Traffic risks by travel mode in the metropolitan regions of Stockholm and San Francisco: a comparison of safety indicators

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ABSTRACT

According to commonly used measures of traffic safety, Sweden has one of the safest road transportation systems in the world, whereas the USA has relatively poor road safety performance. Although national comparisons are useful, they are problematical because they generalise across a diverse mix of travel environments (eg, urban and rural). This study used an array of traffic death rates to determine whether comparable urban regions in Sweden and California—Stockholm and San Francisco—have similar road safety performance for various types of road users. The study found that the Stockholm region is far safer than the San Francisco Bay area for pedestrians and bicyclists, even when comparing the regions' core cities, but may not be any safer for motor vehicle occupants. In addition, comparing traffic safety with traditional measures of exposure such as population and motor vehicle travel produced different results than measures that account for mode-specific exposure.

By most measures, the USA underperforms on road safety compared with other countries with advanced economies. Crash and injury data aggregated to the national level typically provide the basis for such comparative analyses.[1–5] For example, in 2002, the traffic death rate in the USA was 14.9 deaths per 100 000 population, whereas Sweden's rate was only 5.8. The safety disparity between the two countries decreases, but does not disappear, when using auto-kilometres travelled as the measure of exposure. According to this other metric, the traffic death rate in the USA in 2002 was 9.4 deaths per billion auto-kilometres of travel and Sweden's rate was 7.9.[6]

Although national-level analyses are useful, the safety narrative can change when comparing smaller geographical units.[7 8] The safety performance of individual US states, for example, varies widely. Based on traffic fatalities per 100 000 population in 2002, Massachusetts was almost as safe as Sweden, with a traffic death rate of 7.1, and both entities were nearly twice as safe as California (11.7) and nearly three times safer than Texas (17.6). Again, the pattern looks different when using fatalities per billion auto-kilometres travelled. According to this other measure, Massachusetts (5.4) is safer than Sweden (7.9) and California (7.9), whereas Texas remains less safe than the other entities (10.8).[6 9 10]

Furthermore, national and state comparisons obscure differences between urban and rural areas.[11] Slower average speeds in urban areas (due to laws, settlement patterns and the built environment) result in lower traffic death rates compared with rural and suburban areas.[4 12] Urban areas also have higher active travel mode shares (eg, walking, bicycling), as well as higher public transit mode shares, which would influence the relative risk (RR) of urban areas compared with rural areas. This implies that comparative road safety analyses, particularly those that include urban regions, are problematical when they do not account for differences in exposure across travel modes.

Constructing death rates with population as the measure of exposure assumes that each member of the population experiences the same travel hazards. Vehicles and vehicular mobility measures of exposure represent motorised travel conditions, but not the risk landscape for people travelling by active modes of transportation. Moreover, traffic death and injury rates based on vehicle travel measures of exposure imply that the transportation and land use system grows safer as travel increases, even though vehicle travel is the source of the hazard and reducing vehicle traffic would prevent deaths and injuries.[13]

Studies using mode-specific metrics have found that traffic risks to pedestrians and bicyclists have been understated in previous research.[14 15] However, these studies examined safety at the national level and did not account for specific urban landscapes, which might mitigate risks for pedestrians and bicyclists because of slower speeds and higher quality pedestrian and bicycle infrastructure.

In this research, the author has addressed this gap in knowledge and investigated whether urban areas in the USA are as safe as urban areas in other (presumably safer) countries. Research findings are presented based on the question: Are cities in the Stockholm region in Sweden safer than the cities in the San Francisco Bay area in California for various road users? Moreover, does the story change when considering different measures of exposure?

METHODS

The San Francisco Bay area and the Stockholm region were selected for comparison because both are large metropolitan areas known for the quality of their urban environments and progressive thinking about transportation safety. In addition, both regions are relatively affluent, highly motorised with good public transit systems and high rates of walking and bicycling[16 17] (see table 1). Both regions have diverse risk landscapes, each with their own versions of compact central business districts, older streetcar suburbs and newer

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Table 1 Travel mode shares by county and region

