An Analysis of Street Design at Fatal Pedestrian Crash Sites in Tucson, Arizona

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Abstract

The Tucson metropolitan area is the third-deadliest metropolitan area for pedestrians in the United States. Pedestrian fatalities nationwide are increasing. This study analyzes street design elements at sites of fatal pedestrian crashes in the City of Tucson to identify features that are associated with higher rates of pedestrian fatalities. While pedestrian fatalities have seen a rise over the last decade due to factors not inherently linked to street design, such as driver distraction, vehicle weight, hood height, and pedestrian inebriation or distraction, it is critical to utilize street design as a mitigating factor in the wake of these challenges.

Quantitative geospatial analysis of pedestrian crash sites in Tucson found that 87% of fatal crashes occurred on arterial streets. 76% of fatal crashes occurred during the night. On average, there were 2.1 streetlights within 100ft of a fatal crash and 3 streetlights within 100ft of a nonfatal crash. The rate of fatal crashes was higher than the city rate on roads with speed limits at or above 35 mph, and on roads with 2 or more lanes in each direction. Ward 5 had a fatal crash rate of 16.2%, while Ward 4 had a fatal crash rate of only 7%.

To address the rise in pedestrian fatalities, street design in Tucson should prioritize a reduction in speed limits, implemented in conjunction with traffic calming measures, and the installation of street lighting along all major streets and routes in Tucson.

Keywords:

Pedestrian, traffic accidents, road safety, street design, built environment, transportation safety, car-centric infrastructure

Introduction

Pedestrian fatalities by drivers in the United States are now trending upward after decades of improvement (Schneider, 2020). Tucson, in particular, ranks as the third-deadliest metro area for pedestrians in the country, showing an upward trend in deaths from 2013 to 2022 (Smart Growth America, 2024). Identifying built environment features common at sites of traffic crashes that result in injuries or fatalities for pedestrians in Tucson will help planners and the community at large better understand why Tucson suffers from a large number of pedestrian fatalities and help design a safer, more sustainable built environment.

It is important to note the other factors that may result in pedestrian fatalities, including distracted or impaired pedestrians and drivers, and the increased prevalence of larger, heavier vehicles. This research sought to identify features of the built environment that increase or reduce the dangers for pedestrians in the wake of these challenges. Properly identifying these risk features will help inform transportation planning and engineering decisions regarding safety on streets in Tucson and the United States. Residents concerned about safety will understand what changes should occur in their communities to make streets safer for pedestrians. Safer streets for pedestrians would encourage more people to walk and take transit to destinations rather than drive.

This research analyzes built-environment features at sites of fatal and non-fatal traffic collisions involving pedestrians in Tucson. It focuses on Tucson specifically, as every city has unique built environment characteristics. For example, Tucson especially has a notable lack of street lighting in some areas due to its unique status in astronomy, located near several mountains with observatories of significance. The presence of street lighting, the number of lanes in the road, posted speed limits, and sidewalk availability, among other built-environment features at the sites of pedestrian collisions, will be analyzed at crash sites to determine which features are associated with greater risks to pedestrians. It is hypothesized that worse pedestrian crash outcomes will occur on streets with wider streets with a high number of lanes, that pedestrian crashes at night are more often fatal in areas with less street lighting, and that streets without sidewalks are associated with higher fatality rates. Roads that feature many wide lanes are associated with faster traffic (Distefano & Leonardi, 2019), which greatly increases the chance of severe injury or death when a car strikes a pedestrian (Johns Hopkins, 2023; Tefft, 2011). Pedestrian crashes are especially prevalent and dangerous when occurring at night with inadequate street lighting (Stigson, 2023).

Literature Review

To understand how to better protect pedestrians in the wake of a national rise in pedestrian fatalities, it is important to understand the root cause behind pedestrian fatalities: a collision between a pedestrian and a car. While the United States as a whole has a reliance on

car-dependent infrastructure, metro areas in the Sunbelt region in particular overwhelmingly account for the highest numbers of pedestrian fatalities (Smart Growth America, 2024). Unlike other parts of the country, these areas only experienced rapid urban growth after the popularization of the automobile, resulting in a built environment designed primarily for car travel. Car-centric built environments inevitably result in conflicts between fast traffic and pedestrians, as not everyone can drive, for a multitude of reasons.

Pedestrian injuries and fatalities occur when a car strikes a pedestrian. Faster vehicle speeds are associated with more severe injuries. A study published by the AAA Foundation for Traffic Safety outlines the relationship between the speed of the car at the time of collision and the risk of severe injury and death. Tefft highlights a steep increase in the risk of death as the speed of the car reaches the typical speeds of Tucson's arterial roads. There is a 25% risk of death at 32 mph, 50% at 42 mph, and 75% at 50 mph, reaching 90% at 58 mph. Even 31 mph is enough to give a pedestrian a 50% chance of severe injury (Tefft, 2011). Therefore, a significant part of identifying which road conditions lead to worse crash outcomes for pedestrians is identifying which road conditions result in or encourage fast driving in areas with pedestrians.

An analysis by Schneider (2020) of national pedestrian fatality trends highlighted that crashes that result in deaths most often occur on roads with a speed limit at or above 35 mph and on roads with four or more lanes. 70% of fatal crashes occurred with speed limits at or above 35 mph, while 50% occurred on roads with four or more lanes. Both factors experienced a growth in the percentage of pedestrian fatalities over a 5-year period. The percentage of pedestrian fatalities that occurred on roads with speed limits at or above 35 miles per hour rose from 63% to 73%, while fatal crashes on roads with four or more lanes rose from 41% to 58% (Schneider, 2020).

A reduction in speed limit alone is not enough to reduce vehicle speeds, as drivers will drive as fast as they feel comfortable. To reduce vehicle speeds, drivers must be made to feel less comfortable. Traffic calming aims to increase the perceived risk of speeding through street design features like road and lane narrowing, chicanes, and speed tables, naturally resulting in more cautious, slow driving, which in turn results in better pedestrian crash outcomes. A study of urban street design in Italy found that narrowing lane widths resulted in reduced vehicle speeds, as well as reducing the number of lanes on a road to just one in each direction (Distefano & Leonardi, 2019).

