Title:
An Intensive Pedestrian Safety Engineering Study Using Computerized Crash Analysis

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Publication Date:
05-01-2003

Series:
Research Reports

Permalink:
http://escholarship.org/uc/item/871767fh

Additional Info:
Presented at the Institute of Transportation Engineers Annual Meeting and Exhibit Program, August 24-27, 2003, Seattle, WA.

Keywords:
pedestrian injuries, pedestrian safety, pedestrian fatalities, crash analysis, PBCAT, ITS countermeasures, safeTREC

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*FWHA Cooperative Agreement DTFH61-02-X-00017. We acknowledge the extensive assistance of Leverson Boodlal (Technical Manager) and Tamara Redmon (AOTR – FHWA).

INTRODUCTION

Vehicle collisions in San Francisco that involve injuries to pedestrians have created a serious public safety problem. Pedestrian-injury collisions have ranged from 600 to 1,000 per year over several decades, with recent injury collisions running about 800 per year.

Public resources for the protection of pedestrian safety are limited and must be used as efficiently as possible. The Federal Highway Administration (FHWA) funded the San Francisco Department of Parking and Traffic (DPT) to conduct a pedestrian safety project that optimizes use of resources through GIS mapping, advanced methods of crash analysis, and the selection of appropriate and efficient countermeasures. Phase I of the project includes (i) identification of high injury density zones, (ii) collection of data on vehicle and pedestrian patterns and conduct of an environmental audit, (iii) analysis of crash patterns, and (iv) selection of effective countermeasures appropriate for identified problems. Phase II of the project, which is contingent upon successful completion of Phase I and obtaining additional competitive funding, includes implementation and evaluation of countermeasures. This report summarizes Phase I activities and describes plans for Phase II.

San Francisco provides a very useful site for this project, especially when added to the companion studies in Miami and Las Vegas that were also funded by FHWA. First, San Francisco is arguably the leading major Western US city in its dependence on walking and public transit as commuting and utility transportation modes. Second, the city has an extremely challenging physical and social environment. The hills, odd-angled intersections, and on-street transit-boarding islands present safety challenges, and providing outreach to such a large number of visitors and residents who speak different languages is a serious challenge. Third, San Francisco is already actively testing new types of devices, which offers unusual opportunities for depth and breadth of data collection. For example, some 500 intersections are expected to be equipped with pedestrian countdown signals by late 2003 or early 2004. The number of signals is large enough to more easily detect meaningful impacts that might otherwise be obscured by either the novelty factor or small sample sizes. Finally, San Francisco has demonstrated a strong institutional commitment to pedestrian safety through such measures as hiring of a fulltime Pedestrian Program Manager, establishing an interdepartmental committee, and most recently, setting up a Citizens’ Advisory Committee on Pedestrian Safety to the Board of Supervisors.

PROBLEM IDENTIFICATION

Two types of data were used to provide a comprehensive picture of the pedestrian-injury problem in San Francisco. Data from police crash reports[3] (SWITRS, Statewide Integrated Traffic Records System, California Highway Patrol collision reporting system) were used to provide a historic picture of collisions that involved pedestrian injury, including a detailed analysis covering a five-year period (July 1996-June 2001). Since statistics from police crash reports are known to underestimate pedestrian-injury collisions, data from the trauma center at San Francisco General Hospital (SFGH) were also used to estimate the degree to which pedestrian-injury collisions from police reports might be underreported.

In number of pedestrian crashes per capita (i.e., per resident), San Francisco ranks high among US cities, ranking fourth among US cities over 500,000 for highest pedestrian fatality rates[4] (per 100,000 population) (Table 1). San Francisco has a higher pedestrian fatality rate than California cities such as Los Angeles or San Diego[5] (per 100,000 population). However, such comparisons do not take into account the relatively high amount of pedestrian movement in San Francisco and the high daytime employment base, which increases potential pedestrian exposure to injury. For example, the Surface Transportation Policy Report notes that when the estimated amount of walking is taken into account, San Francisco actually ranks only 51st on a "pedestrian danger index." among cities over 100,000 population in California.[6] San Francisco ranks better (i.e., lower danger) than California cities such as San Jose, Los Angeles, Oakland, and Fremont on this index. In contrast to the recent statewide trend, both pedestrian injuries and fatalities dropped in San Francisco between 2000 and 2001.

Table 1. Pedestrian Fatality Rates from all Crashes by City (for Cities over 500,000).
NCSA, NHTSA, FARS 1998-2000, US Census Bureau

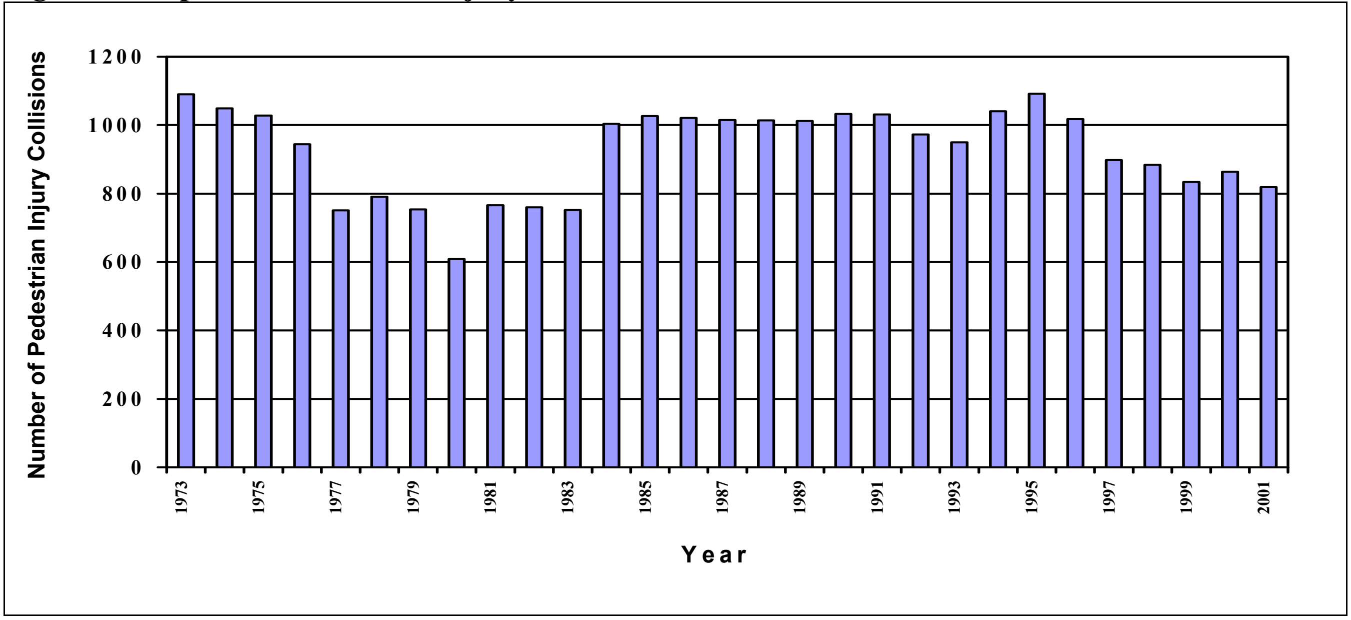
		Average fatalities 1998-2000			Fatality rate per 100,000 population	
Rank	City	Total for all crashes	Total for Pedestrian Injuries	2000 population	Rate from all crashes	Rate from Pedestrian Injuries
1	Detroit, MI	158	48	951,270	16.64	5.05
2	Denver, CO	61	23	554,636	11.06	4.21
3	Phoenix, AZ	187	51	1,321,045	14.18	3.89
4	**San Francisco, CA**	**52**	**30**	**776,733**	**6.65**	**3.82**
5	Dallas, TX	169	42	1,188,580	14.22	3.51

