and STOP signs, respectively, when schools were not in session. Likewise, 81% and 75% of the cases attributed to YIELD and STOP signs, respectively, indicated a decrease in speed during in-school sessions. The standard deviation for more than 99% of the cases ranged from 3 mph to 5mph.

The study areas have similar features, and the individual values can be added to check the overall significance of the differences (Gedafa et al. 2014). The overall tests revealed that the speed reduction due to the traffic signs significantly reduced the average speed; therefore, the null hypothesis was rejected.

Table 11 Significant difference test for traffic speed

Street name	Direction	Time	YIELD sign WO Avg Speed	YIELD sign WO n	YIELD sign W Avg Speed	YIELD sign W n	Sig. Diff. p-value (95% CI)	STOP sign WO Avg Speed	STOP sign WO n	STOP sign W Avg Speed	STOP sign W n	Sig. Diff. p-value (95% CI)
No- School session												
6^{th} Ave N	EB	M	25	193	23	168	<0.0001 S	24	168	23	153	0.0005 S
		A	25	138	23	152	<0.0001 S	25	161	24	145	0.0016 S
	WB	M	28	129	25	128	<0.0001 S	27	68	24	60	<0.0001 S
		A	28	155	26	158	<0.0001 S	27	86	25	58	0.0158 S
11^{th} Ave S	EB	M	27	40	25	52	0.0017 S	27	50	24	67	0.0001 S
		A	28	63	25	86	<0.0001 S	28	56	25	76	<0.0001 S
	WB	M	26	45	25	79	0.0372 S	26	52	25	73	0.0732 N
		A	26	59	24	74	0.0005 S	26	62	25	67	0.0193 S
Cherry St	NB	M	26	53	21	64	<0.0001 S	26	63	23	49	0.0017 S
		A	25	100	23	94	<0.0001 S	25	88	23	82	0.0008 S
	SB	M	26	70	24	89	0.0002 S	26	61	23	66	0.0005 S
		A	26	99	25	84	0.0279 S	26	111	24	90	<0.0001 S
S 25th St	NB	M	25	50	23	63	0.0095 S	25	49	23	52	0.0308 S
		A	25	56	23	67	0.0044 S	25	54	22	56	<0.0001 S
	SB	M	25	57	22	55	0.0006 S	25	44	22	50	0.0004 S
		A	25	84	24	58	0.1942 N	25	68	24	58	0.2206 N
S 34th St	NB	M	32	114	30	98	<0.0001 S	35	53	31	80	<0.0001 S
		A	33	104	30	94	<0.0001 S	34	71	31	76	<0.0001 S
	SB	M	30	69	27	79	<0.0001 S	30	69	28	60	0.0003 S
		A	30	95	27	87	0.0018 S	30	96	27	94	0.0020 S
Overall		M	25.7	820	23.6	875	<0.0001 S	25.4	677	23.8	710	0.0021 S
		A	25.9	952	23.9	954	<0.0001 S	26.1	853	23.9	802	<0.0001 S
School session												
6^{th} Ave N	EB	M	25	102	24	92	0.0015 S	25	96	22	89	<0.0001 S
		A	25	94	23	88	<0.0001 S	25	85	23	94	<0.0001 S
	WB	M	27	73	25	60	0.0004 S	27	89	25	99	0.0039 S
		A	28	67	26	72	0.0067 S	28	80	25	74	0.0003 S
11^{th} Ave S	EB	M	26	70	24	76	0.0023 S	26	60	24	67	0.0011 S
		A	27	62	24	69	0.0035 S	27	73	23	55	<0.0001 S
	WB	M	26	56	22	48	<0.0001 S	26	52	23	45	0.0011 S
		A	25	44	21	54	<0.0001 S	25	43	23	62	0.0027 S
Cherry St	NB	M	22	78	21	80	0.0362 S	21	94	20	83	0.2887 N
		A	23	90	22	71	0.0063 S	23	55	21	67	0.0148 S
	SB	M	22	81	21	62	0.0211 S	22	73	21	81	0.6718 N
		A	23	98	22	75	0.2132 N	23	69	22	59	0.0487 S
S 25^{th} St	NB	M	23	57	22	71	0.1697 N	23	59	21	78	0.0060 S
		A	22	77	22	61	0.4975 N	22	53	22	66	0.3385 N
	SB	M	22	67	20	54	0.0419 S	23	79	21	73	0.0122 S
		A	23	70	21	62	0.0308 S	23	64	21	50	0.1740 N
Overall		M	24.1	584	22.3	543	<0.0001 S	23.9	602	22.4	615	<0.0001 S
		A	24.4	602	22.8	552	<0.0001 S	24.7	522	22.6	527	<0.0001 S

S: Significant at a 0.05 significance level, N: Not significant at a 0.05 significance level.