While the purpose of this analysis is to identify built environment conditions that reduce the chance of pedestrian fatalities, in large part by reducing the speed at which the collisions happen, it is important to identify other factors that put pedestrians at risk that are outside the scope of the analysis but do emphasize the need for changes in the built environment that reduce

the severity of pedestrian crashes. These factors include, but are not limited to, age, race, income, pedestrian inebriation or distraction, vehicle weight, hood height, and driver distraction.

The AAA traffic safety study details how the type of vehicle involved in a pedestrian crash affects the severity of the injury. Tefft (2011) found that both pedestrians hit by light trucks are more likely to be severely injured or killed in a collision than pedestrians who are hit by a car. Pedestrians, on average, would face the same risk when hit by a truck if they were hit by a car going 6.3mph faster than the truck (Tefft, 2011). Gaps in federal regulation on safety standards allow for light trucks to pass with a lower standard of safety than other vehicles (Djekic, 2024). Light trucks have been increasing in popularity over the last decade. The production of light trucks superseded the production of cars in 2018, with the disparity between the two growing into the present day (Environmental Protection Agency, 2024). The average vehicle in the United States has increased in size over the last 30 years, becoming 1,000 pounds heavier, 4 inches wider, 10 inches longer, and 8 inches taller (Insurance Institute for Highway Safety, 2023). The high hood heights associated with light trucks are 45% more likely to result in pedestrian fatalities compared to a lower, less blunt hood profile of a standard car (Hu et al., 2024). Trends in vehicle ownership towards more dangerous light trucks likely account for an increase in pedestrian fatalities, and road design should take into account the increased risk these trucks bring.

Smart Growth America presents fatal pedestrian crash demographic data from the National Highway Traffic Safety Administration's Fatality Analysis Reporting System, highlighting demographics that are overrepresented in fatality statistics. Black and Native American pedestrians are overrepresented compared to other races and ethnicities in fatal pedestrian crashes, with Native American individuals four times more likely to die than white individuals. The most vulnerable age groups for pedestrian fatalities are 50-64 and 75+. On average, 70-year-old pedestrians face the same risk in traffic crashes as 30-year-old pedestrians in crashes hit by cars travelling 10.4mph faster (Tefft, 2011)

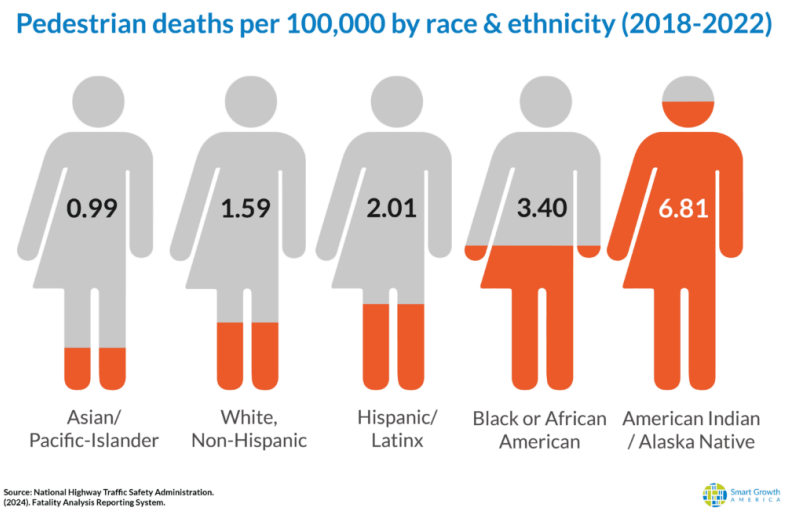

Figure 1: Pedestrian deaths per 100,000 by race & ethnicity, 2018-2022 (Smart Growth America, 2024).

History

To understand why cities in the southwest are overrepresented in pedestrian fatalities, it is important to analyze when and in what manner these cities experienced most of their growth. Cities, like Tucson, that experienced most of their growth after the popularization of automobiles and subsequent suburbanization, will have a built environment that is primarily catered towards the storage and fast movement of cars, which is inherently dangerous for pedestrians.

At the turn of the 20th century, automobiles were rare and reserved only for the wealthy. The automobile industry exploded in popularity during the 1910s and 1920s, with vehicle ownership rates reaching ~45% by 1930 (Gardner, 2023). The Great Depression slowed the increase in popularity, with vehicle ownership rates declining to ~40% by the end of World War II. Ownership rates once again grew post-war, which resulted in vehicle ownership rates of 80% by 1960. This can be attributed to the post-war economic boom, but also the Federal-Aid Highway Act of 1956, which facilitated the construction of interstate highway systems across the country (National Archives, 1956). The distance the average American could travel unrestricted by any rail line increased dramatically. Today, 91.7% of U.S. households own at least one vehicle, leaving 8.3% of households owning no vehicles. In Tucson, 89.9% of households own at least one vehicle, with 10.1% of households owning no vehicles (US Census Bureau, 2023).

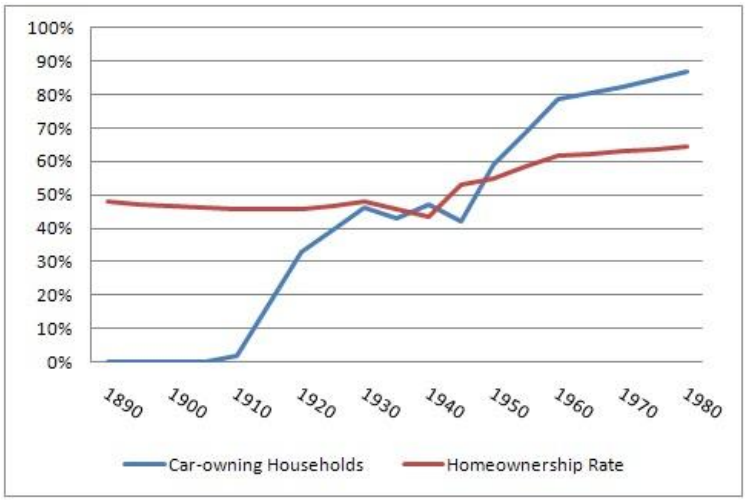

Figure 2: Vehicle Ownership & Home Ownership over time (Gardner, 2023).

