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Safe Urban Form: Revisiting the Relationship Between Community Design and Traffic Safety

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Safe Urban Form

Revisiting the Relationship Between Community Design and Traffic Safety

Eric Dumbaugh and Robert Rae

Problem: While concerns about traffic safety were central to the development of conventional community design practice, there has been little empirical examination of the relationship between community design and the incidence of traffic-related crashes, injuries, and deaths.

Purpose: We examine the relationship between community design and crash incidence.

Methods: We present a brief historical review of the safety considerations that helped shape conventional community design practice and then analyze GIS data on crash incidence and urban form using negative binomial models.

Results and conclusions: We find that many of the safety assumptions embedded in contemporary community design practice are not substantiated by the empirical evidence. While disconnecting local street networks and relocating nonresidential uses to arterial thoroughfares can reduce neighborhood traffic volumes, this does not appear to improve safety, but rather substitutes one set of safety problems for another. We found urban arterials, arterial-oriented commercial developments, and big box stores to be associated with increased incidences of traffic-related crashes and injuries, while higher-density communities with more traditional, pedestrian-scaled retail configurations were associated with fewer crashes. We found intersections to have mixed effects on crash incidence. We conclude by discussing the likely reasons for these findings (vehicle operating speeds and systematic design error) and outline three community design strategies that may help improve traffic safety.

Takeaway for practice: Community design is strongly associated with crash incidence. The speed and operating characteristics of arterial thoroughfares, as well as the design and configuration of commercial and retail uses, appear to be particularly important. Our findings suggest that safety may be enhanced by strictly managing access along arterial thoroughfares and by locating commercial and retail uses away from these roadways, or at least orienting them toward lower-speed access lanes with limited connections to the arterial system. Designing communities to have higher-density, more urban design configurations generally appears to help reduce crash incidence, although four-leg intersections pose potential traffic hazards.

Keywords: traffic safety, community design, urban design, land use planning

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Traffic fatalities are currently the sixth leading cause of preventable death in the United States (Mokdad, Marks, Stroup, & Gerberding, 2004). In 2006, there were more than 38,600 fatal traffic crashes in the United States, resulting in the deaths of almost 43,000 people. Of these, 45% occurred in urban environments, with 22% occurring on urban arterials alone (See Table 1).These numbers have remained relatively constant for more than a decade (National Highway Traffic Safety Administration, 2006), leading many in the transportation community to begin calling for a more safety-conscious approach to transportation system planning and design (Federal Highway Administration, 2003; Transportation Research Board, 2001).

To date, there has been little attention given to the role of community design in the incidence of traffic-related deaths and injuries. Planners and

Table 1. Fatal crashes in the United States, 2006.

Road class	Fatal crashes	Percentage of subcategory	Percentage of total
Urban			
Freeway	3,974	22.9	10.3
Arterial	8,550	49.3	22.1
Collector	1,416	8.2	3.7
Local	3,405	19.6	8.8
Total urban	17,345	100.0	44.9
Rural			
Freeway	2,433	11.7	6.3
Arterial	7,722	37.2	20.0
Collector	6,620	31.9	17.1
Local	4,004	19.3	10.4
Total rural	20,779	100.0	53.8
Unknown location	524		1.4
Total	38,648		100.0

Note: Percentages may not add to 100 due to rounding.

Source: National Highway Traffic Safety Administration (n.d.).

urban designers typically relegate traffic safety concerns to other transportation-related professions, entering the discussion, if they do so at all, principally to advocate for the specific safety needs of pedestrians and bicyclists. Yet, the planning profession has not historically taken such a narrow view of traffic safety. Many of the policies and practices embedded in contemporary community design practice, such as the functional classification of roadways, the development of disconnected residential subdivisions, and the location of retail uses along arterial thoroughfares, are all products of early planning efforts to address traffic safety.

This article revisits the relationship between community design and traffic safety. We begin by identifying the historical safety assumptions that led to contemporary community design practice, and proceed to formally analyze the empirical relationships between crash incidence and urban form. We find that while early 20th-century designers were right to be concerned about the safety effects of gridiron street networks, the design practices that emerged in response created their own unintended safety problems. We conclude by discussing the implications of these findings for planning practice, and identifying areas where additional research is needed.

Community Design and Traffic Safety in the 20th Century

Any attempt to understand the historical relationship between planning and traffic safety must begin with an understanding of gridiron street networks. While often romanticized by contemporary proponents of neotraditional development, the urban grid was popular in the 19th century not to encourage pedestrianism, but to promote rapid land development. Streets of uniform widths spaced at equal intervals effectively maximized the number of premium corner lots and made each street as attractive to development as the next. While some cities, like Savannah, GA, incorporated public spaces and street termini into their designs, cities like New York and Chicago, took the more common approach of simply expanding the grid toward the horizon, interrupting it only where required by physical necessity (Kostof, 1991; see Figure 1).

The planning profession's early interest in traffic safety is conjoined with its critique of the grid. With the widespread adoption of the personal automobile during the first decades of the 20th century, gridded street networks made each street as accommodating to automobile traffic as the next, creating unwanted conflicts between motor vehicle traffic and residential and recreational uses. In an early critique of the grid, Frederick Law Olmsted Jr. (1916) complained that "it has been the tendency of street planners, whether acting for the city or for landowners, to give quite inadequate attention to the need of the public for main thoroughfares laid out with sole regard for the problems of transportation" (p. 8). Olmsted asserted that safety, aesthetics, and operational efficiency could all be enhanced if community designers moved away from standardized grid arrangements and toward streets and networks designed to accommodate specific and distinct traffic functions.

The precedent for designing street networks according to their traffic function can be found in New York's Central Park, where the senior Olmsted designed grade-separated, limited-access thoroughfares to separate through traffic crossing the park from the lower-speed, more recreational activities for which the park was intended (see Figure 2). As the senior Olmsted (1872/1922a) described it, "by this means it was made possible, even for the most timid and nervous, to go on foot to any district . . . without crossing a line of wheels on the same level, and consequently, without occasion for anxiety or hesitation" (p. 47).

This idea was carried forward in the first automobile-era manual on street design, entitled *Width and Arrangement of Streets* (Robinson, 1911). Applying the lessons of Central Park, Robinson recommended that streets be designed to serve specific functional purposes, including "main traffic

