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16. Abstract

This study seeks to understand how urban form—specifically land use and street network configurations—may influence the incidence of traffic-related crashes injuries and deaths. It begins with an historic overview of the safety concepts that directed community design practice during the 20th century and details how these design concepts transformed themselves into contemporary community design practice. It details the development of a database of crash incidence and urban form at the block group level for the City of San Antonio, the first such database of its kind. Data acquired from this database are then modeled using negative binomial regression models to determine how urban form may be associated with the incidence of traffic-related crashes, injuries, and deaths at the block group level. It finds that the presence of arterial thoroughfares, strip commercial uses, and big box stores are significantly related with increased crash risk, while the presence of more traditional, pedestrian-scaled retail configurations are associated with a reduction in crash incidence. The population density of a block group was similarly associated with a reduction in crash incidence. Intersections had a mixed effect, reducing fatal crashes, but at least in the case of 4-leg intersections, also increasing the incidence of total and injurious crashes. Based on these findings, this study discusses the implications for design practice and outlines three strategies for enhancing traffic safety through community design.

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Examining the Relationship between Community Design and Crash Incidence

by

Eric Dumbaugh
Department of Landscape Architecture and Urban Planning

Robert Rae
Department of Landscape Architecture and Urban Planning
&
Douglas Wunneberger
Department of Landscape Architecture and Urban Planning

Performing Agency:
Texas A&M University

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College Station, Texas 77843-3135

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Abstract

This study seeks to understand how urban form—specifically land use and street network configurations— may influence the incidence of traffic-related crashes injuries and deaths. It begins with an historic overview of the safety concepts that directed community design practice during the 20th century and details how these design concepts transformed themselves into contemporary community design practice. It details the development of a database of crash incidence and urban form at the block group level for the City of San Antonio, the first such database of its kind. Data acquired from this database are then modeled using negative binomial regression models to determine how urban form may be associated with the incidence of traffic-related crashes, injuries, and deaths at the block group level. It finds that the presence of arterial thoroughfares, strip commercial uses, and big box stores are significantly related with increased crash risk, while the presence of more traditional, pedestrian-scaled retail configurations are associated with a reduction in crash incidence. The population density of a block group was similarly associated with a reduction in crash incidence. Intersections had a mixed effect, reducing fatal crashes, but at least in the case of 4-leg intersections, also increasing the incidence of total and injurious crashes. Based on these findings, this study discusses the implications for design practice and outlines three strategies for enhancing traffic safety through community design.

Executive Summary

While there has been a great deal of examination into the role that roadway geometry may have on crash incidence, there has been almost no consideration into the role that community design may have on crash incidence. That this is so is somewhat surprising, since most of the design features that characterize contemporary community design practice—such as designing streets for specific traffic functions, designing residential street networks to eliminate cut-through traffic, and relocating commercial and retail uses away from residential areas—were all design practices that were developed during the first half of the 20th century as designers sought to address the traffic safety problems created by growing automobile ownership.

Two ideas directed these design practices. The first was that safety could be best addressed by designing roadways for their specific traffic functions. Streets intended for automobile traffic should be designed to safely accommodate automobile traffic by designing these thoroughfares to be wide and straight and by eliminating intersections along their length. Neighborhood streets, by contracts, should be designed to minimize the amount of non-local traffic by introducing indirection along the street alignments and ultimately, by disconnecting them from the arterial system. Such practices resulted in the development of the contemporary functional classification system.

The second safety idea was that the placement and design of land uses should re-enforce the functional separation of traffic. Directed by the Clarence Perry's neighborhood unit concept and embodied in Clarence Stein's design of Radburn, traffic generating uses, such as retail and commercial uses, were to be moved outside of the boundaries of residential neighborhoods and onto the arterial thoroughfares that bounded them. Such practices were presumed to benefit residents and retailers alike by removing non-residential traffic away from residential areas, while allowing retailers to capture sales from pass-by traffic.

While the safety benefits of such practices make intuitive sense, there has been little formal inquiry into their effects on crash incidence. The guiding work on the subject is a 1957 study by Harold Marks finding that "limited access communities"—specifically, disconnected residential subdivisions—reported fewer crashes than residential communities located along gridded street networks. This study did not, however, control for differences in traffic volumes across the neighborhoods, nor did it consider the safety effects of reorganizing street networks and land uses. Eran Ben-Joseph conducted a similar study in 1995 and largely replicated Marks' findings.

Given the widespread adoption of the design practices promoted by Stein and Perry, as well as the corresponding lack of formal inquiry into their safety effects, we sought to understand how community design influences crash incidence. To do so, we developed a GIS-based database of crash incidence and urban form for the City of San Antonio that

includes detailed information on crash location and severity, street and street network characteristics, parcel-level land use information, neighborhood demographic characteristics, as well as local vehicle miles traveled (VMT). Variables derived from this database were then examined in a series of negative binomial regression models to understand how urban form influences the incidence of total, injurious, and fatal crashes, while controlling for the effects of neighborhood demographics and VMT.

In general, we find that the safety assumptions employed in contemporary community design practice are not supported by the empirical evidence. Even after controlling for VMT, the presence of arterial thoroughfares within a community has profoundly negative effects on crash incidence. Similarly, the presence of arterial-oriented commercial and retail uses and big box stores were also found to increase crash incidence. Conversely, the presence of neighborhood-oriented, pedestrian-scaled commercial and retail uses were associated with a reduction in total and injurious crashes. Higher population densities were likewise associated with reductions in the incidence of total and injurious crashes. The presence and configuration of intersections within a community had a mixed effect on crash incidence. Both 3-leg and 4-or-more leg intersections were found to be associated with reductions in fatal crashes, although 4-or-more leg intersections were also associated with increases in total and injurious crashes.

Considered as a whole, much of the urban traffic safety problem can be understood as the result of designs that mix access and mobility functions. This is clearly evident with the findings on arterial thoroughfares, which were strongly associated with increases in crash incidence. While designed to accommodate higher-speed, mobility-oriented traffic, urban surface streets must typically accommodate lower-speed roadway users as well. The result is the introduction of speed differentials into the traffic stream, which increases the incidence of traffic-related crashes. The problem of speed differentials is exacerbated by the presence of strip commercial uses and big box stores, which increases the amount of lower-speed, access-related traffic occurring along the arterial. That the problem is related to access, and not simply speed, is evident in the findings for freeways, which are designed to eliminate access-related traffic and which were not found to be associated with increases in crashes. Nonetheless, along streets that are likely to experience access-related traffic, or which are likely to need to accommodate lower-speed users such as pedestrians and bicyclists (which is to say, most urban surface streets), speed is the principal safety problem and can be best addressed by designing the streets and surrounding land uses to encourage lower operating speeds.

Based on these findings, this study presents three recommendations for enhancing community design practice to address safety. The first is a need to ***manage the mobility and access functions of urban arterials***. While urban arterials are typically designed and intended for higher-speed vehicle operations, 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. 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 at distances of a ½ mile or more. While access management has

proven effective at both reducing crashes and increasing vehicle operating speeds, it does so by designing arterials to have the limited-access characteristics of freeways and is a solution more appropriate to suburban environments rather than urban ones. The higher operating speeds and greater spacing between signalized intersections found on these roads complicates safe pedestrian crossings and limits developmental access.

In areas where pedestrian activity is present or expected, or where eliminating a roadway's access function is either undesirable or contextually-inappropriate, the primary alternative to access management is to reduce operating speeds to levels that are compatible with its access-related functions. This approach, sometimes referred to as the *livable street approach*, incorporates design features intended to encourage or enforce lower operating speeds, such as aligning buildings to the street, incorporating landscaping or street appurtenances along the roadside, enhancing the aesthetics of pavement and signage, and incorporating other elements intended to explicitly reduce operating speeds, such as traffic calming and full intersection control. In short, access-serving streets should be designed to prioritize access over speed.

Safety may be further enhanced by ***orienting retail and commercial uses towards lower-speed thoroughfares***. Two strategies can be readily applied to accomplish this. The first, often promoted by advocates of neo-traditional development, is to simply design arterial thoroughfares in urban areas for lower operating speeds. In response to concerns about excessive speeds on urban arterials, the Institute of Transportation Engineers (ITE), in partnership with the Congress for the New Urbanism (CNU), are developing design specifications for three new thoroughfare types—boulevards, avenues, and commercial streets—that are intended to carry arterial traffic volumes at design speeds of 35 MPH or less. 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 towards a managed arterial location. Increasingly, developers have begun designing access lanes to look and function like traditional urban commercial streets. Regardless of their specific configuration, the effective result of the provision of access lanes is to relocate access-related traffic from the arterial thoroughfare and onto lower-speed streets that are better able to safely accommodate on-site circulation and access.

Finally, there is a need for a ***network-level approach to land use planning, speed management, and access control***. Traffic safety is a more complicated matter than simply configuring 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 is likely better advanced through community-level design solutions that pay attention to how different land use and street network configurations may influence vehicle speed and systematic design error. Residential, commercial, and retail uses all require developmental access and are likely to attract pedestrian traffic as well, particularly when clustered together. Addressing safety in these environments will likely require streets and street networks to be designed to encourage lower-operating speeds and meaningfully accommodate local access and circulation needs. By contrast, safety on higher-speed, mobility-oriented thoroughfares appear to be best enhanced when

access to these facilities is strictly managed to reduce the hazards posed by traffic conflicts and speed differentials.

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1

Introduction

Whether measured in absolute numbers or in terms of traffic fatalities per capita or per mile traveled, the United States has the most dangerous transportation system in the developed world (World Health Organization, 2004; TRB, 2006). Traffic fatalities are currently the 6th leading cause of preventable death in the United States (Mokdad et. al, 2004), and with the developing world increasingly adopting US-style development patterns and automobile usage rates, the World Health Organization (2004) estimates that traffic fatalities will become the 6th leading cause of preventable death worldwide over the next decade. And the societal costs are enormous. A recent report published by the American Automobile Association estimated that traffic crashes cost the United States more than $160 *billion* each year, roughly two and a half times the better-publicized annual costs of congestion (Cambridge Systematics and Meyer, 2008).

If this safety picture weren't bleak enough, there appear to be few meaningful gains to be made using conventional traffic safety strategies. Traffic fatality rates in the US have held constant in recent years[1] due principally to increases in seat belt use and the demographic characteristics of the driving population (Noland, 2001, Noland and Oh, 2004). Yet seat belt usage rates currently exceed 80% nationally, indicating that only marginal safety gains can be made through increased compliance (NHTSA, 2009). More problematically, the pool of eligible drivers is moving from one consisting of predominantly middle-aged and less crash-prone drivers, to one that is comprised of larger shares of both younger (under 25) and older (over 65) drivers, the two age groups most likely to be involved in an injurious or fatal traffic crash (NHTSA, 2006). One author, using conservative projections of future licensure rates and mileage, estimated that the number of traffic fatalities involving drivers over the age of 65 will *triple* in the US by 2030 (Hakamies-Blomqvist, 2004).