Along with other cities, San Francisco has experienced a significant pedestrian-injury collision problem for many decades (Figure 1). Over the past three decades, the reported number of pedestrian-injury collisions has fluctuated from about 600 in 1980 to over 1,000 for the early 1970s and for most years from 1984 to 1996. Despite recent declines to about 800 per year, these high levels of injury decade after decade constitute a serious public safety problem.

The level of pedestrian-injury collisions reported for 2001 and 2002 are the lowest in almost 20 years. (The dramatically lower levels reported in years 1977 through 1983 may reflect reporting changes or reduced driving due to an oil embargo and a recession). The recent drop in pedestrian-injury collisions parallels a decline in overall traffic injuries and fatalities in San Francisco over the last several years. One likely factor may be the reduction in vehicle miles and employment and visitor levels due to the economic downturn.

There may also be other factors contributing to this drop in pedestrian-injury collisions, such as traffic signal upgrades (particularly mast arms), vehicle improvements (e.g., safer brakes), media attention to traffic and pedestrian safety, and the introduction of an extensive anti-red-light-running project (including cameras at 18 intersections, warning signs, and media campaigns). Intersections equipped with red-light cameras or signal mast arms have experienced substantial reductions in collisions by as much as one half. Although red light violations appear to be a relatively minor component of pedestrian-injury collisions (estimated from three to four percent of all pedestrian collisions), there may be major indirect impacts of the red-light cameras and signal-visibility improvements in promoting a generally more cautious attitude among drivers.

Figure 1. Reported Pedestrian-Injury Collisions, San Francisco, 1973-2001



Source: SFPD reported crashes from the Statewide Integrated Traffic Records System (SWITRS), California Highway Patrol data system, 1973-2001.

Detailed analyses were conducted for various crash characteristics for the five-year period from July 1996 through June 2001. Over half (58 percent) of the primary collision factors (PCF, PCF is a category developed by the California Highway Patrol and are more detailed for driver violations) were attributed to drivers, and most of these were driver violations of pedestrian right-of-way. About 41 percent of PCFs were pedestrian factors. California Vehicle Code (CVC) violations are somewhat more revealing (see Table 2)

Of the top five most significant violations, two were driver violations—"Failure to yield to pedestrians within crosswalks" (35 percent) and "Unsafe speed" (seven percent). The remaining three were pedestrian violations: "Pedestrian failed to yield (midblock, not jaywalking)" (13 percent), "Jaywalking between signal controlled intersections" (about 9 percent), and "Pedestrian running in front of vehicle" (7 percent).

Table 2. Most Common California Vehicle Code (CVC) Violations Attributed to Pedestrian-Injury Crashes, 1997-2001

CVC Violation	Percent of all CVC violations that were Driver responsible	Percent of all CVC violations that were Pedestrian responsible
Driver failed to yield to pedestrians in the crosswalk	34.8	
(Driver making left at signalized intersection failed to yield to pedestrian in crosswalk)	(15.8)	
Pedestrian failed to yield (midblock, not jaywalking)		12.8
Jaywalking between signalized intersections		8.9
Unsafe speed	6.8	
Pedestrian running in crosswalk in front of vehicle		6.8
Red light running	3.0*	
Other violations	13.4	12.4
Subtotal	**58.0**	**40.9**
Unknown or Neither primarily at fault	1.1	

*estimated

Driver violation of pedestrian right-of-way typically involves a turning vehicle hitting a pedestrian, with both reporting (in the police report) that they had the green light. This disproportionately involves left turns and signalized intersections. For a random sample of 50 crashes involving this PCF in the study zones, 58 percent of vehicles were turning left, 22 percent were going straight, and 14 percent were turning right. Also, most (78 percent) were at signalized intersections, 16 percent were at other minor street-STOP locations, and only two percent each were at all-way stop-controlled intersections and uncontrolled locations. For all crashes overall, drivers proceeding straight were responsible for a majority of the crashes (58 percent), compared to those making a left turn (19 percent) and making a right turn (9 percent). Compared to most other western US cities, San Francisco has a lower proportion of intersections with protected left turn phasing. Also, the proportion of pedestrian collisions involving a left turn in San Francisco appears greater than has been indicated in previous studies. One such study found that only 4.6 percent of pedestrian crashes involved a left turn (and that this was less than the observed proportion of left turns among all vehicles).[7]

The data above are based on police-reported incidents. Police records are well known to underestimate of the actual rate of pedestrian injury, and they typically do not include data on pedestrian or driver ethnicity. Data collected at SFGH was used to estimate the level of underreported injuries, to estimate underreporting by ethnicity, and to estimate pedestrian injury rates by ethnicity[8]. SFGH is the only trauma center in San Francisco, and it receives most hospitalized pedestrian injuries and most very serious cases transported by ambulance.

Using SWITRS (Statewide Integrated Traffic Records System) as the sole source of data for San Francisco, 1,909 pedestrian-injury collisions were reported during years 2000 and 2001. An additional 531 pedestrian-injury collisions, or 21.8 percent of a total of 2,440 pedestrian-injury collisions, were reported at SFGH. This means that there were *at least* 531 additional pedestrian-injury collisions in the city during those two years that were not included in the police data. Since the SFGH trauma center does not receive all pedestrian-injury collisions in the city, SWITRS likely underestimates pedestrian-injury collisions by *at least* 21.8 percent. It is likely that the injuries not included in the SWITRS record were generally less severe.

The SFGH data were used to create estimates of pedestrian injury rates by ethnicity (Table 2) using US Census data as the denominator. The rate of pedestrian injuries per 100,000 population was highest for Blacks, followed by Hispanics, Whites, and then Asians. Rates by ethnicity are estimates based on imperfect data since SFGH records do not reflect all citywide pedestrian injuries and since there may be differential use of SFGH by ethnicity due to its proximity to neighborhoods with higher populations of Hispanic and Black residents.