The increased distance from work and home meant that the middle class no longer had to live in city centers or downtown areas to be close to work, where space was limited. Instead, they could live further away, have more space for dwelling, and commute to work in their vehicles. The process of populations moving away from city centers to live in low-density housing on the outskirts is referred to as suburbanization. Before World War II, suburbanization was facilitated by large networks of electric streetcars. By the time World War II ended, the expansive streetcar systems were torn out in favor of gasoline buses. After World War II, the federal government subsidized the cost of suburbanization through the Housing Act of 1949 and the Federal-Aid Highway Act of 1956 (Lang & Sohmer, 2010).

The Housing Act of 1949 facilitated suburbanization both through urban renewal, the clearance of many dense inner-city neighborhoods deemed “slums”, and by increasing federal mortgage insurance under certain discriminatory conditions. These programs did not allow for minorities to participate, blocking access to affordable homeownership and generational wealth building (Lang & Sohmer, 2010). The Federal-Aid Highway Act of 1956 facilitated the construction of interstate highways connecting major cities throughout the United States. These highways were often built through or close to the downtown areas of cities to allow for ease of access to downtown by those living in the suburbs, destroying neighborhoods in the process. The increase in ownership of single-family homes through government subsidies, made possible by the increased ease of transportation through the interstate highway system, resulted in a built environment dominated by low-density development and car travel, creating inhospitable conditions for pedestrians.

Tucson experienced the majority of its growth after World War II, resulting in a built environment that primarily serves the movement of automobiles. In 1900, Tucson’s population was only 7,531, growing to 36,818 by 1940 (US Census Bureau, 1940). The decades after World

War II saw Tucson's population rapidly grow, reaching a population of 212,892 (US Census Bureau, 2020). The City of Tucson underwent its most substantial annexations at this time, with the City Limits stretching eastward, following the development of single-family homes (City of Tucson Data, 2019). Today, the City of Tucson's population is 542,629, with a metro area population of one million (US Census Bureau, 2020). Tucson's built environment is overwhelmingly represented by single-family homes and wide, fast roads.

Sustainability

Providing safer streets to pedestrians will make it more likely for someone to choose to walk or use transit rather than drive. Jeff Speck, author of *Walkable City*, states that for someone to choose to walk rather than drive, a walk must be interesting, comfortable, useful, and safe (Speck, 2012). Understanding what built environment features are associated with higher pedestrian fatality rates will help inform street design decisions that will promote a safer built environment for pedestrians. Removing barriers to walking will help reduce reliance on personal vehicles, in turn reducing reliance on fossil fuels. Transportation accounts for 38% of carbon dioxide emissions in the United States. Approximately 58% of all transportation emissions come from personal vehicle usage, which is the most inefficient mode of transportation by carbon dioxide emissions (Congressional Budget Office, 2022). Encouraging pedestrians to choose to walk by providing them with a safe built environment will further sustainability by reducing carbon dioxide emissions.

Methodology

Research Question

What street design elements are associated with increased pedestrian fatalities?

Conducting a quantitative investigation of the built environment conditions at pedestrian traffic crash sites required extensive geospatial data collection of different street design characteristics and a consolidated traffic crash report dataset. Comparing street design elements at sites of pedestrian injuries and fatalities served to identify built environment characteristics that are associated with increased risk for pedestrians. Secondary data was sourced through local municipality open data sets.

The City of Tucson Information Technology Department and the Pima County Information Technology Department maintain extensive public databases of geospatial data under their respective Geographic Information System (GIS) Sections. The data covers topics ranging from economic development, transportation, and parks & recreation. These datasets contain very specific information concerning built environment conditions in the Tucson metropolitan area.

The study site was limited to the city limits of the City of Tucson, as the main set of data analyzed was collected and managed by the Tucson Police Department (TPD), which does not extend far past jurisdictional boundaries. This particular dataset contains an encompassing list of traffic incidents from 2012 to 2023. All traffic incidents in the dataset were collected and categorized by TPD when filing the reports, according to the specific conditions of the incident. The dataset logs location, time of day, whether a pedestrian was involved, whether a cyclist was involved, and whether they were unharmed, injured, or fatally injured, among other conditions not related to this particular research. Sites of pedestrian injuries were compared against sites of pedestrian fatalities, looking for trends in how nearby built environment conditions may differ, leading to different outcomes.

Datasets used for analysis:

- Traffic Accidents Involving Pedestrians - 2012-2023 (City of Tucson)
- Number of Lanes (Pima County)
- Sidewalks (City of Tucson)
- Speed Limits (City of Tucson)
- Streetlights (City of Tucson)
- Major Streets and Routes (City of Tucson)

Speed Limits, Number of Lanes, and Major Streets and Routes

The speed limits, number of lanes, and Major Streets and Routes (MS&R) datasets all represent road attributes with line data, and therefore are applied to the pedestrian crash dataset using the same GIS geoprocessing methods. To join the street data to the pedestrian crash dataset, the crash point searches for the data line closest to the point within 50 feet, in case there is no data in the immediate vicinity. With the closest line data found, it is then applied to that specific piece of crash data.

If a point was not able to find data within 50 feet, it was given the default attribute for each dataset. For example, the default speed limit in Tucson residential areas that do not have a speed limit posted is 25 mph (City of Tucson). The dataset only includes roads with posted speed limits, so if a pedestrian crash occurs in the middle of a neighborhood with no speed limit posted, the crash is then assigned with “25 mph.” The number of lanes dataset, maintained by Pima County, only represents roads with more than two lanes in each direction. If a crash point did not find any data within 50 feet, it was assigned with “1”, indicating one lane in each direction. The MS&R dataset only highlights roads that are designated as Arterials or Collectors. Pedestrian crashes on roads that did not meet those criteria were assigned to “Local Street.”

Sidewalks

The sidewalk dataset maintained by the City of Tucson displays the location and length of each segment of Tucson’s sidewalk network, totaling over 1,600 miles throughout the city. The aim of analyzing the sidewalk line data was to identify how much sidewalk was available

near each pedestrian traffic crash. To achieve this, several GIS geoprocessing tools were used to convert the sidewalk line data into images that can be analyzed. Line data does not have any width in GIS, as it only displays a line between two points. All line data was buffered by four feet and rasterized, or converted to an image with pixels. Every pedestrian crash point was buffered by 100 feet to analyze sidewalk coverage in that area, then rasterized. The new sidewalk raster data was then laid over the 100-foot pedestrian crash buffer. With the images combined, sidewalk pixels are assigned a value of "1", and non-sidewalk pixels are assigned a value of "0". The image is then processed using the zonal statistics tool to generate the average of the 1 and 0 pixels, resulting in a number that reflects the sidewalk coverage in the space surrounding the traffic crash.