What can be done to stem the tide of traffic-related deaths and injuries? While contemporary planners often relegate traffic safety issues to the fields of traffic engineering and law enforcement, this has not traditionally been the case. Traffic safety was a central concern to the profession during the first half of the 20th century, as planners sought to address the effects of automobile use on the safety and livability of urban neighborhoods. Indeed, many of the site and community design practices that have come to embody conventional community design, including 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 study revisits the profession's relationship with traffic safety to better understand how the activities of planners may influence the incidence of traffic-related deaths and injuries. Chapter 2 details the historical concerns about traffic safety, as well as the types of community design strategies that were developed to address them. Because there have been few empirical studies examining the actual safety effects of the resulting practices, Chapters 3 and 4 detail a study aimed at understanding how community design influences crash incidence. Chapter 3 details the assembly of a GIS-based database of urban form and crash incidence, while Chapter 4 presents the results of analyses aimed at understanding how community design includes the incidence of traffic-related crashes, injuries, and deaths. Finally, Chapter 5 revisits the relationship between community design and crash incidence in light of these findings, discussing the specifics means by which urban form may influence crash incidence and detailing three community design strategies that are likely to effectively reduce crash incidence.

2

Traffic Safety and Community Design in the 20th Century

Any attempt to understand the historical relationship between planning and traffic safety must begin with an understanding of the "grid-iron" street network. While often romanticized by contemporary proponents of neo-traditional development, the urban grid was popular in the 19th century not as a means for promoting pedestrianism, but instead as a tool for encouraging the rapid development of unsettled land. Streets were typically designed at uniform widths, and spaced at equal intervals, with the net effect of maximizing the number of "premium" corner lots, and making each street as accommodating to development as the next. While some cities, like Savannah, incorporated public spaces and street termini into their designs, more common was the application of the concept in cities like New York and Chicago, which simply expanded the grid *ad infinitum* towards the horizon, permitting interruptions only where required by physical necessity (Kostof, 1991; see Figure 1).

The 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 early decades of the 20th century, gridded street networks had the side effect of making each street as accommodating to motor vehicle traffic as the next, creating unwanted conflicts between motor vehicle traffic and residential and recreational uses. In a critique of the grid, no less than Frederick Law Olmstead (Jr.) 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" (1916, p. 8). In Olmstead's view, safety, aesthetics, and operational efficiency could all be enhanced if the profession moved away from standardized street arrangements and toward streets and networks designed to accommodate specific and distinct traffic functions. He also knew of a precedent for such a radical departure from the grid: his father's design for Central Park.

Traffic Safety and the Functional Design of Urban Thoroughfares

One of the major issues that the senior Olmsted confronted when designing Central Park was the need for cross-access between the eastern and western edges of Manhattan. The large scale of the park meant that many of the park's users would not be casual recreational users seeking to commune with nature, but would instead be "coal carts and butcher's carts, dust carts, and dung carts; engine companies… those on one side of the park rushing their machines across it with frantic zeal at every alarm from the other" (Olmstead 1858, in Olmstead. Jr., and Kimball, 1922, p. 217) (See Figures 2 and 3). To

maintain the park's aesthetic integrity, Olmstead's solution was to remove this non-recreational traffic from the park's surface, relegating it to direct routes running beneath the park's surface. As Olmstead 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" (Olmstead, 1872, in Olmstead Jr., and Kimball, 1922, p. 47).

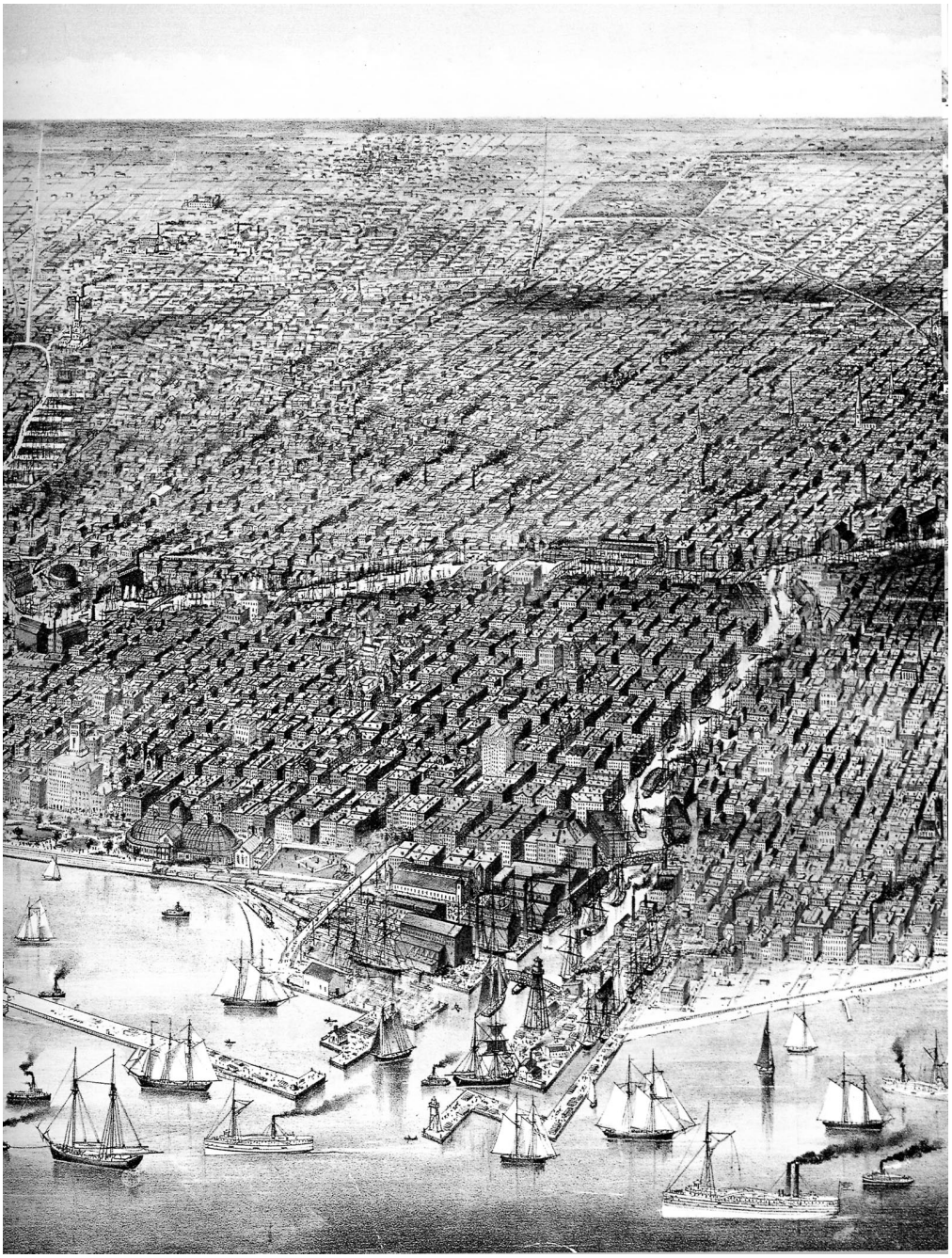


Figure 1 Chicago's Expanding Grid (Currier and Ives, 1892)

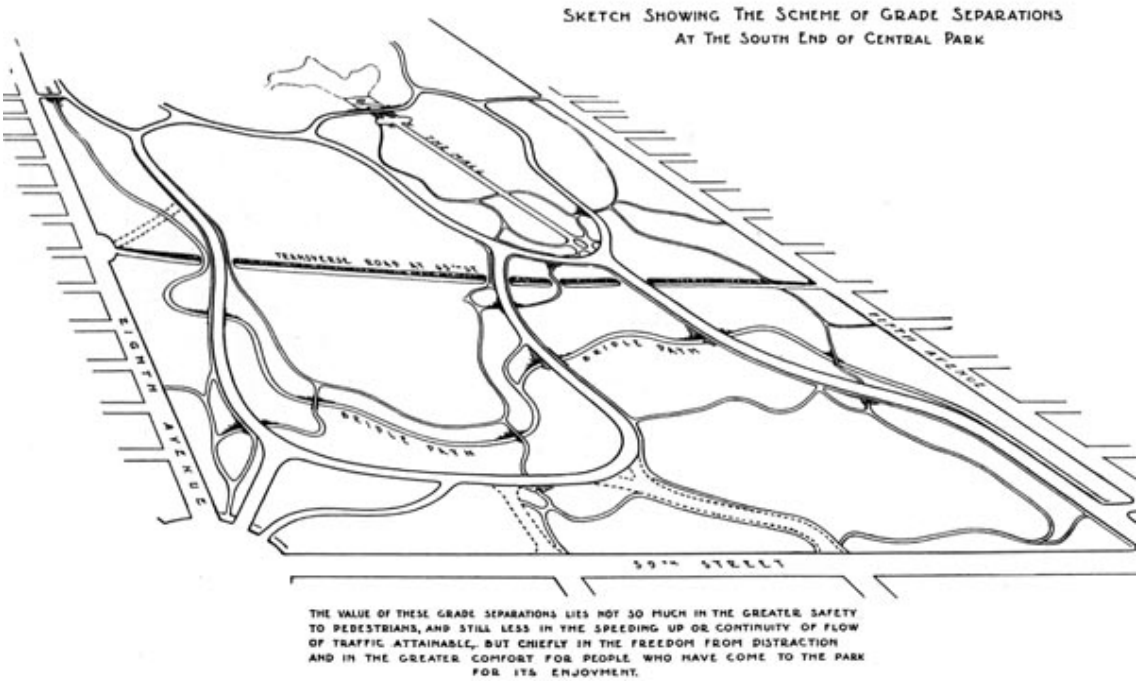


Figure 2 Olmstead's Plan for Transverse Roads in Central Park (Olmstead, 1858)