Table 3. Rates of Pedestrian Injuries at SFGH in 2000-2001 by Ethnicity

	Total SFGH		SF Population, 2000*		# per 100,000
Race	N	(%)	N	(%)	
White	484	(36.6%)	338,909	(43.6%)	71.4
Black	229	(17.3%)	58,791	(7.6%)	194.8
Hispanic	243	(18.4%)	109,504	(14.1%)	111.0
Asian	263	(19.9%)	241,775	(31.1%)	54.4
Other	21	(1.6%)	27,754	(3.6%)	37.8
Unknown	104	(7.9%)			
Total	1323	(100.0%)	776,733	(100.0%)	85.2

* US Census, 2000

ZONE ANALYSIS – IDENTIFICATION OF HIGH INJURY DENSITY ZONES

Zone Analysis is a systematic method that focuses on clusters of injury in concentrated geographic areas or zones. The objective is to address a large proportion of injury within relatively small zones. This method, developed and tested in an FHWA-funded project in Phoenix, is efficient in resource allocation and in reaching a significant portion of the target population[9]. In addition, substantial indirect impacts are expected as a result of concentrating highly visible improvements in one area, such as, increasing pedestrian and driver safety awareness overall. We applied the zone analysis method to San Francisco to identify areas that (i) have a high injury density and (ii) are homogeneous with respect to street types, vehicle types, pedestrian traffic, area (e.g., business, residential), and resources.

San Francisco is a relatively dense city, with 800,000 residents in 47 square miles, or 15,500 residents per square mile. (This is higher density compared to Las Vegas with about 3,100 residents per square mile or Miami with about 10,000 residents per square mile). Pedestrian-injury collisions in San Francisco tend to be highly concentrated in clusters. These clusters were examined to identify high injury density zones (i.e., street segments or areas). Zones were further analyzed to identify the most promising locations to improve pedestrian safety using cost-effective engineering improvements and outreach efforts. Utilizing the zone analysis method, the following steps were conducted as outlined in the Zone Guide for Pedestrian Safety[10].

Step 1. Select the crash problem.

Based on police collision data, 4,791 pedestrians were involved in collisions from July 1996 through June 2001, or an average of about 2.6 per day. Injury severity (based on available information) was concentrated among minor to moderate injuries. (See below.)

No Injury	72	(1.5%)
Complaint of pain	2,427	(50.7%)
Visible injury	1,711	(35.7%)
Severe injury	454	(9.5%)
Fatal injury	127	(2.7%)

These injuries occurred to men and women of all ages, and the distribution of injuries by age and gender was close to the city's general population. Hence, we decided to focus on injured pedestrians of all ages and for both men and women within. While we did not focus exclusively on particular demographic groups, we have considered different age and gender patterns in our focus on specific geographic areas.

Step 2. Map pedestrian crashes and develop candidate zones

Using GIS software[11], pedestrian-injury collisions were mapped by severity (see Appendix). The map shows that the collisions are highly concentrated in (i) the greater downtown area and (ii) along major arterials in the rest of the city. Therefore two types of candidate zones were identified for further analysis: *linear* (i.e., sections of single streets with clusters of collisions) and *area* zones (i.e., neighborhoods with clusters of collisions).

The process for selection of an initial set of "candidate" zones was developed and implemented by a working group of city and county staff who were highly knowledgeable about pedestrian safety, crash statistics, GIS, and traffic in San Francisco. The group included:

- The Pedestrian Program Manager of the Department of Parking and Transportation (DPT), a transportation planner who specializes in pedestrian safety;
- A Department of Public Health (DPH) epidemiologist, a manager of a traffic and medical data-linkages project;
- A DPH injury-control specialist with several years experience managing pedestrian safety outreach efforts;
- The Transportation Authority's GIS/transportation planner; and
- UC Berkeley's Director of the Traffic Safety Center, an epidemiologist specializing in transportation safety.

Through visual inspection of the mapped data, we identified 20 zones (9 *area* and 11 *linear* zones) that had high clusters of pedestrian-injury collisions. These zones were adjusted so that they were homogeneous with respect to factors that might affect pedestrian-injury collisions and the application of countermeasures. Specifically, each zone was required to be relatively homogeneous for (i) profile of pedestrian crashes (i.e., distribution by time of day, and ages of victims), (ii) traffic and road conditions, (iii) business/residential mix, and (iv) demographic and economic profiles of the surrounding population.

Step 3. Efficiency Ratios (Injury Density)

Efficiency Ratios (equivalent to an injury density) were calculated for each of the candidate zones. For *area* zones, the injury density of pedestrian-injury collisions per square mile was calculated by dividing the percentage of total injuries for an area by the percentage of total surface area of the city represented by the area. For *linear* zones, the injury density of pedestrian-injury collisions per roadway mile was calculated by dividing the percentage of total injuries represented by the segment by the percentage of the total street length represented by the segment (These calculations are such that the efficiency ration for the city as a whole is equal to 1. An efficiency ration greater than 1 indicates an injury density greater than the average). In both cases (area and linear), injuries were weighted by severity, with severe and fatal injuries assigned a score of three points and complaint of pain or visible injury assigned a score of one point.

The efficiency ratios for the 20 candidate areas ranged from a low of 1.7 to a high of 24.6, and the 20 areas accounted for about 48 percent of total pedestrian injury problem citywide. Nine *area* zones accounted for 31 percent of total pedestrian injury but only about six percent of the surface area of the city. Eleven *linear* zones account for almost 17 percent of pedestrian injury but only about two percent of the total street length of the city.

Step 4. Selection of final zones

Potential resources in this project were not sufficient to significantly address pedestrian collisions in all 20 zones. Therefore, the zones were reviewed and evaluated to choose a subset of zones optimal for this project. Several of the zones had potential overlap and even conflict with other pedestrian or traffic projects. In several other zones, major transportation projects (e.g., light rail) were underway that would change the nature of the area considerably. Finally, in several zones, major construction projects were underway that would make implementation and evaluation difficult.

We selected seven finalist study zones (three area and four linear zones) for inclusion in the *PedSafe* report. These zones had efficiency ratios ranging from 4.5 to 10.4 and accounted for nearly 19 percent of pedestrian injury in San Francisco, which is several times the contribution expected based solely on their size. Table 4 lists these zones, along with boundaries, their respective efficiency ratios, and percents of pedestrian injury.

Table 4. Seven final zones showing boundaries, percent of pedestrian-injury collisions represented, and efficiency ratios

Zone	Boundaries	Efficiency Ratio (Injury Density Ratio)	Percent of Pedestrian-Injury Collisions in the City
Area Zones			
Chinatown/North Beach	Kearney to Filbert, to Stockton, to Bay, to Columbus, to Mason, to Sacramento, to Kearney	5.6	4.1
SOMA (South of Market) West	4th, 10th, Mission, Harrison	6.2	5.7
North Mission	Guererro, 13th, 17th, Potrero, Division	4.5	3.7
Linear Zones			
Geary Richmond	Geary from Parker to 28th Avenue	9.9	1.8
Upper Market	Market from Van Ness to Castro	8.9	1.1
Outer Mission	Mission from I-280 to Geneva	7.5	0.9
Geary/Cathedral Hill	Geary from Van Ness to Baker	10.4	1.3
Total			**18.6**

The selected zones represent the demographic diversity of the city, with varying distributions of ethnicity. For example, the proportion of Asians varied from 11 to 58 percent by zone, compared to 31 percent citywide. The proportion of Hispanics or Latinos (of any race) was higher in the North Mission (41 percent) and Outer Mission zones (32 percent).