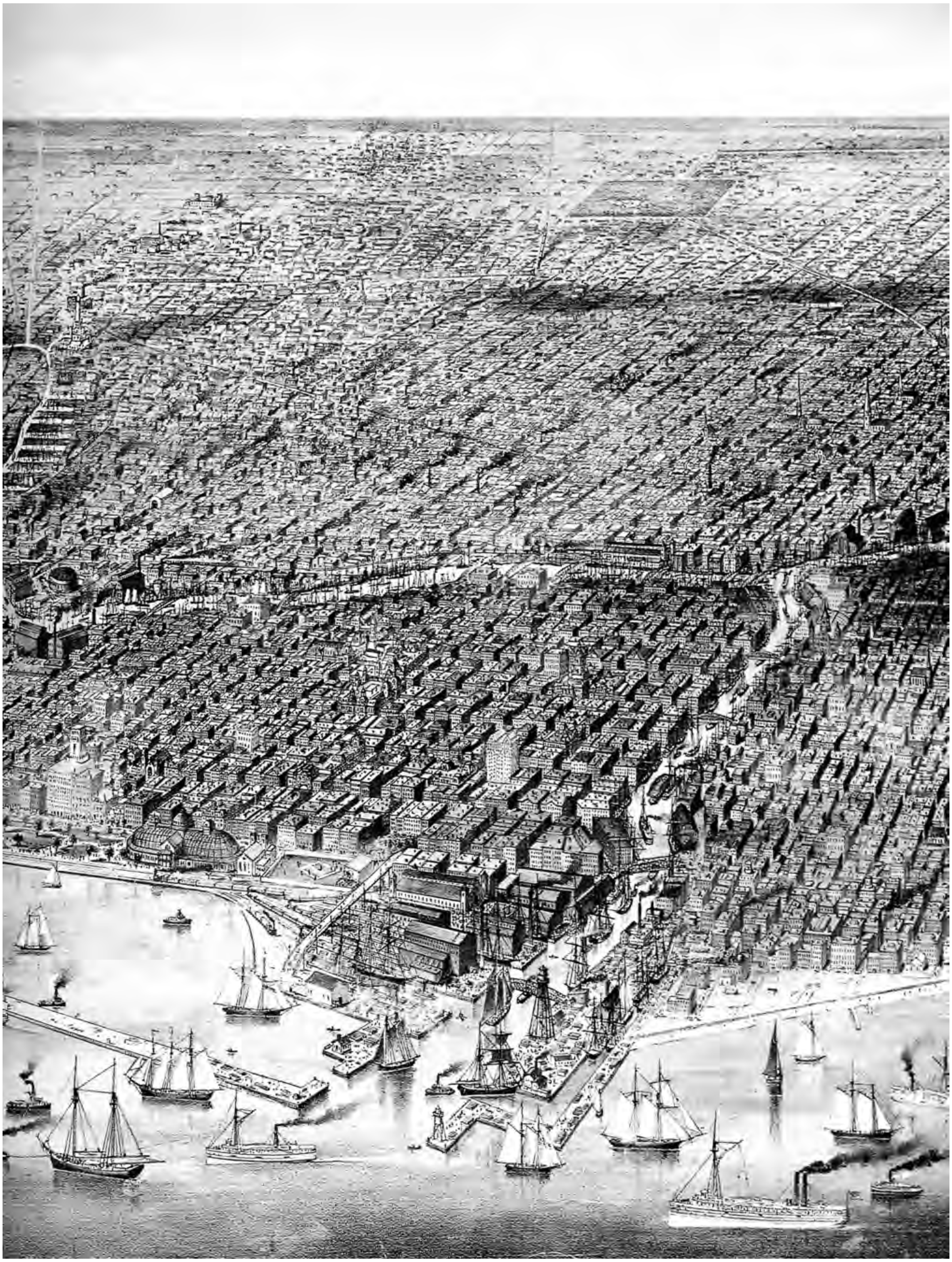

Figure 1. Chicago's expanding grid.

Source: Currier & Ives (1892/1991).

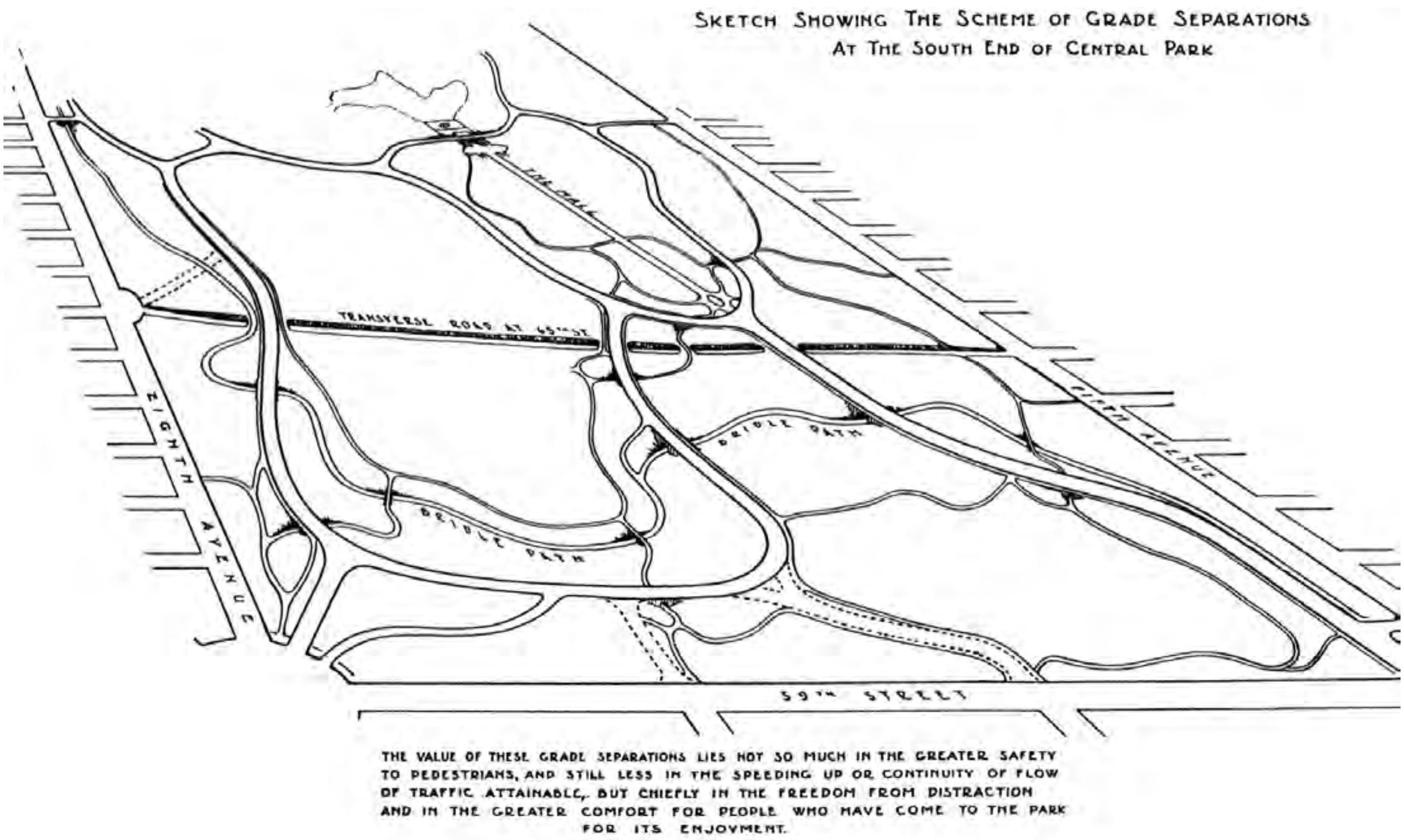

Figure 2: Functionally separated thoroughfares in Central Park.

Source: Olmstead (1858/1922b).

channels that in location and arrangement shall be so nearly ideal that traffic will naturally concentrate upon them, to the end that streets which we do not design for traffic highways shall not be unduly used for traffic" (p. 48). Neighborhood streets, by contrast, should be designed with "some permanent physical handicap, such as indirection, heavy grades or a break in continuity" (p.10) to encourage automobile traffic to use the main traffic channels.

Beyond simply preserving the residential character of urban neighborhoods, this approach was also presumed to enhance traffic safety. As enumerated in the early professional guidebook *City Planning*:

> If there were a pronounced differentiation between main thoroughfares intended for traffic carriers and secondary or intermediate ones intended for local development, the necessity of very frequent crossings would not exist. Wide traffic streets would afford a better view of vehicles approaching from intersecting streets and good speed could be safely maintained where stopping points were a considerable distance apart. (Haldeman, 1916, p. 288)

There are two safety ideas embedded here. First, by widening and straightening these new automobile thoroughfares, designers would enhance a motorist's ability to see a hazard in the right-of-way well before physically encountering it, providing the driver with ample time to decelerate or change course. Stated in contemporary terms, these thoroughfares would be designed to enhance *sight distance*. The second idea was that safety would be enhanced by eliminating intersections. Logically, fewer intersections would result in fewer intersection conflicts, thereby reducing the number of opportunities for crossing vehicles and pedestrians to be involved in traffic crashes.

Perry, Stein, and the Advent of Conventional Community Design

While Olmsted provided the conceptual framework for the design and configuration of contemporary urban streets and street networks, it was Clarence Perry and Clarence Stein who translated these ideas into their conventional form. For Perry, who summarized his life's work in *Housing for the Machine Age* (1939), the problem with turn-of-the-century development practices was that they failed to address community design in a comprehensive, integrated manner. To remedy this, Perry promoted the idea of the neighborhood unit, designed as a self-contained community large enough (6,000–10,000 people) to populate a local elementary school.

In addition to encouraging the use of functionally designed streets, Perry further proposed reconfiguring land uses to reinforce the separation of traffic functions. He recommended that only residential and neighborhood-supporting civic uses, such as schools and churches, be included in a neighborhood unit and that all other uses, such as retail and commercial, be relocated onto the arterial thoroughfares that bounded the neighborhood. While acknowledging that this would result in retail configurations oriented to automobiles, rather than pedestrians (see Figure 3), Perry viewed this as benefiting residents and retailers alike. The relocation of these activities to arterial locations would remove cut-through traffic from their neighborhoods, while still allowing neighborhood residents to conveniently access retail stores on their trips to and from work. It would also benefit retailers by allowing them to capture both shopping trips from the adjacent neighborhood as well as new pass-by trips from traffic traveling along the arterial thoroughfare.