County/region	Private auto	Transit	Walk	Bike
Stockholm County	0.42	0.26	0.27	0.05
Uppsala County	0.49	0.13	0.26	0.13
Örebro County	0.57	0.06	0.24	0.13
Västmanland County	0.58	0.06	0.23	0.14
Södermanland County	0.59	0.07	0.26	0.09
Stockholm region	0.47	0.19	0.26	0.08
San Francisco County	0.53	0.20	0.23	0.02
Alameda County	0.77	0.08	0.12	0.02
San Mateo County	0.83	0.05	0.08	0.02
Marin County	0.84	0.04	0.09	0.02
Napa County	0.85	0.01	0.10	0.01
Santa Clara County	0.86	0.02	0.08	0.01
Contra Costa County	0.87	0.05	0.07	0.01
Solano County	0.87	0.02	0.08	0.01
Sonoma County	0.90	0.01	0.06	0.01
San Francisco Bay area	0.80	0.06	0.10	0.02

Stockholm region and counties shares for 2009; San Francisco Bay area and counties shares for 2000. San Francisco shares do not include 'other' modes and thus do not sum to one.

car-oriented subdivisions. It is thus possible that their urban landscapes produce similar road safety outcomes despite the broader safety differences between Sweden and the USA. This is particularly probable when comparing San Francisco County and Stockholm County because travel patterns in these two urban cores are most similar compared with their larger regions. However, a regional approach is also important, because both regional and local contexts produce travel and its associated risks.

For the analysis, the Stockholm region was defined as the Stockholm–Mälar region, which comprises the five counties of Stockholm, Uppsala, Södermanland, Örebro and Västmanland. This regional definition is based on a European administrative unit established in 1995. The San Francisco Bay area has nine counties: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano and Sonoma. Swedish counties and Californian counties are comparable administrative units.

The study used five different measures to assess traffic risk in the two regions and counties within them: (1) traffic deaths by mode per 100 000 population; (2) age-adjusted rate of traffic deaths by mode using the European standard population; (3) traffic deaths by mode per vehicle-kilometres of travel; (4) traffic deaths by mode per person-minutes of travel (by mode); and (5) traffic deaths by mode by per person-minutes of travel (by mode) adjusted for pedestrian access to transit.

There are limitations and uncertainties within this palette of indicators, the main being that none of these measures fully describes travellers' true exposure to hazards in the transportation system. Each metric also has strengths. For example, metrics using population measures of exposure are useful for comparing the incidence of traffic injury and death with other causes of morbidity and mortality. Metrics using vehicle-kilometres of travel as a measure of exposure are advantageous because they reflect the fact that fast-moving motor vehicles are the main source of hazard in the transportation and land use system. Nevertheless, these metrics do not work well for comparing the risk of travel across modes, and they obscure some of the mechanisms that cause traffic fatalities and injuries. Therefore, measuring travel risk by person-minutes of travel by mode is a better metric for comparing road safety across regions and modes because it illuminates some of the heterogeneity of the transportation risk.

This study used both aggregated and disaggregated traffic death records. Local police departments collect traffic crash and injury records for California, which are maintained in the California Statewide Integrated Traffic Records System (SWITRS) database by the California Highway Patrol.[18] Similar disaggregated data are available for Sweden in the database, Swedish Traffic Accident Data Acquisition (STRADA). STRADA compiles both police-reported and hospital-reported injuries as well as crashes. These data are currently maintained by the Swedish Transport Agency (Transportstyrelsen), and were previously maintained by the Swedish Road Administration (Vägverket).[19] For this analysis, only the police-reported data from STRADA are used. Police-reported road safety data in Sweden and California are essentially the same.

The analysis focuses on fatalities only instead of fatalities and injuries in order to maintain comparability across the two cases. Considering injury is important, but in a comparative analysis based on police data it is not possible to know how differences in police coding of injury would bias the results.

This analysis uses population and two kinds of travel data to account for exposure. The two kinds of travel data are vehicle-kilometres of travel in each region, and person-minutes of travel by mode. Vehicle-kilometres of travel data for counties in the San Francisco Bay area are from model estimates by the Metropolitan Transportation Commission. These model data are for 1998, 2000 and 2007.[20] California Department of Transportation annual highway travel data were used for San Francisco Bay area counties to scale the model data for other years.[21] The vehicle-kilometres of travel data for the Stockholm region are reported by the Statens Institut för Kommunikationsanalys (SIKA) and are based on annual inspections of vehicles, reported by county.[22]

The second kind of travel data, person-minutes of travel by mode, are from travel diary surveys. In Sweden, a consortium of transportation agencies conducts annual national travel surveys at the household level to collect information about the trips made by people between the ages of 6 and 84 years.[23] The Metropolitan Transportation Commission conducts a similar, although less frequent, survey in the San Francisco Bay area, from which one can construct similar measures of exposure.[16] To maintain the comparability between data for California and Sweden, this analysis does not analyse transit users or motorcyclists separately, and these categories of travel are included in the category 'motor vehicle occupants'. It is important to know the risks for transit users and travellers using two-wheeled vehicles, therefore future research should aim to disaggregate these modes.