FOCUS ON INDIVIDUAL ZONES

The selection of the seven zones for the *PedSafe* project was based on (i) the concentration of pedestrian injuries per unit area, (ii) homogeneity, (iii) relative absence of other pedestrian safety projects, and (iv) relative absence of major transportation projects or construction. These criteria were intended to enhance the potential to make significant improvements in each study zone. (Other significant planning studies or projects underway in candidate zones would have complicated the assessment of impacts of the *PedSafe* countermeasures.)

The next major step was to collect and analyze detailed information relevant to each zone for the problem identification, countermeasure selection, and countermeasure implementation. For each zone, several types of data were examined: (i) collision data, (ii) environmental characteristics, and (iii) observed pedestrian and vehicle behavior. Collision data were analyzed by zone and for patterns citywide. Collision data from police collision reports provided information on the characteristics and severity of pedestrian collisions, vehicle and pedestrian movement, and interaction and characteristics of roadways and intersections.

Collision Data—Profiles

As stated above, a total of 4,791 collisions that resulted in pedestrian injury were recorded in police records from July 1996 through June 2001. The collision reports contain the following information:

- Pedestrian and driver characteristics (age, sex, alcohol impairment)
- Crash characteristics (primary collision factors, violations, preceding vehicle movement)
- Environmental characteristics (month, day of week, time of day, lighting, weather)

Generally, distribution of injured pedestrians by age and gender for San Francisco were similar to the city population in general; about 10 percent of injuries were among children under age 15, and about 13 percent were among adults ages 65 and older. While the age distribution of injured pedestrians in study zones was similar to the entire city, age varied significantly by zone. A detailed accounting of zone-level collision factors is beyond the scope of this report. However, generally, the zones showed very wide variation in most of the collisions characteristics, tending to justify the concept of identifying and developing tailored countermeasure plans for individual zones. Several collision characteristics showed especially wide variability across zones (Table 5).

Table 5. Collision characteristics – range within zones and city-wide

Collision Characteristic	Lowest	Highest	City-Wide
Pedestrians 65 and over	2.2	31.4	13.2
Pedestrians who were male	43.0	84.8	54.5
Pedestrians who were alcohol impaired	1.4	13.3	4.3
Primary collision factors (PCF) was pedestrian-related	16.5	47.8	40.9
Left turn as preceding vehicle movement	13.0	26.4	21.1

<u>Collision Data—PBCAT Analysis</u>

PBCAT[12] (Pedestrian and Bicycle Crash Analysis Tool) crash-typing software was used for an analysis of crash types that was conducted for 21 intersections within the seven zones (i.e., the three intersections with the highest number of crashes per zone). PBCAT is an analysis tool for information associated with crashes between motor vehicles and pedestrians or bicyclists[13] that can be ordered online at no cost[14]. Collision data can be put into the software by collision and the software can then create tables and graphs by selected variables. Additionally, its most unique feature is "typing" collisions by precipitating actions and factors that can be targeted for intervention[15]. Each crash type is linked to a set of possible causal factors, and each possible causal factor is linked to a set of potential countermeasures.

The process involves several steps. First, crash types are provided by following a menu-driven algorithm with which the user is led through a specific sequence of questions. Police-reported data from SWITRS, supplemented with hard copy reports, were used in this process. Using PBCAT, we "crash-typed" a total of 163 vehicle-pedestrian collisions in the 21 intersections. While fifteen crash types accounted for all collisions examined, just seven crash types accounted for 151 of the collisions (i.e., over 92 percent) (Table 6).

Table 6. PBCAT crash types for 21 selected intersections

	Crash Type Code	Total	Percentage
Motorist failed to yield	770	41	25.2
Left turn	723/724	36	22.1
Ped failed to yield	761/769	31	19.0
Turn-merge	729	18	11.0
Dash	741	12	7.4
Right turn	721/722	9	5.5
Off roadway	810	4	2.5
Other	-	12	7.4
Total		**163**	**100.0**

Second, each of several possible underlying causes associated with specific crash types is generated. For example, the crash type "Ped failed to yield" is associated with several possible underlying causes, including:

- Large number of pedestrians and/or left turn vehicles;
- Substantial number of school children crossing and large left-turn movement; and
- Inadequate sight distance and/or intersection geometrics.

Third, a list of potential countermeasures is provided for each crash type. For example, for crash type "Pedestrian failed to yield" and underlying cause "Large number of pedestrian and/or left turn vehicles," several of the listed countermeasures are:

- Prohibit left turns.
- Provide separate left-turn phase and WALK/DON'T WALK signals.
- Add special pedestrian signal phasing (e.g., exclusive protected pedestrian signal interval)
- Convert to one-way street network (if justified by surrounding area-wide pedestrian and traffic patterns)
- Install warning signs for pedestrians and/or motorists (see MUTCD).
- Develop/provide PSA safety messages.
- Add curb extensions.

We used PBCAT in this way to generate a general set of countermeasures for each of our study intersections (see section on Countermeasure Selection below), supplementing the PBCAT output with data from other sources.

PBCAT offers the advantage of an exhaustive crash-typing list that is tied to specific underlying factors and countermeasures. A systematic process leading from crash data to countermeasures is greatly needed, and PBCAT is an excellent first step. PBCAT is now undergoing evaluation and revision by staff at the University of North Carolina. One of the tasks specified by FWHA was to evaluate and make suggestions concerning possible improvements for PBCAT. Following are some observations about PBCAT.

The first output of PBCAT is a single "type" for each crash. The central concept of reducing a collision to a single "crash type" may be a limitation. For example, the three crash types that were most frequently identified for San Francisco study zones (i.e., motorist failed to yield, left turn, and pedestrian failed to yield by walking into the vehicle) mix elements of violation and non-compliance with vehicle movement. These single crash types do not address such critical factors as the time-of-day of crashes , which might suggest potential lighting improvements. The logic of crash typing seems to be to try to first classify a crash by its more unusual or highly specific factors (e.g., hit by ice cream truck). If the crash cannot be matched to more unusual patterns, it is tested against a series of increasingly more general crash types. If a single crash type is to be used, it should be based on the factor that is most amenable to correction.

An additional limitation may be that some of the crash types seem to have significant overlap (e.g., left turn vs. turn and merge, or the pedestrian failed to yield vs. intersection dash) in terms of underlying causal factors and countermeasures. The crash-typing step in PBCAT is time-consuming to use, especially when dealing with a large number of crashes, and programming could be utilized instead of a menu driven structure when dealing with large numbers of crashes.

The second outcome from PBCAT is the presumed causal factor. There should be guidance (e.g., recommendations for structured observations) that could be used to determine the most appropriate causal factor out of the set provided by PBCAT. The third output from PBCAT is a set of recommended countermeasures. Unfortunately, the list of countermeasures is dated and does not include some of the most recent innovations such as pedestrian countdown signals. Furthermore, PBCAT does not provide assistance in the difficult process of analysis to select the most appropriate countermeasures from an extensive list of candidates. However, this is being addressed by other FHWA research aimed at providing expert systems.

