Crash report for Palo Alto, 2010-2019

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In a sustainably safe road traffic system ...

... the road and the vehicle protect you and those around you against major traffic hazards ... traffic professionals work together and check one another to achieve a maximally safe result ... the road is intended to facilitate traffic flow or exchange across traffic, but not both ... every child can safely walk or cycle to school, thanks to proper neighbourhood planning, a safe road lay-out, safe speeds, and being sufficiently physically protected ... the older road user understands how the traffic system is intended to work and can thus safely operate in traffic situations ... the government accepts ultimate responsibility for a casualty-free traffic system ... unsafety and each party's responsibility in connection with it are acknowledged and acted on using a risk-based approach ... all fatal crashes are investigated to establish why things still go wrong. [34]

1 Introduction

This report analyses pedestrian, bicyclist, and motor vehicle occupant crash data for the City of Palo Alto during the years 2010-2019. This time span is recent, but excludes the COVID-19 pandemic and the associated changes in travel patterns. In addition, this time span is long enough to gather reasonable statistics. The data used in this report comes from different academic studies and the Transportation Injury Mapping System (TIMS) [29], which is maintained by the Safe Transportation Research and Education Center (SafeTREC) at the University of California, Berkeley. The data in TIMS is the same data as the Statewide Integrated Traffic Records System (SWITRS) data of the state of California [6], but it is geocoded for easier mapping.

1.1 Crash reporting

The crash data in the SWITRS database is from police reports, which means that two caveats have to be mentioned: (i) pedestrian and bicyclists crashes are seriously under reported in police reports [32, 19, 11], and (ii) a police officer is no medical professional. A quick analysis of the level of injury at the crash scene is not the same as a full medical evaluation at a hospital [24]. For this reason crash severity is only listed as severe or non-severe in this report, where severe is defined as severe or fatal as used in the SWITRS database and non-severe all other crashes. The under reporting of crashes means that probably many more crashes happened in the period 2010 -2019 than are reported in this report. This includes solo bike crashes that did not involve any other vehicles, which can make up up to 60% of all bicycle crashes in hospital crash data [37].

1.2 Normalization

Another difficulty, especially in the analysis of pedestrian and bicycle crash data, is normalization. To accurately compare the number of crashes between different areas, one needs to know how many miles are traveled per mode of transportation. Generally, this data is not available for pedestrians and bicyclists. When its is available [30], short trips, and thus active transportation modes, tend to be undercounted in travel surveys [20].

To compare crashes between different intersections, one needs to know the volume per mode. This data is generally also not available. However, there is a recent study funded by Caltrans to model the pedestrian exposure along their roads [16]. This makes it possible to rank the intersections along El Camino Real for pedestrian safety.

Lastly, even when crash data can be normalized it is important to realize that there are other factors, apart from road safety measures, that affect risk. For vehicle occupants fatality rates this includes factors such as the level of urbanization, traffic congestion, and the mean vehicle age [26]. These kinds of factors can also be expected to influence pedestrian and bicyclist safety.

In a couple of figures in this report the crash data is presented by age group. Figure 1 shows the age distribution of the population of Palo Alto (2019) and is provided as a reference. The data comes from the American Community Survey (ACS) 2015-2019. However, the mode share in each age group is not known. Neither does this figure take into account all the students living on the Stanford University campus who go to Palo Alto regularly, or all the workers who commute to Palo Alto for their work [9].

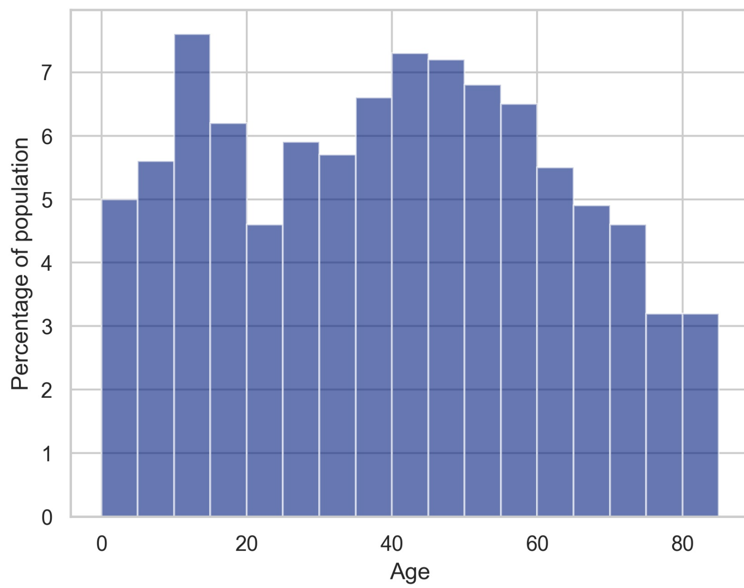

Figure 1: Age distribution of the population of Palo Alto (2019). From American Community Survey (ACS) 2015-2019.

2 Pedestrian road safety

2.1 Overall safety

A first question one can ask is how does Palo Alto perform on pedestrian road safety compared to other towns and cities in California. The California Office of Traffic Safety (OTS) releases a crash ranking and Palo Alto scores quite poorly, with a score of 19/102 in 2018 [7]. However, this crash ranking illustrates the importance of selecting the right denominator to normalize crash data. The OTS crash ranking uses vehicle miles traveled (VMT) to compute the exposure of pedestrians, which is a very poor choice. If everyone only walks and bikes, there would be no vehicle miles traveled, and the ranking would go to infinity. This creates an artificially high collision rate for pedestrians and bicyclists and results in a poor ranking for towns like Palo Alto.

Figure 2 and Figure 3 show the results of a study which normalizes pedestrian crash data with pedestrian kilometers traveled [30]. Using data from the 2010-2012 California Household Travel Survey (CHTS) a model is created that estimates the pedestrian kilometers traveled per census tract.

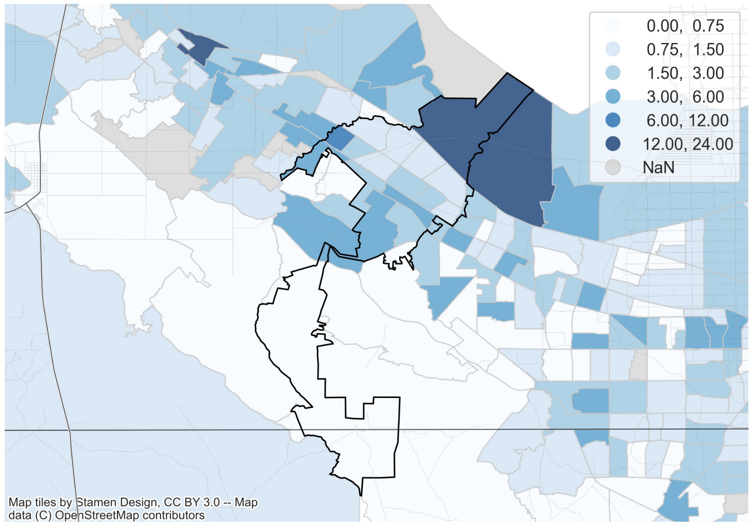

Figure 2: Non-severe pedestrian crashes per million km traveled walking. In the light gray census tracts not enough data is available to estimate the kilometers walked. The Palo Alto city limits are shown in black. The data in this plot comes from Reference [30].

This data is combined with crash data from TIMS to compute the non-severe (Figure 2) and severe (Figure 3) pedestrian crashes per million km traveled walking. Severe is defined as a crash that results in severe injury or death, and non-severe is defined as all other crashes. Information on the severeness of a crash is present in the SWITRS database. Since the model computes kilometers traveled per census tract, it does not make good predictions for areas where a lot of people visit compared to their population. This includes locations like the Baylands and Foothills Park. However, for other areas the model allows for a comparison of the road safety between Palo Alto and neighboring communities. The Palo Alto city limits are shown in black.

Looking at non-severe injuries, Figure 2 suggest that Palo Alto's road safety for pedestrians is slightly worse than neighboring communities. The difference being, that census tracts with a rate of $0.0 - 0.75$ crashes per million km are more common outside of Palo Alto. For severe injuries, Figure 3 indicates that Palo Alto's road safety for pedestrians is slightly better than neighboring communities. Census tracts with a rate of $2.0 - 4.0$ crashes per million km seem more common outside of Palo Alto. Overall, Palo Alto does a lot better on pedestrian road safety than its OTS crash

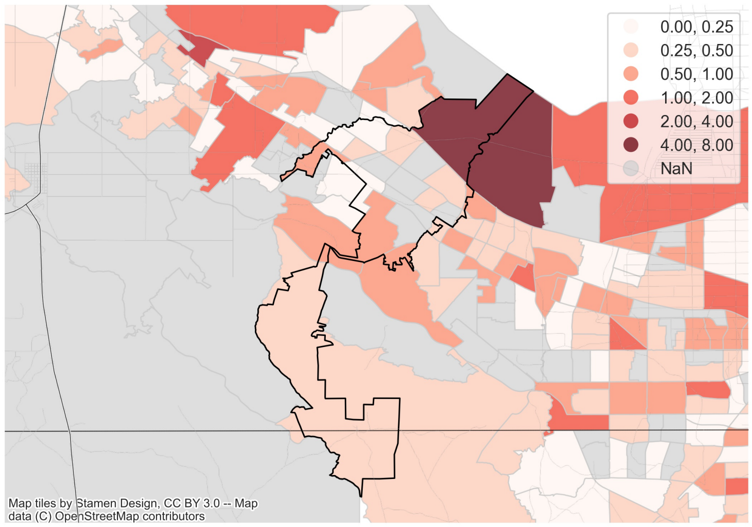

Figure 3: Severe pedestrian crashes per million km traveled walking. In the light gray census tracts not enough data is available to estimate the kilometers walked. The Palo Alto city limits are shown in black. The data in this plot comes from Reference [30].

ranking suggests.