Travel diary data sources are valuable because they provide information about travel times and distances for multiple modes, yet they generally undercount pedestrian trips because people forget to include them as they list their daily travel, and because walk trips are not as easy to define as motor vehicle trips (eg, they may be combined with transit, or motor vehicle trip chains, and they may begin and end in the same area).[24] Moreover, walking to take public transit is considered a transit trip, not a walk trip. This problem of undercounting pedestrian trips, and overstating pedestrian traffic risk, would be present in both the Swedish and San Francisco Bay area surveys. This measurement problem may not have a strong effect when comparing places where transit has a small mode share, but transit mode shares in San Francisco and Stockholm counties are substantial.[25] [26] To adjust for this, the amount of pedestrian travel was increased by adding two pedestrian trips, each 5 min in length, for each transit trip to account for access to transit. This adjustment assumes that people walk approximately 5 km/h (3 miles/h), and that the typical journey to a transit stop

Table 2 Traffic death rates and RR for the San Francisco Bay area (1995–2008) and Stockholm region (1999–2007)

Type of deceased	Region	Traffic death rate: 100 000 Population	RR	1 Billion vehicle-kilometres of travel	RR	1 Billion person-minutes of travel (by mode, adjusted)	RR
All travellers	San Francisco Bay area	8.1		7.5		1.9	
	Stockholm region	5.5	*1.5*	7.1	*1.1*	1.7	*1.1*
Motor vehicle occupants	San Francisco Bay area	6.2		5.6		1.7	
	Stockholm region	4.4	*1.4*	5.7	*1.0*	2.8	*0.6*
Pedestrians	San Francisco Bay area	1.5		1.6		4.9	
	Stockholm region	0.7	*2.1*	0.9	*1.8*	1.2	*4.1*
Bicyclists	San Francisco Bay area	0.3		0.3		5.5	
	Stockholm region	0.4	*0.8*	0.5	*0.6*	3.2	*1.7*

Motor vehicle fatalities include private automobiles, light and heavy trucks, motorcycles, mopeds and buses. Travel adjustment reflects increasing person-minutes of walking to include 10 min of walking for each transit trip.

is approximately 400 m (0.25 miles) from one's origin or destination.[27] This assumption probably overestimates pedestrian exposure to hazards and is thus conservative for comparing risks across modes.

RESULTS

According to commonly used safety indicators with population and vehicle-kilometres of travel representing exposure, the risk of traffic death for all travellers in San Francisco Bay area is approximately 10–50% higher than in the Stockholm region[16 18 21–23] (see table 2). As expected, the indicator using vehicle-kilometres of travel as the measure of exposure shows smaller safety disparities between the two regions than the population-based measure because people in the San Francisco Bay area make more automobile trips per capita. Introducing the age-adjusted measure of traffic death rates also reduces the disparities across the two regions somewhat, but does not change the overall pattern (not shown in table).

In addition, according to the population and vehicle travel-based metrics, the RR across modes within regions shows that pedestrians and bicyclists are safe compared with motor vehicle occupants, who have the highest risk.

However, the narrative changes when looking at traffic death rates with exposure represented with person-minutes of travel by mode. According to this indicator, the overall traffic risk in the San Francisco Bay area is similar to that of the Stockholm region—approximately 10% higher—yet in contrast to the other indicators the death risk to motor vehicle occupants is actually lower in the San Francisco Bay area than in the Stockholm region (RR 0.6). The largest disparity is that the death risk to pedestrians is approximately four times higher in the San Francisco Bay area than in the Stockholm region (the results are similar for the transit-adjusted and unadjusted measures of exposure, and table 2 presents only the adjusted figures). Accounting for person-minutes of bicycling in each region indicates that the San Francisco Bay area has a higher risk for bicyclists than is indicated by the traditional measures. Furthermore, these alternative metrics reveal that in the San Francisco Bay area walking and cycling are relatively dangerous modes compared with automobile travel, whereas walking is actually the safest mode of travel in the Stockholm region, where bicycling is the least safe mode of travel.