6.7. Effect of Traffic Signs on Yielding to Pedestrians

The proportion of drivers who yielded to pedestrians to the total number of scored drivers for each location was calculated and used for the statistical analysis. Table 12 presents the summary of the significant tests. The raw data illustrates that the YIELD and STOP signs both increased the proportion of drivers yielding to pedestrians; however, the yielding proportion was significant for only 56% and 68% of the individual cases for YIELD and STOP signs, respectively. The traffic sign conditions resulted in higher yielding proportions; however, sites such as 6th Ave N and Cherry St exhibited more cases where the results were insignificant. This discrepancy might be linked to higher driving speeds and relatively elevated instances of speeding violations at these locations.

The statistical tests demonstrated that the presence of traffic signs significantly increased the proportion of drivers yielding to pedestrians across all locations. Specifically, the STOP sign condition exhibited a higher number of significant cases. The null hypothesis can be rejected based on the calculated overall p-values, which were all below the significance level.

6.8.Comparison of the Effect of In-Crosswalk YIELD and STOP Signs

Table 13 summarizes the effectiveness comparison of the traffic signs on speeding. The results indicate that the overall effectiveness of the within-crosswalk STOP and YIELD signs was comparable. The effectiveness of the signs was significantly different at 6th Ave N at times when schools were not in session. The STOP signs resulted in a relatively lower average speed value than the YIELD signs; however, the average speeds for both cases had p-values higher than the confidence level at the other three locations. Furthermore, the differences in average speed values at all locations due to the traffic signs were insignificant. The null hypothesis cannot be rejected since the p-values for the overall cases were higher than 0.05.

Another comparison between the effectiveness of the two signs was performed using the effect on yielding to pedestrians. Table 14 presents the yielding proportion differences between the two signs. The significance proportion test indicated that the yielding proportion differences between the two signs were insignificant at all locations; therefore, the signs had a comparable effect and can be used to reduce speed and increase yield to pedestrians on two or three-lane streets.

Table 12 Significant difference test using Chi-square (χ2) and Proportion test for yielding