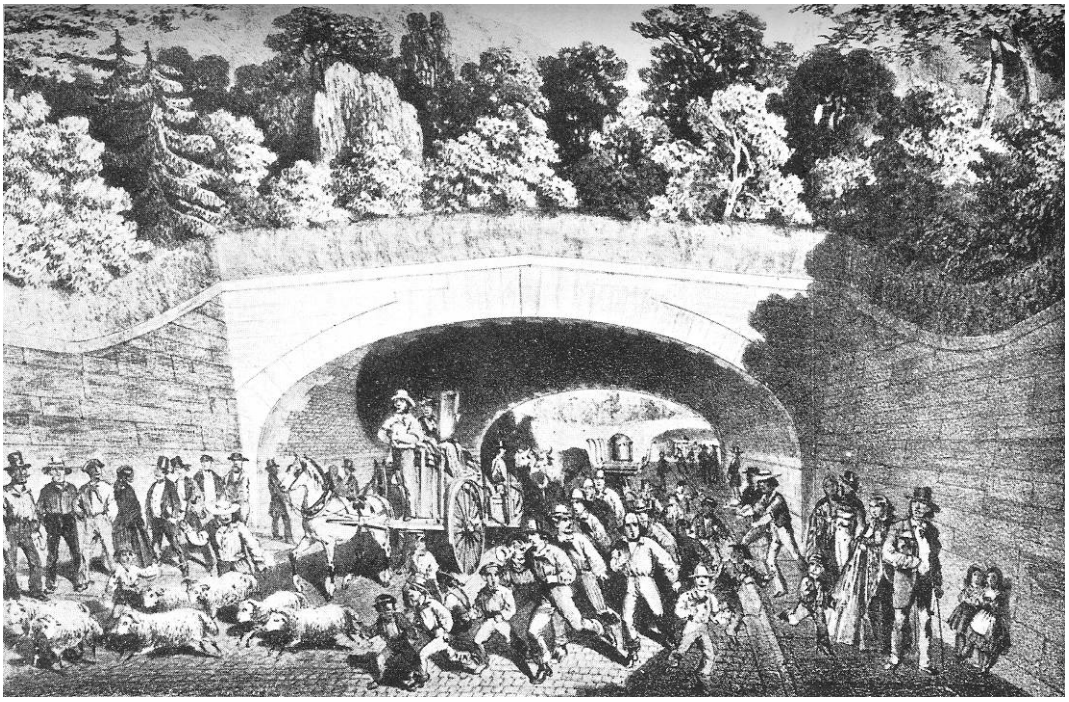


Figure 3 Olmstead's Depiction of Riff-raff using the Central Park's Transverse Roads (Olmstead, 1859)

For Olmstead Jr., the lessons of Central Park could be applied to address the automobile-related traffic issues of the 20th century. To wit, planners should attempt to separate vehicular traffic from recreational or neighborhood traffic through the design of roadways intended for each exclusive function.

This idea was carried forward into what is perhaps the first automobile-era manual on street design, entitled *Width and Arrangement of Streets* (Robinson, 1911). In this critique of the grid, Robinson "plead[s] for less standardization, for widening main streets, and for narrowing those which have little traffic value" (p. 3). While this manual provides detailed street specifications, what is essential for understanding of its influence on community design is not Robinson's recommended designs (which, except for his generous sidewalk provisions, are much narrower than contemporary urban streets), but instead the designation of a community's streets to serve specific *functional* purposes, with roadways classified as belonging to two principal types. The first are:

> "main traffic 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).

Community streets, by contrast, should be designed with…

> "…some permanent physical handicap, such as indirection, heavy grades or a break in continuity. Their traffic function, as regards the street plan… is only to harbor the little eddies left at the side by the mighty streams of travel which flow main thoroughfares" (pp. 10-11).[2]

Collectively, this approach was intended to enhance safety by channeling traffic away from residential neighborhoods and onto facilities better designed to accommodate automobile use. While such an approach makes intuitive sense, what about the safety of these new "main traffic channels"? In the 1916 text *City Planning*, an early professional guidebook edited by John Nolen, Benjamin Haldeman makes the case, asserting that

> "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" (p. 288).

There are two safety ideas embedded here. The first, which represented a radical departure from the urban grid, was to eliminate intersections along the main thoroughfare and thus disconnect it from the surrounding street network. Eliminating intersections

would eliminate the number of conflicts created by vehicles and pedestrians attempting to cross the main thoroughfare, thereby reducing the likelihood that crashes would occur. The second strategy was to design these roadways to be as wide and as straight as possible, which would enable a motorist to see a potential hazard in the right-of-way well before they physically encountered it, providing the driver with ample time to decelerate or change course.

Taken as a whole, these thoroughfare concepts provided the theoretical foundation for the modern functional classification system, which categorizes a roadway as being an arterial, collector, or local roadway based exclusively on its intended traffic function, and which is the guiding framework used in the design of contemporary urban thoroughfares (American Association of State Highway and Transportation Officials [AASHTO], 2004). Of particular importance is the emergence of a new type of urban thoroughfare—the urban arterial—which was intended to carry heavy traffic volumes at high operating speeds.

Perry, Stein, and the Advent of Conventional Community Design

While Olmstead and others provided a conceptual framework for the design and configuration of "safe" urban street networks, it was Clarence Perry and Clarence Stein who translated these ideas into contemporary community design practice. 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. Instead, Perry promoted the idea of a neighborhood unit, designed as a self-contained community large enough to populate a neighborhood elementary school (6,000-10,000 people). Following the guidance of Olmstead and Haldeman, its street network would be "designed to facilitate circulation within the unit and to discourage its use by through traffic" (p. 51). To address the needs of motorists, the neighborhood would be surrounded by wide arterial thoroughfares. As Perry describes the concept:

> "The most important reason for wide highways as boundaries arises from their relation to *street safety*. The unit district is not too large… to be treated as a partly closed cell in urban street systems, without doing violence to the highway requirements for general circulation. With adequate express channels in the circumference of the unit, through traffic will have no excuse for invading its territory, and its own internal streets can fairly and deliberately be made inconvenient and forbidding for vehicles having no destination within the neighborhood confines" (*emphasis added*, Stein, 1957, p. 56).

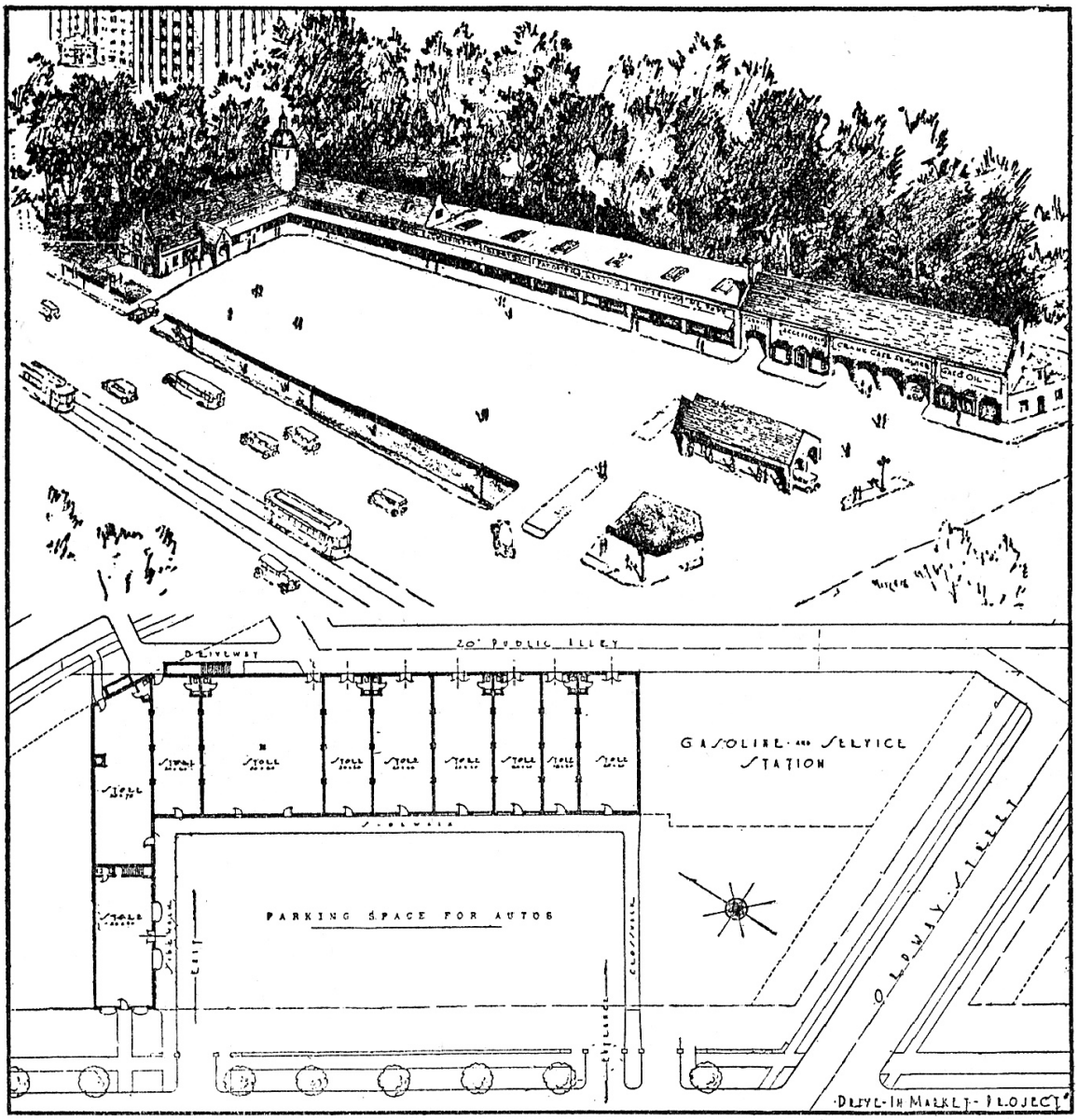
Perry's professional contribution extended beyond simply reconfiguring the street network, however; he also detailed strategies for enhancing traffic safety through the rearrangement of land uses. To discourage unsafe cut-through traffic, the neighborhood unit would include only residential and neighborhood civic uses, such as schools and churches, within its confines. All other uses, including neighborhood-supporting

commercial and retail, would be removed to the arterial thoroughfares that bounded the community. While this relocation would require commercial and retail uses to be configured more towards the automobile than towards the pedestrian (see Figure 4), he nevertheless view this arrangement as a benefit to neighborhood residents and businesses alike:

> "It is the one of the advantages of the unit scheme that it makes good business locations definite and easily found. Each neighborhood, being a concentration of families, whose workers pass through one, two, or possibly three main portals, the canalization of traffic is automatic. These portals are naturally located at the… traffic junctions, on the main highways which bound the unit. Despite the telephone, the facile delivery services, and the automobile, residents frequently find is convenient to shop at a local store on their way to or back from "town." It is that convenience and the courses of the traffic streams which determine the neighborhood portals as the proper location for shopping districts" (Perry, 1939, p. 69).