Streetlights

The City of Tucson's streetlight dataset displays the location of 22,781 streetlights within the city. To determine if streetlights or the absence of streetlights affects the outcomes of pedestrian traffic crashes, each pedestrian crash point will be labeled with the number of streetlights near the crash site. Using GIS, each crash point was given a 100-foot buffer, then spatially joined with the streetlight dataset, counting every streetlight datapoint within each individual crash buffer.

To analyze these results, crashes that occurred at night were separated from the rest and examined by the severity of injury. When filling out crash reports, the Tucson Police Department describes the amount of light present when the crash took place under the "Light Conditions" column. All crashes labeled with "DARK" were separated. An Analysis of Variance (ANOVA) test was conducted against the number of streetlights at each pedestrian crash and the injury severity. The ANOVA test displayed the average number of streetlights at each level of injury severity.

Statistical Analysis

The statistical analysis method differed depending on what type of data was being analyzed. A continuous variable like the sidewalk coverage attribute was analyzed with an ANOVA test or a t-test, depending on whether it was being tested by injury severity or fatal vs nonfatal, while nominal variables like City Ward or MS&R type were approached differently. Continuous variables were analyzed based on whether the crash was fatal or nonfatal. The rates of particular fatal crashes within each individual category, like City Ward, were compared against the city-wide fatality rates. Comparing these figures showed which categories were overrepresented in bad pedestrian outcomes and which were overrepresented in good outcomes. Discrete variables like speed limit and number of lanes were analyzed using both methods, except for the streetlights variable, which was analyzed only with ANOVA due to its large range.

Ward Analysis

The Major Streets & Routes dataset, which originally only contained line data of Tucson's arterial and collector streets, was expanded to include speed limit, feet per streetlight, number of lanes, and ward, for each line of road data. The method of joining the datasets to the MS&R data was similar to that of pedestrian crash data, with the only exception being the streetlights dataset. The MS&R data was buffered 100ft to count the number of streetlights within, which was then added to each segment. The road length was then divided by the number of streetlights to account for the varying lengths of each segment of road data.

Roads with attributes that were found to result in above-average pedestrian fatalities were given a point for each of the following: speed limit above 35 miles per hour, two lanes or more in each direction, and if it had fewer than 2.1 streetlights per 100 feet. These roads were analyzed by adding the total number of miles of road in each condition and comparing them to the totals of the different wards. To ensure that Ward 4 and 5 could be compared with the other Wards, the arterial and collector roads that are undeveloped and located away from any residential uses in the "Southlands" area of Tucson were left out of the analysis.

Results

Speed Limits

An analysis of speed limit averages at pedestrian crash sites found that as the speed limit at crash sites increased, so did the average injury severity level. The Analysis of Variance test rejected the null hypothesis, that there is no difference in speed limits between injury levels, with a statistically significant p-value ($p=0.0002$). The variance in the fatal group was only 23.28, while all other groups had variances of 30-33, indicating that there was less of a spread compared to the other groups.

Comparing the proportion of fatal injuries of each speed limit to the city-wide proportion of fatal injuries revealed a similar trend to the ANOVA test. The rate of fatal crashes increased as the speed limit increased. The fatal crash rate at and above speed limits of 35 mph had higher fatality rates than the city as a whole.

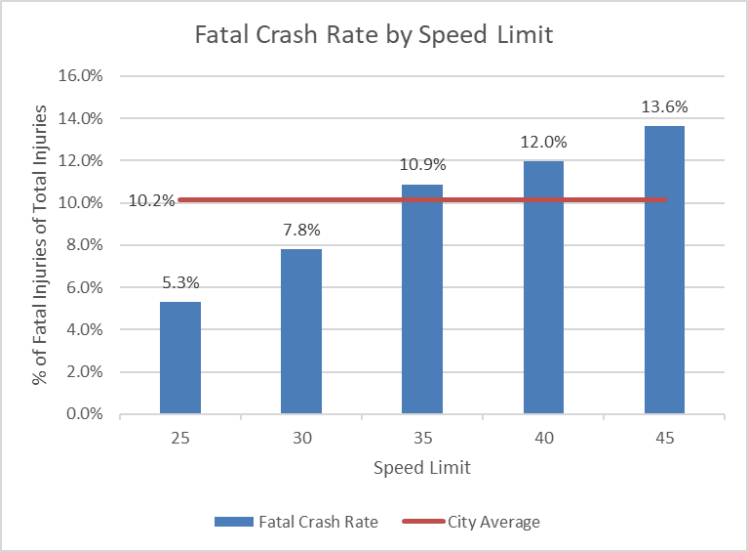

Figure 3: Fatal injury rate by speed limit.

Major Streets and Routes Types

A count of all pedestrian crash site locations indicated that crashes most often occurred on arterials, with the arterial category accounting for 76% of all crashes and 87% of all fatal crashes. Collectors accounted for 10% of all crashes, while roads without a Major Streets and Routes classification represented 13% of all pedestrian crashes.

Fatal pedestrian crashes were analyzed by the site's Major Streets and Routes classification. The MS&R plan separates arterial roads into three categories: arterial gateway, arterial scenic, and arterial. Fatal crash rates were analyzed by these separate classifications, as well as a merge of all arterial types into one unifying arterial count. Arterials accounted for the highest rates of fatal crashes, with gateway arterials accounting for the most out of all arterials.

