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ROADWAY AND INFRASTRUCTURE DESIGN AND ITS RELATION TO PEDESTRIAN AND BICYCLIST SAFETY: BASIC PRINCIPLES, APPLICATIONS, AND BENEFITS

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ABSTRACT

Road deaths are forecast to double by 2020, with the burden falling most heavily on low- and middle-income countries and, within those countries, on the most vulnerable and poorest road users. Half of the 1.2 million people killed and 50 million injured in road crashes each year are pedestrians, motorcyclists, bicyclists, and users of unsafe public transport; and more than 90 percent are from low- and middle-income countries. Because these are the areas where rapid motorization is taking place, the issue of safety in increasingly multi-modal environments is now of critical importance, particularly for pedestrians and bicyclists, since as vulnerable road users (VRU), they comprise a large proportion of injuries and deaths, and similar strategies for prevention of injuries and fatalities for these two groups are available. Although a great deal of additional research is needed to determine the costs and benefits of various proposed solutions, some basic principles can be identified to guide roadway and infrastructure design for improved pedestrian and bicyclist safety. The three broad but separate strategies for reducing the probability of an injury or fatality are: (i) reducing exposure, (ii) reducing the probability of a collision given exposure, and (iii) reducing the probability of injury given a collision. The purpose of this paper is to describe and illustrate these principles, discuss issues related to each one, and discuss the benefits—indeed, imperativeness—of the application of these principles by planners and traffic engineers.

INTRODUCTION

Road deaths are forecast to double by 2020, with the burden falling most heavily on low- and middle-income countries and, within those countries, on the most vulnerable and poorest road users. Currently, half of the 1.2 million people are killed and 50 million injured are pedestrians, motorcyclists, bicyclists, or users of unsafe public transport (e.g., passengers hanging from the sides of buses, or overcrowded minibuses) (*1*). Among those killed and injured, more than 90 percent are from low- or middle-income countries (*1*). These are also where rapid motorization is taking place, creating a road environment where vulnerable road users (VRUs) share space with increasing numbers of motor vehicles, making the issue of safety of critical importance.

In this paper, we focus on pedestrians and bicyclists, since they comprise a large proportion of VRU injuries and deaths, and similar strategies for prevention of injuries and fatalities for these two groups are available.

A very large number of articles and reports have been or are being published on various countermeasures to reduce pedestrian and bicyclist injury risk either through reducing the probability of a crash or reducing the probability of injury in the event of a crash (*2*). Although a great deal of additional research is needed to determine the costs and benefits of various proposed solutions, using a conceptual approach, some basic principles can be identified to guide roadway and urban infrastructure design for improved pedestrian and bicyclist safety. These principles can be applied in a wide variety of road settings with various mixes of transportation modes, while considering urban structure design in a broad sense, and not limited to the traditional roadway network. The purpose of this paper is to describe and illustrate these principles, examine issues related to each one, and discuss the benefits—indeed, imperativeness—of the application of these principles by planners and traffic engineers at the varying levels of jurisdiction responsible for roadway and infrastructure design.

As a theoretical framework we start with the basic model used for decomposition of roadway risk (*3*,*4*). Within this framework, the probability of being injured in a road collision is the product of several components:

$P(I) = P(E) \times P(C|E) \times P(I|C)$, where E = exposure and C = collision, where:

- P(I) is the probability of injury;
- P(E) is the probability of exposure;
- P(C|E) is the probability of a collision given exposure; and
- P(I|C) is the probability of injury given a collision.

This framework, defined by the mechanism of action, provides a way of categorizing various countermeasures in order to prioritize them in terms of effectiveness in preventing injury.

Epidemiologically, *exposure* is defined as the condition of being subjected to something which may have a harmful effect (*5*). It is important in this case to define “exposure” precisely. Virtually all risk for pedestrians and bicyclists takes place in what might be called a “conflict domain” with vehicles, defined here broadly as the space/time domain in which a vehicle could potentially collide with the pedestrian or bicyclist. Typically, exposure to this conflict domain has been defined as the distance travelled by a pedestrian or bicyclist, the interval time involved, or the number of trips made. However, pedestrians and bicyclists are not necessarily “exposed” to the same degree of conflict with vehicles during the entire length of the journey; similarly they are not necessarily exposed to the same amount of conflict on every trip. We maintain that exposure measures should be defined accordingly to reflect these gradations in risk over time and distance. *Collisions* are defined as harmful events involving a pedestrian or a bicyclist. By definition, all collisions occur within the conflict domain. *Injury* is defined as any physical trauma, including fatal injury.

This formulation suggests three broad but separate strategies for reducing the probability of an injury:

1. Reducing P(E), or reducing exposure.
2. Reducing P(C|E), or reducing the probability of a collision given exposure.
3. Reducing P(I|C), or reducing the probability of an injury given a collision (The P(I|C) can be presented as P(I|C)*P(F|I) when there is a value in separating injury and fatality)

Although these three principles are fairly evident and are not original to this analysis (*3,4,2*), they are presented here in terms of a conceptual framework involving a shift in emphasis from motor vehicles to other modes, and involving a negotiation between modes within the realm of urban design and traffic engineering.