Clarence Stein, in partnership with Perry, gave these design concepts their archetypal form in the design of Radburn. While much attention is given to Radburn's larger influence on contemporary community design (see especially Garvin, 1995; Lee & Ahn, 2003; Parsons, 1994; Schaeffer, 1982), its intended role as a strategy for enhancing traffic safety is often overlooked. In describing "The Need for Radburn," Stein (1957) writes:

> American cities were certainly not places of security in the twenties. The automobile was a disrupting menace to city life . . . [and] pedestrians risked a dangerous street crossing 20 times a mile. The roadbed was the children's main play space. Every year, there were more Americans killed and injured in automobile accidents than the total American war causalities in any year. The checkerboard pattern made all streets equally inviting to through traffic. Quiet and peaceful repose disappeared along with safety....It was in answer to such conditions that the Radburn plan was evolved. (p. 41)

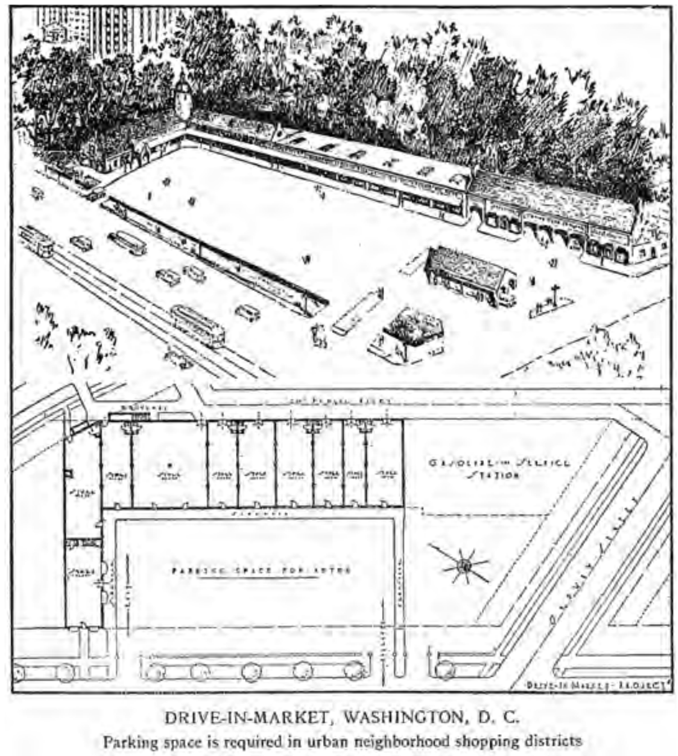

Figure 3. Representative location and configuration for neighborhood retail uses.

Source: Perry (1939).

To address these problems, Stein designed a disconnected residential subdivision, characterized by functionally defined roadways "planned and built for one use, instead of for all uses," recognizing that this design entailed "a radical revision of relation of houses, roads, paths, gardens, parks, blocks, and local neighborhoods" (p. 41). Residential uses, if they were to be designed with traffic safety in mind, should be separated from all others and located along disconnected streets and cul-de-sacs. All other uses should be relocated to arterial thoroughfares (see Figure 4).

The safety benefits of *conventional community design* were based on three premises. The first was that safety could be enhanced by developing a new class of roadway (the arterial thoroughfare) designed to address the specific safety needs of motorists. These roadways should be designed to be wide and straight to increase sight distances, thereby allowing motorists to readily observe and respond to potential traffic conflicts in the right-of-way. The second safety premise was that street networks should be reconfigured to prevent vehicle traffic from entering residential areas and to reduce the number of conflicts between opposing streams of traffic. This was to be achieved by replacing

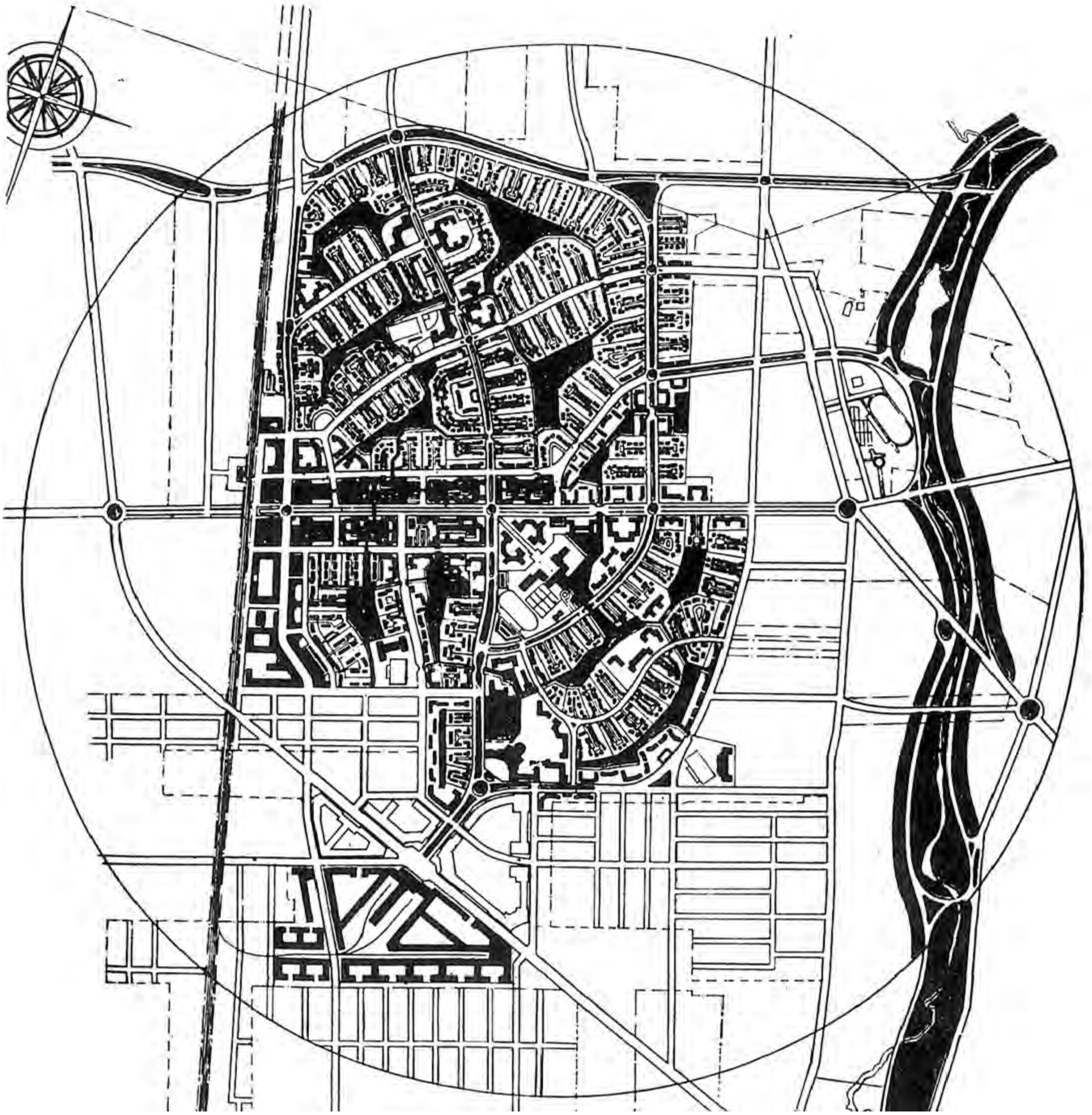

Figure 4. Stein's plan for Radburn.

Source: Stein (1957).

four-way intersections with T intersections and cul-de-sacs and limiting the number of access points to the surrounding arterials, with the optimal configuration being a community with exactly one connection to the external street network. The third premise was that land uses should be designed to reinforce the functional separation of traffic. Residential uses were to be located principally on disconnected local street networks, while traffic-generating uses, such as neighborhood retail and commercial uses, should be moved to arterial thoroughfares designed to carry heavier traffic loads. These three design concepts were subsequently institutionalized into contemporary land development practices (Southworth and Ben-Joseph, 1995), and their lasting influence can be seen in the form and configuration of communities built during the latter half of the 20th century (see Figure 5).

Evidence of the Effects of Conventional Community Design on Traffic Safety

But what of the empirical evidence used to justify these practices? Are the communities that emerged in fact safer than the development forms they sought to replace? The guiding study on this subject is Harold Marks' *Subdividing for Traffic Safety* (1957). In this work, Marks sought to examine whether the disconnected residential subdivisions he called "limited-access" communities were safer than those with gridiron street networks. He found that gridiron neighborhoods had seven times the number of crashes as the limited access communities. He further looked at safety performance of three- and four-leg intersections. The three-leg (T) intersections experienced fewer crashes than four-leg intersections whether located in gridiron or limited-access communities. Based on these results, Marks concluded that "our new subdivisions have built-in traffic safety" (p. 324).

While Marks' results are compelling, three issues bear noting. First, the study did not control for differences in traffic volumes. Local streets in gridiron networks typically carry heavier traffic loads than those in disconnected subdivisions, which is what led planners to disconnect residential street networks in the first place. Differences

Figure 5. Conventional community design.

in traffic volumes are likely to explain at least some of the differences in crash incidence across the different network types. Second, the safety effects of rearranging neighborhood land uses were not explicitly considered. Instead, Marks simply examined differences in crash incidence for residential areas with different network configurations. Finally, Marks only examined neighborhood streets and did not consider the safety effects of relocating local traffic and nonresidential uses onto arterial thoroughfares. While such network and land use configurations may reduce traffic volumes and crash frequency within a neighborhood's boundaries, it is possible that these localized crash reductions may be offset by substantial increases in the frequency and severity of crashes occurring on the adjacent arterial roads.