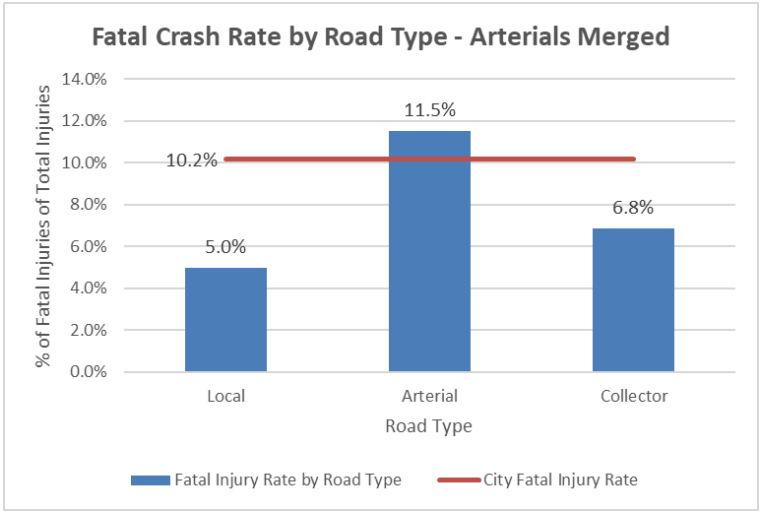

Figure 4: Fatal crash rate by road type - arterials merged.

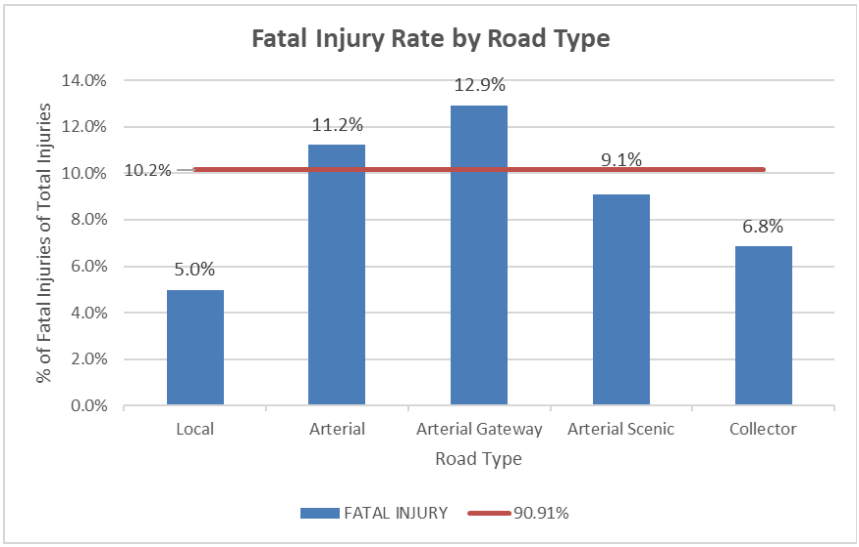

Figure 5: Fatal crash rate by road type.

Number of Lanes

Of all pedestrian crashes, 48.2% occurred on roads with two lanes in each direction, 32.3% on roads with three lanes in each direction, and 19.6% on roads with only one lane in each direction. Pedestrian crashes on roads with one lane in each direction had the lowest fatality rate, below the 10.16% city-wide average, while the two and three-lane roads were both above the city-wide rate. Roads with two lanes in each direction had the highest fatal crash rate.

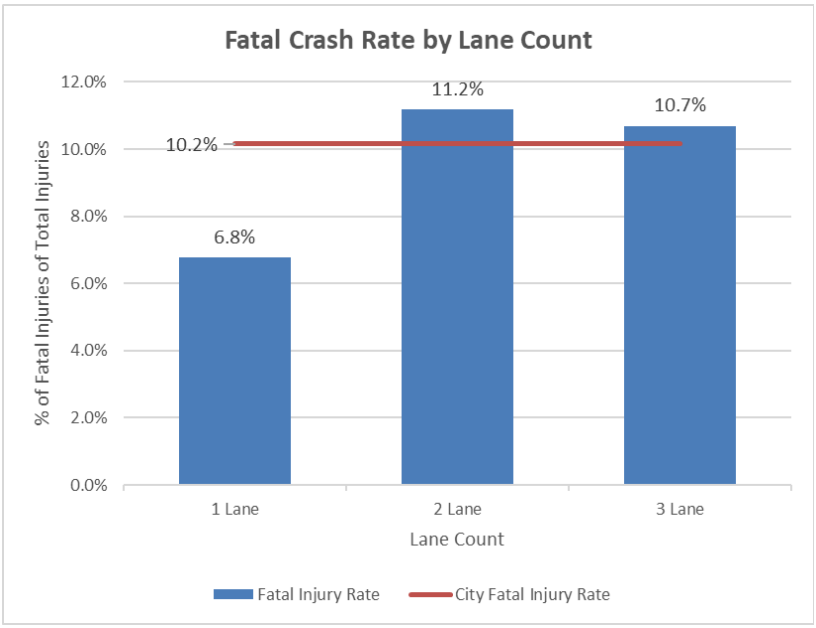

Figure 6: Fatal crash rate by lane count.

Sidewalks

The two-tailed t-test conducted on sidewalk coverage between fatal and nonfatal crashes produced a p-value inadequate to reject the null hypothesis, indicating that there is no statistical difference in sidewalk coverage between fatal and nonfatal crashes. The average sidewalk coverage city-wide remained nearly the same between fatal and non-fatal crashes, with an average of 5.44% and 5.37%, respectively. The ANOVA test between sidewalk coverage and injury severity, however, did produce a p-value high enough to reject the null hypothesis. Still, the average sidewalk coverage did not increase or decrease with the increase or decrease in injury severity.

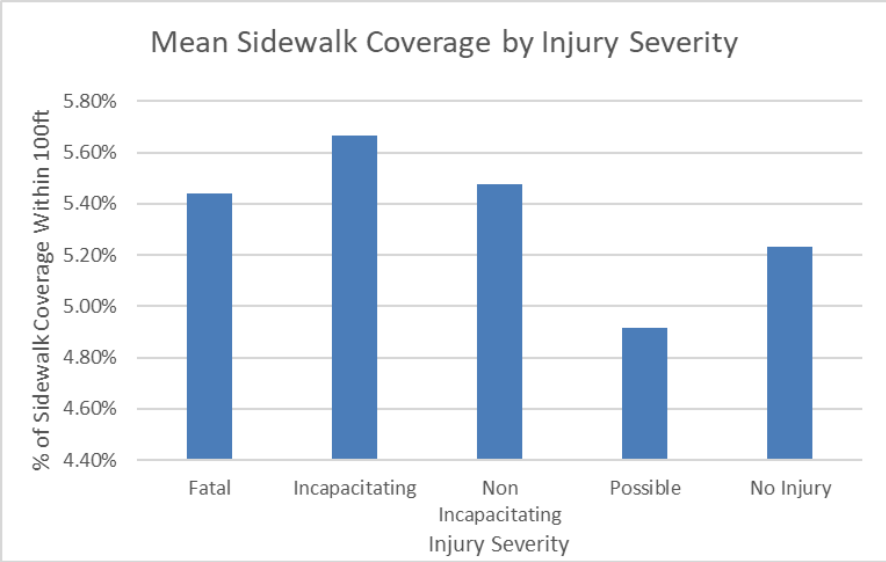

Figure 7: Mean sidewalk coverage by injury severity.