Finally, an overall strategy for using PBCAT should be developed. For example, guidance should be provided for how PBCAT should be used when there are large sets of crashes (e.g., what should one do when there are a wide variety of crashes at a site? Are there any statistics that should be used to identify relevant clusters of crash types?).

The San Francisco *PedSafe* team supplemented use of PBCAT with Crossroads™ and a statistical package[16]. Crossroads is specialized crash analysis software that can be integrated with ArcView[17] (GIS software). It allows quick queries and reports on several years of data, including rapid production of collision diagrams and GIS maps. It is relatively easy to identify locations meeting several different criteria (e.g., intersections with at least one crash annually after dark within 20 feet of an intersection). A statistical package has the advantage of allowing customized queries on large amounts of data with powerful data management tools and statistical modules. However, unlike PBCAT, Crossroads does not generate potential causal factors or countermeasure suggestions.

Field Observation to Observe Vehicle/Pedestrian Conflicts and Other Surrogate Measures

Due to the relative rarity of pedestrian injury collisions at individual intersections and the potential difficulty in identifying significant changes in injury rates within a year or so after treatment, we conducted field observations at the same 21 intersections used for the PBCAT analyses to gather information on "surrogate" measures for vehicle-pedestrian crashes (i.e., factors that correlate with pedestrian injury collisions). We spent about two person-hours at each of the 21 intersections to observe and document the following surrogate measures:

- Vehicle/pedestrian conflicts (a near miss, defined as a pedestrian changing stride or gait to avoid a collision, or a vehicle making an evasive maneuver or braking suddenly);
- Pedestrian running or aborting their crossing;
- Pedestrian compliance with pedestrian signals and crosswalk markings; and
- Driver compliance with traffic signals.

As with collisions factors across zones, pedestrian and vehicle actions varied widely (Tables 7 and 8) across intersections.

Table 7. Observed pedestrian action at 21 selected intersections (Percent of all pedestrians)

	All 21 Intersections	Minimum	Maximum
Start on flashing red hand (where ped signals available)	9.6	0.8	18.8
Start on red ball	5.2	0.0	19.4
End on red ball	9.1	3.1	24.3
Vehicle-pedestrian Conflicts	1.4	0.0	6.2
Run or abort	4.2	1.5	11.7
Out of cross walk	2.4	0.0	8.6

Table 8. Non-compliance and vehicle-pedestrian conflicts at 21 selected intersections (Percent of all vehicles observed)

Vehicle Action	Minimum	Maximum
Entering on red	0.0	6.1
Exiting on red	1.1	11.8
Non-compliance with signals	0.0	7.0
Vehicle/pedestrian conflicts	0.0	3.6

COUNTERMEASURE PLAN

There were two distinct steps in developing a countermeasure (countermeasure is a term used by the FHWA for treatments or interventions aimed at specific problem) plan for the seven study zones. The first step consists of identifying countermeasures and matching them with appropriate locations. The second step is developing a plan for funding and implementation.

Selecting Countermeasures

An extensive review of the literature was conducted on existing pedestrian-injury countermeasures. For the review, an initial list of countermeasures was developed based on sources, such as, the FHWA Pedestrian Users Guide and PBCAT, the FHWA Safety Synthesis, and the ITS/Nazir Lalani publication[18]. For each countermeasure, we identified and listed (i) a brief description; (ii) justification for its use, (iii) typical applications; (iv) crash types addressed; (v) presumed safety effectiveness, (vi) cost range; (vii) cost-effectiveness; and (viii) where used (i.e., in San Francisco or elsewhere).

The available literature provides an imperfect basis for selection of countermeasures. This is because a number of countermeasures have been developed recently, and adequate evaluation studies have not yet been conducted. Also, even for relatively established countermeasures, there are relatively few adequately controlled evaluation studies, and only very few studies evaluate pedestrian injury as an outcome. Most studies focus on behavior of pedestrians or drivers (i.e., on surrogate measures of vehicle-pedestrian crashes) rather than on pedestrian injury itself. Finally, the decision to employ a particular countermeasure at a specific location involves a complicated set of factors that may include, for example, the cost and effectiveness of the countermeasure, the physical characteristics of the target location, the type of crash problem, and the types of pedestrians involved.

The challenge is to narrow the long list of countermeasures to one or to a few that will be most suitable for a specific location. Constraints may include high cost, the need for public and policy-maker review, the need for experimental authorization, technical or physical requirements or barriers, and uncertainty about effectiveness. There is a great cost range for different countermeasures, with sidewalk-widening projects costing hundreds of thousands of dollars compared to sign installations that cost only a few hundred dollars. Traffic-calming measures require a significant outreach effort under formal guidelines adopted by the City of San Francisco, with neighborhood meetings and a final public hearing. Traffic control devices that regulate traffic require legislative approval. Devices that are not included in federal *Manual of Uniform Traffic Control Devices*[19] (MUTCD) or the state *Traffic Manual* should be approved as experiments, typically requiring a formal evaluation. Some ITS countermeasures, such as automated pedestrian detection by video, microwave, or infrared devices require sophisticated technical knowledge by city staff or a contractor. Some countermeasures may not be feasible due to competing needs (e.g., installation of curb bulbs to protect pedestrians vs. leaving curb structures as they are to accommodate trucks turning at narrow intersections or to accommodate the presence of bike lanes).

The selection process started with development of a short list of countermeasures deemed most suitable. All countermeasures were ranked on several criteria and given a plus or minus. A double-plus rating indicated highly favorable rating for inclusion, while a double-minus rating indicated highly unfavorable rating. The selection criteria included:

- Cost
- Presumed safety effectiveness
- Ease of implementation
- Appropriateness for study zone environment
- Potential impact on traffic mobility
- Potential impact on pedestrian/bicycle/transit mobility
- Visibility/outreach benefits
- Use by Miami or Las Vegas in counterpart studies
- Ability to attract needed funding not otherwise available
- Legal requirements and other considerations

Cost was considered as a separate category used to rank countermeasures within broad suitability categories.

Funding Levels

The data gathered in the problem-identification phase of the study demonstrated high levels of pedestrian injury across multiple intersections and street segments within each of the seven zones. Measurable benefits are expected from the current FHWA program and other ongoing efforts in these zones. Nevertheless, a substantially higher level of resources will eventually be required to fully address problems identified in each. We therefore view the FHWA program as one step in an ambitious long-range plan to fully address pedestrian injuries within these study zones. Accordingly, a three-level countermeasure plan has been developed.

The Level 1 Basic Funding Plan is set for the expected FHWA Phase II time frame and budget. The Level 2 Expanded Funding Plan assumes a higher level of funding based on aggressive and successful efforts by San Francisco to obtain additional funding. In addition, a framework for a Level 3 Financially Unconstrained Plan is described, but its implementation would require a major new funding source. Table 9 provides a summary of countermeasures proposed under Level 1 and Level 2 funding.