Only one other formal study has addressed this issue in the last 50 years. Ben-Joseph (1995) examined crash frequency in nine suburban communities in the San Francisco Bay area, all with densities of six or fewer dwelling units per acre and local street traffic volumes at or below 1,500 average daily trips. He classified each community as having a cul-de-sac, loop, or gridded street network. The three gridded communities reported 68 injurious crashes over a 5-year period, compared to 34 for loop communities, and 18 for cul-de-sac communities. This study also considered the effects of traffic volumes on crash incidence. On average, neighborhoods with gridded street networks reported 3 crashes per 100,000 vehicle trips, loop communities experienced 2.8, and cul-de-sac communities reported 2 crashes per 100,000 vehicle trips. In general, the study confirmed Marks' earlier findings, although like Marks' study, it did not examine the safety effects of rearranging land uses or rerouting local traffic onto arterial thoroughfares.

Several recent studies have sought to develop crash forecasting models for use in long-range transportation planning applications. While these models were neither designed nor intended to examine the effects of urban form on crash incidence, they include various measures of the built environment at the census tract or traffic analysis zone (TAZ) level, and their results are worth noting. Where density was included in the models, areas with more people, households, or higher population densities generally had higher crash rates (Hadeyeghi, Shalaby, & Persaud, 2003; Hadeyeghi, Shalaby, Persaud, & Cheung, 2006; Ladron de Guevara, Washington, & Oh, 2004; Lovegrove, & Sayed, 2006). Where intersection density was examined, it was found to have mixed effects, with two studies finding higher intersection densities to be associated with increased crash incidence (Hadeyeghi et al., 2003, 2006), and one study finding them to be associated with significantly fewer crashes (Ladron de Guevara et al., 2004). Nevertheless, one should be cautious about inferring specific design relationships from these results, as all used TAZs or census tracts, units of analysis too large to draw inferences on crash incidence for individual neighborhoods.

Revisiting the Relationship Between Traffic Safety and Urban Form

Given the widespread adoption of the design practices espoused by Perry and Stein, and the limited information on their actual safety effects, we sought to re-examine the relationship between urban form and traffic safety. To do so, we developed a GIS-based database of crash incidence and urban form for the City of San Antonio.

We selected San Antonio for both theoretical and practical reasons. From a theoretical perspective, San Antonio is a rapidly growing Sunbelt city containing a diverse array of design environments including an historic urban core, streetcar suburbs adjacent to downtown, and conventionally designed neighborhoods on the city's periphery. Its overall form is diverse enough to provide the variation needed to model the relationship between community design and crash incidence.

From a practical perspective, selecting San Antonio allowed us to acquire consistent and reliable information for crashes occurring on local streets, which is otherwise a major barrier to examining traffic safety for large geographic areas. While state departments of transportation compile crash information for state-operated roadways, crash data for local streets are typically maintained by local police departments. There is often a great deal of variation in the way individual police departments collect and compile individual police accident reports (PARs), and many jurisdictions do not systematically compile this information at all.

Because roughly 90% of the San Antonio metropolitan region's 1.4 million residents reside within the City of San Antonio itself, we were able to acquire crash data for the majority of the region from a single agency, the San Antonio Police Department (SAPD), in a consistent and reliable form (see Figure 6). A second benefit is that these data contain information for all crashes to which the SAPD responded, including those occurring on private properties. Thus, unlike most safety analyses, this study includes information for crashes occurring not only along public streets, but also those occurring in residential driveways and the parking lots of shopping centers.

While these data allow us to overcome many of the practical barriers to conducting such an analysis, their principal shortcoming is that they were recorded in a very simplified form. The data only provide information on crash location and severity and do not identify whether those involved in the crash were motorists, pedestrians, or bicyclists, nor do they provide information on crash type (e.g., sideswipe, angle, head-on, run-off-road, etc). This limits our analysis to crash frequency and severity, and does not allow us to examine the incidence of specific crash types or user groups.

Measuring Neighborhood-Level Crash Incidence

To develop our database of crash incidence and urban form, we integrated the crash data supplied by the SAPD with parcel-level land use data supplied by the Bexar County Appraisal District, street and road network information supplied by the San Antonio–Bexar County Metropolitan Planning Organization, information on traffic volumes from the Texas Department of Transportation and the City of San Antonio, as well as demographic information from the U.S. Census.

Analyzing crash data at the neighborhood level requires definitions and several methodological assumptions. First, we identified the appropriate measures of traffic safety. In addition to examining total crash incidence, we also examined the incidence of injurious and fatal crashes, as the design factors that lead to injurious and fatal crashes may have unique characteristics. For this study, total crash incidence is simply the sum of all crashes occurring within a neighborhood. A fatal crash is defined as a crash leading to the death of one or more persons, while an injurious crash is one that resulted in a serious but nonfatal injury. To avoid drawing conclusions based on short-term distortions or fluctuations in crash incidence (i.e., regression to the mean) we used data for the period 2004 through 2006 for each of these three safety measures. Descriptive statistics for crashes in the City of San Antonio for this period by crash type and location are shown in Table 2.

Secondly, we operationally defined neighborhoods as census block groups. From a practical perspective, we needed geographic units for which we could obtain reliable information on population characteristics, limiting us to either census geography or TAZs. Because larger geographic units mask internal community design variation, we used census block groups, which provide accurate population information, but which are also small enough to have relatively homogeneous design characteristics. We excluded block groups that overlapped with jurisdictions for which we lacked data, as well as block groups with missing or incomplete data, leaving us with a total of 747 block groups for the region.

Two additional issues were how we would address micro-level spatial variation associated with the use of different GIS layers, and the related problem of how to

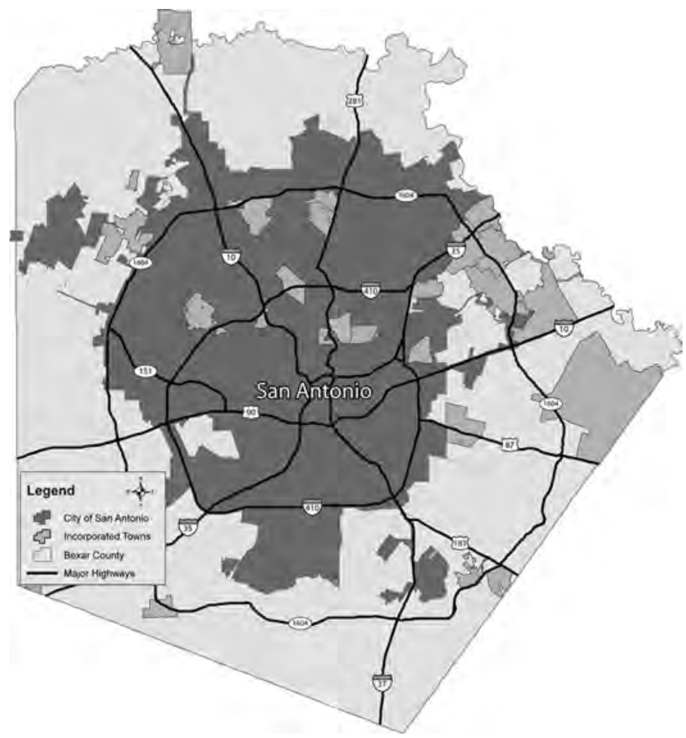

Figure 6. The San Antonio/Bexar County metropolitan region.

meaningfully assign information occurring along a neighborhood's boundaries. Previous researchers have sought to avoid these attribution problems by simply eliminating information occurring on the boundaries of their units of analysis (Ladron de Guevara et al., 2004). The problem with this approach, however, is that both TAZs and census geography often use arterial thoroughfares as geographic boundaries. Since arterial roadways often carry an overwhelming share of the traffic generated by a neighborhood, they are likely to experience a large share of its crashes. Thus, eliminating boundary information is likely to lead to underestimating neighborhood crash incidence.

To resolve this problem, we defined each neighborhood as a block group plus the streets along its edges. To capture the relevant information, we defined a buffer around each block group roughly the width of a fully designed principal arterial right-of-way (200 feet), and assigned the roadway and crash information occurring within that buffer area to the block group it adjoined. This approach treats streets located on neighborhood edges as part of the neighborhood, an approach that roughly corresponds to the way individuals define the boundaries of their neighborhoods (Lynch, 1960). While this approach does assign some streets and crashes to more than one neighborhood, it is important to restate that the unit of the analysis is the neighborhood, not the

Table 2. Number and percentages of crashes in the City of San Antonio, by crash type and location, 2004–2006.