How do these numbers fit in a broader context? Using data from the same study it is also possible to compute the average fatality rate for different jurisdictions. Figure 4 shows the pedestrian fatality rate per million kilometres walked in California, Santa Clara County, San Mateo County, Mountain View, Palo Alto, and Menlo Park, for the period 2003–2012. Census tracts in the Foothills and Baylands are not considered in the calculations for Mountain View, Palo Alto, and Menlo Park because they are outliers compared to the rest of these cities. Census tracts that are gray in Figure 2 and Figure 3 because of a lack of collision data, do contribute to the number of kilometers walked. The pedestrian fatality rate in Palo Alto is lower than the average fatality rates of California, Santa Clara County, and San Mateo County. Factors that can contribute to this difference include: walking infrastructure and street design, the level of urbanization, and traffic congestion [26, 5]. Comparing the pedestrian fatality rate of Palo Alto with Menlo Park and Mountain View shows that walking in Mountain View is relatively unsafe, while walking in Menlo Park is a slightly safer than in Palo Alto.

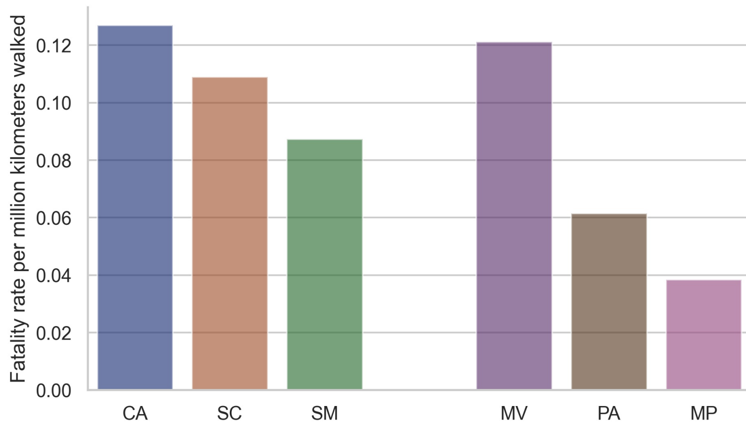

Figure 4: Pedestrian fatality rate per million kilometres walked in California, Santa Clara County, San Mateo County, Mountain View, Palo Alto, and Menlo Park, 2003–2012 [30]. Census tracts in the Foothills and Baylands are not considered in the calculations for Mountain View, Palo Alto, and Menlo Park.

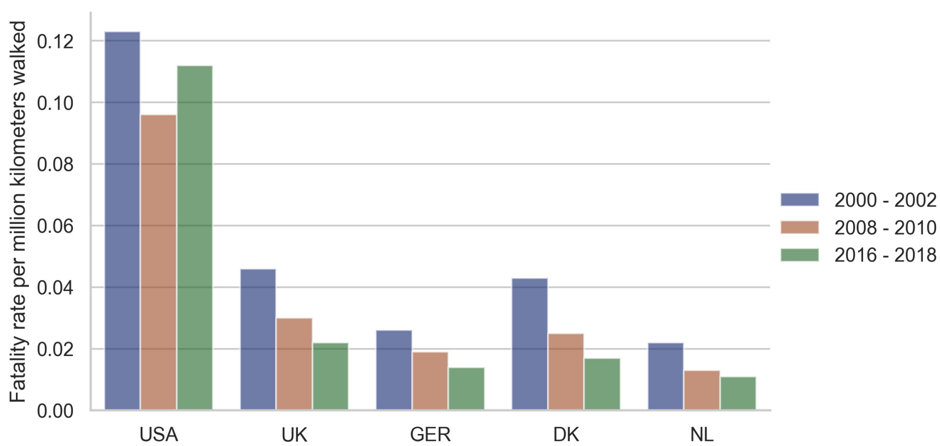

Figure 5: Pedestrian fatality rate per million kilometres walked in the USA, the UK, Germany, Denmark, and the Netherlands, 2000–2018 [5].

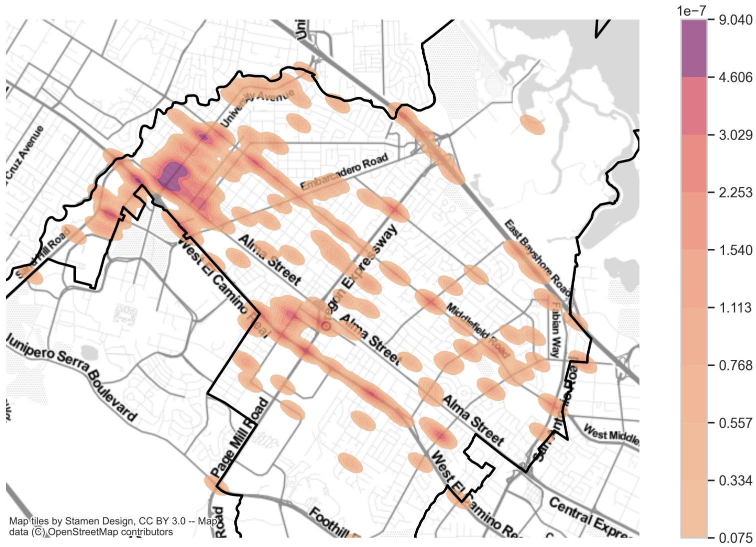

Figure 6: Probability density map of pedestrian victims, 2010-2019. The integral of the probability density map over all of Palo Alto is one. The color map indicates the probability of a pedestrian crash per meter squared.

Broadening our view even further, Figure 5 shows the pedestrian fatality rate per million kilometers walked for the US, UK, Germany, Denmark, and the Netherlands [5]. One can see that in the last two decades there were about 0.11 pedestrian fatalities per million km walked in the US. This is in line with the fatality rate for California. This figure also shows that while Palo Alto does relatively well on road safety compared to other jurisdictions in the US, there is plenty of room to improve. While the pedestrian fatality rate in the US has been relatively stable, many western countries have steadily improved their road safety over the last two decades. Some of the factors that play a role include: walking infrastructure and street design, speed limits, traffic calming, parking restrictions, traffic laws and enforcement, alcohol-related traffic fatalities, traffic education, vehicle size, vehicle km traveled, and the population age distribution [5].

2.2 High crash areas and corridors

Where do these pedestrian crashes occur? Figure 6 shows the probability density map of pedestrian victims, 2010-2019. The integral of the probability density map over all of Palo Alto is one. The color map indicates the probability of pedestrian crash victims per meter squared. Downtown has the highest pedestrian crash probability in Palo Alto. Whether this is due to a large amount of pedestrian traffic or whether this area is also relatively unsafe is impossible to say without pedestrian traffic count data. The fact that University Ave is both a shopping street and a thoroughfare for motorized traffic does not help from a safety perspective. Safe road design guidelines suggest that a road should have a traffic flow function or an exchange function, but not both [34].

California Ave is another area with a heightened crash probability. However, not at the same levels as downtown. Other corridors that stand out are El Camino Real, Middlefield Road, and Embarcadero Road. These are all high-speed, multi-lane, thoroughfares designed only for cars. Apart from the major intersections and Downtown, Alma St does not stand out as a crash corridor for pedestrians. Since the design of Alma does not differ significantly from other major thoroughfares in town, this can most likely be attributed to a lack of destinations and thus pedestrian traffic along this corridor. In addition, due to the presence of the train tracks all destinations along Alma, are only on one side of the road. Lastly, the pedestrian crashes along 101 stand out. Both at the junction of Embarcadero/Oregon Expressway and south of Colorado. These crashes are responsible for the bad safety track record of the Baylands in Figures 2 and 3.

As mentioned before, for most of Palo Alto there is no data available on pedestrian traffic volumes and crash data cannot be normalized. However, this data is available for El Camino [16]. In this study, pedestrian traffic volumes are modeled along roads operated by Caltrans using counts and parameters that correlate with pedestrian traffic. The crash data are from TIMS and only crashes within 75m of the center of an intersection are considered. Figure 7 and Table 1 show the results for Palo Alto. Data for the intersection with Embarcadero Rd is not provided by this study. While all of El Camino is dangerous to pedestrians, the most hazardous intersections for pedestrians along El Camino are: Barron Ave, S California Ave, Sand Hill Rd, and Hansen Way. Like nearly all intersections along El Camino these intersections lack basic pedestrian safety measures, including median islands, bulb-outs to look past parked cars, removal of slip lanes, and traffic signal phasing that prevents conflicts between pedestrians and motorized traffic.