The **Level 1** ***basic funding plan*** concentrates on initial engineering improvements and outreach efforts that could be implemented within the time frame and budget specified in the FHWA program. This basic funding level assumes a budget of $700,000 (i.e., an average of $100,000 per study zone) with implementation between Fall 2003 and Winter 2005. This funding level would allow implementation of initial countermeasures that should, at the very least, yield detectable differences in surrogate measures of pedestrian-injury collisions.

The **Level 2** ***expanded funding plan*** assumes a budget of about $2.1 million beyond the basic funding, with a slightly longer time frame for completion of the work. The expanded-funding scenario reflects DPT staff estimates of the maximum funding likely to be obtained from existing funding sources. The Level 2 funding plan would require major grants from the State

Transportation Improvement Program (STIP) or other competitive programs. However, given the severe financial constraints facing the State of California and local governments, the chances of getting such awards are uncertain at this point, and funding delays as much as one to three years would be expected. This funding level will allow implementation of additional substantial countermeasures that should yield detectable differences in surrogate as well as actual measures of pedestrian injury.

Implementation of specific measures will depend on funding availability and further engineering and environmental analysis. While the concept plan has been approved by the engineering staff of DPT and the Board of Directors of its policy body, the Municipal Transportation Agency, the funding and regulatory situation is very dynamic.

Table 9. Traditional Engineering and ITS Countermeasures for Basic and Expanded Funding Plans

		Funding Plan	
		Level 1 Basic	Level 2 Expanded
General Engineering Countermeasures			
1.	ADA curb ramps and detectable warning strips*	X	X
2.	Advance limit lines and red curb program	X	
3.	Curb bulbs		X
4.	Distribution of retroreflective materials (patches, collars, etc.)	X	
5.	Impactable YIELD TO PEDESTRIAN signs	X	
6.	Median refuge island improvements	X	X
7.	Modify signal timing	X	
8.	Pavement stencils	X	
9.	Pedestrian head start	X	
10.	Pedestrian scramble	X	
11.	Vehicle left turn phase		X
ITS Countermeasures			
12.	Animated eyes signals	X	
13.	Automated detection of pedestrians to adjust signal timing		X
14.	Modern flashing beacon	X	
15.	Pedestrian countdown signals	X	X
16.	New pedestrian signal with countdown device		X
17.	Radar speed display signs	X	
18.	Roadway lighting improvements and Smart Lighting	X	X
19.	Signal improvements such as audible signals, signal visibility improvements, and left turn phases		X

*Not primarily a safety measure, but a response to city policy and accessibility concerns

The Level 3 financially unconstrained plan would require funding from new sources. It includes countermeasures that are recommended for further investigation. The plan will only be feasible if totally new substantial sources of funding can be found, since it will likely require over $10 million in additional funds. Potential funding sources include reauthorization of the Federal Transportation Funding Program, the Transportation Equity Act (TEA-21, likely by fall 2003) or reauthorization of the San Francisco local sales tax for transportation (a strong possibility for the November 2003 or Spring 2004 ballot).

The rationale for including specific countermeasures in the Level 1 and Level 2 plans is described below. It should also be noted that San Francisco has already been active in testing innovative devices, some of which were not proposed for specific testing in the *PedSafe* project per se. For example, there are four installations of in-pavement crosswalk lights in the city that are being evaluated outside the program. Due to uncertainty over future installations, no request is being made to FHWA for additional funding for these devices.

Specific Countermeasures

- ADA curb ramps – This is not primarily a safety measure, but a response to City accessibility concerns. Improvements are selected where construction would affect curb return and where the San Francisco Department of Public Works has rated existing ramps deficient. Besides safety benefits to wheelchair and stroller users, these improvements may tend to channel all pedestrians beneficially in the center of the crosswalk.

- Advance limit lines and red curb program – This measure was selected at locations with higher level of driver failure to yield to pedestrians in the crosswalk. Retting and Van Houten[20] found that use of advance limit lines and a red curb program was associated with an 18 percent improvement in drivers stopping outside or four feet before the crosswalk. By improving driver views of pedestrians and (at uncontrolled crosswalks) reducing the multiple threat problem, this measure is an effective and low cost change, and therefore appropriate for the Level 1 Basic Funding Plan. Parking removal and turn storage impacts are potential negative impacts.

  Recently, a motorcycle advocacy group, based in San Francisco, has argued for widespread replacing of regular corner on-street parking spaces with motorcycle stalls to improve visibility.

- Curb bulbs – Curb bulbs extend the sidewalk into a crosswalk area, typically at corners. The traffic-calming literature discusses benefits associated with curb bulbs that include making pedestrians more visible and less likely to be cut off by turning vehicles and giving pedestrians a shorter crossing distance. In addition, curb bulbs provide additional sidewalk space for queuing, street furniture, and ADA curb ramps. Because of their moderate cost, significant difficulty in implementing, and the potential for utility conflicts, curb bulbs are more appropriate for the larger budget Expanded Funding plan.

- Impactable YIELD signs – These were recommended at uncontrolled crosswalks with higher numbers of injuries where there is sufficient space in the median. They are more noticeable than roadside signs, and they may also exert a minor traffic-calming effect by effectively narrowing the inside lanes slightly. The City of Madison found that such signs increased drivers yielding to pedestrians by six to 15 percent.[21] Their low cost, ease of implementation, and San Francisco's experience with this countermeasure are all positive, although at some locations, they have been quickly damaged by drivers or vandals.

- Median refuge island improvements – These were recommended at intersections with a higher number of driver failed to yield crashes on left turns, wider crossings (where surrogate data indicate insufficient time to cross), and existing median islands that could be improved. Findings suggest that median islands may decrease pedestrian crashes and casualties by as much as 57-82%. This measure should make pedestrians feel more comfortable about crossing wider streets and stopping instead of running across on red. Extending median islands into crosswalks (with an at-grade channel) may also slow down left turn vehicles. This is a high-cost measure, and accordingly, most costs are included in the Level 2 Expanded Funding Plan.

- Modify signal timing – This was recommended at locations where pedestrian crossing times are not close to departmental objectives (to accommodate those crossing as slowly as 2.5 feet per second) and where surrogate data suggest insufficient time to cross. There has been little or no research on the impacts of such incremental changes.

- Pavement stencils and animated eyes signals – These were recommended where there were higher numbers of pedestrian-responsible crashes or observed vehicle/pedestrian conflicts. Animated eyes signals and pavement stencils both remind pedestrians to look for vehicles. Studies have found that pedestrian failure to observe vehicles was reduced by 22-29% by the animated eyes signals, and conflicts were reduced by 59-94%. The animated eye signals are of moderate cost and of medium complexity to implement, while the stencils are very low cost and easy to implement. Pavement stencils provide an inexpensive alternative. Salt Lake City found "such strong public acceptance that they were installed at all downtown crosswalks (and most elementary school crossings)."[22]

- Pedestrian "head start" phasing – Leading pedestrian intervals give pedestrians a 2- to 4-second crossing time before conflicting vehicles get the green. This is already being used in San Francisco near the Moscone Convention Center, principally where there are dual turn lanes. This countermeasure was recommended for selected locations with heavy turn movements and vehicle/pedestrian conflicts, and where surrogate data suggest some have insufficient time to cross.