	Fatal		Injurious		Total	
		%		%		%
Freeway	104	24.0	5,349	20.4	29,843	19.8
Arterial	128	29.6	9,799	37.4	51,523	34.2
Collector	27	6.2	1,916	7.3	10,001	6.6
Local	103	23.8	6,615	25.2	39,619	26.3
Private/off-network	71	16.4	2,555	9.7	19,640	13.0
Total	433	100.0	26,234	100.0	150,626	100.0

Note: Percentages may not add to 100 due to rounding.

Source: National Highway Traffic Safety Administration (n.d.).

individual street or crash location. This operational definition provides a consistent framework for addressing problems associated with differences in the spatial definition of individual GIS layers, while also ensuring that we do not lose essential information on crash incidence.

Nevertheless, two problems with geography remain unresolved. The first is the modifiable area unit problem (MAUP), which relates to the effects that different geographic aggregations may have on the values observed for a variable of interest (Openshaw & Taylor, 1979). Because values for many variables computed for a geographic area will vary depending on how the area is bounded, the observed values of such variables are not truly random, but are products of how the geographic areas are defined. A second and related problem is the issue of spatial autocorrelation. Because the characteristics of one geographic area are likely to be similar to, and perhaps influenced by, the characteristics of adjacent areas, the individual observations can not be said to be truly independent.

While several studies have sought to examine how MAUP and spatial autocorrelation may affect the results of geographic analyses of the relationship between transportation and urban form (Buldoc, Laferrier, & Santarossa, 1992; Horner & Miller, 2001; Miller & Shaw, 2001; Zhang & Kukadia, 2005), none of these studies have examined how these issues may relate to crash incidence nor how to adjust negative binomial regression models to address these issues. Resolving the problems of MAUP and spatial autocorrelation is beyond the scope of this study.

Independent and Control Variables

To examine the relationship between urban form and crash incidence, we included the following variables in this analysis.

Block Group Acreage. The U.S. Census Bureau defines block groups to have varied sizes, with larger block groups generally located at the periphery of metropolitan areas, where they are likely to generate traffic destined for other, more central locations. To account for whatever statistical effects block groups of differing sizes might have on our results, we included block group acreage as a control variable.

Vehicle Miles Traveled (VMT). Because heavier traffic volumes have been shown to increase crash incidence, our analysis controls for the effects of VMT within a neighborhood. Developing neighborhood-level VMT estimates proved methodologically complex, and warrants a brief description. The Texas Department of Transportation provided average daily traffic volumes (ADT) for all state highways (freeways and principal arterials) in the metropolitan area. The City of San Antonio also gave us traffic counts at 804 locations not on the state highway system. Taken together, we had data for all freeways, principal arterials, minor arterials, and collector roadways in the region.[1] Because the state provided ADT for roadway segments and the city provided ADT for single points, we made the two compatible by assuming that point ADT remained the same along a road segment for half the distance to the next data point, where we assumed it changed to the ADT recorded for the next data point.

It was also necessary to subdivide roadway segments so they did not cross block group boundaries. For this purpose we again used a 200-foot buffer around each block group in order to include all related roadways in the analysis. Once the road segments were subdivided, we calculated VMT for each road segment by multiplying that segment's ADT by its length, and then multiplying this value by 365 days and 3 years. We then summed the VMT thus computed for all roadway segments in the block group and divided this number by one million. The resulting value is neighborhood-level VMT in millions.

Median Household Income. Households with higher incomes can afford newer and more crashworthy vehicles, which should in turn reduce the incidence of injurious and fatal crashes, if not of total crashes. This variable controls for the effect of income on crash incidence, and we report it in thousands of dollars.

Persons Aged 18 to 24. Young drivers are disproportionately more likely to be involved in total, injurious, or fatal crashes than other age groups. This variable controls for the number of young adults residing in the neighborhood.

Persons Aged 75 and Older. While crash rates decline for persons between the ages of 25 and 74, there is an increase in crash incidence among individuals aged 75 or older. This variable controls for the presence of adults aged 75 or older residing in a neighborhood.

Net Population Density. Several recent studies have identified higher population densities as a crash risk factor. To understand the effects that population density might have on crash incidence, we calculated the net population density of each block group. *Net population density* is measured as the total population of the block group, divided by the total acreage of residential parcels located in the block group.

Intersection Counts. Because three-way intersections have been found to have different effects on safety than other types of intersections, we included the numbers of three-leg intersections and four-or-more-leg intersections as separate variables. These variables simply count the number of intersections of each type within the neighborhood.

Miles of Freeways and Miles of Arterials. As described earlier, the development of freeways and arterial thoroughfares was presumed to enhance safety by providing roadways appropriate for automobile use. Because this study already controls for VMT, these variables seek to identify what safety effects, if any, are associated with the presence of freeway and arterial facilities within urban neighborhoods. These variables are the sums of the centerline miles of roadways classified as freeways and arterials in each neighborhood.

Number of Arterial-Oriented Retail and Commercial Uses. Locating commercial and retail uses along arterial thoroughfares was presumed to enhance safety by eliminating nonresidential traffic from neighborhoods. Nonetheless, there has been little formal examination of how the presence of these land uses on arterial thoroughfares may affect crash incidence. To calculate this variable, we used GIS to identify each parcel in a commercial or retail use that is located adjacent to an arterial thoroughfare. This variable is that total for each neighborhood.

Big Box Stores. An outcome of encouraging arterial-oriented retail, perhaps unforeseen by Perry and Stein, was the advent of the big-box store. For this study, we define a *big box store* as a parcel in a retail use, with a single building occupying 50,000 square feet or more, and having a floor-area ratio (FAR) of 0.4 or less. A big box store typically serves a large market area, drawing significant vehicle traffic which then circulates through the site in search of parking, potentially leading to some off-street crashes. Our variable is the number of big box stores in a neighborhood.

Number of Pedestrian-Scaled Retail and Commercial Uses. The design configurations promoted by Perry and Stein also hastened the decline of pedestrian-scaled businesses. In this study we defined these as parcels whose retail or commercial uses occupy buildings of 20,000 square feet or less, and with FARs of 1.0 or greater. Such development, which generally covers most of a parcel's land surface with structures, may front on the street directly. Our variable is simply the number of such parcels in a neighborhood to allow us to examine what safety effects, if any, more traditionally scaled retail and commercial uses have on crash incidence.

Model Specifications and Results

Because the dependent variables are count data that are overdispersed (i.e., the variance is greater than the mean), we used negative binomial regression models for this analysis. Negative binomial regression models have been widely applied in the recent traffic safety literature and are regarded as the preferred statistical model for analyzing crash frequency and severity (Ladron de Guevara et al., 2004). The model coefficients report the percentage change of the dependent variable that occurs with each unit of change in the independent variable.

Total Crash Incidence

Table 3 presents the results of the total crash incidence model. As expected, areas with more VMT experience more crashes, with crash incidence increasing by roughly 0.75% with every million miles of vehicle travel. Income did not prove to be related to total crash incidence, while the numbers of both young and older drivers were associated with higher numbers of total crashes. Of the two intersection variables, three-leg intersections had a slightly positive, but statistically insignificant effect on total crashes, while four-leg intersections were associated with a small but significant (0.5%) increase in total crashes. Freeways were not associated with total crash incidence, although arterial thoroughfares were, with each additional mile of arterial

Table 3. Total crash incidence model.

	Coeff.	z	p
Constant	4.6896	69.84	0.000***
Block group acreage	−0.0006	−3.69	0.000***
Vehicle miles of travel (millions)	0.0075	11.67	0.000***
Median household income	0.0003	0.22	0.829
Population aged 18 to 24	0.0010	5.98	0.000***
Population aged 75 and older	0.0006	1.67	0.096$^{\psi}$
Net population density	−0.0005	−1.80	0.073$^{\psi}$
Number of three-leg intersections	0.0008	0.52	0.600
Number of four-or-more-leg intersections	0.0050	2.39	0.017*
Freeway miles	−0.0181	−1.12	0.262
Arterial miles	0.1495	5.08	0.000***
Number of arterial-oriented retail and commercial uses	0.0131	6.53	0.000**
Number of big box stores	0.0658	4.23	0.000***
Number of pedestrian-scaled retail and commercial uses	−0.0218	−1.84	0.066$^{\psi}$

Log likelihood = −4662
N = 747

$^{\psi}p < .10$ $^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$

thoroughfare being associated with a 15% increase in total crashes. Of the land use variables, each additional arterial-oriented retail or commercial parcel increased total crashes by 1.3%, and each additional big box store increased total crashes by 6.6%. Pedestrian-scaled commercial or retail uses, by contrast, were associated with a 2.2% reduction in crash incidence. Population density was also significantly associated with fewer crashes, with each additional person per net residential acre decreasing crash incidence by 0.05%.