Streetlights

An Analysis of Variance test examining the number of streetlights at each pedestrian crash by injury severity reveals a p-value sufficient to reject the null hypothesis, indicating that there is a statistically significant ($p=0.00008$) difference in injury severity depending on the number of streetlights present at the crash site. The average number of streetlights within 100ft of each site by injury severity reveals a decrease in streetlights as injury severity increases. Of the 946 total fatal crashes that occurred at night, 163 were fatal, and 66 resulted in no injury. Analyzing the variance reveals that fatal crash sites have a consistently lower, less spread-out number of street lights, at 3.8. Crash sites with no injury have a much higher variance in the number of streetlights, at 12.8.

The two-tailed t-test examining the number of streetlights between fatal and nonfatal crashes produced a p-value low enough to reject the null hypothesis confidently, signifying statistical significance ($p=0.00002$). There are fewer streetlights on average at fatal crash sites than at non-fatal crash sites.

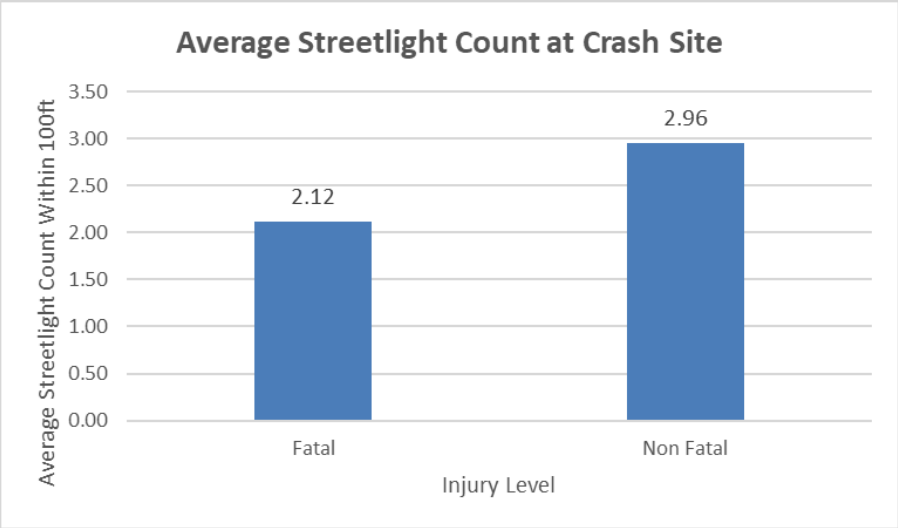

Figure 8: Average streetlight count at crash site.

Ward Application

An analysis of fatal pedestrian traffic crash injuries by each Tucson Ward highlights significant proportional differences. Compared against a city-wide fatality rate of 10.13%, Wards 1, 2, and 5 are above the city average, while Wards 3, 4, and 6 are below the city average. Ward 5 had the highest percentage while Ward 4 had the lowest. The wards were also analyzed to determine which ward had the most amount of crashes per capita. Ward 6 had the most pedestrian crashes per capita, with 672.29 crashes per 100,000 residents, while Ward 4 had the fewest pedestrian crashes per capita, at 94.25 per 100,000 residents. When analyzing by pedestrian fatalities only, Ward 3 had the highest per capita, at 4.9 per 100,000 residents, while Ward 4 had the least, at 0.6 per 100,000 residents.

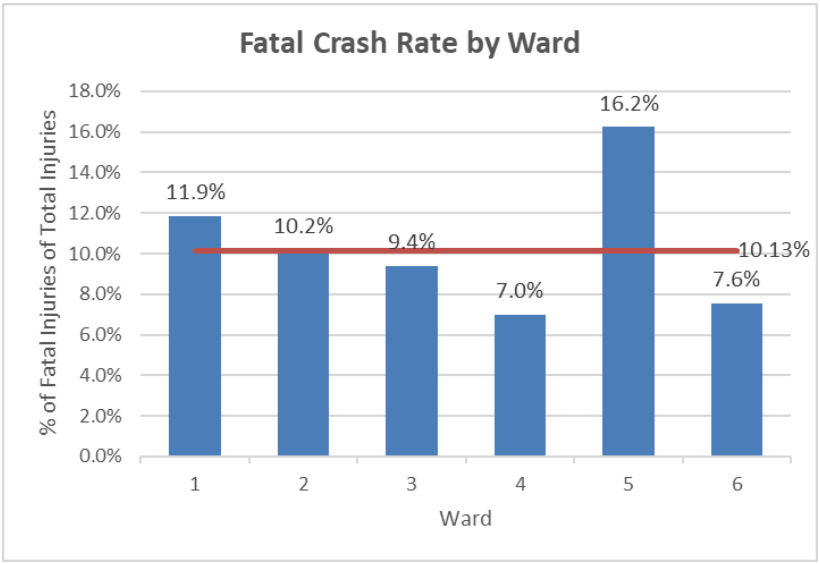

Figure 9: Fatal crash rate by ward.

The wards were then analyzed by the specific designs previously established to result in worse outcomes for pedestrians. Ward 5 had consistently higher numbers of road miles with design elements associated with higher rates of pedestrian fatalities. Ward 5 had the most miles of roads with 2 or 3 dangerous street design elements, and had the least amount of roads with no street design elements that were identified to have an above-average risk for pedestrians.