Street name	Direction	Time of the day	Yielding data (Proportion)		Significance test		Combined
			WO	W	χ2 (p-value)	z-score, (p-value)	
YIELD Sign							
6th Ave N	East	M	57 (66.7)	64 (89.1)	8.964 (0.003) S	-2.994 (0.003) S	-4.627 (<0.00001) S
		A	66 (69.7)	67 (91.0)	9.634 (0.002) S	-3.104 (0.002) S	
	West	M	63 (69.8)	56 (83.9)	3.270 (0.071) N	-1.808 (0.070) N	
		A	59 (67.8)	68 (79.4)	2.216 (0.137) N	-1.487 (0.136) N	
11th Ave S	East	M	54 (72.2)	61 (90.2)	6.177 (0.012) S	-2.485 (0.013) S	-4.492 (<0.00001) S
		A	63 (76.2)	60 (91.7)	5.406 (0.020) S	-2.325 (0.020) S	
	West	M	53 (84.9)	47 (91.5)	1.023 (0.312) N	-1.011 (0.313) N	
		A	56 (76.8)	59 (96.6)	9.955 (0.002) S	-3.155 (0.002) S	
Cherry St	North	M	90 (68.9)	84 (83.8)	4.951 (0.026) S	-2.225 (0.026) S	-2.950 (0.0032) S
		A	83 (71.1)	81 (77.8)	0.964 (0.326) N	-0.982 (0.327) N	
	South	M	80 (68.8)	84 (81.0)	3.254 (0.071) N	-1.804 (0.072) N	
		A	70 (82.9)	76 (86.8)	0.452 (0.501) N	-0.672 (0.503) N	
S 25th St	North	M	73 (74.0)	78 (92.3)	9.176 (0.002) S	-3.029 (0.002) S	-4.804 (<0.00001) S
		A	75 (76.0)	73 (86.3)	2.559 (0.109) N	-1.599 (0.109) N	
	South	M	83 (75.9)	87 (92.0)	8.191 (0.004) S	-2.862 (0.004) S	
		A	80 (73.8)	85 (87.1)	4.669 (0.031) S	-2.161 (0.031) S	
STOP Sign							
6th Ave N	East	M	58 (60.7)	74 (93.2)	11.908 (0.001) S	-3.451 (0.001) S	-3.753 (0.0002) S
		A	59(76.3)	70 (80.0)	0.262 (0.609) N	-0.512 (0.610) N	
	West	M	63 (76.2)	64 (84.4)	1.345 (0.246) N	-1.159 (0.246) N	
		A	65 (75.4)	71 (91.5)	6.539 (0.011) S	-2.557 (0.011) S	
11th Ave S	East	M	58 (72.4)	67 (91.0)	5.949 (0.015) S	-2.439 (0.015) S	-4.070 (<0.00001) S
		A	63 (73.0)	68 (92.6)	5.556 (0.018) S	-2.357 (0.018) S	
	West	M	56 (83.9)	49 (91.8)	1.507 (0.219) N	-1.227 (0.219) N	
		A	46 (73.9)	43 (90.7)	4.246 (0.039) S	-3.061 (0.039) S	
Cherry St	North	M	81 (69.1)	78 (89.7)	10.26 (0.001) S	-3.203 (0.001) S	-4.273 (<0.00001) S
		A	74 (73.0)	77 (84.4)	2.958 (0.085) N	-1.720 (0.085) N	
	South	M	70 (72.9)	73 (83.6)	2.412 (0.120) N	-1.553 (0.121) N	
		A	73 (76.7)	75 (89.3)	4.198 (0.041) S	-2.049 (0.040) S	
S 25th St	North	M	79 (74.7)	82 (90.2)	6.781 (0.009) S	-2.604 (0.009) S	-4.761 (<0.00001) S
		A	88 (73.9)	75 (88.0)	5.128 (0.024) S	-2.265 (0.024) S	
	South	M	76 (68.4)	79 (83.5)	4.875 (0.027) S	-2.208 (0.027) S	
		A	79 (69.6)	74 (86.5)	6.289 (0.012) S	-2.508 (0.012) S	

S: Significant at a 0.05 significance level, N: Not significant at a 0.05 significance level.

Table 13 Significant difference test between YIELD and STOP signs: Speed data summary

Location	No-school Session				Sig. Diff (95% CI)	In-School Session				Sig. Diff (95% CI)
	YIELD sign		STOP sign			YIELD sign		STOP sign		
	Avg Speed	n	Avg Speed	n		Avg Speed	n	Avg Speed	n	
6th Ave N	24.1	606	23.5	416	0.0017 S	24.2	312	24.1	356	0.6599 N
11th Ave S	24.8	291	24.9	283	0.7064 N	23.0	247	23.2	229	0.5866 N
Cherry St	23.2	331	23.4	287	0.5447 N	21.3	288	21.0	290	0.3122 N
S 25th St	23.1	243	23	216	0.7359 N	21.2	248	21.3	267	0.8949 N
Overall	23.9	1471	23.7	1202	0.3410 N	22.5	1095	22.5	1142	0.8144 N

S Significant at a 0.05 significance level, N Not significant at a 0.05 significance level.

Table 14 Significant difference test between YIELD and STOP signs: Yield data summary

Location	YIELD	STOP	z-score (p-value)	Combined z-score (p-value)
6th Ave N	255 (85.9)	279 (87.5)	-0.535 (0.596) N	-0.497 (0.617) N
11th Ave S	227 (92.5)	204 (91.2)	0.506 (0.610) N	
Cherry St	325 (82.2)	303 (86.8)	-1.603 (0.110) N	
S 25th St	323 (89.5)	310 (87.1)	1.036 (0.298) N	

S Significant at a 0.05 significance level, N Not significant at a 0.05 significance level.