Table 3 presents the figures for only the core, and most comparable, counties in each region: San Francisco County and Stockholm County.[16 18 19 21–23] When exposure is measured as population or person-minutes of travel by mode, traffic death rates are generally lower in the core counties compared with the regions as a whole, which one would expect because of slower speeds, different infrastructure and different vehicle mix. The exception is that the death rates per billion vehicle-kilometres travel in San Francisco County are higher than those of the region as a whole (total vehicle-kilometres of travel in San Francisco County are half the regional average). Again, the main differences between the two regions are that pedestrian risk in San Francisco County is 3.6 times higher than in Stockholm County, and that the risk to motor vehicle occupants is lower in San Francisco County than in Stockholm County.

DISCUSSION

This analysis illustrates how traditional measures of traffic risk using population and vehicular mobility to represent exposure tell a different story than that based on mode-specific representations of exposure. Including the indicator based on person-minutes of travel by mode strengthens the evidence that the Stockholm and San Francisco regions have similar traffic risks overall, but with different traffic risks across the modes. The mode-specific measure of exposure shows that motor vehicle occupants in the San Francisco Bay area face a relatively lower

Table 3 Traffic death rates and RR for San Francisco County (1995–2008) and Stockholm County (1999–2007)

Type of deceased	Region	Traffic death rate: 100 000 Population	RR	1 Billion vehicle-kilometres of travel	RR	1 Billion person-minutes of travel (by mode, adjusted)	RR
All travellers	San Francisco county	6.1		10.6		1.4	
	Stockholm county	2.9	*2.1*	4.0	*2.7*	1.2	*1.2*
Motor vehicle occupants	San Francisco county	2.7		4.7		1.3	
	Stockholm county	2.1	*1.3*	2.9	*1.6*	2.1	*0.6*
Pedestrians	San Francisco county	3.1		5.4		3.6	
	Stockholm county	0.6	*5.2*	0.8	*6.8*	1.0	*3.6*
Bicyclists	San Francisco county	0.3		0.5		3.8	
	Stockholm county	0.2	*1.5*	0.3	*1.7*	3.6	*1.1*

Motor vehicle fatalities include private automobiles, light and heavy trucks, motorcycles, mopeds and buses. Travel adjustment reflects increasing person-minutes of walking to include 10 min of walking for each transit trip.

What is already known on this subject

The USA underperforms on road safety compared to many countries, but cities in the USA may have similar safety performance compared with cities in other countries.

What this study adds

- This study investigated the relative safety of the San Francisco and Stockholm regions using multiple indicators of road safety risk.
- Pedestrians and bicyclists are safer in Stockholm than in San Francisco, but motorists face similar risk across the two regions.

risk compared with the Stockholm region, whereas pedestrians in the San Francisco region face far greater risks.

Within the regions, walking is the safest mode in Stockholm, whereas it is the least safe mode in the San Francisco region. This is consistent with other findings in the literature, but here the finding is stronger because of the adjustment for pedestrian transit access trips and the comparability of the metropolitan regions.[14 15]

The strengths of this study are that it compared safety across regions using indicators that reveal the heterogeneous risk of regions and different modes of travel. The study was limited to only two regions, and future research should extend the analysis to include a larger set of regions. Despite its limitations, the study's findings highlight the need for transportation and land use systems that protect people both inside and outside of motor vehicles.

With respect to infrastructure, most cities in the two regions have high quality automobile infrastructure with complete sidewalk networks, and they make ample use of traffic control devices and marked crosswalks. The main differences between the regions probably appear in three areas: traffic calming, the physical separation of travel modes and the physical separation of travel and activity spaces. The Stockholm region relies more on traffic-calming measures to facilitate pedestrian and bicycle access and to protect travellers by lowering travel speeds, which is critical. In addition, pedestrian and bicycle infrastructure in the Stockholm region is more likely to be physically separated from motorised travel lanes. Finally, high-speed arterial streets in the Stockholm region are less likely to be the location of major activity centres such as schools and shopping districts. Separating activity spaces from travel spaces decreases pedestrian and bicycle exposure to hazards. Overall, Swedish safety planning emphasises reducing exposure as well as reducing hazards. This implies that safety improvements need to address all modes of travel, not only pedestrian and bicycle infrastructure, and it needs to encompass land use and urban design.

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