While Perry developed the design ideas that would serve as the foundation of contemporary community design, it was Clarence Stein who gave these ideas their archetypal form. With guidance from Perry, Stein applied the neighborhood unit concept at Radburn to create "a town in which people could live peacefully with the automobile, or rather in spite of it… a setting for safe motor age living" (Stein, 1957, p. 37). Despite the attention given to Radburn's influence on contemporary community design (see esp. Garvin, 1995; Lee and Ahn, 2003; Parsons, 1994; Schaeffer, 1982), its intended role as a means for enhancing traffic safety is often overlooked. Stein designed Radburn *expressly* for the purpose of enhancing traffic safety. In describing "The Need for Radburn," Stein writes:

> "American cities were certainly not places of security in the twenties. The automobile was a disrupting menace to city life… 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. Porches faced bedlams of motor throughways with blocked traffic, honking horns, noxious gases. Parked cars, hard grey roads, and garages replaced gardens. It was in answer to such conditions that the Radburn plan was evolved" (Stein, 1957, p. 41).



DRIVE-IN-MARKET, WASHINGTON, D. C.
Parking space is required in urban neighborhood shopping districts

Figure 4 Representative Location and Configuration for Neighborhood Retail Uses (Perry, 1939)

To address these problems, Stein synthesized the design concepts outlined by Olmstead and Perry to design a disconnected residential subdivision, with "specialized roads 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, located along disconnected streets and culs-de-sac (see Figure 5).

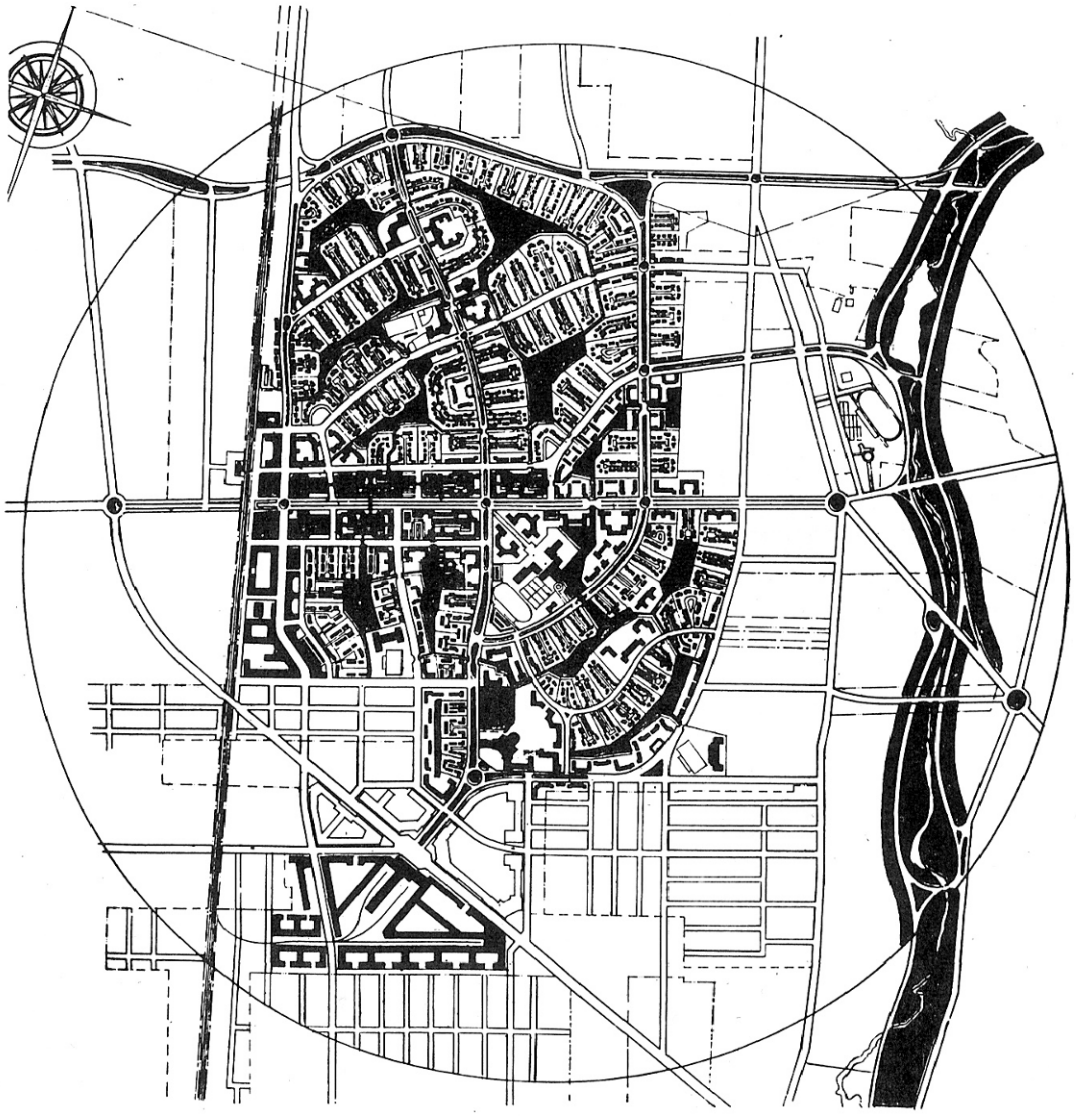


Fig. 28—Plan for the complete town.

Figure 5 Functionally-Classified and Use-Separated – Stein's Plan for Radburn (Stein, 1957)

These design concepts were subsequently institutionalized into contemporary development practices (Southworth and Ben-Joseph, 1995), and their lasting influence

can be readily seen in the shape and form taken by communities built during the latter half of the 20th century.

The (Limited) Empirical Basis for Conventional Community Design

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 a 1957 publication by Harold Marks entitled "Subdividing for Traffic Safety." In this work, Marks sought to examine whether the "limited-access" communities—specifically, disconnected residential subdivisions—were safer than gridiron configurations. In comparing the two types of communities, Marks found that gridiron neighborhoods had fully seven times the number of crashes as the limited access communities. He further looked at safety performance of 3- and 4-leg intersections. 3-leg ("T") intersections, whether located in gridiron or limited-access communities, reported fewer crashes than 4-leg intersections. 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 lead planners to disconnect residential street networks in the first place. Differences 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 re-arranging 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 non-residential 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.

During the last 50 years, the only study to formally revisit Mark's findings is a 1995 study by Eran Ben-Joseph, which examined crash frequency for 9 lower-density (6 DU/acre or less) suburban communities in the San Francisco Bay area, all of which were comprised of local streets carrying low traffic volumes (1,500 ADT or less). The communities were divided into three types based on their street network configurations: cul-de-sac, loop, or grid. 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, while cul-de-sac communities reported 2 crashes per 100,000 vehicle trips. In general, the study confirms Marks' earlier findings, although like Marks' study, it did not examine the safety effects of re-arranging land uses or re-routing 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, et al., 2003; Hadeyeghi et. al., 2006; Lovegrove and Sayed, 2006; Ladron et al., 2004). Where intersection density was examined, it was found to have mixed effects, with two studies finding higher intersection densities to be associated with increases in crash incidence (Hadeyeghi et. al., 2003; 2006), and one study finding them to be associated with significantly fewer crashes (Ladron et al., 2004). Nevertheless, one should be cautious about inferring specific design relationships from these results, as their units of analysis—TAZs or census tracts—are all too large to draw specific inferences on crash incidence at the level of the individual community.

3

Developing a Database of Crash Incidence and Urban Form

Given the widespread adoption of the safety practices espoused by Perry and Stein, and the surprising absence of supporting empirical research, this study sought to formally examine the relationship between urban form and crash incidence. To do so, we developed a GIS-based database on traffic safety and urban form for the City of San Antonio, the first such database of its kind, to our knowledge. This database includes geo-located crash data supplied by the San Antonio Police Department, parcel-level land use data supplied by the Bexar County Appraisal District, street and network information supplied by the San Antonio-Bexar County Metropolitan Planning Organization (MPO), information on traffic volumes, acquired from the Texas Department of Transportation and the City of San Antonio, as well as demographic information acquired from the U.S. Census. Synthesized together, this database permits the most detailed examination into the relationship between traffic safety and urban form attempted to date.

Data Sources

Data were collected and catalogued from multiple agencies, including information on crash incidence, roadway and road network characteristics, traffic volumes, land use characteristics, and demographic characteristics. These data sources, their provider, and the form in which they were provided, are detailed below.

Crash Data (Point Form Data)

San Antonio was selected for both theoretical and practical reasons. From a theoretical perspective, San Antonio is a high-growth sunbelt city containing a diverse array of design environments, ranging from an historic urban core, streetcar suburbs in the areas adjacent to downtown, and more conventionally-designed communities located on the City's periphery. As such, its overall form is diverse enough to provide the requisite level of design variation needed to meaningfully model the relationship between community design and crash incidence.

From a practical perspective, the selection of San Antonio allowed us to bypass a major practical barrier to examining traffic safety for large geographic areas—the difficulty of acquiring consistent and reliable information for crashes occurring on local streets. 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 the majority of the San Antonio metropolitan region is consolidated within the city limits (roughly 90% of the 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 (see Table 1).