Each of these broad strategies can be achieved in part or whole through appropriate roadway and urban designs (Figure 1). In this paper we will:

- Briefly describe each of the strategies and provide examples of facility design that can be used to implement them;
- Describe potential benefits for pedestrians and bicyclists;
- Identify impacts on other modes (i.e., motor vehicles);
- Determine potential barriers to implementation;

Finally, we will outline several recommendations for future research that involve constructing information databases on facility design, constructing data systems to guide deployment and conduct evaluation, and institutionalizing concepts of facility design by developing training programs for traffic engineers and planners.

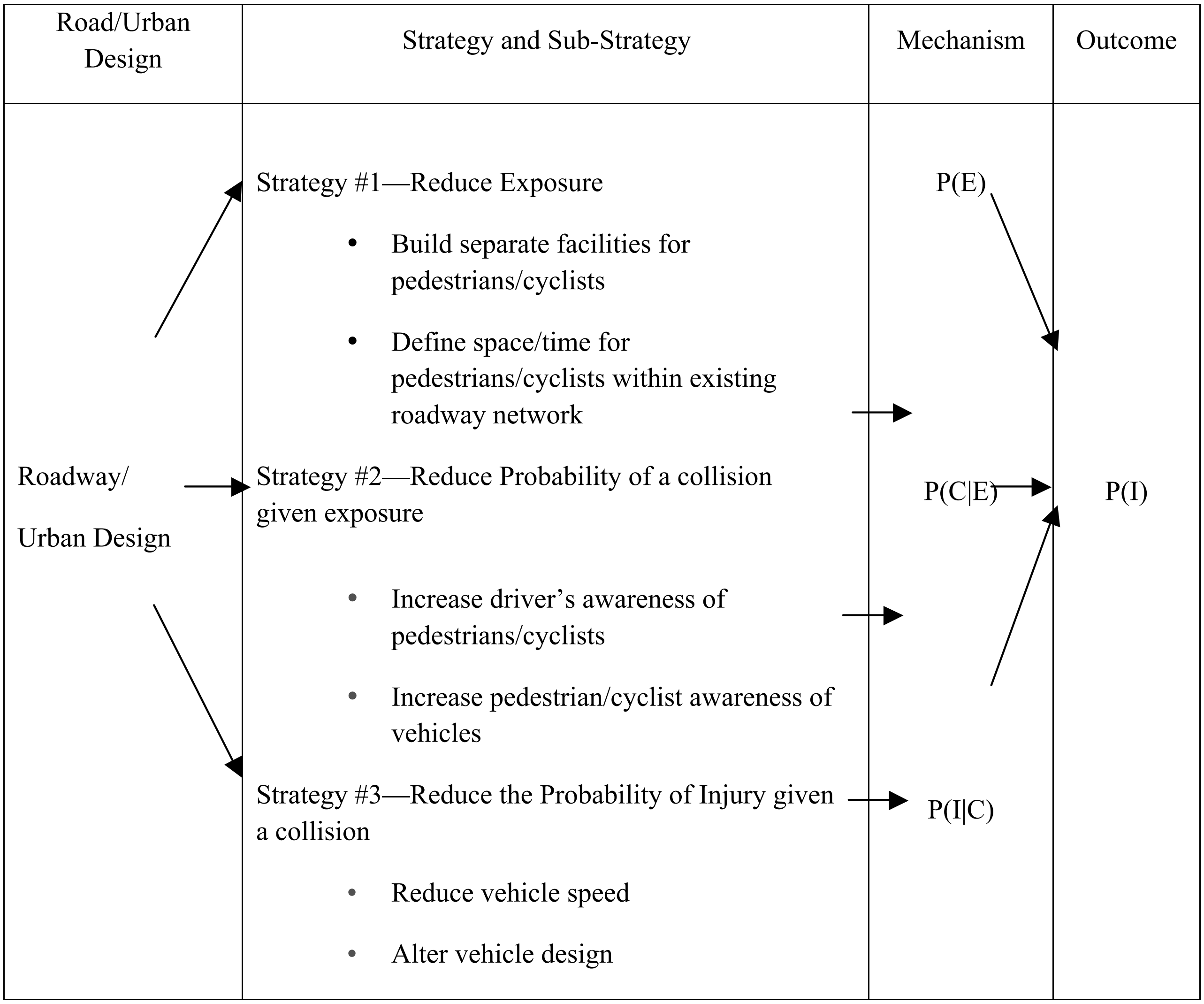

FIGURE 1 Roadway/Urban Design and Pedestrian/Bicycle Injury

A comprehensive summary of pedestrian and bicycle safety countermeasures and facility design features has been developed by the United States Department of Transportation's Federal Highway Administration (FHWA), the Clearinghouse for Crash Modification Factors (CMF) (*6*) and a Desktop Guidebook (*7*) that categorizes countermeasures for improving pedestrian and bicyclist road safety. In addition, there are a number of other sources of countermeasure descriptions (*8,9*). While further research is needed for specific CMFs, the intention here is not to repeat or even summarize this information, but, instead, to provide a conceptual framework for all three strategies with an acknowledgment that exposure to the risk domain varies over time and space.