Injurious Crash Incidence

Table 4 shows that the factors associated with the incidence of injurious crashes are in large part similar to those influencing total crashes, with two exceptions. The presence of older adults ceases to be a significant predictor of injurious crashes, while higher income is associated with a significant reduction in injurious crashes. Arterial thoroughfares again have a profoundly negative effect on traffic safety, with each additional centerline mile of arterial roadway increasing injurious crashes by roughly 17%. Four-leg intersections, where conflicting traffic streams cross, are likewise associated with significant increases in injurious crashes. This was not true, however, for three-leg intersections, which were associated with fewer injurious crashes, although not at statistically significant levels. Each additional arterial-oriented retail or commercial parcel was found to increase injurious crashes by 1.1%, and each additional big box store was found to increase injurious crashes by an additional 4%. Conversely, the number of pedestrian-scaled commercial and retail uses was again associated with significantly fewer injurious crashes, with each additional such use corresponding to a 3.4% injurious crash reduction. Population density was again associated with a significant reduction in injurious crashes, with each additional person per net residential acre being associated with a 0.06% decrease in injurious crashes.

Fatal Crash Incidence

The factors influencing the incidence of fatal crashes differ notably from those affecting total and injurious crashes (see Table 5). While higher median income was associated with decreases in fatal crash incidence, none of the remaining demographic or land use variables entered the model at significant levels. Instead, fatal crashes appear to be principally influenced by the effects that roadway and street network design have on vehicle speeds. Each additional mile of freeway within a neighborhood was associated with a 5% increase in fatal crashes, although only at a 75% level of statistical confidence. Arterial thoroughfares, by contrast, are associated with significant increases in fatal crashes, with each additional arterial mile associated with a 20% increase in fatal crashes. Conversely, both three- and four-leg intersections were associated with significantly lower incidences of fatal crashes, with each additional three-leg

Table 4. Injurious crash model.

	Coeff.	*z*	*p*
Constant	3.1297	45.78	0.000***
Block group acreage	−0.0004	−2.44	0.015*
Vehicle miles of travel (millions)	0.0064	9.78	0.000***
Median household income	−0.0044	−3.31	0.001**
Population aged 18 to 24	0.0008	4.57	0.000***
Population aged 75 and older	0.0003	0.71	0.478
Net population density	−0.0006	−2.30	0.021*
Number of three-leg intersections	−0.0009	−0.58	0.559
Number of four-or-more-leg intersections	0.0068	3.16	0.002**
Freeway miles	−0.0028	−0.17	0.866
Arterial miles	0.1714	5.57	0.000***
Number of arterial-oriented retail and commercial uses	0.0111	5.43	0.000***
Number of big box stores	0.0401	2.58	0.010*
Number of pedestrian-scaled retail and commercial uses	−0.0218	−2.78	0.005**

Log likelihood = −3339
N = 747

*$p < .05$ **$p < .01$ ***$p < .001$

intersection reducing fatal crash incidence by 0.7%, and each additional four-leg intersection reducing fatal crashes by 1%. This is likely due to the fact that intersections force one or more streams to decelerate or come to a stop, which reduces vehicle speeds and thus crash severity.

Discussion

Conventional community design attempts to enhance safety by channeling traffic onto arterial thoroughfares, eliminating intersections on local street networks, and relocating traffic-generating uses away from residential areas. While such strategies may appreciably reduce neighborhood traffic volumes, it is not clear that they also improve traffic safety. Two related factors appear to be involved.

The first and perhaps most obvious factor is the effect of speed on traffic safety. The original safety assumption regarding arterial roadways, espoused in *City Planning* (Nolan, 1916) and other early professional works was that widening and straightening thoroughfares would reduce crash incidence by lengthening sight distances, thus making it easier for drivers to identify and respond to hazards in the right-of-way. This assumption was undoubtedly true in 1916, when vehicle speeds were constrained by the performance capabilities of automobiles, rather than a roadway's design characteristics. The Model T, for example, could travel at maximum speeds of no more than 40–45 miles per hour, and likely traveled at much lower speeds given pavement conditions at the time. With these constraints in place, widening and straightening arterial thoroughfares would likely have increased sight distances without also increasing operating speeds.

Subsequent advancements in automotive engineering now allow vehicles to readily travel at speeds in excess of 100 miles per hour, making a roadway's geometric design characteristics the primary constraint on operating speeds. Under these conditions, wider and straighter roadways lead motorists to travel at higher speeds, thus offsetting any safety benefits associated with increased sight distances (Aschenbrenner & Biehl, 1994; Wilde, 1994). These effects, predicted under risk homeostasis theory,[2] are readily evidenced by the safety performance of freeways, which have no statistically meaningful effect on crash incidence, either positive or negative. Instead, their principal effect is simply to enable vehicles to travel at higher speeds (see Table 6).

A second and related factor is one that can best be described as systematic design error. *Systematic design error* deals with human behavior, and occurs when the real-world use of a designed environment differs from its intended use in a predictable, nonrandom manner. The resulting errors that occur, and the crashes, injuries, and deaths that result, are thus systematic outcomes of the design itself, and an indicator of faulty design (Dumbaugh, 2005b, 2006b).

Table 5. Fatal crash model.

	Coeff.	*z*	*p*
Constant	−0.5095	−2.81	0.005**
Block group acreage	0.0005	1.11	0.265
Vehicle miles of travel (millions)	0.0056	3.41	0.001**
Median household income	−0.0083	−2.09	0.036*
Population aged 18 to 24	0.0004	1.06	0.289
Population aged 75 and older	−0.0002	−0.19	0.847
Net population density	−0.0005	−0.82	0.412
Number of three-leg intersections	−0.0073	−1.79	0.073$^{\psi}$
Number of four-or-more-leg intersections	−0.0099	−1.67	0.095$^{\psi}$
Freeway miles	0.0488	1.16	0.248
Arterial miles	0.1998	2.51	0.012*
Number of arterial-oriented retail and commercial uses	0.0053	0.98	0.327
Number of big box stores	−0.0367	−1.11	0.267
Number of pedestrian-scaled retail and commercial uses	−0.0218	−0.40	0.689

Log likelihood = −865
N = 747

$^{\psi}p < .10$ $^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$

Urban Arterials

The safety problem with urban arterials can best be understood as a product of systematic design error. Widening and straightening these roadways to increase sight distances also has the effect of enabling higher operating speeds, which in turn increase *stopping sight distance*, or the distance a vehicle travels from the time when a driver initially observes a hazard, to the time when he or she can bring the vehicle to a complete stop.[3] Higher stopping sight distances pose little problem when vehicles are traveling at relatively uniform speeds and have few reasons for braking. When these operating conditions can be met, as they are on grade-separated freeways, higher operating speeds have little or no effect on crash incidence.

But these operating conditions typically cannot be met on urban surface streets, where pedestrians, bicyclists, and crossing vehicles are all embedded in the traffic mix. Avoiding crashes under these conditions often requires motorists to bring their vehicles to a quick stop, which higher operating speeds and stopping sight distances make more difficult (Dumbaugh, 2005b; 2006; see Figure 7). The result is a systematic pattern of error in which drivers are unable to adequately respond to others entering the roadway, leading to increased crash incidence. This is confirmed by the results of our study as summarized in Table 6, showing each additional mile of arterial thoroughfare to be associated with a 15% increase in total crashes, a 17% increase in injurious crashes, and a 20% increase in fatal crashes.

Numbers of Parcels in Retail and Commercial Uses Along Arterials and Big Box Stores

The land use changes encouraged by Perry and Stein exacerbate the systematic error problem. While they were correct that relocating these uses would channel traffic away from neighborhoods, they failed to consider how the location of these uses on arterial roadways would affect arterial operating conditions. Commercial and retail uses, whether placed within neighborhoods or along arterials, require access to the streets on which they are located. In the case of arterials, this leads to the placement of driveways along the arterial thoroughfare, which in turn results in lower-speed, access-related traffic being introduced into the arterial traffic stream. Where through-moving traffic is traveling at greater speed than vehicles turning into and out of driveways, the result is an increased incidence of rear-end collisions. At arterial locations that also lack a raised median, this can further introduce cross-traffic conflicts as vehicles attempt left-turning maneuvers, leading to an increased incidence of side-impact (angle) collisions (Dumbaugh, 2005b). As shown in Table 6, each additional arterial-oriented commercial use in a community increases both total and injurious crashes by slightly more than 1%,

Table 6. Comparison of total, injurious, and fatal crash model coefficients.