7. CONCLUSIONS

The subsequent conclusions can be drawn based on the results of the analysis:

- The Emerging Hotspot Analysis is effective in identifying spatiotemporal crash clustering. There were more crashes in the winter when snow accumulation was high and the weather was cold.
- The Anselin Local Moran's I and Getis Ord Gi* statistical tools can be used to identify hotspots in a road network, which are areas that need significant attention.
- The EPDO and CR can be used as input parameters to identify hotspots; however, the EPDO input parameter yields more hotspots than the CR.
- The streets such as 17th Ave S, Demers Ave, and 24th Ave S roads have more speed citation record. Moreover, Demers Ave, S Washington St, S Columbia Rd, 32nd Ave, and the intersections between these roads have more frequent speed violations and crashes.
- The introduction of crosswalk STOP and YIELD signs led to a decrease in both average and 85th percentile speeds, establishing significant reductions in speed.
- The changes in vehicle speed were significant across various times, including mornings, afternoons, and whether or not schools were in session. Implementing these regulatory signs could effectively lower the risk of speed-related traffic crashes.
- The presence of traffic signs significantly enhanced yielding behavior toward pedestrians. Placing these signs at the crosswalk could potentially reduce traffic-related pedestrian crashes.
- There was no significant difference between the impact of the two types of traffic signs on speeding and yielding behaviors. This finding implies that transportation planners have the flexibility to use either sign to enhance pedestrian and overall road safety.

FUTURE WORKS

- Analysis of the effectiveness of other traffic calming measures will be done using a cross-sectional approach, and safety approach recommendations that consider the context of Grand Forks will be made.
- Analysis for signal warrants at intersections will be done. The hot spot analysis result will be used as an initial criterion.

REFERENCES

AASHTO (2011). *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, Washington, DC.

Abdulhafedh, A. (2016). "Crash Frequency Analysis." *Journal of Transportation Technologies*, 6(04), 169.

Amiri, A. M., Nadimi, N., Khalifeh, V., and Shams, M. (2021). "GIS-Based Crash Hotspot Identification: a Comparison Among Mapping Clusters and Spatial Analysis Techniques." *International Journal of Injury Control and Safety Promotion*, 28(3), 325-338.

Anselin, L. (1995). "Local Indicators of Spatial Association—LISA." *Geographical Analysis*, 27(2), 93-115.

Audu, A. A., Iyiola, O. F., Popoola, A. A., Adeleye, B. M., Medayese, S., Mosima, C., and Blamah, N. (2021). "The Application of Geographic Information System as an Intelligent System Towards Emergency Responses in Road Traffic Accident in Ibadan." *J. Transp. Supply Chain Manag.*, 15, 17.

Bangsund, D., Nancy, H., Olson, K., Dogbey-Gakpetor, J., Hukriede, C., Ndembe, E., and Schroeder, K. (2022). "2022 North Dakota Statewide Housing Needs Assessment." North Dakota Housing Finance Agency.

Basheer Ahmed, M. I., Zaghdoud, R., Ahmed, M. S., Sendi, R., Alsharif, S., Alabdulkarim, J., Albin Saad, B. A., Alsabt, R., Rahman, A., and Krishnasamy, G. (2023). "A Real-Time Computer Vision Based Approach to Detection and Classification of Traffic Incidents." *Big Data and Cognitive Computing*, 7(1), 22.

Beaulieu, E., Naumann, R. B., Deveaux, G., Wang, L., Stringfellow, E. J., Lich, K. H., and Jalali, M. S. (2022). "Impacts of alcohol and opioid polysubstance use on road safety: Systematic review." *Accident Analysis & Prevention*, 173, 106713.

Bennett, M. K., Manal, H., and Van Houten, R. (2014). "A Comparison of Gateway In-street Sign Configuration to Other Driver Prompts to Increase Yielding to Pedestrians at Crosswalks." *Journal of Applied Behavior Analysis*, 47(1), 3-15.

Bonneson, J. A. (2010). "Highway Safety Manual." American Association of State Highway and Transportation Officials, Washington, D.C.

Chee, C.-H., Jaafar, J., Aziz, I. A., Hasan, M. H., and Yeoh, W. (2019). "Algorithms for Frequent Itemset Mining: A Literature Review." *Artificial Intelligence Review*, 52, 2603-2621.