- Pedestrian scramble – Exclusive pedestrians phases are recommended for selected locations with heavy turn movements and vehicle/pedestrian conflicts, but with relatively narrow streets that can accommodate extra time for exclusive pedestrian phases (ideally including diagonal crossings). San Francisco has used exclusive pedestrian signal phases for decades, and over ten intersections already have pedestrian-scramble phasing. In June 2002, pedestrian countdown signals were installed at four intersections on Stockton Street (in the Chinatown North Beach Zone) using scramble phasing. Anecdotal information and staff field observations suggest significantly improved pedestrian compliance with signals, and there is community support for expanding the scrambles to an adjacent intersection (i.e., Sacramento and Stockton Streets). National research suggests that at appropriate locations this countermeasure can reduce pedestrian/vehicle conflicts sufficiently to improve safety.

- Vehicle left turn phase – This countermeasure was recommended for locations with a higher number of crashes where the driver failed to yield on left turns.

- Audible signals – This countermeasure was included with new countdown signals at locations near major civic buildings or destination points (key crossings). Although primarily intended for the visually impaired, it may be found that taped warning messages improve the compliance of sighted pedestrians as well.

- Automated detection of pedestrians – This countermeasure was selected at locations where the pedestrian crossing time was not consistent with the departmental objective (i.e., to accommodate those crossing as slowly as 2.5 feet per second), or where surrogate data suggest some have insufficient time to cross. Automated devices for detection of pedestrians in crosswalks allow additional time to cross when pedestrians are detected "late" in the crosswalks. This countermeasure is expected to reduce the number of pedestrians "trapped" on the red light. This device has had mixed evaluation results including a reported 89% reduction in conflicts, but also an increase in conflicts in Los Angeles when only automated detection was used (compared to locations that also had pedestrian push buttons). Los Angeles and Phoenix have removed automated pedestrian detection at trial locations because of too many false calls. Portland (Ellen Vanderslice) reported positive impacts. Implementing automated detection of pedestrians would be technically very challenging to implement. Because of the high level of staff engineering time anticipated, this has been included in the Level 2 Expanded Funding Plan.

- Modern flashing beacon – This countermeasure is aimed at intersections where the main street is uncontrolled, meets or close to meeting traffic signal warrants (typically with higher levels of pedestrian injuries), but not planned for traffic signal. Initially, San Francisco was considering using the HAWK signals ("High-intensity activated crosswalk"), which provide a signal similar to a traffic signal that is dark most of the time, but which moves to yellow and then flashing (wig wag) red when actuated by the pedestrian. Tested in Tucson and Los Angeles, these have received mixed evaluations and may conflict with MUTCD.

  There are other similar and less expensive alternatives that may be useful such as solar-powered pedestrian-activated flashing beacons or traffic signals that rest on flashing yellow and change to red only when activated. Although flashing beacons are a moderately expensive and fairly challenging countermeasure, its potential for a major impact leads it to being included in the Level 1 Basic Funding Plan.

  Salt Lake City has used pedestrian-activated overhead flashing lights and found these devices "well received by the public" and "relatively inexpensive to install compared to in-pavement lighting systems, particularly if existing utility poles can be used and overhead power is nearby"[23].

- Pedestrian countdown signals – San Francisco is installing these devices universally except for especially narrow streets and alleys. In one of the most ambitious conversion programs in the country, over 500 intersections are scheduled to receive the countdown signals by late 2003.

  San Francisco obtained approval to experiment with the devices from both FHWA and the California Traffic Control Devices Committee. DPT already conducted a preliminary evaluation of its pilot installation at 14 intersections, and it has committed to a much broader evaluation Citywide. Preliminary findings suggest that:
  - The percentage of pedestrians still in the crosswalk when the signal turns red decreased significantly after installation of countdown units.
  - The percentage of pedestrians leaving the crosswalk during the "Flashing Red Hand" decreased slightly.
  - The percentage of pedestrians running or aborting their crossings decreased significantly.
  - The percentage of observed vehicle/pedestrian conflicts decreased.

  The most notable finding was that for eight intersections observed, pedestrians who finished crossing an intersection on a red light dropped from 14% to 9%, a statistically significant decrease. (That is, probability less than 1% of a difference due to random sample variation, pre-installation N=591, post N=916, on a two-tailed z-test of the difference of proportions).

  In addition, DPT compared pedestrian injury collisions at countdown-controlled crosswalks during the nine months before and during the nine months after installation of the countdown signals. They reported a reduction from eight to three crashes. While not statistically significant, the finding is very promising.

- Radar speed display sign – This countermeasure is being used where speed surveys indicate a vehicle speeding problem, typically near schools. In San Jose and other cities, such devices have produced significant reductions in vehicle speed, although no data on injuries is available. This device has moderate cost and is somewhat difficult to implement (e.g., given the need to provide electrical service).

- Roadway lighting improvements including "smart lighting" – Lighting improvements are being recommended for locations with relatively high numbers of pedestrian-injury crashes during dark (nighttime) conditions. While the contribution of lighting conditions is unknown in those cases, enhanced roadway lighting is generally considered one of the more cost-effective traffic safety measures. Two reports described positive impact on pedestrian safety from lighting improvements including reduction in pedestrian-related collisions when light levels were increased at high-risk locations for nighttime-related pedestrian collision.[24]

  "Smart lighting" provides higher levels of lighting when a pedestrian is detected. Not only is the additional illumination directly helpful to drivers in seeing pedestrians, the obvious increase in illumination is an indication (a "wake-up call") that drivers need to scan the roadway more carefully. This measure could have significant non-safety impacts by making pedestrians more comfortable walking at night and possibly contributing to crime reduction. This measure is a fairly high-cost measure.

COUNTERMEASURE EVAULATION

For the basic funding level proposed for Phase II of the project, a total of 14 types of countermeasures (nine general engineering countermeasures and five ITS countermeasures) are proposed for 36 intersections with the seven study zones. There will be two different levels of evaluation. The first level of evaluation will focus on the separate impact of each of the 14 types of countermeasures. This evaluation will combine observations from across the seven zones. This level of evaluation will address the specific impact of different types of countermeasures. The second level of evaluation will focus on the impact of all countermeasures combined within each of the study areas. This level of evaluation will determine whether a coordinated set of countermeasures within an area of high injury density will have an overall impact.

Several different categories of measures of effectiveness (MOE) will be considered. When enough installations of a countermeasure are involved, and when data are available for a sufficient time span, collisions and injury data will be used to evaluate countermeasures. When this is not possible, various surrogate measures will be used, including vehicle or pedestrian violations, vehicle-pedestrian conflicts, or other behaviors of vehicles and pedestrians. When possible, vehicle and pedestrian volumes will be assessed to (i) calculate rates (injury rates, rates of various surrogate measures) and (ii) calculate the impact of various countermeasures on volumes.