	Total	Injurious	Fatal
Block group acreage	−0.0006***	−0.0004*	0.0005
Vehicle miles of travel (millions)	0.0075***	0.0064***	0.0056**
Median household income	0.0003	−0.0044**	−0.0083*
Population aged 18 to 24	0.0010**	0.0008***	0.0004
Population aged 75 and older	0.0006ψ	0.0003	−0.0002
Net population density	−0.0005ψ	−0.0006*	−0.0005
Number of three-leg intersections	0.0008	−0.0009	−0.0073ψ
Number of four-or-more-leg intersections	0.0050*	0.0068**	−0.0099ψ
Freeway miles	−0.0181	−0.0028	0.0488
Arterial miles	0.1495***	0.1714***	0.1998*
Number of arterial-oriented retail and commercial uses	0.013***	0.0111***	0.0053
Number of big box stores	0.0658***	0.0401*	−0.0367
Number of pedestrian-scaled retail and commercial uses	−0.0218ψ	−0.0335**	−0.0120

ψ$p < .10$ *$p < .05$ **$p < .01$ ***$p < .001$

while each big box store increases total crashes by 6.6%, and injurious crashes by 4%.

Interestingly, areas with concentrations of arterial-oriented commercial and retail uses were not associated with significant increases in fatal crashes. We suspect this may be because arterials lined with retail and commercial businesses are likely to be congested, which reduces operating speeds and may in turn reduce crash severity, if not crash frequency. Future research is needed to test this hypothesis.

While the data we used in this analysis did not permit us to examine pedestrian and bicyclist crashes explicitly, it is likely that arterials with concentrations of big box stores and commercial uses are particularly problematic for these groups. A study by Miles-Doan and Thompson (1999) examined pedestrian crash incidence in Orlando, FL, finding that the majority of pedestrian crashes occurred along arterial thoroughfares lined with strip commercial uses. Locating commercial and retail uses in proximity to each other, or near residential areas, can create an environment that makes foot travel viable, thus adding pedestrians into the traffic mix. As described above, vehicle speeds along arterials are often too high to permit vehicles to stop quickly in the event that a pedestrian enters the travelway unexpectedly.

Perry (1939) acknowledged that placing commercial uses on arterial thoroughfares created a pedestrian safety problem, though he left this problem unsolved.[4] In practice, the solution to this problem in the United States has been to continue to locate such uses on arterial thoroughfares, but to reduce posted speed limits. In the absence of aggressive police enforcement, however, such practices have been uniformly unsuccessful at reducing vehicle operating speeds (Armour, 1986; Beenstock, Gafni, & Goldin, 2001; Zaal, 1994). The principal alternative, adopted by European designers, is to design urban surface streets to reduce vehicle speeds to safe levels.

Pedestrian-Scaled Retail

We found pedestrian-scaled retail (the type of retail that was abandoned during the postwar period) to be associated with reductions in all types of crashes, and at significant levels for both total and injurious crashes. This is consistent with recent research on the subject, which finds that the pedestrian-scaled nature of these environments communicate to motorists that greater caution is warranted, leading to increased driver vigilance, lower operating speeds, and thus a better preparedness to respond to potential crash hazards that may emerge. The effective result is a reduction in crash incidence (Dumbaugh, 2005a; 2005b; 2006b; Garder, 2004; Naderi, 2003; Ossenbruggen, Pendharkar & Ivan, 2001).

Intersections, Street Networks, and Traffic Control

Intersections are a more complicated matter. Both of the intersection types examined in this study improve safety by reducing the incidence of fatal crashes. Yet, at least in the case of four-way intersections, these reductions are accompanied by significant increases in total and

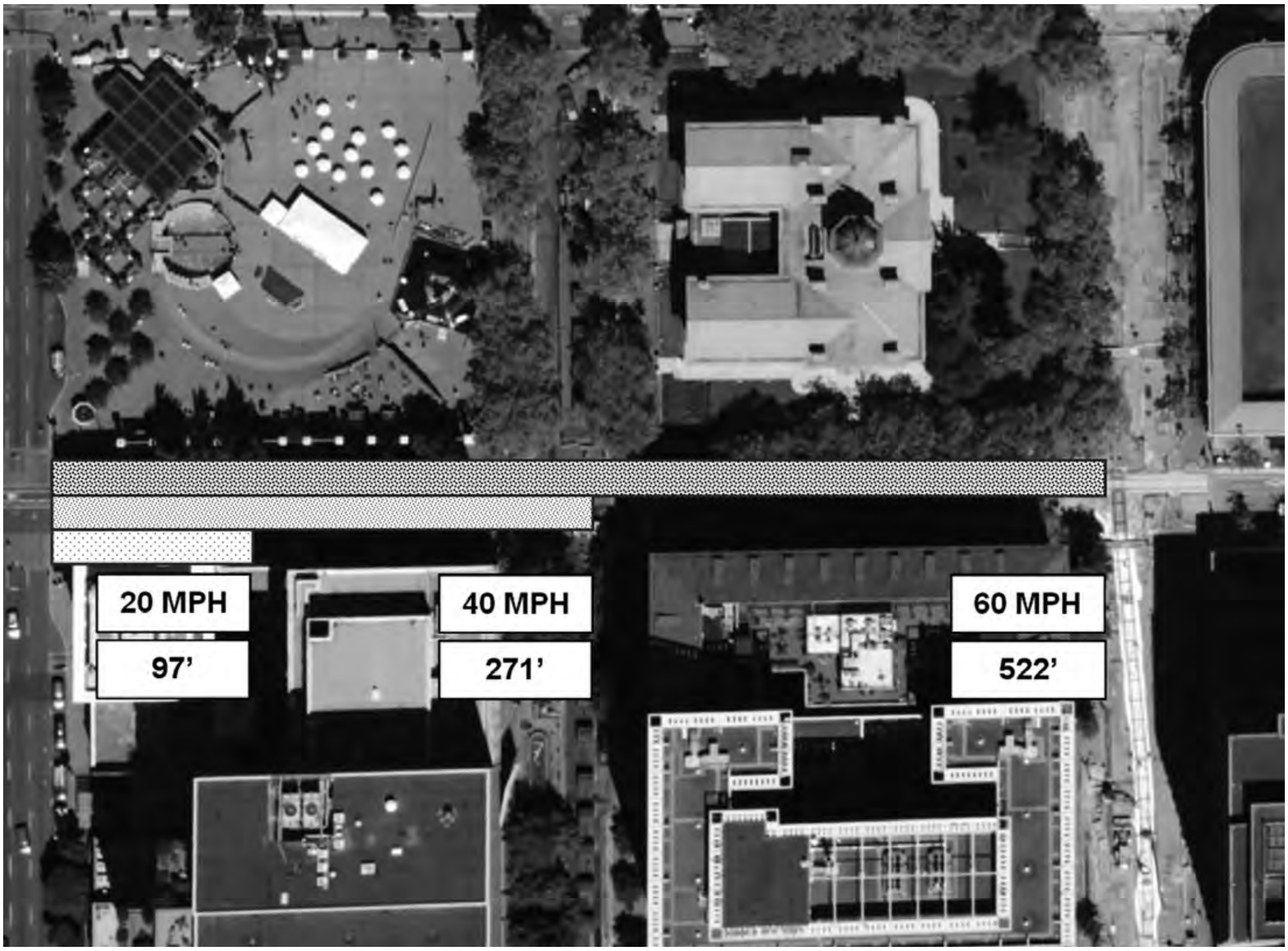

Figure 7. Average stopping sight distances for different vehicle speeds, superimposed on the Portland, OR, street grid.

Note: The stopping sight distances in this figure assume a reaction time of 2 seconds, and a vehicle deceleration rate of 11.2 ft/s^2. They further presume that the driver is reasonably alert to oncoming hazards, is driving a vehicle that provides adequate braking performance, and maintains adequate pavement friction during deceleration. Actual stopping sight distances may increase substantially if a driver is not alert to oncoming hazards or is driving a substandard vehicle.

injurious crashes. By contrast, three-leg intersections were associated with fewer injurious crashes and more total crashes, although not at conventional levels of statistical significance. This apparent contradiction results from the differing effects that intersections have on traffic conflicts and vehicle speeds. Intersections are locations where conflicting streams of traffic cross, creating locations where crashes are more likely to occur. T-intersections are safer than four-way intersections in that they produce fewer intersection conflict points. Nonetheless, both intersection types force through-moving vehicles to decelerate, if not to stop completely (U.K. Department for Transport, 2007), which in turn reduces impact speeds, and thus the incidence of fatal crashes. All else equal, hybrid street networks, which contain dense concentrations of T-intersections, appear to be preferable to either disconnected residential subdivisions or gridiron configurations.