Figure 7: Pedestrian crash victims per year per one million pedestrian crossings, 2010-2019. The most dangerous intersections are listed in Table 1.

Intersection with El Camino	Victims	Volume	Rate
Barron Ave	0.3	100000	3.00
S California Ave	0.4	180000	2.20
Sand Hill Rd	0.3	150000	2.00
Hansen Way	0.2	100000	2.00
Stanford Ave	0.3	220000	1.40
Oregon Expy/Page Mill Rd	0.5	390000	1.30
Oxford Ave	0.2	170000	1.20
Kendall Ave	0.1	86000	1.20
Wilton Ave	0.1	90000	1.10
Margarita Ave	0.1	99000	1.00
Military Way	0.1	100000	1.00
Shopping Center Way	0.1	120000	0.83
Quarry Rd	0.1	130000	0.77
Los Altos Ave/Cesano Ct	0.1	160000	0.63
Palo Alto Sq	0.1	170000	0.59

Table 1: List of the most dangerous intersections for pedestrians on El Camino Real, 2010-2019. Victims is the average number of pedestrian victims per year (TIMS). Volume is number of pedestrians crossing at an intersection per year [16]. Rate is the number of victims per year per one million pedestrian crossings.

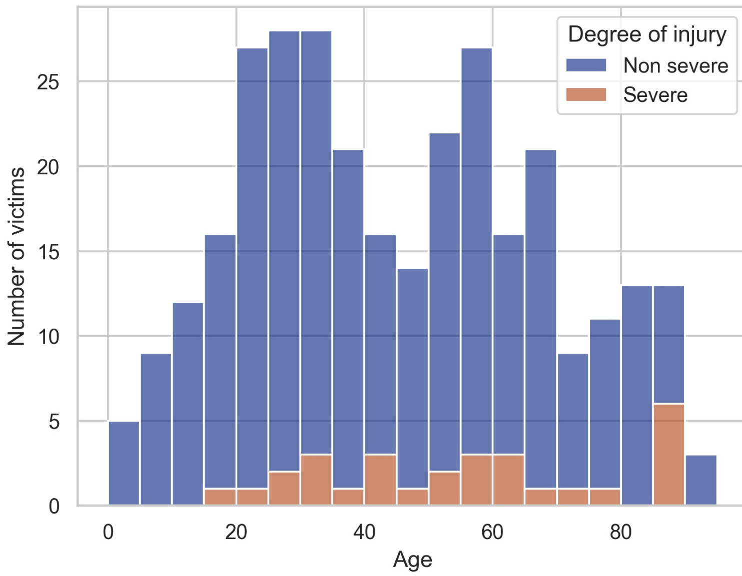

Figure 8: Age distribution of pedestrian victims, 2010-2019.

2.3 Age distribution and crash times

In this last section on pedestrian road safety a closer look is taken at the TIMS data over the period 2010 - 2019. Figure 8 shows the age distribution of pedestrian crash victims. Comparing the age distribution of the population of Palo Alto in Figure 1 with the crash data age distribution, the age groups of 20 to 35 years and 50 to 60 years are overrepresented in the data. This is surprising because, as can be seen in Figure 9, in pedestrian fatality data of the US overall, these are not age groups that are at a higher risk [4]. However, Stanford University is nearby with lots of people in the 20 to 35 years age range and many people commute to Palo Alto for work, which could skew the age distribution. The high number of severe crashes for seniors, on the other hand, is consistent with the literature [4]. Figure 9 shows that during the years 2008–2009, in the US, 0.215 people of 65 and over got into a fatal pedestrian crash per million km walked, which is more than twice as high as the average over all age groups. The data for Germany shows that the same trends can be observed internationally, but at much lower fatality rates.

Figure 10 shows the times at which pedestrian crashes occur for different age groups. There are three distinctive peaks in the data: the morning

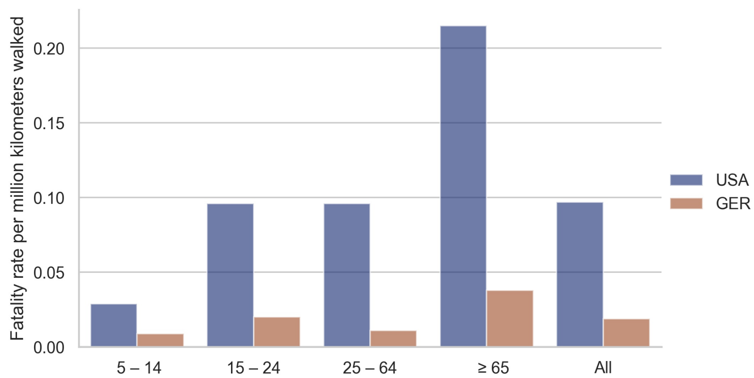

Figure 9: Pedestrian fatalities for different age groups per 1 million km walked in the USA and Germany, 2008-2009 [4].

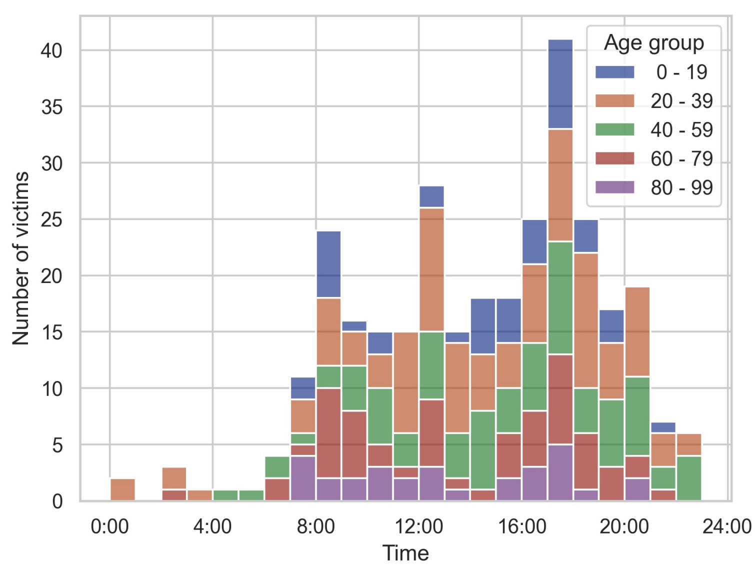

Figure 10: Time of crash by age group for pedestrians, 2010-2019.

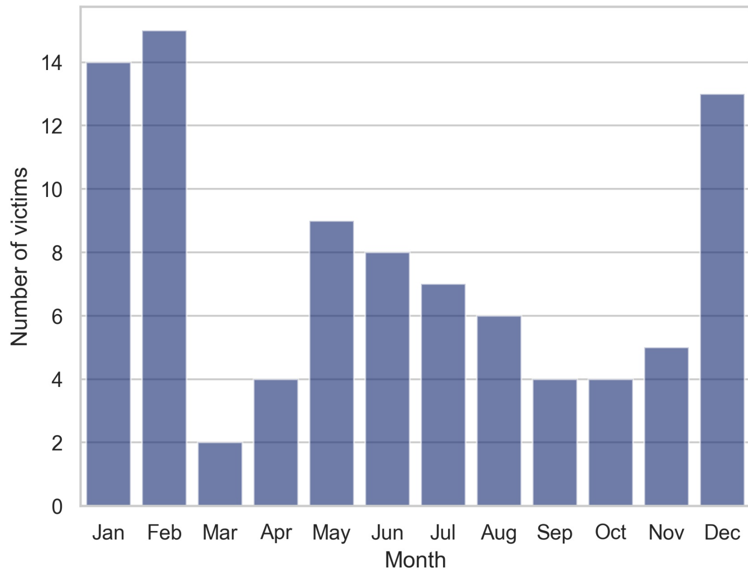

Figure 11: Crashes per month between 16:00h and 19:00h for pedestrians, 2010-2019.

commute, lunch hour, and the evening commute. These are all times that one can expect both many people walking and driving. However, there are especially many crashes during the evening commute. On the shortest day of the year, December 21st, sunrise in Palo Alto is at 7:20, right before the morning rush hour, and sunset is around 17:00h, right in the middle of the evening rush hour. It is known from the literature that sun glare can negatively affect road safety [25]. To evaluate whether people being blinded by the sun and poor street lighting could be contributing factors in the evening commute crashes in Palo Alto, Figure 11 shows the crashes per month that happen between 16:00h and 19:00h for pedestrians. There is a large peak in the number of crashes for December, January, and February, which suggests that this could indeed be the case. The more modest increase of crashes in the summer months needs to be investigated further.