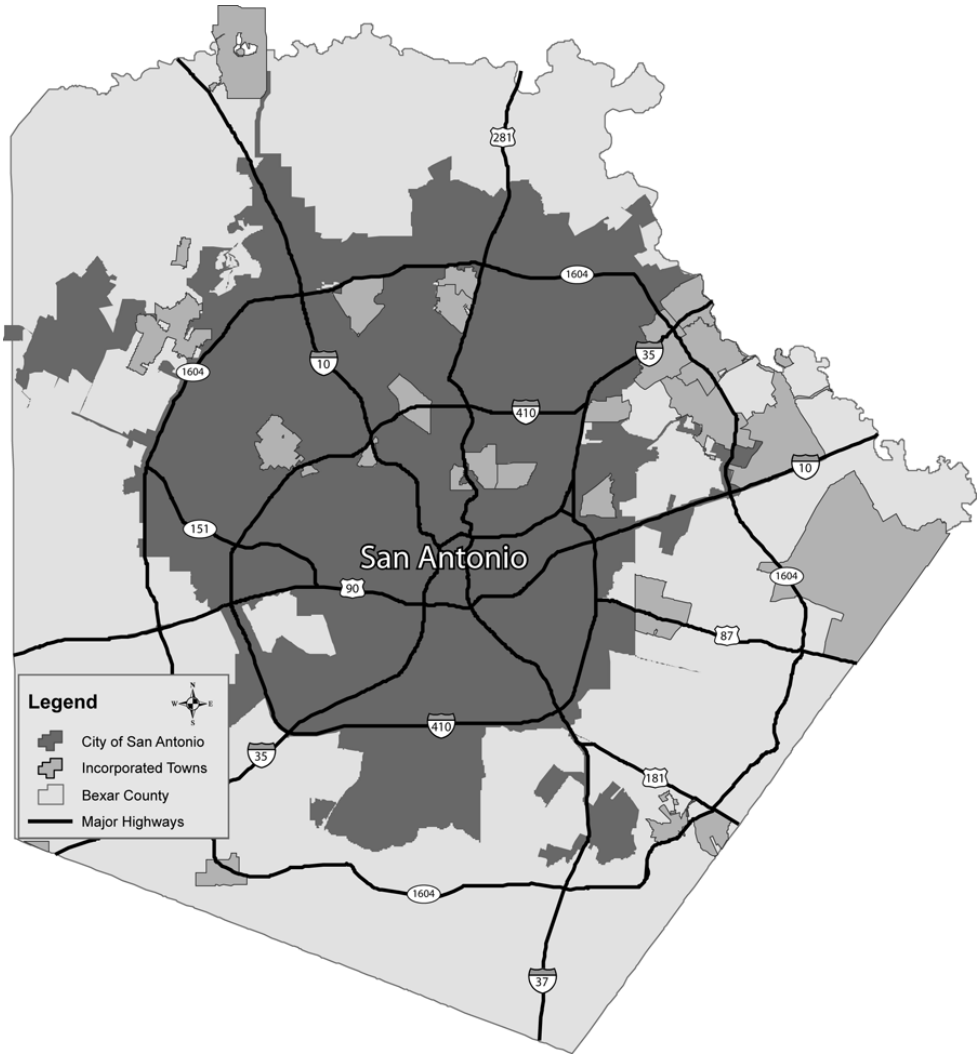


Figure 6 The San Antonio-Bexar County Metropolitan Region

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 the specific users involved in a crash (i.e., motorists, pedestrians, or bicyclists), nor do they provide information on crash type (e.g., sideswipe, angle, head-on, run-off-road, etc). As such, this analysis is limited to crash frequency and severity, rather than examining the incidence of specific crash types involving different user groups.

Different agencies within a metropolitan area are responsible for the collection and assembly of crash data. Federal planning requirements in the United States require state departments of transportation (DOTs) to compile and report crash data for all highways incorporated on state highway systems, which typically consist of roadways classified as freeways or principal arterial thoroughfares. These data are reported in a consistent and reliable manner, and as a result, most traffic safety analyses conducted in the U.S. rely heavily on state data for analyzing safety relationships. Nonetheless, the major shortcoming of these data are that they provide crash information for a very limited subset of the roadways in a metropolitan area—freeways and principal arterials incorporated onto state highway systems—and do not provide information pertaining to crashes occurring on lower-order roadways or for crashes occurring on private property, such as driveways or parking lots. Because this study was interested in safety at the community level, local crash data were essential for the success of this effort.

Table 1 Crash Incidence for the City of San Antonio, by Crash Type and Location, 2004-2006

	Fatal		Injurious		Total	
	Num.	**Pct.**	**Num.**	**Pct.**	**Num.**	**Pct.**
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%

Street and Street Network Data (Line Form Data)

U.S. metropolitan regions develop GIS layers of major roadways for use in federally-required regional transportation planning applications. Most, if not all, also supplement this with more comprehensive street network files to assist in planning and programming of local transportation improvements. Correspondingly, we were able to acquire information on the regional road network directly from the San Antonio-Bexar County

MPO. The roadway shapefile was provided in line form and included information on the location and mileage of all roadways in the metropolitan region, as well as their functional class (i.e., freeway, principal arterial, minor arterial, collector, local, freeway access lane, and freeway ramp). Note that there are two ways of quantifying roadway mileage: either by the total lane mileage, which is measured as the number of miles of a roadway multiplied by the number of lanes, or by the centerline mileage, which is simply the total miles of a facility, regardless of the number of lanes. Because the San Antonio data did not provide information on the number of lanes, we developed measures of the centerline mileage for each roadway class.

Another valuable source of information are the geometric characteristics of the roadways themselves, i.e., right-of-way width, the number of lanes, the presence or absence of curbing, and the widths of shoulders and medians, among others. Such information, when available, are typically also included in line form, dividing roadways up into road segments based on their design characteristics. Nonetheless, while many state departments of transportation compile these data for state highways, these data were unfortunately not available in a useable form for San Antonio. Some local jurisdictions may likewise have these data for roadways that are not located on the state highway system, although the availability and quality of such data are likely to vary across individual jurisdictions.

Intersections and Street Networks

Because the location and configuration of an intersection may affect crash incidence, we developed operational definitions of different intersections using the above described road file. We used the connectivity function in ArcMap to define intersection locations from the road network shapefile. False intersections (pseudo-nodes) were eliminated from the data set by identifying only nodes associated with three or more links (See Figure 7). As earlier research has found that 3-leg intersections report substantially-fewer crashes than 4-leg intersections (Marks, 1957), we proceeded to distinguish between these intersection types in our data. Each intersection was then defined as being 3-leg ("T"), 4-leg, or 5-or-more leg (see Figure 7).

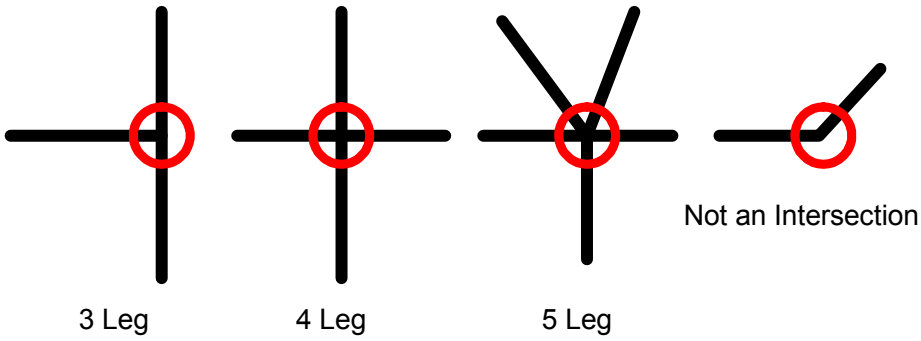


Figure 7 Operational Definition of an Intersection

Parcel-Level Land Use Data (Polygon Form)

Because local taxes are assessed on property values, tax appraisal districts typically maintain a parcel-level database of individual properties within their jurisdiction. In the case of the San-Antonio region, this information was collected by the San Antonio-Bexar County Appraisal district and included information on the boundaries, size, and values of parcels throughout the region, as well as the gross and rentable square footage of non-residential buildings location on the parcel. It also provided rough classifications of each parcel's land use, with parcels being designated as single-family residential, multi-family residential, rental apartments, commercial and retail uses, industrial uses, vacant properties, and tax exempt properties (e.g., governmental buildings, parks, and churches), among others. The square footage of commercial and retail uses and commercial apartments were likewise provided. These data were provided in polygon form.

The parcel-level data were then used to develop urban form indicators that would permit a more thorough examination of the role of urban design on urban form and crash incidence. Dumbaugh (2006b) found that roadways in more urbanized environments, characterized by street-oriented buildings and pedestrian-oriented roadside features, reported fewer crashes, injuries, and deaths, than roadways with more suburban characteristics. Conversely, arterial roadways with more suburban characteristics, such as arterial-oriented commercial uses and large parking lots, were found to report higher levels of crash incidence. To account for the effects that different developmental forms might have, we created the following measures.

Traffic Volumes (Point and Line Form)

While traffic volumes are often a significant predictor of crash incidence, assembling these data proved methodologically complex. The Texas Department of Transportation provided average daily traffic volumes (ADT) in linear form for all state highways (freeways and principal arterials) in the metropolitan area. The City of San Antonio supplemented this information with traffic counts at 804 locations off of the state system. These streets consist of all principal arterials, minor arterials, and collector roadways in the region. Traffic volumes for select local roadways were also provided, but because of the limited number of roadways for which local ADT was available (roughly 10% of all local road mileage in the City), we omitted this information from our calculation of VMT. As such, our data present ADT for freeways, arterials, and collectors.

A second issue related to the integration of the state and City ADT information. Unlike the state data, the City's ADT data were provided in point form. To make these data compatible, we converted the San Antonio point data into a linear form and extrapolated the corresponding point value for the length of the roadway (see Figure 8). Where multiple ADT values were present on a given roadway, the extrapolated values were extended outwards towards the midpoint between them. This procedure allowed us to merge the ADT information from both the State DOT and the City of San Antonio into a single, master ADT shapefile.

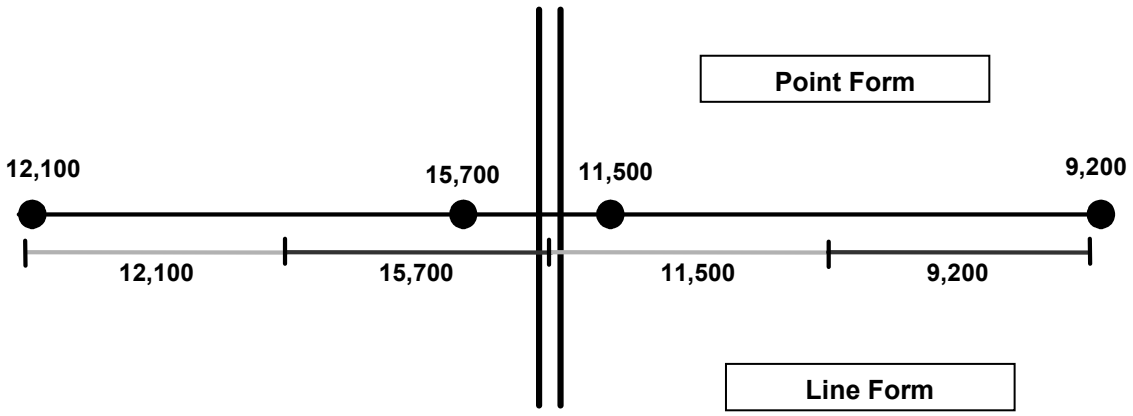


Figure 8 Converting ADT from Point Form to Line Form

Demographic Information (Polygon Form)

To account for the effect that population characteristics may have on crash incidence, we sought to further obtain information on the demographic characteristics of the local population. Demographic information is collected as part of the U.S. Decennial Census, and more recent data may be available from the MPO at the level of the traffic analysis zone. Because larger geographic units mask internal community design variation, we used census block groups, which provide accurate population information, but are nevertheless small enough to be relatively homogeneous in their design characteristics. Information available at the block group level includes total population of the block group, the number of persons by race, age, and sex, as well as information on median incomes and median home values.