Nevertheless, the safety performance associated with the presence of intersections in a community is a result of their mixed effects on speed and traffic conflicts. Design strategies that target these effects directly are likely to offset the disadvantages associated with any specific network or intersection type. Traffic calming devices such as speed humps, chokers, and chicanes reduce speeds even where intersections are infrequent. Likewise, modifications in the type of intersection control used in well-connected street networks may help reduce both traffic conflicts and crash incidence. Roundabouts and traffic circles, which reduce conflict points between opposing streams of traffic, have proven very effective at reducing crash incidence, and appear promising for balancing traffic safety with network connectivity (Ewing, 1999; Zein, Geddes, Hemsing, & Johnson, 1997).

With the exception of a limited number of speed humps, the City of San Antonio does not use traffic calming devices. Given this, our study results reflect only the safety effects of the presence or absence of intersections. While we conclude that hybrid street networks are likely preferable to other network configurations, we strongly suspect that using other network configurations with an appropriate suite of traffic calming and traffic control devices may provide safety benefits that are equivalent or even better. On this subject, future research is needed.

Density and VMT

Finally, it is important to observe that this study's findings for population density differed notably from those of previous studies, which reported population density to be a significant crash risk factor. Our study, which addresses the built environment in a more comprehensive manner, found population density to be associated with significantly fewer total and injurious crashes. While the safety benefits of higher densities are minor at the level of the individual neighborhood, we suspect that the benefits may be agglomerative at larger geographic levels. Individuals living in higher density environments drive less (Ewing & Cervero, 2001), thus reducing their overall exposure to crashes. When these reductions in VMT are aggregated across a larger population, they can potentially add up to notable reductions in population-level crash incidence. Indeed, this is strongly suggested by a recent study by Ewing, Scheiber and Zegeer (2003) which found that more sprawling counties, characterized by lower residential densities and larger blocks, experienced significantly higher traffic fatality rates than denser, more compactly developed counties. Differences in per person VMT are likely responsible for at least part of this difference. As with intersections and network configurations, however, future research is needed to understand the moderating influence that VMT may have on developmental density and crash incidence.

Implications for Planning Practice

Considered as a whole, these results have three implications for professional practice. Each is addressed below.

1. Manage the Mobility and Access Functions of Urban Arterials

While urban arterials are typically designed and intended for vehicles operating at higher speeds, the presence of commercial and retail uses forces them to accommodate lower-speed, access-related functions as well, resulting in the speed differentials and traffic conflicts that produce traffic crashes. Two strategies are available for addressing the problem of mixed traffic on urban arterials. The first is *access management,* which attempts to enhance the arterial's mobility function by reducing or eliminating its access function. This is typically achieved by consolidating or eliminating arterial driveways, installing a raised median to restrict left-turning movements, and increasing the spacing between signalized intersections, preferably to distances of half a mile or more (Florida Department of Transportation, 2006; Transportation Research Board, 2003). While access management has proven effective at both reducing crashes and increasing vehicle operating speeds (Dumbaugh, 2006a), it does so by designing arterials to have the limited-access characteristics of freeways, and is a solution more appropriate to suburban, rather than urban environments. The higher operating speeds and greater spacing between signalized intersections access management requires make it more difficult to provide safe pedestrian crossings and limits direct access to development.

In areas where pedestrian activity is present or expected, or where eliminating a roadway's access function is either undesirable or inappropriate, the primary alternative to access management is to reduce operating speeds to levels that are compatible with the street's access-related functions (see Figure 8). This approach, sometimes referred to as the *livable street* approach, incorporates design features that encourage lower operating speeds, such as making buildings front on the street, incorporating aesthetic street lighting or landscaping along the roadside, enhancing the visual quality of pavement and signage, and adopting traffic calming or intersection control measures. In short, livable streets emphasize access over mobility. When compared to conventional arterial treatments, livable streets report roughly 35–40% fewer crashes per mile traveled, and completely eliminate traffic-related fatalities (Dumbaugh, 2005a; Naderi, 2003).

2. Orient Retail and Commercial Uses Toward Lower-Speed Thoroughfares

Safety may be further enhanced by orienting retail and commercial uses towards lower-speed thoroughfares. Two strategies can accomplish this. The first, often promoted by advocates of neotraditional development, is simply to design urban arterial thoroughfares for lower operating

Figure 8. Conventional (top), access-managed (middle), and livable (bottom) urban arterial configurations.

speeds. In response to concerns about excessive speeds on urban arterials, the Institute of Transportation Engineers and the Congress for the New Urbanism have partnered to develop specifications for three new thoroughfare types (boulevards, avenues, and commercial streets) intended to carry arterial traffic volumes at design speeds of 35 miles per hour or less (Institute of Traffic Engineers, 2006).

The second approach, often employed by access management proponents, is to require developments located along arterials to incorporate *internal access lanes* that manage their connections to the arterial system. These access lanes are lower-speed, collector-type facilities that consolidate the traffic generated by a development and channel it toward a managed arterial location. Increasingly, developers have begun designing access lanes to look and function like traditional urban commercial streets (see Figure 9). The effective result of providing access lanes is to relocate access-related traffic away from the arterial thoroughfare, and onto lower-speed streets that are better able to safely accommodate onsite circulation and access.

3. Plan Land Use, Speed Management, and Access Control at the Scale of the Network

Urban traffic safety is more complicated than simply configuring individual streets and land uses to prevent residential cut-through traffic, and there is no one-size-fits-all solution to the resulting safety problems that occur on urban arterials. Instead, safety requires community-level design solutions that pay attention to how different land use and street network configurations influence vehicle speed and systematic design error. Residential, commercial, and retail uses all require access, and are likely to attract substantial pedestrian traffic as well, particularly when these uses are clustered together. Addressing safety in these environments requires streets and street networks that are designed to both encourage lower-operating speeds and meaningfully accommodate local access and circulation needs. By contrast, safety on higher-speed, mobility-oriented thoroughfares is enhanced when access to these facilities is strictly managed to reduce the hazards posed by traffic conflicts and speed differentials.

While our results suggest that hybrid street networks are preferable to gridiron or functionally separated networks, the thoughtful use of traffic calming and intersection control at the network level is likely to remedy the deficiencies of particular development configurations. Considered broadly, it is the tension between speed and access that leads to crash incidence, and many design configurations may be able to address this conflict.

Figure 9. Site plan for a lifestyle center retail configuration at the intersection of two urban arterials.

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Conclusion

Designers during the early half of the 20th century were rightly concerned about the safety effects of four-way intersections and gridiron street networks, and this study should not be used to infer that a return to 19th century gridiron street configurations is desirable. Instead, our results suggest that many of the community design practices that became conventional responses to these concerns, such as the development of functionally designed streets and street networks and the relocation of commercial and retail uses to arterial thoroughfares, are practices that have substituted one set of safety problems for another.

We have attempted to identify general trends in the relationship between community design and crash incidence, and have examined the existing safety literature to outline likely causes and potential solutions. Yet, cross-sectional analyses like this one should not be used to derive explicit inferences about causality. Future research is needed to develop our professional understanding of how community design affects behaviors that lead to traffic crashes, as well as how it affects the frequency and severity of crashes that occur. With these caveats in mind, we conclude by observing that the relationship between community design and traffic safety is an important one, and that the activities of planners can advance, or hinder, urban traffic safety objectives. It is our hope that this study will serve as a starting point for better understanding the relationship between community design and traffic safety.

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Notes

1. Traffic volumes for select local roadways were also provided, but because of the limited number of roadways for which local ADT was available (only about 10% of all local road mileage in the city) we omitted this information from our calculation of VMT.

2. Risk homeostasis theory, as detailed by Wilde (1994), asserts that individuals make decisions on whether to engage in specific behaviors or activities by weighing the relative utility of an action against its perceived risk. While all actions involve some risk, risk homeostasis theory asserts that individuals will adjust their behavior to maintain a static level of exposure to perceived hazard or harm. With respect to driving behavior, risk homeostasis theory posits that drivers intuitively balance the relative benefits of traveling at higher speeds or engaging in other risky behavior against their individual perceptions of how hazardous engaging in such behavior might be.

3. Stopping sight distance is the sum of the brake reaction distance (the distance traveled during the time between when a driver observes a hazard and when he or she applies the brakes), as well as the braking distance itself (American Association of State Highway Transportation Officials, 2004).

4. Perry (1939) struggled with the issue of pedestrian safety on arterials, suggesting that "it might be possible to provide an underpass, accessible by stairs or a ramp, of each side of the street" or, in a notable flight of fancy, exceptionally wide bridges could be located over the arterial, resulting in "new store sites thus created 'out of the air'—literally in the air— . . . bring[ing] a revenue that would take care of both construction and maintenance" (p. 71).

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