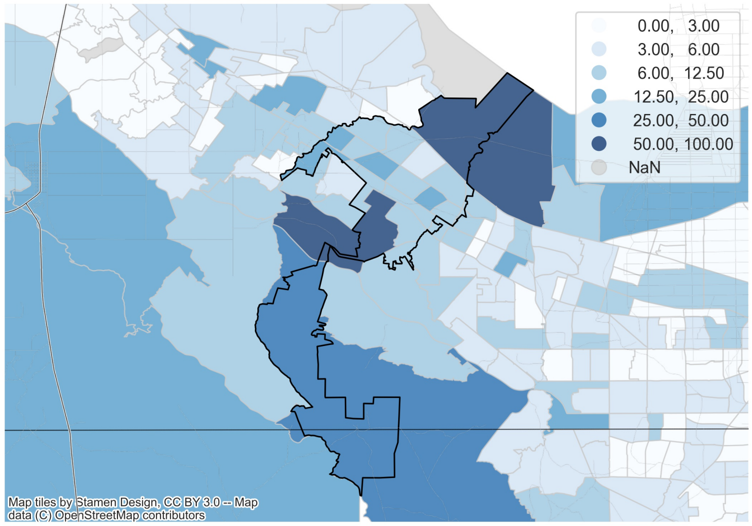

Figure 12: Non-severe bicyclist crashes per million km traveled cycling. In the light gray census tracts there is not enough data available to estimate the kilometers cycled. The Palo Alto city limits are shown in black. The data in this plot comes from Reference [30].

3 Bicycle road safety

3.1 Overall safety

In addition to the pedestrian ranking, the California Office of Traffic Safety (OTS) also releases a crash ranking for bicyclists. In 2018 Palo Alto ranked very poorly with a score of 2/102. The same study, cited above, that evaluates the pedestrian crash rate also analyzes bicyclist crash rates using kilometers bicycled [30]. The results are shown in Figure 12 and Figure 13. Again, severe is defined as a crash that results in severe injury or death, and non-severe is defined as all other crashes. Since the model computes kilometers traveled per census tract, it does not make good predictions for areas where a lot of people visit compared to their population. This includes locations like the Baylands and Foothills Park. The Palo Alto city limits are shown in black. Looking at non-severe injuries, Figure 12 suggest that Palo Alto's road safety for bicyclists is worse than neighboring communities. Nearly all of Palo Alto is in the $6.0 - 12.5$ crashes per million km cycled range, while outside of Palo Alto the $3.0 - 6.0$ crashes per million km cycled range is more common. The results in Figure 13 are consistent

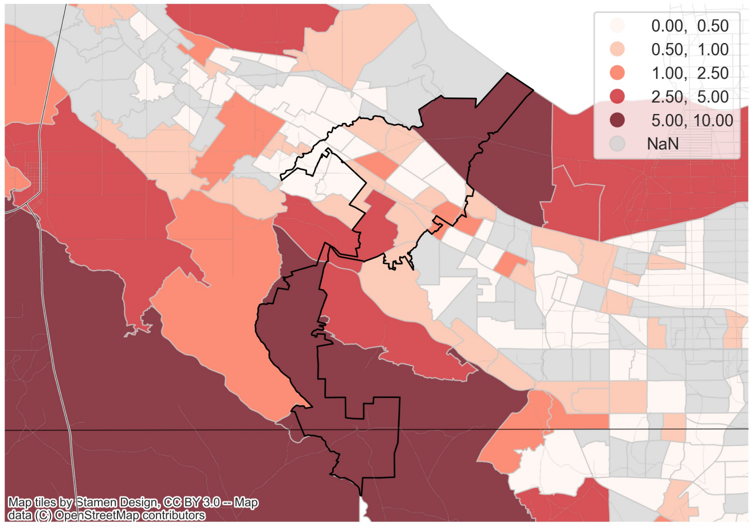

Figure 13: Severe bicyclist crashes per million km traveled cycling. In the light gray census tracts there is not enough data available to estimate the kilometers cycled. The Palo Alto city limits are shown in black. The data in this plot comes from Reference [30].

with this finding. In Palo Alto, neighborhoods with a crash rate of $0.5 - 1.0$ crashes per million km cycled are quite common, while the range of $0.0 - 0.5$ crashes per million km cycled is more common in Palo Alto's neighboring communities. As a mitigating factor it has to be mentioned that one has to wonder whether the model fully captures the high mode share of Palo Alto Unified School District (PAUSD) students bicycling to school [10]. The distance they travel to and from school might not be fully captured by the California Household Transportation Survey (CHTS) and since their high bicycling mode share is unique in California, it might not correlate well with the parameters chosen in the model.

How do these numbers compare with other jurisdictions? Figure 14 shows the pedestrian fatality rate per million kilometres bicycled in California, Santa Clara County, San Mateo County, and Palo Alto, for the period 2003–2012. During this time there were no fatal crashes in Mountain View and Menlo Park, so there is not enough data for a comparison. The fatality rate in Palo Alto is based on one fatal crash. Another fatal crash happened in 2016 and two more in 2020 [29]. Census tracts in the Foothills and Baylands are not considered in the calculations for Palo Alto, because they are

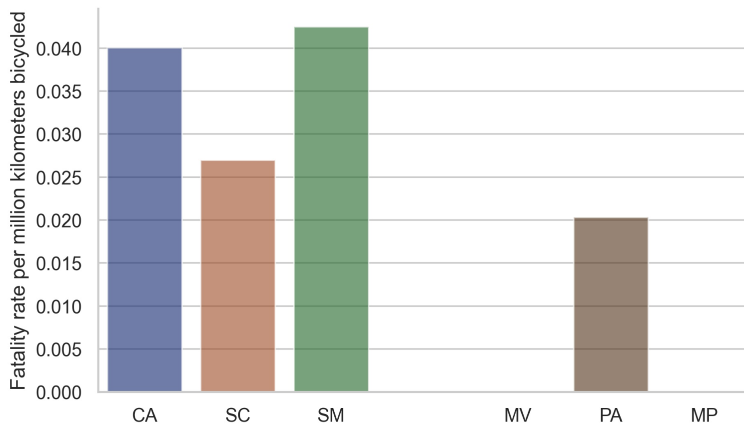

Figure 14: Bicyclist fatality rate per million kilometres bicycled in California, Santa Clara County, San Mateo County, Mountain View, Palo Alto, and Menlo Park, 2003–2012 [30]. Census tracts in the Foothills and Baylands are not considered in this calculation. The statistics in Palo Alto are based on only one fatality. There were no fatalities in Mountain View and Menlo Park during this period.

outliers compared to the rest of the city. Census tracts that are gray in Figure 12 and Figure 13 because of a lack of collision data, do contribute to the number of kilometers bicycled. The bicyclists fatality rate in Palo Alto is lower than the average fatality rates of California, Santa Clara County, and San Mateo County. Factors that can contribute to this difference include: bicycling infrastructure and street design, the level of urbanization, and traffic congestion [26, 5].

Figure 15 shows the bicyclist fatality rate per million kilometers cycled for the US, UK, Germany, Denmark, and the Netherlands [5]. In the last two decades there were about 0.06 bicyclist fatalities per million km cycled in the US. California has a lower bicyclist fatality rate than the US as a whole and, with the caveat of a very small sample size, Palo Alto is at half the rate of California. As is the case with the pedestrian fatality rate, this figure also shows that while Palo Alto does relatively well on bicycle road safety compared to other jurisdictions in the US, there is plenty of room to improve. Some of the factors that the City of Palo Alto can influence to improve safety include: bicycle infrastructure and street design, speed limits, traffic calming, parking restrictions, traffic enforcement, and traffic education, [5].

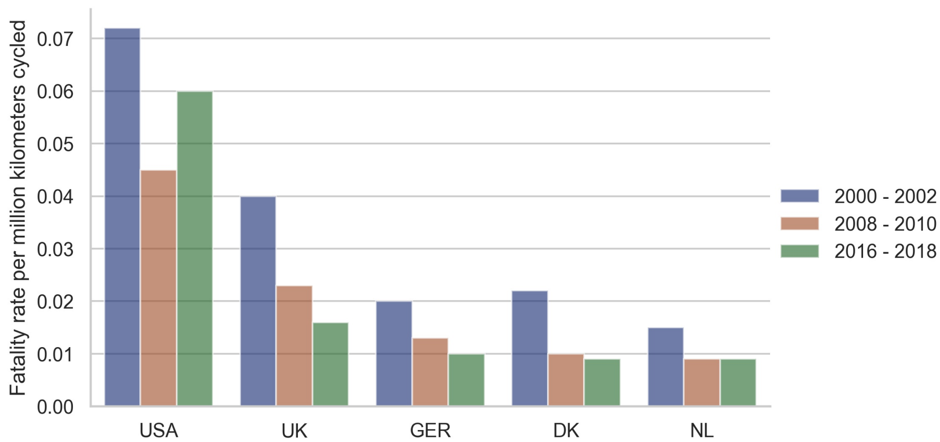

Figure 15: Bicyclist fatality rate per million kilometres cycled in the USA, the UK, Germany, Denmark, and the Netherlands, 2000–2018 [5].

3.2 High crash areas and corridors

Figure 16 shows the probability density map of bicyclist victims, 2010-2019. The integral of the probability density map over all of Palo Alto is one. The color map indicates the probability of bicycle crash victims per meter squared. The crashes are distributed more evenly than the pedestrian crashes. However, several black spot areas and corridors can still be identified. The largest black spot is again downtown, an area with a lot of bicycle traffic and car traffic. Many black spots can also be found along El Camino Real (Sandhill, Embarcadero, California, El Camino Way, & Charleston), a high speed road designed for motorized vehicles. Charleston/Arastradero is another crash corridor (Los Palos, El Camino, Alma, Middlefield, Fabian), but the redesign should make this road safer in the future. Then there is Middlefield road where all the black spots are in the 4 lane stretch in South Palo Alto (Colorado, Loma Verde, Meadow, & Charleston). Lastly, there are Oregon & Cowper, Oregon & Greer, Churchill & Castilleja, and a couple of black spots along Bryant (Churchill, Embarcadero, & California). Bryant is a major corridor for bicyclists, which is probably contributing significantly to large number of crashes there. However, it might also indicate that there is room for improvement from a road safety perspective.