The evaluation of individual types of countermeasures represents a challenge, since a number of intersections will receive more than one countermeasure. However, in most cases we will be able to distinguish the impacts of separate countermeasures because (i) the impacts are independent and (ii) installation of countermeasures will be sequential.

For each of the evaluations, statistical analyses will be conducted that focus on before-treatment and after-treatment changes. For each type of treatment, data for different intersections will be combined. Individual intersections will be represented as a categorical variable, and tests will be conducted to determine whether there is variation in effect across intersections.

In addition to evaluation of individual countermeasures, we will also focus on the impact of all countermeasures combined within each of the study areas. We expect that over time, the coordinated set of countermeasures will have a general impact within the study zones. We expect that most of the impact will be at the specific sites where countermeasures have occurred. However, we expect that some impacts may be felt throughout the zones. Our evaluation of the impact on zones will focus on pedestrian injury, and we will compare injury within the study zones with injury rates throughout the city. Injury rates will be calculated for three periods including the five-year period before the beginning of Phase II, the period of countermeasure installation for Phase II, and the year following the completion of countermeasure installation. We will conduct an analysis of changes within the study zones compared to other areas in the city over these three times periods. As control variables, we will obtain information on pedestrian volume, vehicle volume, and demographics within each of the three time periods.

OUTREACH

Community outreach, education and awareness are important elements in pedestrian safety efforts in San Francisco. The *PedSafe* outreach plan, based on demonstrated community organization principles, consists of parallel strategies to weave *PedSafe* countermeasure outreach and awareness into ongoing efforts, as well as to promote project-specific outreach efforts that include:

1) working with municipal agencies responsible for pedestrian safety through the Internal Stakeholders Advisory Group active in Phase I of *PedSafe*, and
2) working with grassroots community groups, including the External Stakeholders Advisory Group active in Phase I of *PedSafe*, which are committed to pedestrian safety projects.)

All outreach activities will focus on promoting understanding and use of new countermeasures and building awareness of good walking patterns and of state and local pedestrian and traffic laws. Information collected as part of the Problem Identification and Countermeasure Selection processes will be used to tailor the outreach plan to the particular zones and intersections selected.

When countermeasures consist of traffic-calming methods, the City's outreach plan currently in place to address traffic-claming measures, will be used. This consists of: community workshops to explain processes, define problems and goals and prioritize interests; guided walk-throughs; presentation of countermeasures; and public hearings. Certain traffic control measures, especially involving regulatory control, need legislative approval, along with the opportunity for public comment.

CONCLUSION

While it is too early to determine how successful the *PedSafe* approach is, it is a promising strategy to improve pedestrian safety. Similar plans in Miami and Las Vegas were already being implemented as of Spring 2003, while San Francisco and FHWA were completing work on the Phase I plan. Negotiations over Phase II funding are expected to follow.

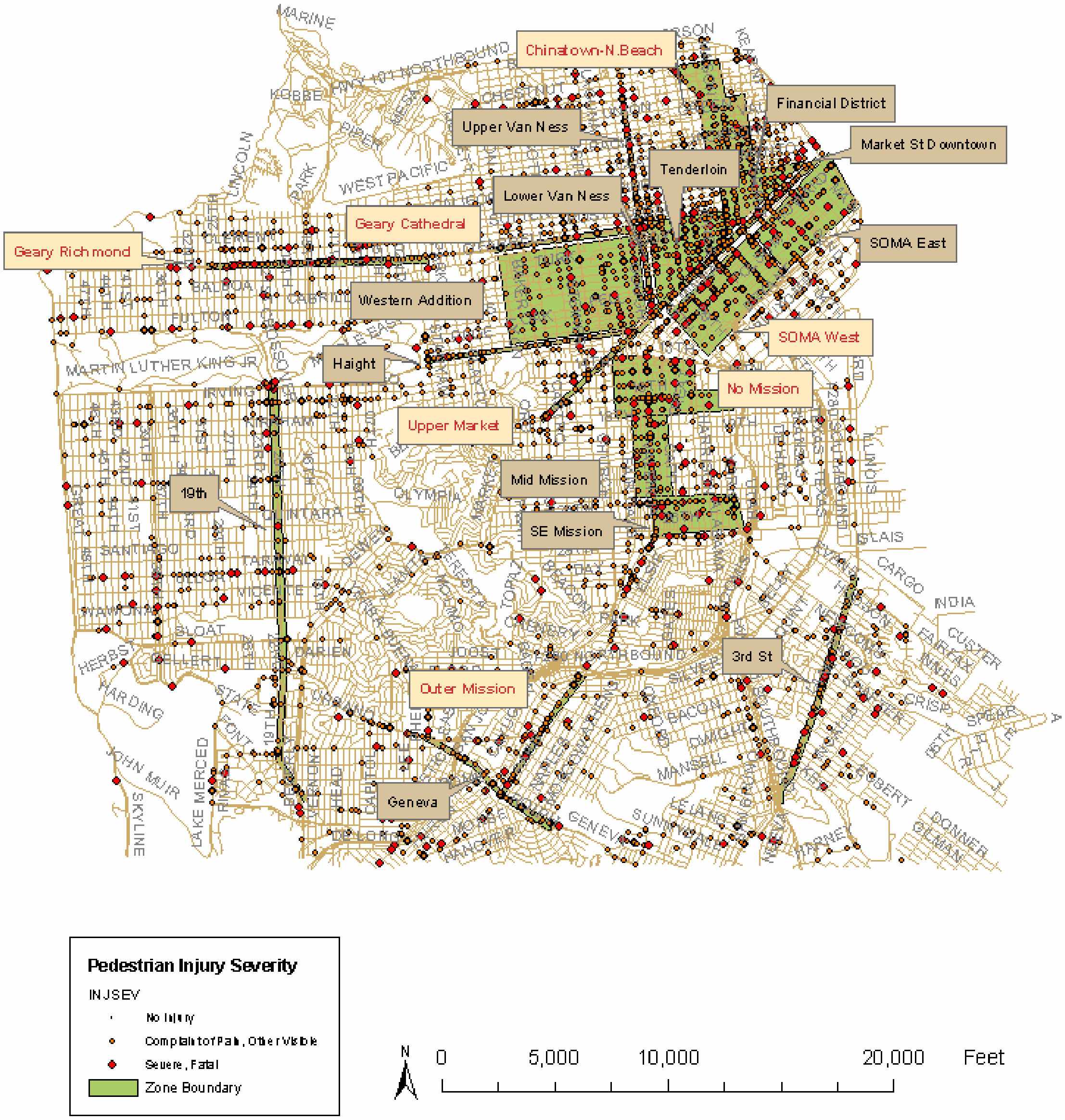
Other cities can learn from this approach for efficient use of resources. In summary, this requires the following steps:

- Focusing on high injury-density areas
- Collecting and using appropriate data
- Selecting appropriate and effective countermeasures
- Evaluating outcomes.

APPENDIX

San Francisco PedSafe - High Pedestrian Collision Zones
SWITRS July 1, 1996 - June 30, 2001

(20 zones, 7 finalist = red font, light caption)



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