Cheng, W., and Washington, S. P. (2005). "Experimental Evaluation of Hotspot Identification Methods." *Accident Analysis & Prevention*, 37(5), 870-881.

Das, S., Dutta, A., Avelar, R., Dixon, K., Sun, X., and Jalayer, M. (2019). "Supervised Association Rules Mining on Pedestrian Crashes in Urban Areas: Identifying Patterns for Appropriate Countermeasures." *International Journal of Urban Sciences*, 23(1), 30-48.

Egly, J., and Ricca, R. (2023). "Injury Prevention." *Pediatric Trauma Care: A Practical Guide*, Springer, 9-17.

Ellis, R., Van Houten, R., and Kim, J.-L. (2007). "In-Roadway 'Yield To Pedestrians' Signs: Placement Distance and Motorist Yielding." *Transportation Research Record*, 2002(1), 84-89.

ESRI (2019). *Spatial Analysis With ArcGIS Pro*, ESRI, USA.

FHWA (2009). "Manual on Uniform Traffic Control Devices for Streets and Highways 2009 Edition." Washington DC.

FHWA (2009). "Manual on uniform traffic control devices for streets and highways. 2009 Edition, Rev. 2." *Washington, DC: US Department of Transportation, Federal Highway Administration*.

FHWA (2011). "Roadway Safety Information Analysis: A Manual for Local Rural Road Owners." US Department of Transportation (USDOT) Washington, DC, USA.

FHWA (2014). "Engineering Speed Management Countermeasures: A Desktop Reference of Potential Effectiveness in Reducing Speed." Federal Highway Administration, US Department of Transportation.

FHWA (2017). "Traffic Calming ePrimer [Online]." Federal Highway Administration, US Department of Transportation.

Forbes, G., Gardner, T., McGee, H., and Srinivasan, R. (2012). "Methods and Practices for Setting Speed Limits: An Informational Report by the Institute of Transportation Engineers and Federal Highway Administration." *Institute of Transportation Engineers. ITE Journal*, 82(8), 20.

Gedafa, D., Kaemingk, B., Mager, B., Pape, J., Tupa, M., and Bohan, T. (2014). "Impacts of Alternative Yield Sign Placement on Pedestrian Safety." *Transportation Research Record*, 2464(1), 11-19.

Gedafa, D. S., Kaemingk, B., Mager, B., Pape, J., Tupa, M., and Bohan, T. (2014). "Impacts of alternative yield sign placement on pedestrian safety." *Transport Res Rec*, 2464(1), 11-19.

Hammad, H. M., Ashraf, M., Abbas, F., Bakhat, H. F., Qaisrani, S. A., Mubeen, M., Fahad, S., and Awais, M. (2019). "Environmental factors affecting the frequency of road traffic accidents: a case study of sub-urban area of Pakistan." *Environmental Science and Pollution Research*, 26, 11674-11685.

Herbel, S., Meyer, M. D., Kleiner, B., Gaines, D., and Systematics, C. (2009). "A Primer on Safety Performance Measures for the Transportation Planning Process." U.S. Department of Transportation, Federal Highway Administration, Washington DC.

Hossain, A., Sun, X., Thapa, R., and Codjoe, J. (2022). "Applying Association Rules Mining to Investigate Pedestrian Fatal and Injury Crash Patterns Under Different Lighting Conditions." *Transportation Research Record*, 2676(6), 659-672.

Huang, H., Zegeer, C., and Nassi, R. (2000). "Effects of Innovative Pedestrian Signs at Unsignalized Locations: Three Treatments." *Transportation Research Record*, 1705(1), 43-52.

Ivajnsic, D., Horvat, N., Ziberna, I., Kotnik, E. K., and Davidovic, D. (2021). "Revealing the Spatial Pattern of Weather-Related Road Traffic Crashes in Slovenia." *Applied Sciences-Basel*, 11(14), 12.

Johnson, R. S. (2005). "Pedestrian safety impacts of curb extensions: A case study." Oregon. Dept. of Transportation. Research Unit.

Kannel, E. J., Souleyrette, R. R., and Tenges, R. (2003). "In-Street Yield to Pedestrian Sign Application in Cedar Rapids, Iowa."