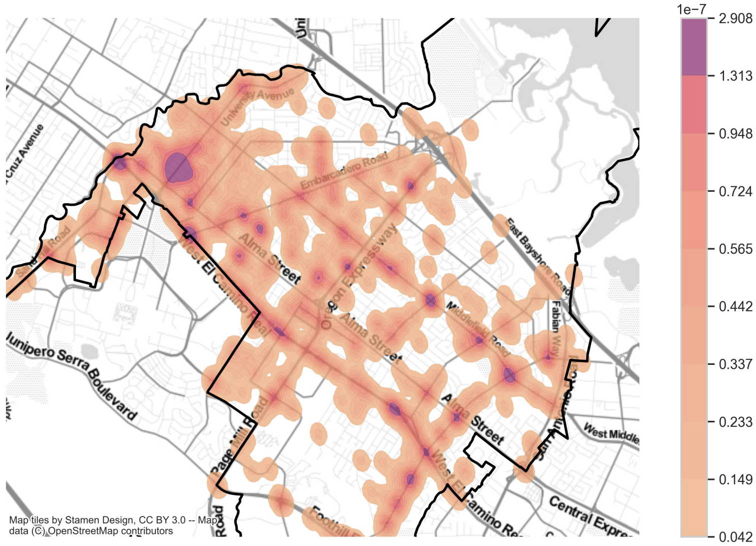

Figure 16: Probability density map of bicyclists victims, 2010-2019. The integral of the probability density map over all of Palo Alto is one. The color map indicates the probability of a bicycle crash per meter squared.

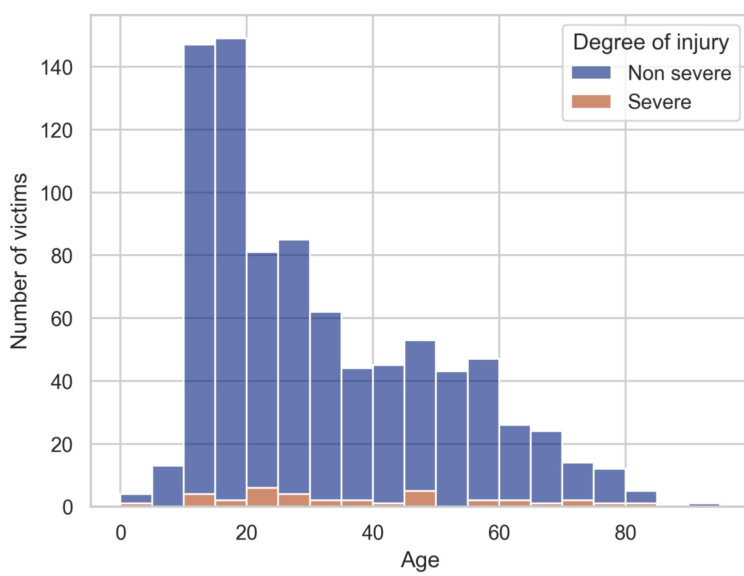

Figure 17: Age distribution of bicyclist victims, 2010-2019.

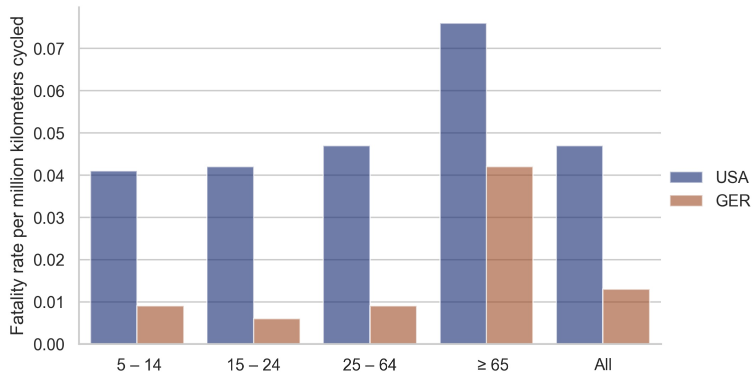

Figure 18: Bicycle fatalities for different age groups per 1 million km cycled in the USA and Germany, 2008-2009 [4].

3.3 Age distribution and crash times

Figure 17 shows the age distribution of bicycle crash victims. Comparing the age distribution of the population of Palo Alto in Figure 1 with the crash data age distribution, the age group of 10 - 20 years is very over represented for non-severe crashes. While there is no data available on how many kilometers each age group rides, a very rough estimate can be made using school and commute trips. The mode share of Palo Alto Unified School District (PAUSD) middle and high school students riding to school was between 40 and 60% during the years 2010 to 2019 [10], while the mode share of commute trips to and from Palo Alto was only 5% according to the 2011 to 2015 American Community Survey (ACS) [3]. Working adults make a total of about 70,000 trips to and from work a day [3], which comes down to $70,000 \times 0.05 = 3,500$ bicycle trips a day. The age group of 18 to 66 years old was involved in 517 crashes during the years 2010 to 2019. PAUSD middle and high school students make about 14,000 trips a day [27], which results in about $14,000 \times 0.5 = 7,000$ bicycle trips a day. The age group of 11 to 18 years old was involved in 277 crashes during the years 2010 to 2019. Assuming a similar distribution of trip distances for students and working adults, the ratio of crashes/trips a day for working adults, $517/3500 = 0.15$ is higher than for PAUSD students, $277/7000 = 0.04$. In addition, these young riders are not over represented in the severe crashes, and are thus at relatively low risk. As can be seen in Figure 18, this is consistent with the averages for the US as a whole [4]. In the years 2008-2009, 5-14 year olds had a fatality rate of 0.041 casualties per million km cycled. This number is

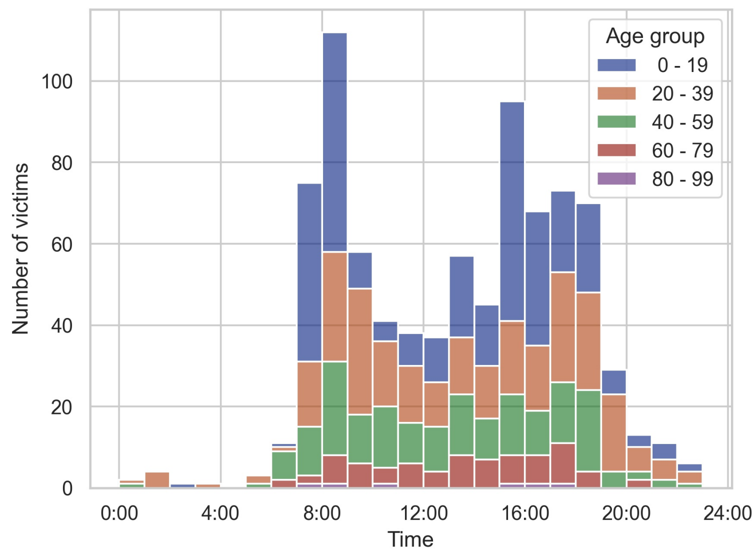

Figure 19: Time of crash by age group for bicyclists, 2010-2019.

lower than the overall averages of 0.047 casualties per million km cycled. On the other hand, Figure 18 shows that for adults of 65 and over there were 0.076 casualties per million km cycled in 2008-2009. This same trend is also observed for pedestrian fatality rates and can be observed internationally as well. Lastly, the age group of 20 to 35 years is also slightly over represented in the crash data. As is the case for the pedestrians, this could be due to the presence of Stanford University nearby.

Figure 19 shows the times at which bicyclist crashes occur for different age groups. This time there are two distinctive peaks in the data: the morning commute/ride to school ride, and the evening commute/ride from school. The morning commute peak is the highest peak. This could be caused by everyone being on the road at the same time in the morning, while in the afternoon commuters and students ride home at different times.

To evaluate any seasonal effects, Figure 20 shows the crashes per Month that happen between 15:00h and 19:00h for bicyclists. The trend is not as clear as the pedestrian data, but again there are more crashes in January, and February, suggesting that people being blinded by the sun and poor street lighting could be contributing factors. Like the pedestrian data, also a peak can be observed for May, which needs closer examination.