Neighborhood-Level Database Assembly

While the definition of a neighborhood seems obvious at a nominal level, defining neighborhoods in an operational form proved methodologically complex. Each jurisdiction is likely to classify neighborhoods in a locally-unique manner, and there is no single "right" means for doing so. Because we sought reliable information on the demographic characteristics of a geographic area, we relied on block group definitions from the U.S. Census to determine neighborhood's boundaries. While such an approach best suited the larger research objectives of this effort, other neighborhood definitions are available, such as defining neighborhoods based on the jurisdictional boundaries of neighborhood or homeowner's associations.

Regardless of how neighborhood boundaries are operationalized, two additional issues that emerge are the methods for addressing micro-level spatial variation associated with the use of different GIS layers, as well as the related problem of how to meaningfully assign information occurring along a neighborhood's boundaries. Previous researchers developing crash forecasting models have sought to avoid these attribution problems by eliminating information occurring on the boundaries of their units of analysis (Ladron et

al., 2004). The problem with this approach, however, is that both TAZs and census geography typically use arterial thoroughfares as geographic boundaries. Since arterial roadways often carry an overwhelming share of the traffic generated by a community, and are thus likely to experience a large share of the crashes occurring in a community, the effective result of eliminating boundary information is that neighborhood crash incidence is likely to be severely underestimated.

To resolve this problem, we defined neighborhoods as being comprised of the block group itself, plus the streets along its edges. To capture the relevant information, we developed 200-ft buffers around each block group (roughly the Right-of-way width of a fully-designed principal arterial), and assigned the roadway and crash information occurring within the buffer area to the block group it adjoined (see Figure 9). This approach thus regards streets located on the edges of neighborhoods as being part of the neighborhood itself, an approach that roughly corresponds with the way individuals define the boundaries of their neighborhood. While such an approach does result in some streets and crashes being assigned to more than one neighborhood, it is important to reiterate that the unit of the analysis is the neighborhood, not the individual street or crash location. This operational decision provides a consistent framework for addressing problems associated with differences in the spatial definition of individual GIS layers, while also ensuring that essential information on crash incidence was not lost due to the means by which the unit of analysis was operationalized.

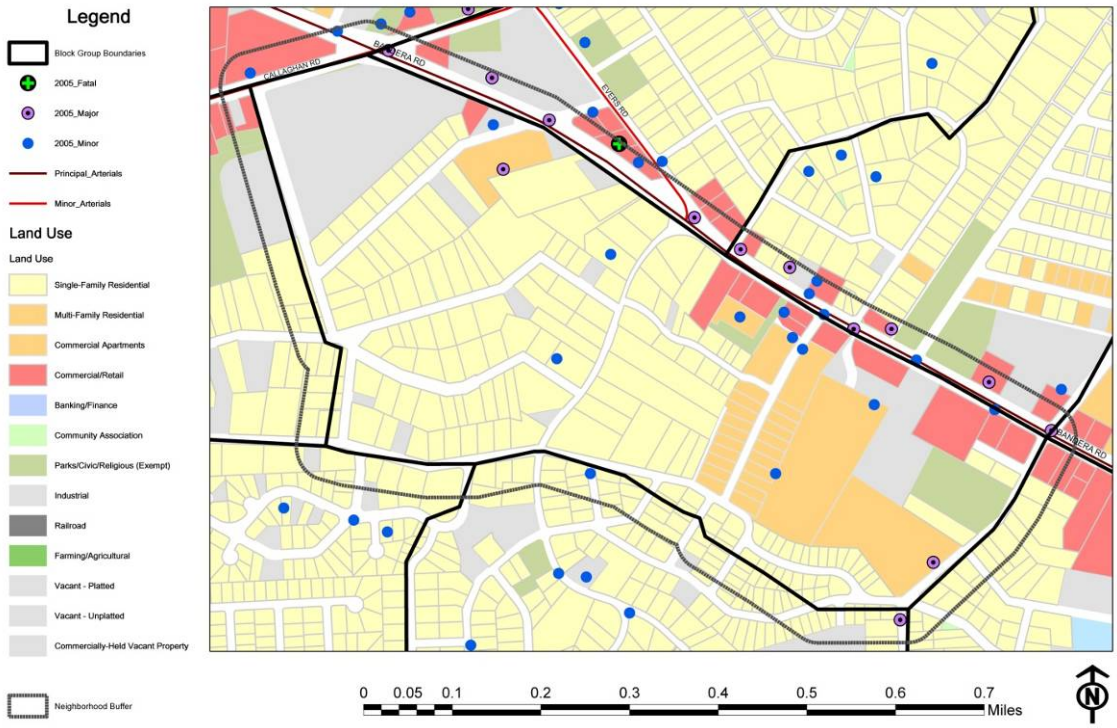


Figure 9 Illustrative Census Block Group and Buffer

Nevertheless, two remaining operational problems remain unresolved. The first is the modifiable area unit problem (MAUP), which relates to the effects that different geographic aggregations may have on the observed values for a variable of interest (Openshaw and Taylor, 1979). Because values for a specific variable, such as population or median income, will vary based on the manner in which an area is bounded, the specific values observed are not truly random, but are instead a product of the means by which a geographic area is defined. A second and related problem is the issue of spatial autocorrelation, which relates to the independence of our observations. Because the characteristics of a geographically-defined area are likely to be similar to, and perhaps influenced by, the characteristics of adjacent areas, the specific observations cannot be said to be truly independent. Such issues have not been examined in the context of traffic safety analyses and are an important area for future research.

Variable Development

Using this database of crash incidence and urban form, we proceeded to develop urban form indicators that we could examine for their effects on crash incidence. The following variables were included in the models:

- Block Group Acreage. Under conventional practices applied by the U.S. Census, block groups vary in size, with larger block groups located at the periphery of the metropolitan area, in areas that are likely to export much of their traffic to other, more central locations. To account for whatever statistical effects block group definitions might have on our results, we included block group acreage as a control variable.
- MVMT. Unlike Marks' study, this analysis accounts for the affects of VMT on crash incidence. Information on traffic volumes were acquired from the Texas Department of Transportation and the City of San Antonio and aggregated to the block group level. To address the VMT associated with streets located on the boundaries of neighborhoods, we again used a 200-ft buffer surrounding each block group to clip the individual line segments, thus ensuring all related roadways were included into the analysis. Once the road segments were clipped, the VMT for each road segment was calculated by multiplying the segment ADT by the length of the road segment, and then multiplying this value by 365 (days) and 3 (years). As such, block group VMT is computed as: $\sum SegADT * SegLength * 365 * 3$. To ensure that the variable was scaled so that model coefficients could be meaningfully interpreted, we converted VMT to million vehicle miles traveled (MVMT), or VMT/1,000,000.
- Population Density. While many studies of the relationship between travel and the built environment examine the density of housing units, rather than population, and while these measures are correlated, traffic conflicts are created by individuals, not housing units. Correspondingly, it is population density, and not residential density, that is likely to matter more from the perspective of traffic safety. Higher population concentrations create more opportunities for conflicts among roadway users. As such, one would expect that higher population densities to be associated with higher numbers of crashes, *ceteris paribus*. Population density is calculated as the sum of the population from the 2000 census, divided by the block group's acreage.

- Density of 3- and 4-way intersections: Marks reported that 3- and 4-way intersections have different safety effects. To account for these effects, the density of intersections with 3 legs and 4 or more legs are modeled as separate variables in this analysis. The intersection density variables used in this analysis identify the number of intersections per 100 acres of the block group.
- Miles of Freeways and Arterials. Planners encouraged the development of thoroughfares designed and intended for higher-speed, higher-volume vehicle use, under the safety assumption that roadways designed explicitly for this use would be safer than those that were not. Because this study already controls for VMT, this variable seeks to identify what safety effects, if any, are associated with the presence of freeway and arterial facilities within urban neighborhoods. These variables are simply the sum of the centerline miles of roadway within a block group that are classified as either a freeway or an arterial.
- Arterial-oriented Commercial Uses. Planners encouraged the relocation of retail and commercial uses to arterial roadways as a means enhancing traffic safety. This variable seeks to determine how the presence of arterial-oriented commercial uses influences neighborhood crash incidence. It is defined as the count of commercial or retail uses located along an arterial thoroughfare.
- Big Box Stores. An outcome of encouraging arterial-oriented retail, unforeseen by Perry and Stein, was the advent of the big box store. Big box stores draw traffic from a large geographic area and typically have internal circulation lanes to accommodate off-street traffic movement (which potentially leads to off-street crashes that are not counted in conventional street-level traffic safety analyses). For this study, a big box store is identified as a retail use comprised of 50,000 square feet or more and having a floor-area ratio (FAR) of 0.4 or less.
- Pedestrian-Scaled Retail Uses. One of the major outcomes of conventional community design was the decline of pedestrian-scaled retail uses. Pedestrian-scaled retail is defined in this study as a commercial or retail use of 20,000 square feet or less, but developed at FARs of 1 or greater (i.e., buildings that front the street or otherwise have little undeveloped surface space). The resulting variable is the count of such used in a neighborhood. This measure serves as a rough indicator of a neighborhood's "urbanism," and examines what safety effects, if any, the presence of more traditional retail and commercial configurations has on crash incidence.

4

Modeling Crash Incidence and Urban Form

Because the dependent variables are count data that are overdispersed (i.e., the variance is greater than the mean), negative binomial regression models are used 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 et al., 2004). While crash data can be converted to a more normally-distributed form by dividing crashes by either the number of persons or vehicle miles traveled, and using the natural log of the corresponding value, this approach is discouraged since it forces crashes to be understood principally as a factor of the denominator of the measure, an unwarranted methodological assumption (Hauer, 1997). Negative binomial models allow crash frequency to be measured directly, and the inclusion of block group acreage, population density, and vehicle miles traveled as independent variables in the models account for whatever influence these factors might have on differences in crash incidence.

A second issue is the identification of the appropriate test statistics. In the conventional application of regression models, null hypothesis testing is used, and only coefficients and test statistics for variables entering at "statistically-significant" levels are reported. This approach has received a good deal of criticism in the recent traffic safety literature, since it presumes that if we cannot be statistically confident in our results at some arbitrary level (typically the 0.05, or 95% level), then we should regard our results as empirically meaningless. As Hauer (2004) has shown, using statistical methods in this manner has led to the adoption of policies that have proven detrimental to safety, since it encourages researchers to ignore meaningful associations that exist in their data.[3] To address this issue, we report the coefficients and test statistics for all modeled variables, and include 95th percentile confidence intervals. While significance levels and test coefficients are included for their usefulness in discussing the model results, the range of crash variation specified by 95th percentile confidence intervals should be regarded as the best possible estimate of a variable's actual safety effects.