Kashani, A. T., Moghadam, M. R., and Amirifar, S. (2022). "Factors affecting driver injury severity in fatigue and drowsiness accidents: a data mining framework." *Journal of injury and violence research*, 14(1), 75.

Knoblauch, R., Nitzburg, M., and Seifert, R. (1999). "Pedestrian crosswalk case studies." *Center for Applied Research, for Federal Highway Administration*.

Kong, C., and Yang, J. (2010). "Logistic regression analysis of pedestrian casualty risk in passenger vehicle collisions in China." *Accident Analysis & Prevention*, 42(4), 987-993.

Lan, H., Ma, X., Ma, L., and Qiao, W. (2023). "Pattern Investigation of Total Loss Maritime Accidents Based on Association Rule Mining." *Reliability Engineering & System Safety*, 229, 108893.

Le, K. G., Liu, P., and Lin, L.-T. (2020). "Determining the Road Traffic Accident Hotspots Using GIS-based Temporal-Spatial Statistical Analytic Techniques in Hanoi, Vietnam." *Geo-Spatial Information Science*, 23(2), 153-164.

Lee, M., and Khattak, A. J. (2019). "Case Study of Crash Severity Spatial Pattern Identification in Hot Spot Analysis." *Transportation Research Record*, 2673(9), 684-695.

Li, K., Fan, X., and Yin, Z. (2015). "Pedestrian injury patterns and risk in minibus collisions in China." *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research*, 21, 727.

Li, R., Pereira, F. C., and Ben-Akiva, M. E. (2018). "Overview of Traffic Incident Duration Analysis and Prediction." *European Transport Research Review*, 10(2), 1-13.

Lord, D., and Mannering, F. (2010). "The Statistical Analysis of Crash-Frequency Data: A Review and Assessment of Methodological Alternatives." *Transportation Research Part A: Policy and Practice*, 44(5), 291-305.

Mafi, S., AbdelRazig, Y., Amirinia, G., Kocatepe, A., Ulak, M. B., and Ozguven, E. E. (2019). "Investigating Exposure of the Population to Crash Injury Using a Spatiotemporal Analysis: A Case Study in Florida." *Applied Geography*, 104, 42-55.

Malin, F., Norros, I., and Innamaa, S. (2019). "Accident risk of road and weather conditions on different road types." *Accident Analysis & Prevention*, 122, 181-188.

Manual, H. C. (2000). "Highway Capacity Manual." Transportation Research Board, Washington, DC

Maze, T. H., Agarwal, M., and Burchett, G. (2006). "Whether Weather Matters to Traffic Demand, Traffic Safety, and Traffic Operations and Flow." *Transportation Research Record*, 1948(1), 170-176.

Mendenhall, W., Beaver, R. J., and Beaver, B. M. (2012). *Introduction to Probability and Statistics*, Cengage Learning.

Mesquitela, J., Elvas, L. B., Ferreira, J. C., and Nunes, L. (2022). "Data Analytics Process Over Road Accidents Data—A Case Study of Lisbon City." *ISPRS International Journal of Geo-Information*, 11(2), 143.

METROCOG (2021). "West Fargo Traffic Calming Study, West Fargo, North Dakota.".

NDDOT (2021). "2021 Traffic Volume Map: Grand Forks County." North Dakota, USA.

NDDOT (2021a). " 2020 NORTH DAKOTA CRASH SUMMARY." Highway Safety Division, North Dakota Department of Transportation (NDDOT).

NDDOT (2021b). "NDDOT Highway Safety Improvement Program Guidebook." P. D. T. O. Section, ed.North Dakota, USA.

NDDOT (2022). " 2021 NORTH DAKOTA CRASH SUMMARY." Highway Safety Division, North Dakota Department of Transportation (NDDOT).

NHTSA (2022). "Traffic safety facts: Speeding, 2020 [USA]." Department of Transportation, National Highway Traffic Safety Administration, USA, Washington, DC 20590, 1-18.

NHTSA (2022). "Traffic safety facts: Summary of Motor Vehicle Crashes, 2020 [USA]." Department of Transportation, National Highway Traffic Safety Administration, USA, Washington, DC 20590, 1-18.