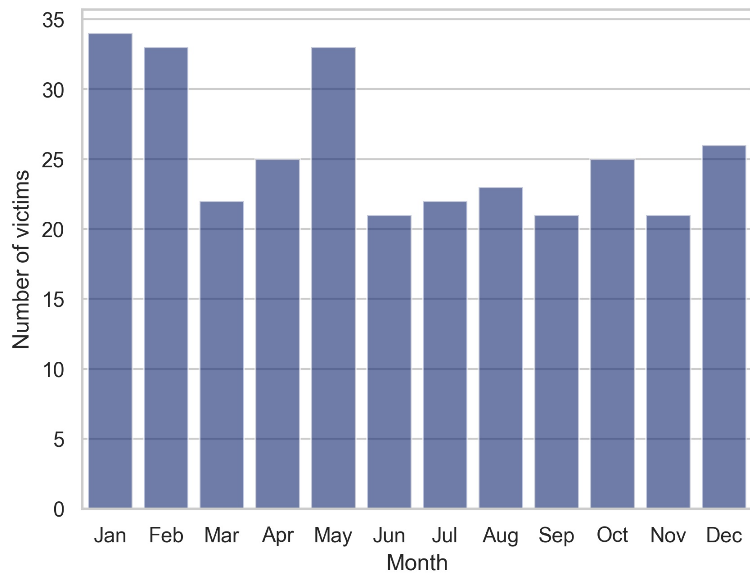

Figure 20: Crashes per month between 15:00h and 19:00h for bicyclists, 2010-2019.

4 Motor vehicle occupants road safety

This last section covers motor vehicle occupant (drivers and pedestrians) road safety. Motor vehicle occupant fatality rates are often given as fatalities per billion person miles/kilometers traveled. This might give the impression that travel by motor vehicle is much safer than walking or bicycling. However, a typical bicycle trip covers a larger distance than a typical walk, and a typical motor vehicle trip covers a longer distance than a typical bicycle ride. Figure 21 shows that on average in the US, when looking at trips instead of kilometers traveled, walking is about one and a half times more dangerous than traveling by personal vehicle, and bicycling is about twice as dangerous as traveling by personal vehicle [2]. The other vehicles category includes pickup trucks, SUV's, etc, and trips in these vehicles are about 3 times as dangerous as personal vehicle trips. Riding a motor cycle is by far the most dangerous mode of transportation. These are of course averages for the whole US and walking and bicycling is much safer in Palo Alto than in the US as a whole. In addition, the expected gain in life expectancy from an active lifestyle ranges from 3 - 14 months, the expected loss of life expectancy because of air pollution ranges from 0.8 - 40 days, and

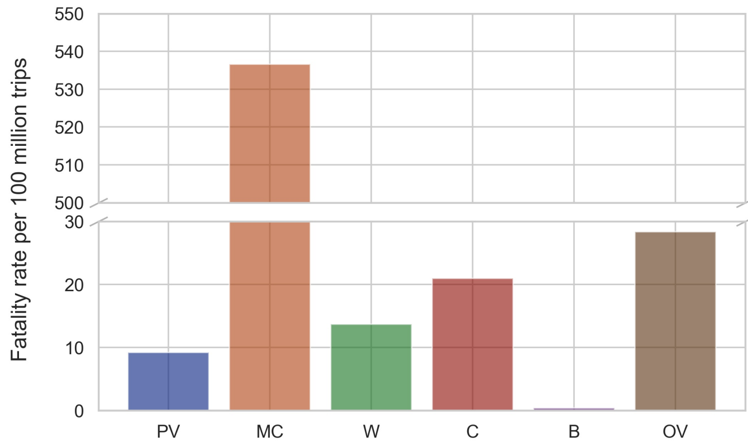

Figure 21: Fatality rate per 100 million person trips for Personal Vehicles, Motor Cycles, Walking, biCycling, Busses, and Other Vehicles, 1999–2003 [2]

the expected loss of life expectancy because of traffic accidents is 5 - 9 days [12]. While these numbers are calculated for a Dutch context, even in the US context the benefits of walking and bicycling should outweigh the risks.

4.1 Overall safety

For 2018 Palo Alto received a total fatal and injury crash ranking of 38/102 and a composite crash ranking of 73/102 from the California Office of Traffic Safety (OTS). This suggests that Palo Alto has a higher than average number of fatal and injury crashes compared to cities of the same size but a better than average ranking on crashes involving alcohol or speeding. While there is no motor vehicle crash information available on the census tract level, there are vehicle miles traveled (VMT) estimates available for Palo Alto from the Highway Performance Monitoring System (HPMS) [13]. This can be combined with the US average vehicle occupancy of 1.67 to compute person miles traveled [14]. Over the period 2010 - 2019 there were 3.26 billion vehicle miles traveled. With 15 motor vehicle occupant fatalities during this same period, this gives a rate of 1.7 fatalities per billion person kilometers traveled. Figure 22 shows the vehicle occupant fatality rate per billion person kilometres in California, Santa Clara County, San Mateo County, Mountain View, Palo Alto, and Menlo Park, for the period 2010–2019. The HPMS estimate of vehicle miles traveled includes all roads within a juris-

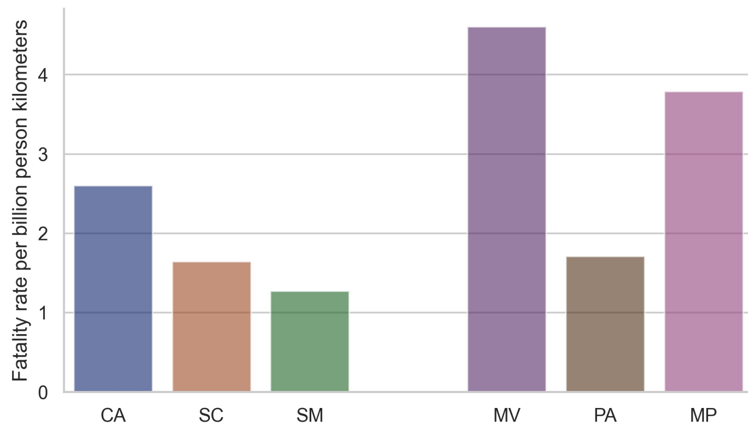

Figure 22: Motor vehicle occupant fatality rate per billion person kilometres in California, Santa Clara County, San Mateo County, Mountain View, Palo Alto, and Menlo Park, 2010–2019.

diction, including interstates, so also interstate fatalities are included in the fatality rate estimate. This does result in a skewed view of the road safety in these cities; in Palo Alto 5 out of 15 fatalities were on I-101, in Menlo Park 8 out of 12 fatalities were on I-101 and US-84, and in Mountain View 12 out of 27 fatalities were on I-101 and US-85. While cities can make safety improvements on roads like El Camino Real, e.g. Mountain View is in the process of installing protected bicycle infrastructure there, their influence on the road safety of interstates is negligible. The motor vehicle occupant fatality rate in Palo Alto is in line with the rate of Santa Clara County, which in turn is below the fatality rate of California.

These numbers can also be compared with the fatality rates for the US and other countries. Figure 23 shows the motor vehicle occupant fatality rate per billion person kilometers traveled for the US, UK, Germany, Denmark, and the Netherlands [5]. In contrast to pedestrian and bicycle safety, the fatality rate for vehicle occupants has decreased with time in the US and is now at about 4.5 fatalities per billion person kilometers traveled. This is still about twice as large as the fatality rate in other countries, but the difference is not as large as for walking and bicycling. Figure 22 is based on Highway Performance Monitoring System data and Figure 23 is based on National Household Travel Survey data, but assuming these data sets give similar estimates for person miles traveled, both Palo Alto and California as a whole have a better safety track record than the US. One major factor in

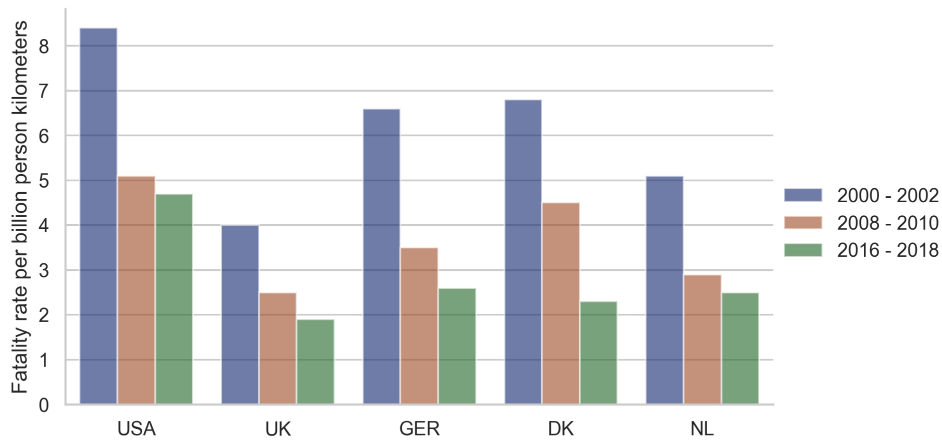

Figure 23: Motor vehicle occupant fatality rate billion person kilometres in the USA, the UK, Germany, Denmark, and the Netherlands, 2000–2018 [5].

road safety is the level of urbanization. In 2019 the number of motor vehicle crash deaths per billion person kilometers traveled was 6.2 for rural areas and 3.2 for urban areas [17]. While Palo Alto's vehicle occupants fatality rate is good compared to neighboring communities, Figure 23 suggests that even here gains can be made. For example, it has been found that cycling cities are safer for everyone, including motor vehicle occupants. This may be due to the traffic calming effect of protected/separated bike facilities [23].