Total Crash Incidence

Table 2 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, 3-leg intersections had a slightly positive, but statistically-insignificant effect on crash incidence, while 4-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 thoroughfare being significantly associated with a 15% increase in total crashes. Of the land use variables, the number of arterial-oriented commercial uses and big box stores within a community were associated with significant increases in crash frequency, with each additional arterial-oriented commercial use increasing total crashes by 1.3%, and each additional big box store increasing total crashes by 6.6%. Neighborhood-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%.

Table 2 Total Crash Incidence Model

Total Crash Incidence	Coef.	z	P	95% Conf. Interval	
Block Group Acreage	-0.0006	-3.690	0.000	-0.00086	-0.00026
MVMT	0.0075	11.670	0.000	0.00625	0.00877
Median Income	0.0003	0.220	0.829	-0.00226	0.00282
Pop. Aged 18-24	0.0010	5.980	0.000	0.00066	0.00130
Pop. Aged 75 and Older	0.0006	1.670	0.096	-0.00010	0.00129
Net Population Density	-0.0005	-1.800	0.073	-0.00104	0.00005
# 3-Leg Intersections	0.0008	0.520	0.600	-0.00210	0.00364
# 4 or More Leg Intersections	0.0050	2.390	0.017	0.00091	0.00915
Freeway Miles	-0.0181	-1.120	0.262	-0.04971	0.01355
Arterial Miles	0.1495	5.080	0.000	0.09181	0.20725
No. of Commercial Arterial Uses	0.0131	6.530	0.000	0.00917	0.01704
No. of Big Box Stores	0.0658	4.230	0.000	0.03529	0.09628
No. of Neighborhood Retail Uses	-0.0218	-1.840	0.066	-0.04499	0.00148
Constant	4.6896	69.840	0.000		

Log Likelihood = -4662

N = 747

Injurious Crash Incidence

The factors associated with the incidence of injurious crashes are largely part similar to those influencing injurious crashes, with two exceptions. The presence of older adults ceases to be a significant predictor of injurious crashes, while 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% (see Table 3). 4-leg intersections, which are locations where conflicting traffic streams cross, are likewise associated with significant increases in injurious crashes. This was not true, however, for 3-leg intersections, which were associated with fewer injurious crashes, although not at statistically-significant levels. Each additional arterial-oriented commercial 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, pedestrian-scaled retail uses were again associated with significantly fewer injurious crashes, with each additional pedestrian-scaled retail 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.

Table 3 Injurious Crash Incidence Model

Injurious Crash Incidence	Coef.	z	P	95% Conf. Interval	
Block Group Acreage	-0.0004	-2.440	0.015	-0.00070	-0.00008
MVMT	0.0064	9.780	0.000	0.00513	0.00771
Median Income (000)	-0.0044	-3.310	0.001	-0.00697	-0.00178
Pop. Aged 18-24	0.0008	4.570	0.000	0.00044	0.00109
Pop. Aged 75 and Older	0.0003	0.710	0.478	-0.00047	0.00100
Net Population Density	-0.0006	-2.300	0.021	-0.00119	-0.00010
# 3-Leg Intersections	-0.0009	-0.580	0.559	-0.00383	0.00207
# 4 or More Leg Intersections	0.0068	3.160	0.002	0.00259	0.01107
Freeway Miles	-0.0028	-0.170	0.866	-0.03550	0.02989
Arterial Miles	0.1714	5.570	0.000	0.11111	0.23175
No. of Commercial Arterial Uses	0.0111	5.430	0.000	0.00713	0.01517
No. of Big Box Stores	0.0401	2.580	0.010	0.00970	0.07060
No. of Neighborhood Retail Uses	-0.0335	-2.780	0.005	-0.05704	-0.00991
Constant	3.1297	45.780	0.000		

Log Likelihood = -3339

N = 747

Fatal Crash Incidence

The factors influencing the incidence of fatal crashes differ notably from those affecting total and injurious crashes (see Table 4). While 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 community 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 is associated with a 20% increase in fatal crashes. Conversely, both 3- and 4-leg intersections were associated with significant reductions in fatal crashes, with each additional 3-leg intersection reducing fatal crash incidence by 0.7%, and each additional 4-leg intersection reducing fatal crashes by 1%. This reduction in fatal crashes is likely attributable 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.

Table 4 Fatal Crash Incidence Model

Fatal Crashes	**Coef.**	**z**	**P**	**95% Conf. Interval**	
Block Group Acreage	0.0005	1.11	0.265	-0.00035	0.001265
MVMT	0.0056	3.41	0.001	0.002364	0.008763
Median Income (000)	-0.0083	-2.09	0.036	-0.016	-0.00053
Pop. Aged 18-24	0.0004	1.06	0.289	-0.00038	0.00128
Pop. Aged 75 and Older	-0.0002	-0.19	0.847	-0.00217	0.001783
Net Population Density	-0.0005	-0.82	0.412	-0.00164	0.000671
# 3-Leg Intersections	-0.0073	-1.79	0.073	-0.01523	0.000685
# 4 or More Leg Intersections	-0.0099	-1.67	0.095	-0.02164	0.001745
Freeway Miles	0.0488	1.16	0.248	-0.03402	0.131716
Arterial Miles	0.1998	2.51	0.012	0.043818	0.355799
No. of Commercial Arterial Uses	0.0053	0.98	0.327	-0.0053	0.015898
No. of Big Box Stores	-0.0367	-1.11	0.267	-0.10159	0.028174
No. of Neighborhood Retail Uses	-0.0120	-0.4	0.689	-0.07098	0.046885
Constant	-0.5095	-2.81	0.005		

Log Likelihood = -865

N = 747

5

Community Design and Traffic Safety

Conventional community design practice 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, unseen and unaccounted for during the early half of the 20th century, appear to be involved.

The first and perhaps most obvious factor is the moderating effect of **speed** on traffic safety. The original safety assumption regarding arterial roadways, espoused in *City Planning* (Haldeman, 1916) and other early professional works, was that widening and straightening these thoroughfares would reduce crash incidence by enhancing sight distances, thus increasing a driver's preparedness to identify and respond to hazards in the right-of-way. Such an 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 instance, could travel at maximum speeds of no more than 40-45 MPH and likely traveled at much lower speeds given the pavement conditions of the time. With these performance constraints, widening and straightening arterial thoroughfares would likely have increased sight distances without also increasing operating speeds.

In the intervening century however, advancements in automotive engineering now allow vehicles to readily travel at speeds in excess of 100 MPH, 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, which in turn consumes whatever safety benefits may have been associated with increasing sight distances (Wilde, 1993; Aschenbrenner and Biehl, 1994). These effects, predicted under risk homeostasis theory,[4] 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 5).

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, non-random 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).

Surface Arterial Thoroughfares

The safety problem with urban arterials can be best understood as a product of systematic error. Widening and straightening these roadways to increase sight distances has the unintended side effect of also enabling higher operating speeds, which in turn increases *stopping sight distance*, or the distance a vehicle travels from the point at which a driver initially observes a hazard, to the point at which he or she can ultimately bring their vehicle to a complete stop. Higher stopping sight distances pose no particular problem when vehicles are traveling at relatively uniform speeds, with little or no interruption to the through-moving traffic stream that would require immediate braking. When these operating conditions can be met, as they are on grade-separated freeways, higher operating speeds would be expected to have little or no effect on crash incidence.

Table 5 Holistic Results for Crash Incidence and Urban Form

	Total	Injurious	Fatal
Block Group Acreage	-0.0006***	-0.0004**	0.0005
MVMT	0.0075***	0.0064***	0.0056***
Median Income (000)	0.0003	-0.0044***	-0.0083**
Pop. 18-24	0.0010***	0.0008***	0.0004
Pop. 75 and Older	0.0006*	0.0003	-0.0002
Net Population Density	-0.0005*	-0.0006**	-0.0005
No. 3-Leg Intersections	0.0008	-0.0009	-0.0073*
No. 4 or More Leg Intersections	0.0050**	0.0068***	-0.0099*
Freeway Miles	-0.0181	-0.0028	0.0488
Arterial Miles	0.1495***	0.1714***	0.1998**
No. of Commercial Arterial Uses	0.0131***	0.0111***	0.0053
No. of Big Box Stores	0.0658***	0.0401***	-0.0367
No. of Neighborhood Retail Uses	-0.0218*	-0.0335***	-0.0120

* Significant at the 0.1 level

** Significant at the 0.05 level

*** Significant at the 0.01 level

But the problem is that the operating conditions for which arterials are intended typically *cannot* be met on urban surface streets, where pedestrians, bicyclists, and crossing vehicles are all embedded into the traffic mix. Avoiding crashes under these

conditions often requires motorists to brake quickly, an action that higher operating speeds and stopping sight distances make them less able to successfully do (see Figure 10).[5] The result is a systematic pattern of error—an inability to quickly respond to other roadway users entering the travelway—that leads to increased crash incidence. This is confirmed by the results of our study, with each additional mile of arterial thoroughfare being associated with a 15% increase in total crashes, a 17% increase in injurious crashes, and a 20% increase in fatal crashes.

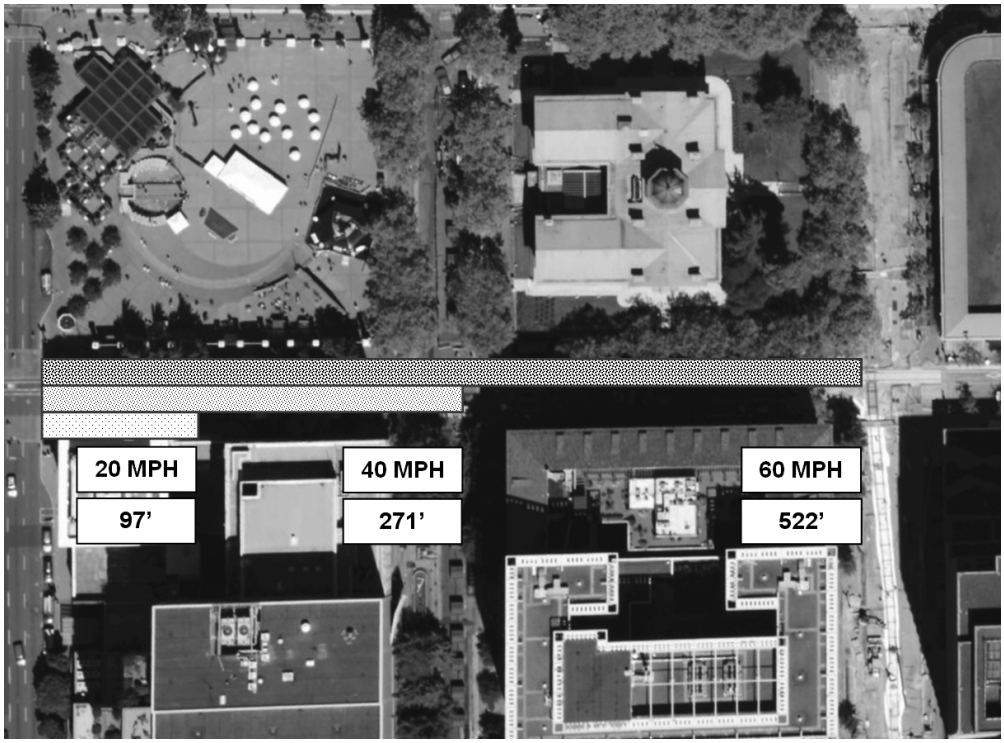


Figure 10 Average Stopping Sight Distances for Different Vehicle Speeds, Superimposed on the Portland, OR, Street Grid

Arterial-Oriented Commercial Uses and Big Box Stores

The land use changes encouraged by Perry and Stein exacerbate the systematic error problem. While they were correct in 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 speeds greater than that of 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 5, each additional arterial-oriented commercial use in a community increases both total and injurious crashes by slightly more than 1%, while each big box store increases total crashes by 6.6%, and injurious crashes by 4%.