Table 1: Miles of road by Ward and street design

Miles	Ward 1	Ward 2	Ward 3	Ward 4	Ward 5	Ward 6	City	Ward Avg
Total	64.14	61.53	74.14	83.63	89.52	53.89	429.84	71.14
Arterial	40.44	51.05	52.83	73.39	75.54	32.09	327.74	54.22
Collector	23.70	10.48	21.31	10.25	13.97	21.80	102.10	16.92
Streetlight	14.92	13.34	12.54	29.71	33.43	7.74	114.53	18.61
Lane	37.08	41.54	52.56	35.46	58.80	45.01	272.42	45.08
Speed Limit	45.02	53.49	57.17	67.62	72.69	29.49	325.48	54.25
0 Points	4.70	4.77	8.99	4.76	2.93	4.91	31.05	5.18
1 Point	23.47	8.69	12.05	29.58	16.88	16.44	108.27	17.85
2 Points	34.37	44.54	49.07	44.69	61.10	31.81	267.40	44.26
3 Points	1.61	3.53	4.03	4.61	8.62	0.72	23.12	3.85

Discussion

Speed Limits

As speed limits increased, so did the rate of fatal pedestrian crashes. Fatal crash rates at 35 mph and above were more than the city-wide average, aligning with nationwide pedestrian fatality research, and supporting the hypothesis. Schneider (2020) found that, across the United States, fatal crashes occurred mostly on roads with speed limits above 35 mph. Vehicle speeds above 35 mph are when vehicle collisions with pedestrians are more likely than not to result in a fatality, with a 50% chance at 42 mph, and a 75% chance at 50 mph (Tefft, 2011).

Sidewalks

The average sidewalk coverage did not increase or decrease with the injury severity of the site, but the ANOVA test examining sidewalk coverage and injury severity successfully rejected the null hypothesis, indicating that the difference is not due to chance. When the data was arranged to compare just sidewalk coverage at fatal sites versus nonfatal sites, the null hypothesis was accepted, with no major difference between the two conditions.

These factors reject the hypothesis that more severe pedestrian injuries are more likely to occur at sites with less sidewalk coverage. To investigate this further, it is important to recognize what results in pedestrian fatalities: the speed of the vehicle. Tucson's wide, fast arterial roads had slightly more sidewalk coverage on average than collectors, at 4.42% compared to 4.18%. 87% of fatal pedestrian crashes occurred on arterial streets, while only 7% occurred on collectors

and 6.5% occurred on local streets. Perhaps the fatal crashes on arterials had consistent sidewalk coverage, while the non-fatal crashes on collectors and local streets had less consistent sidewalk coverage, leading to data that does not associate sidewalk coverage with injury severity. Street sidewalk coverage by road type was determined by joining the sidewalk dataset to the Major Streets and Routes dataset in the same manner that the sidewalk dataset was joined to the pedestrian crash dataset.

Major Streets and Routes Type

Arterial roads were overrepresented in the analysis of fatal crashes by road type. According to the Major Streets and Routes plan, arterials are roads that carry over 12,000 vehicles per day, and are a step down in road classification from collector streets, and have higher speeds and more lanes on average. Collector streets carry anywhere between 2,500 to 12,000 vehicles and are a step down from arterials on the roadway hierarchy (City of Tucson, 1982). The definitions of arterials and collectors provided in the plan match their associated rates of pedestrian fatalities. Roads whose primary use is to move traffic efficiently and quickly lead to worse pedestrian crash outcomes.

Streetlights

Walking at night is consistently more dangerous for pedestrians than walking during the day. Approximately 76% of fatal pedestrian crashes occurred during the night. The importance of street lighting was identified by a study in the Traffic Safety Research journal, which found fatal crashes in Sweden occurred more in dark conditions (Stigson et al., 2023). Only 3.8% of pedestrian crashes were fatal during the day, while 16% were fatal during the night. The difference in the average number of streetlights at fatal and nonfatal crashes highlights the need for consistent street lighting to help improve pedestrian crash results. The variance in the number of streetlights at fatal crashes was only 3.8, while non-fatal crashes had a variance of 11, indicating that fatal crashes consistently occur on streets with less lighting.

Number of Lanes

Roads with more than two or more lanes in each direction had higher rates of fatal pedestrian crashes than the city average. Roads with two lanes in each direction had the highest rate by a thin margin, going against the stated hypothesis that the higher number of lanes a road has would be associated with a higher chance of fatal pedestrian outcomes. Roads with one lane in each direction have a significantly lower rate of fatal pedestrian crashes, aligning with established literature (Distefano & Leonardi, 2019)

Ward Application

Ward 5, which had the highest fatal pedestrian crash rate, had the highest mile count of roads with design elements established to be dangerous for pedestrians. However, Ward 4, which had the lowest fatal crash rate, also had higher-than-average mile counts of dangerous roads. The

built environment of Ward 4 is made up of low-density subdivisions that sprawl along Interstate 10, which likely results in a lower number of pedestrians, therefore reducing the amount of pedestrian crashes. Ward 5, which does sprawl southward, also consists of urban areas closer to the core of Tucson, likely resulting in an increased number of pedestrians. There is also a disparity in income levels between the two wards, with the 2018 median income in Ward 4 at $58,200 and Ward 5 at $36,300 (United Way Tucson, 2020), likely helping account for the discrepancy in pedestrian crashes between the two wards. Analyzing each ward by miles of dangerous roads may help inform general trends, but other factors like income and pedestrian counts should also be considered.

Conclusions

Targeted Investment

Some areas of Tucson have it worse than others. A nearly 10% swing in the percentage of crashes that were fatal in Ward 5 compared to Ward 4 highlights the need for targeted investment in some Tucson communities. Significant investment in Ward 5, as well as other wards with above-average fatality rates, should be made to address inequities in transportation

Street Lighting

Street lighting is essential for addressing pedestrian fatalities and should be consistently implemented where not already along all urban Major Streets and Routes. While it is important to protect the dark sky, it is also important to address the undeniable impact street lighting has on pedestrian fatalities. Street lighting technologies like shielding can lessen the impact of street lighting on the night sky while protecting pedestrians

Sidewalks

While the presence of sidewalks is not directly associated with the chance of a fatal outcome, sidewalks should still be an inherent part of any street retrofit project. Sidewalks provide necessary accessibility and comfort to pedestrians, which may encourage one to walk rather than drive.