4.2 High crash areas and corridors

Figure 24 shows the probability density map of motor vehicle occupant crash victims, 2010-2019. The integral of the probability density map over all of Palo Alto is one. The color map indicates the probability of motor vehicle occupant crash victims per meter squared. Apart from the interstate, it can be seen that the same roads that are hazardous for pedestrians and bicyclists also carry significant risk for motor vehicle occupants. This includes El Camino Real, Oregon Expressway, and Embarcadero Road. On many of these roads Level Of Service (LOS) has been prioritized over road safety. This includes but is not limited to unsignalized intersections with residential streets, unprotected left turns crossing multiple lanes, the absence of median strips, driveways entering into high speed traffic, and parking along thoroughfares.

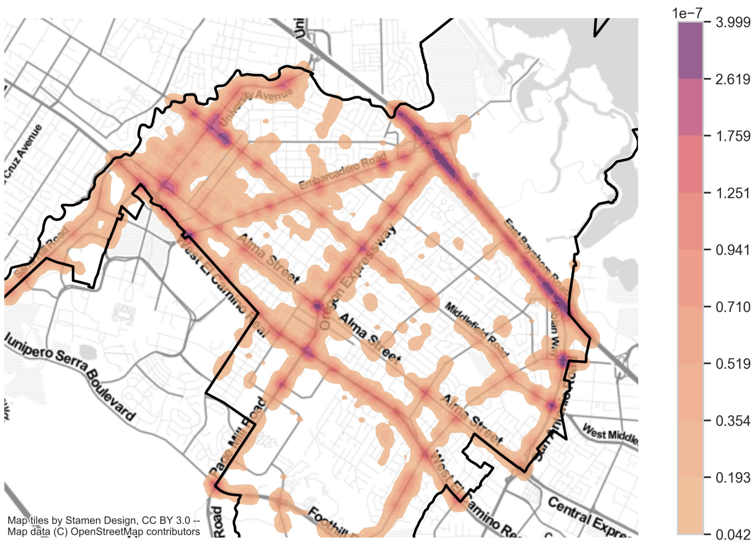

Figure 24: Probability density map of motor vehicle occupants crashes, 2010-2019. The integral of the probability density map over all of Palo Alto is one. The color map indicates the probability of a motor vehicle occupant severe injury per meter squared.

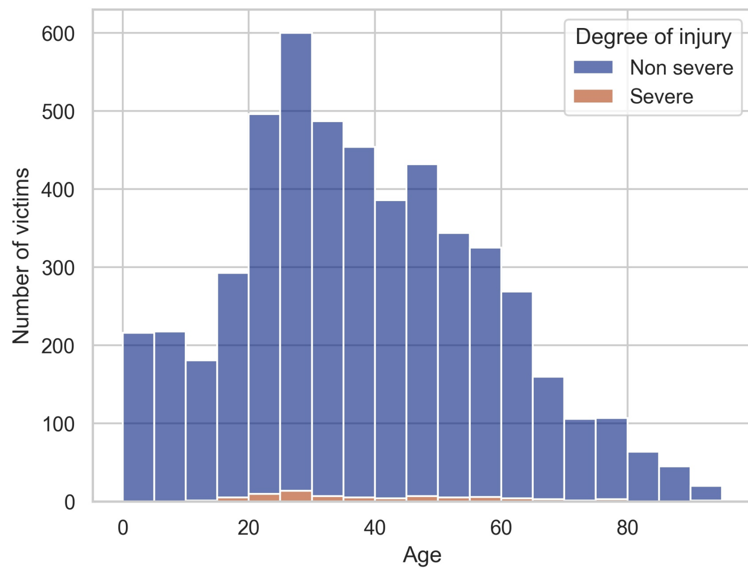

Figure 25: Age distribution of motor vehicle occupant victims, 2010-2019.

4.3 Age distribution and crash factors

Figure 25 shows the age distribution of all motor vehicle occupant crash victims in Palo Alto, 2010-2019. There is a clear peak for vehicle occupants aged $25-30$. As is the case for pedestrian crashes, this is probably due to the presence of Stanford University nearby and people commuting to Palo Alto for work. While this age group is generally found to be at slightly higher risk, as can be seen in Figure 26, the highest risk is found for teenager and older drivers. Especially the fatality rate of teenage drivers is well documented [39]. It is found that teenage passengers increase this risk even further [33].

Figure 27 shows the times at which motor vehicle occupant crashes occur for different age groups. The two major peaks are during lunch hour and evening commute hours. Interestingly, there is no large peak during morning commute hours. For pedestrian crashes the morning commute peak is also the smallest, but does not disappear.

To evaluate any seasonal effects, Figure 28 shows the crashes per Month that happen between 15:00h and 19:00h for motor vehicle occupants. Opposed to the pedestrian and bicyclist data, there is no clear seasonal trend. This suggests that other factors might be at play. For example, drivers might be more alert in the morning, or there might be differences in traffic

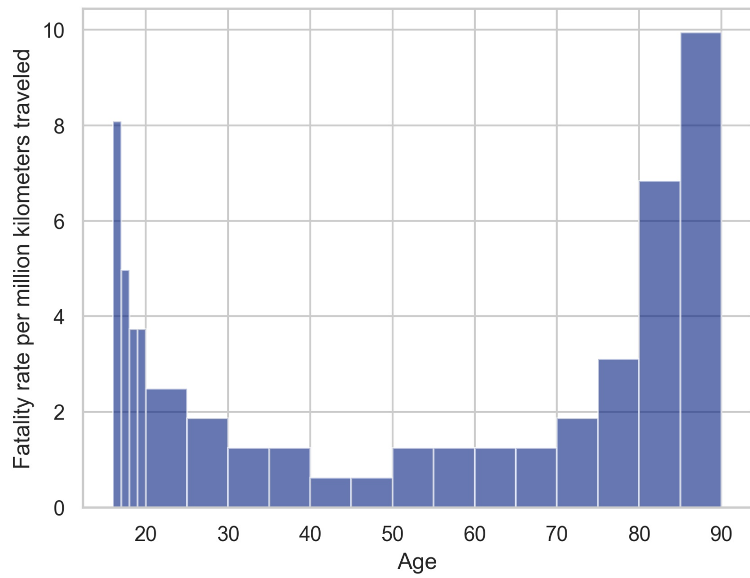

Figure 26: Driver fatal crash involvements per million kilometers traveled, 1995 [39]

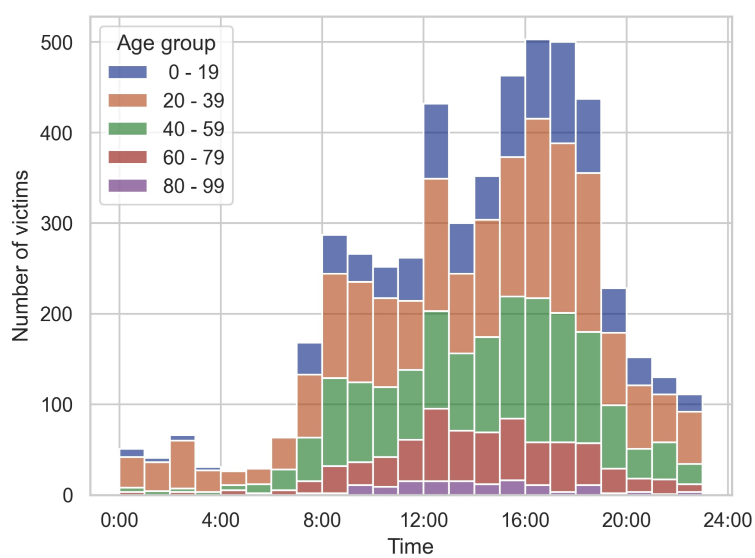

Figure 27: Time of crash by age group for motor vehicle occupants, 2010-2019.

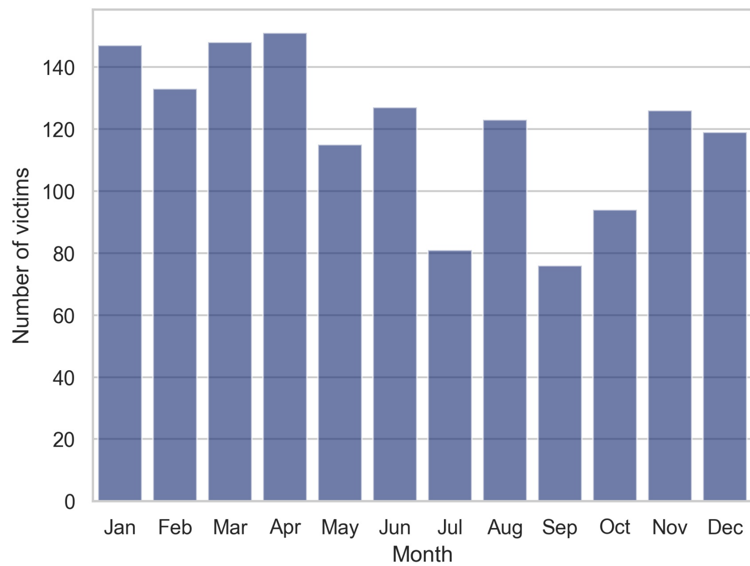

Figure 28: Crashes per month between 15:00h and 19:00h for motor vehicle occupants, 2010-2019.

congestion and travel patterns between the morning and evening commutes. This would require further study.