Interestingly, these land uses were not associated with significant increases in fatal crashes. We suspect this is probably attributable to the heavier levels of traffic congestion occurring when retail and commercial uses are present on arterials, which reduces operating speeds and may in turn reduce crash severity, if not crash frequency. Nevertheless, future research is needed to bear this assertion out.

While the data used in this analysis did not permit pedestrian and bicyclist crashes to be explicitly examined, 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. The concentration of commercial and retail uses near each other, or near adjacent residential areas, can reduce trip distances to levels that make pedestrian travel viable, thereby adding pedestrians into the overall traffic mix. As described above, vehicle speeds occurring along arterials are often too high to permit vehicles to quickly stop in the event that a pedestrian unexpectedly enters the travelway.

To Perry's (1939) credit, he acknowledged that placing commercial uses on arterial thoroughfares likely created a pedestrian safety problem, but it was a problem he ultimately left unsolved.[6] 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 et al., 2001; Zaal, 1994). The principal alternative, adopted by European designers, is to simply design urban surface streets to reduce vehicle speeds to safe levels.

Pedestrian-Scaled Retail

Pedestrian-scaled retail—the type of retail that was largely abandoned during the postwar period—was found 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 et al., 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 4-way intersections, these reductions are accompanied by significant increases in total and injurious crashes. 3-leg intersections, by contrast, reported fewer injurious crashes and more total crashes, although not at conventional levels of statistical significance. The seemingly conflicting nature of these results can be understood as the result of the tension between their effects 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 4-way intersections in that they produce fewer intersection conflict points and interrupt longer roadway segments, thus preventing vehicles from achieving higher operating speeds. Nonetheless, both intersection types force through-moving vehicles to decelerate, if not stop completely (UK Department for Transport, 2007), which in turn reduces impact speeds, and thus the incidence of fatal crashes. Considering intersections exclusive of other exogenous factors, it would appear that hybrid street networks, which contain dense-concentrations of T-intersections, would appear to be preferable to either disconnected residential subdivisions or grid-iron 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. The speed-reducing benefits associated with frequent intersections can likely be achieved in limited-access communities through the use of speed-reducing traffic calming devices such as speed humps, chokers, and chicanes. 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 would appear to be a promising strategy for balancing traffic safety with network connectivity (Ewing, 1999; Zein et. al., 1997).

With the exception of the limited installation of speed humps, traffic calming devices are not used by the City of San Antonio, and our study results are limited to the safety effects of the presence or absence of intersections. Thus, while we conclude that hybrid street networks are likely preferable to other network configurations, *ceteris paribus*, we strongly suspect that other network configurations, used in conjunction with an appropriate suite 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 community, we suspect that they benefits may be agglomerative at larger geographic levels. Individuals living in higher density environments drive less (Ewing and Cervero, 2001), thus reducing their overall exposure to a crash event. 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 assertion is strongly suggested by a recent study by Ewing et al. (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 VMT are likely responsible for at least part of this difference. As with intersections and network configurations, however, future research is needed to explicitly 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. The first is a need to **manage the mobility and access functions of urban arterials**. While urban arterials are typically designed and intended for higher-speed vehicle operations, 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 at distances of ½ 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 environments rather than urban ones. The higher operating speeds and greater spacing between signalized intersections found on these roads complicate safe pedestrian crossings and limits developmental access.

In areas where pedestrian activity is present or expected, or where eliminating a roadway's access function is either undesirable or contextually-inappropriate, the primary alternative to access management is to reduce operating speeds to levels that are compatible with its access-related functions (see Figure 11). This approach, sometimes referred to as the *livable street* approach, incorporates design features intended to encourage or enforce lower operating speeds, such as aligning buildings to the street, incorporating landscaping or street appurtenances along the roadside, enhancing the aesthetics of pavement and signage, and incorporating other elements intended to explicitly reduce operating speeds, such as traffic calming and full intersection control. In short, livable streets emphasize access over higher speed mobility. When compared against conventional arterial treatments, livable streets report roughly 35-40% fewer

crashes per mile traveled, as well as a complete elimination of traffic-related fatalities (Dumbaugh, 2005a; Naderi, 2003).

Safety may be further enhanced by **orienting retail and commercial uses towards lower-speed thoroughfares**. Two strategies can be readily applied to accomplish this. The first, often promoted by advocates of neo-traditional development, is to simply design arterial thoroughfares in urban areas for *lower operating speeds*. In response to concerns about excessive speeds on urban arterials, the Institute of Transportation Engineers (ITE), in partnership with the Congress for the New Urbanism (CNU), are developing design specifications for three new thoroughfare types—boulevards, avenues, and commercial streets—that are intended to carry arterial traffic volumes at design speeds of 35 MPH or less (ITE, 2006).

Figure 11 Conventional (Left), Access-Managed (Center), and Livable (Right) Arterial Configurations

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 towards a managed arterial location. Increasingly, developers have begun designing access lanes to look and function like traditional urban commercial streets (see Figure 12). Regardless of their specific configuration, the effective result of the provision of access lanes is to relocate access-related traffic from the arterial thoroughfare and onto lower-speed streets that are better able to safely accommodate on-site circulation and access.

Finally, there is a need for a **network-level approach to land use planning, speed management, and access control**. Traffic safety is a more complicated matter than simply configuring 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 is likely better advanced through community-level design solutions that pay attention to how different land use and street network configurations may influence vehicle speed and systematic design error. Residential, commercial, and retail uses all require developmental access and are likely to attract pedestrian traffic as well, particularly when clustered together. Addressing safety in these environments will likely require streets and street networks designed to encourage lower-operating speeds and meaningfully accommodate local access and circulation needs. By contrast, safety on

higher-speed, mobility-oriented thoroughfares appear to be best 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 grid-iron or functionally-designed networks, the thoughtful use of traffic calming and intersection control at the network level is likely to remedy the specific deficiencies associated with different developmental configurations. Considered broadly, it is the tension between speed and access that leads to crash incidence, and there are likely multiple design configurations that may meaningfully balance them.

Figure 12 "Lifestyle Center" Retail Configuration at the Intersection of Two Arterials

Conclusion

Designers during the early half of the 20th century were rightly concerned about the safety effects of 4-way intersections and grid-iron street networks, and this study should not be used to infer that a wholesale return to 19th century grid-iron configurations is desirable. Instead, our results suggest is that many of the community design practices that emerged in response to these concerns, such as the development of functionally-designed street networks and the relocation of commercial and retail uses to arterial thoroughfares, are practices that have largely substituted one set of safety problems with another.

This study has sought to identify general trends in the relationship between community design and crash incidence and has examined the existing safety literature to outline likely causes and potential solutions. Yet we should observe that cross-sectional analyses, such as this one, should not be used to derive explicit inferences on causality. Future research is needed to develop our professional understanding of the specific ways in which community design affects the behaviors that result in traffic crashes, as well as the frequency and severity of the crashes that occur. With these caveats in mind, we conclude by observing that the relationship between community design and traffic safety appears to be an important one, and that the activities of planners may help 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] In absolute terms, traffic fatalities have actually *increased* by roughly 150 deaths per year since 1991. The "improvements" in safety that are often trumpeted in the media are not attributable to fewer deaths, but instead to dramatic increases in the denominator of measures used to derive traffic fatality rates—population and VMT. In real terms, more people are being killed on US highways each year.

[2] Another important idea emerging from this work is the idea that planners should design for traffic as hydraulic engineers address the flow of water. While slightly outside the scope of concern of the present study, this idea is so central to contemporary planning and engineering assumptions on traffic flow and distribution that it is worth citing in detail. As stated by Robinson:

> [I]n building new towns and cities and in adding to the old, we have created broad thoroughfares in recognition that, whatever the cost, we must make it possible for traffic to move… We have witnessed a flood that filled old channels to overflowing, and we have taken the primitive step in flood control of widening the channels. Then, following the further example of the hydraulic engineers, we have both straightened the lines and from the original street have removed those projections or irregularities which might retard the progress of the current. All of this action, in so far as it refers to traffic highways, has been wise and natural (pp. 45-46).

[3] An example of this is the research used to justify the adoption of permitted right-turn-on-red policies during the 1970s and 1980s. Despite every study on the subject reporting that crashes involving pedestrians increased following the adoption of permitted right-turns-on-red, the limited number of observations in each individual study failed to identify the relationships as being statistically significant. As such, researchers and policymakers concluded that right-turns-on-red did not increase the hazards to pedestrians, despite the obviously higher absolute numbers of pedestrian crashes evidenced in their data. In a re-examination of this subject, Hauer aggregated the results of these studies together, thereby increasing the total number of observations and found that when considered as a whole, such practices did, in fact, result in a significant increase in crashes involving pedestrians (Hauer, 2004).

[4] 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 against their individual perceptions of how hazardous engaging in such behavior might be.

[5] Stopping sight distance is calculated as the sum of the brake reaction distance, which is the distance traveled between when a driver observes a hazard and applies the brakes, as well as the braking distance itself (AASHTO, 2004). The stopping sight distances presented in this figure represent "average" estimates that assume a reaction time of 2 seconds, and a vehicle deceleration rate of 11.2 ft/s^2. They further presume that drivers are reasonably alert to oncoming hazards and are driving vehicles that provide adequate braking performance and maintain adequate pavement friction during deceleration. Actual stopping sight distances may increase substantially if drivers are not alert to oncoming hazards or are driving a substandard vehicle.

[6] Perry 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" (1939, p. 71).