Traffic Calming

Traffic calming measures should be implemented on roads with high rates of pedestrian fatalities. Reducing the number of lanes and the width of the lanes has been shown to reduce vehicle speeds, in turn improving pedestrian crash safety outcomes.

Recommendation Example

The stretch of Fort Lowell Road between 1st Avenue and Oracle Road is entirely comprised of street design features associated with high pedestrian fatality rates, and has historically had a high number of pedestrian crashes. This section of road has no street lighting, a

speed limit of 40 mph, no traffic calming, and two lanes in each direction. There are also no sidewalks on this stretch of road.

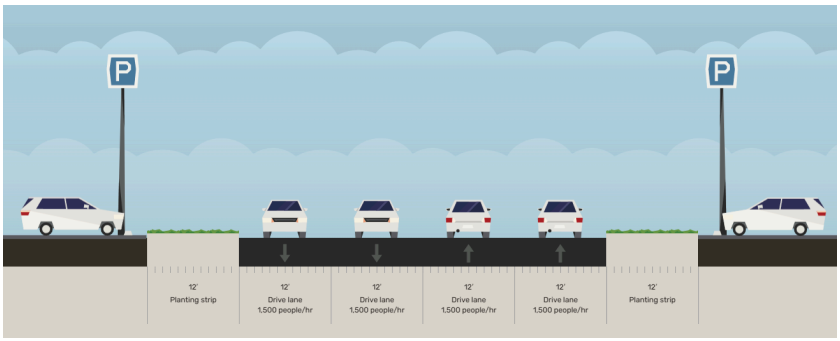

Figure 10: Fort Lowell street design between 1st Avenue and Oracle Road (Streetmix).

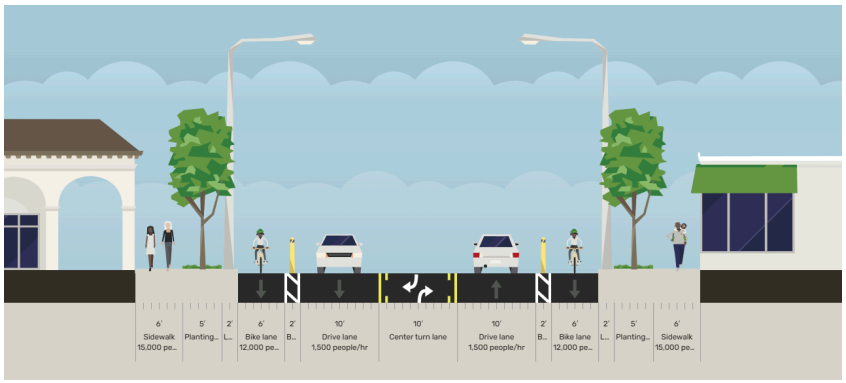

Figure 11: Proposed pedestrian improvements (Streetmix).

Adjusting the street design to improve pedestrian crash outcomes involves removing a lane of travel in each direction, adding street lighting, and reducing the speed limit while also implementing traffic calming measures. Simply reducing the speed limit while not adding traffic calming would not be enough to slow vehicle speeds. Narrowing lane widths and repurposing street space for other modes of transportation separated by barriers will make drivers feel less comfortable driving fast. Providing pedestrian amenities like shade and sidewalks will help them feel more comfortable and safe, encouraging them to choose to walk rather than drive.

Limitations

When conducting analysis with secondary data sources, the largest limitation is often the completeness or validity of the data. While the geospatial datasets that were collected for this research were extensive, almost all had their own limitations.

Pedestrian Accidents

While each point in the “Pedestrian Accidents” dataset represents an incident, the locations are all approximate. By default, the geospatial points of each pedestrian crash are placed at the nearest major intersection from where the crash took place. Tucson Police

Department then specifies a closer approximation to the location of the crash if the data is available. For example, a completed accompanying location data for a point of data would read "Grant Road, 300 Ft West of Alvernon."

510 of the 2,236 pedestrian crashes were moved manually according to those instructions within the dataset to increase the accuracy of the geospatial analysis. Every piece of data that indicated it was more than 100ft from its default point was moved. Those less than 100ft were not moved due to their proximity to the intersection. 576 of the 2,236 crashes were labeled "unk", or an unknown distance from the default point. 557 of 2,236 crashes did not specify their distance from their associated point. Of the 1,103 points with some distance measured from the default point, the accuracy varies. Under the accuracy attribute, only 26 points are "measured", 5 points are listed as "N/A", and the remaining 1,072 are listed as "Approximate".

119 of the 2,236 recorded pedestrian crashes did not detail the severity of injury for the crash. These datapoints were discarded when analyzing injury severity and fatal vs. non-fatal crashes.

Number of Lanes

The number of lanes dataset does not factor in middle turn lanes or any additional right turn lanes that may be found at intersections. The number of lanes dataset only identifies the number of lanes of broad road segments. The data also does not contain information about road or lane width.

There may also be errors in the dataset. For example, the dataset states that Ring Road surrounding the University Medical Center has two lanes in each direction for its entire length. However, it only features two lanes in each direction for one 300-foot segment of the 4,100-foot road.

Future Work

While speed limit is often tied to the design of the road, there are outliers. Some new roads are being designed with upwards of three wide lanes in each direction, but only maintain a speed limit of 30 mph. For example, the Broadway Boulevard underpass West of Aviation Highway, and the Maclovio Barraza Parkway. Drivers will only drive as fast as they feel comfortable, often regardless of the speed limit, especially with a lack of enforcement. This leads to excessive speeding and an increased risk to pedestrians that is not reflected in the street design data. The relevant datasets for this issue, Speed Limits and Number of Lanes, do not contain information about average vehicle speeds, lane width, or road width. Future analysis of fatal pedestrian crashes should gather the missing data to identify roads with speed limits that do not match the design of the road and analyze their fatal pedestrian crash rates.

Cities other than Tucson that are both overrepresented and underrepresented nationally in pedestrian fatalities should undergo a similar analysis of city-wide street design and street design at sites of pedestrian fatalities. Developing an inventory of pedestrian-unsafe street designs in each city would help inform planning decisions going forward. Expanding this research to other cities will help identify common trends in pedestrian fatalities and help promote best practices to reduce the likelihood of traffic crashes involving pedestrians resulting in fatal outcomes.

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