Lastly, Figure 29 shows the Primary Collision Factor (PCF) for motor vehicle occupant crash victims, 2010-2019. Generally, two major contributions to road fatalities are speeding and driving under influence [18]. Figure 29 shows that crashes caused by driving under influence are relatively rare in Palo Alto, but that speed related crashes are a problem that should be addressed. Speeding tickets are a commonly used tool to deter speeders. While it is found there is a significant amount of recidivism among drivers receiving speeding citations [21], there is a temporary effect. Each conviction leads to a 35% decrease in the relative risk of death over the next month for drivers and other road users [28]. In this same study it is found that there is only a 2% overall risk reduction from manual speed enforcement, but a 19% overall reduction from automated speed enforcement [28]. An alternative approach is to modify the road design and create a "self-explaining" road (SER). The idea is to use road designs that evoke correct expectations and driving behaviours from road users. On residential streets this could include restricting forward visibility using urban landscaping [8]. Self-explaining roads have been found to result in a 30% reduction crash numbers and an

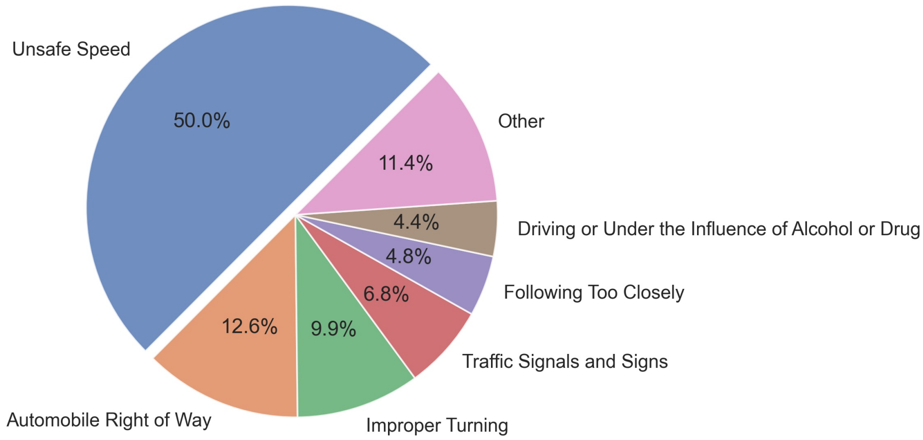

Figure 29: Primary Collision Factor (PCF) for motor vehicle occupant crash victims, 2010-2019.

86% reduction in crash costs per annum [22].

5 Conclusions & recommendations

This report shows that the City of Palo Alto generally does well on road safety compared to neighboring communities. Walking and bicycling is safer in Palo Alto than in Santa Clara County as a whole. Traveling by motor vehicle is about as dangerous as in Santa Clara County. However, considering that 60% of middle and high school PAUSD students walk and bike to school every day [10], and that the City of Palo Alto is in the top 5 nation-wide of cities with the most bicycle commuters for cities with a population over 60.000 [36], it is surprising that the City does not have a road safety policy in place to protect these vulnerable road users. To improve road safety, the City of Palo Alto should adopt a Safe System Road Safety policy and set an ambitious, 2030, timeline to pursue zero traffic fatalities and severe injuries on Palo Alto streets, including El Camino Real. This would significantly improve the road safety for the thousands of students walking and riding to school every day. In addition, these measures serve community members of all ages and abilities who walk and bike for recreation, transportation, and to maintain fitness, and will help the City to achieve its climate and sustainability goals.

Too often the traditional approach to road safety does not fully consider the human tendency to make mistakes. The overarching principle behind a safe system approach is the acknowledgement that:

> **As humans, we are vulnerable to injury and make mistakes. However, mistakes should not lead to serious injury or death.** [35]

Instead of waiting for tragic mistakes to happen, we need to more proactively apply known safety principles in our routine maintenance of existing roads and in our planning for new projects [31]. These principles include:

Mono-Functionality: Crashes are more likely to occur on Residential Arterial and Arterial streets that serve both a traffic flow function and an exchange function, where "flow" means that traffic participation does not involve interaction with the environment, and "exchange" indicates interaction with the environment (e.g. parking, driveways, and crossings). Examples in Palo Alto include El Camino Real, Middlefield, Alma, and University Avenue between El Camino and Middlefield. Ideally, these types of streets should serve either a traffic flow or exchange function, but not both [22]. Currently, this sort of function prioritization is seen on local streets as embodied in Policies T-4.2 and T-4.3 of the Comprehensive Plan [9]. However, with the notable exception of Policy T-4.4, there is no equivalent policy to improve the road safety of arterials. In practice, such a policy would involve eliminating street parking, driveways, and unprotected left turns whenever possible, and building (protected) bike lanes. Where it is impossible to prioritize one function over the other, an alternative would be to designate space for a service road so that the main road can continue to provide a traffic flow function while the new low speed service road provides the exchange function and allows for safe access to adjacent properties (e.g. the existing service road on Alma near Meadow Drive, Oregon Avenue, and San Antonio Avenue). Additionally, a street like University Avenue between El Camino and Middlefield should be reclassified as a local street where the exchange function is prioritized over the flow function. For local streets the City should consider revoking Policy T-4.1. As can be appreciated on the Bryant Street Bicycle Boulevard, creating a barrier for motorized traffic which is permeable for pedestrians and bicyclists is demonstrably one of the most cost effective ways of eliminating through traffic on a local street.

Homogeneity of Mass, Speed, and Direction: In a crash, risk is significantly reduced if the participants have a similar direction, mass, and speed. For example, roundabouts are safer than normal intersections. At any vehicle speed over 20mph the risk of death for pedestrians and bicyclists in a crash starts to increase exponentially. This suggests that raised crosswalks and continuous sidewalks can significantly improve the safety of pedestrians. On thoroughfares with lots of traffic and speeding drivers, bicyclists and pedestrians should have their own (protected) infrastructure. In addition, we ask that the City work to identify all streets in Palo Alto where the speed limit can be reduced pursuant to the recently passed AB43 to enhance bicycle and pedestrian safety.

Self-explaining road: A self-explaining road is a traffic environment which elicits safe behavior simply by its design. For example, a driver may intuitively drive slower and more cautiously if the lane is narrower, or if there are other traffic calming measures in place (e.g. limiting forward visibility or increasing surface roughness). The self-explaining road also makes it easier for users to know where to walk, ride, drive, and park. Examples include: using green paint to identify bicycle infrastructure, paving parking lanes with a different material than the driving lane, and installing bulb outs at intersections to prevent drivers from parking too close to the intersection and thus limiting visibility.

In furtherance of the City's Road Safety Goal (Goal T-6 of the Comprehensive Plan) [9], the City should consider adopting the following additional measures:

Safe System Assessment The City should develop an assessment matrix that will be used to objectively evaluate how well repaving and new infrastructure projects meet the above Safe System principles [38, 15].

Post-Crash Engineering Investigation Currently after a severe or fatal crash the City completes a police report and engineers come out to evaluate whether the road is up to code. We ask that the City conduct a more comprehensive evaluation to determine, beyond mere code compliance, what additional steps can be taken to make the road in question safer and to avoid future crashes. This investigation should be made available to the public [34].

Prioritize High Frequency Collision Corridors The 2012 Bicycle and Pedestrian Transportation Plan identified 14 high frequency bicycle and pedestrian collision locations [1]. As of this writing, only the locations Embarcadero Road/Middlefield Road and Foothill Expressway/Arastradero Road have seen some safety improvements completed. Work is ongoing, planned, or on hold along the Charleston/Arastradero corridor, Page Mill Road, Alma Street/Churchill Avenue, and El Camino Real/Embarcadero Road. This means that 7 out of 14 of these locations have not received any attention in the past decade. We ask that the City more expeditiously address these remaining and similar locations.

Pursue the goals of zero severe injuries and roadway fatalities Palo Alto's Comprehensive Plan already contains policy T-6.2 "Pursue the goal of zero severe injuries and roadway fatalities on Palo Alto city streets.", but it has not identified a particular target date to achieve this goal. We believe that this work requires more urgency and that we need to set and meet a specific date for achieving zero fatalities and severe injuries on Palo Alto city streets, including El Camino Real. This exercise has been done in other neighboring communities, including:

- Mountain View: eliminate fatal traffic collisions in Mountain View by 2030
- Redwood City: eliminating traffic fatalities and serious injuries for all modes by 2030.
- Sunnyvale: 50% reduction of fatalities and serious injuries by 2029
- South San Francisco: zero traffic deaths and severe injuries on city streets by 2025
- Fremont: getting to zero by 2025
- Berkeley: reach zero severe and fatal traffic crashes by the year 2028

Periodic policy updates The Safe System Road Safety Policy should be updated every 5 years to evaluate the performance of the policy and to make sure the safety principles are up to date.

The City has made great strides so far, but there is still so much to do in support of safety for increasing numbers of bicyclists and pedestrians, and even drivers. The Federal Highway Administration recently adopted its own Safe System program and the recent Infrastructure Investment and

Jobs Act allocated $5B for a "Safe Streets for All" program. The City of Palo Alto should take advantage of these funds and should provide a safe transportation network for people of all ages and abilities who walk, bike, ride transit and drive, including our youngest, most vulnerable commuters on their way to school.

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