Nie, J., Li, G., and Yang, J. (2014). "A study of fatality risk and head dynamic response of cyclist and pedestrian based on passenger car accident data analysis and simulations." *Traffic injury prevention*, 16(1), 76-83.

Nie, J., Yang, J., and Li, F. (2010). "A study on pedestrian injuries based on minivan and sedan real-world accidents." *2010 International Conference on Optoelectronics and Image Processing*, IEEE, 160-163.

NOAA (2022). "NOWData–NOAA Online Weather Data." *National Weather Service, National Oceanic and Atmospheric Administration.* , <https://www.weather.gov/wrh/Climate>. (07, 2023).

Ott, R. L., and Longnecker, M. T. (2015). *An Introduction to Statistical Methods and Data Analysis*, Cengage Learning.

Pulugurtha, S. S., Nambisan, S. S., Dangeti, M. R., and Vasudevan, V. (2012). "Evaluation of Effectiveness of Traffic Signs to Enhance Pedestrian Safety." *Transportation Research Board* 2299(1), 100-109.

Rahman, M. A., Sun, X., Das, S., and Khanal, S. (2021). "Exploring the Influential Factors of Roadway Departure Crashes on Rural Two-Lane Highways With Logit Model and Association Rules Mining." *International Journal of Transportation Science and Technology*, 10(2), 167-183.

Strong, C., and Ye, Z. (2010). "Spillover Effects of Yield-to-Pedestrian Channelizing Devices." *Safety Science*, 48(3), 342-347.

Tefft, B. C. (2013). "Impact speed and a pedestrian's risk of severe injury or death." *Accident Analysis & Prevention*, 50, 871-878.

Trenberth, K. E. (1983). "What are the Seasons?" *Bulletin of the American Meteorological Society*, 64(11), 1276-1282.

Turner, S., Fitzpatrick, K., Brewer, M., and Park, E. S. (2006). "Motorist yielding to pedestrians at unsignalized intersections: Findings from a national study on improving pedestrian safety." *Transport Res Rec*, 1982(1), 1-12.

USDOT (2021). "Traffic Calming to Slow Vehicle Speeds." US Department of Transportation, Washington, DC 20590, 1-18.

Van Houten, R., McCusker, D., Huybers, S., Louis Malenfant, J., and Rice-Smith, D. (2002). "Advance yield markings and fluorescent yellow-green RA 4 signs at crosswalks with uncontrolled approaches." *Transport Res Rec*, 1818(1), 119-124.

Varhelyi, A. (2016). "Road Safety Management – The Need for a Systematic Approach." *The Open Transportation Journal*, 10(1).

Wemple, E., Colling, T. K., and Systematics, C. (2014). "Improving safety on rural local and tribal roads." United States. Federal Highway Administration. Office of Safety.

WHO (2021). "Global Health Observatory Data Repository: Road Traffic Deaths Data by Country." World Health Organization.

WHO (2021). "Global Health Observatory Data Repository: Road Traffic Deaths Data by Country." World Health Organization.

Yang, Y., Yuan, Z., and Meng, R. (2022). "Exploring Traffic Crash Occurrence Mechanism Toward Cross-Area Freeways via an Improved Data Mining Approach." *Journal of Transportation Engineering, Part A: Systems*, 148(9), 04022052.

Zaitouny, A., Fragkou, A. D., Stemler, T., Walker, D. M., Sun, Y., Karakasidis, T., Nathanail, E., and Small, M. (2022). "Multiple Sensors Data Integration for Traffic Incident Detection Using the Quadrant Scan." *Sensors*, 22(8), 2933.

Zegeer, C., Seiderman, C., and Lagerwey, P. (2013). "Pedestrian safety guide and countermeasure selection system." *Education*, 392.
Zegeer, C. V., Richard Stewart, J., Huang, H., and Lagerwey, P. (2001). "Safety effects of marked versus unmarked crosswalks at uncontrolled locations: analysis of pedestrian crashes in 30 cities." *Transport Res Rec*, 1773(1), 56-68.
Zhai, X., Huang, H., Sze, N., Song, Z., and Hon, K. K. (2019). "Diagnostic analysis of the effects of weather condition on pedestrian crash severity." *Accident Analysis & Prevention*, 122, 318-324.