Strategy #1: Reducing P(E), or Reducing Exposure

Separation of modes in space and time should be the guiding principle in reducing risk for pedestrians and bicyclists, particularly in locations where mass and speed of various transportation modes are vary drastically. There are two broad methods for achieving this aim:

first, by providing space for them outside the roadway system (separate pathways, trails, etc.); second, by expanding or more precisely defining their space within the existing roadway network.

Providing Space for Pedestrians and Bicyclists Outside the Roadway System

Space outside the roadway system includes dedicated trails or paths, “cycle tracks,” protected sidewalks, and pedestrian and bicycle overpasses. The feasibility of this approach depends largely on the availability of land for such features and resources for construction and maintenance. This strategy can be enhanced by designing pedestrian and bicycling travel networks and identifying and closing the gaps in these networks.

Providing space for pedestrians and bicyclists outside the roadway system by definition effectively reduces risk from a motor vehicle collision to zero except where the space crosses a roadway. Additionally, separated facilities attract people who might otherwise be reluctant to walk or bicycle (*10*). This is critical in achieving the goal of increasing walking and bicycling. It is important to recognize that this involves expanding the definition of travel networks beyond the traditional focus on the roadway network.

Expanding or More Precisely Defining the Space for Pedestrians and Bicyclist Within the Existing Roadway Network

This requires reducing the “conflict domain,” i.e., reducing either the distance or the time that pedestrians and bicyclists are exposed to risk when sharing the roadway system with motor vehicles. A large number of countermeasures and design elements have been developed for which the mechanism is reducing the space or time during which a pedestrian or bicyclist is exposed to risk (See the FHWA Clearinghouse for Crash Modification Factors [*6*]). This requires a critical re-examination of traditional roadway and traffic engineering principles that allocate space and time on the basis of facilitating or optimizing the roadway’s motor vehicle capacity and re-directs them to accommodate the needs of all road users.

Some designs that separate pedestrians and vehicles in space include: bulb outs/curb extensions (reducing the distance during which a pedestrian shares space with motorized traffic while crossing the road) and medians (which also reduce exposure distance and provide a “refuge” for pedestrians to wait until there is more room for them on the roadway, if needed). Designs that separate pedestrians and vehicles in time include: traffic signals (provide separate phases for different directions of traffic flow and for pedestrian crossings) and extending pedestrian walking phase at a signalized intersection (provide adequate time for pedestrians with slower walking speeds).

Designs that separate bicycles and vehicles in space include: bicycle lanes (provide separate space for bicycles adjacent to the traffic lane; though additional research is needed to quantify the safety benefit), and bicycle boxes (provide space in lane before an intersection solely for bicycles; whose safety is also not well documented). Designs that separate bicycles and vehicles in time include: bicycle-sensitive detectors for extending signal phase (allows bicyclists time to clear the intersection, either straight ahead or while turning left).

Conclusion—Separating Modes in Space or Time

All of these approaches reduce the absolute amount of distance and time that a pedestrian or bicyclist remains in a conflict domain. The crash modification factors for all of these are relatively robust when measured in terms of road crossings and other measures. From the viewpoint of a pedestrian or bicycle trip, these countermeasures also reduce the proportion of the trip that is in a conflict domain. We hypothesize that this might also serve to emphasize to pedestrians and bicyclists that the conflict zone is something unusual that should be paid close attention to. Such enhanced awareness is relevant to Strategy #2, reducing the probability of a collision given exposure, as discussed below.

Strategy #2: Reducing P(C|E), or Reducing the Probability of a Collision Given Exposure
If separation in space/time cannot be accomplished, or can only be accomplished in a limited fashion, then another principle follows: Reduce the probability of a collision by (i) altering behavior of drivers via increasing awareness of pedestrians and bicyclists and reducing vehicle speed to increase the time for driver reaction, and by (ii) altering behavior of pedestrians and bicyclists through increasing their awareness of vehicles.

Alter Driver Behavior and Reduce Vehicle Speeds
Avoiding a collision first requires driver perception of the pedestrian or bicyclist. Borowsky et al. (*11*), and others have described the situation in terms of "hazard perception" … "The ability to anticipate an upcoming hazardous situation depends on drivers' expectations and past experience." While past experience is important, there are a number of features of the roadway infrastructure that can enhance the driver's expectation that a pedestrian or bicyclist will appear. Features such as roadway lighting, flashing beacons, pedestrian/bicycle warning signs, and "zones" (e.g., school zone, hospital zone) alert drivers to locations or times (in the case of school zones) where pedestrian or bicyclists are more likely to be present.

Some roadway features designed to communicate to drivers that pedestrians may be present can have an adverse effect on pedestrian safety by altering pedestrian perceptions. A large-scale study by Zegeer et al. (*12*) demonstrated that the risk of a collision increases at marked versus unmarked crosswalks on four-lane roads with heavy vehicle volumes. A study conducted by Mitman, Ragland and Zegeer (*13*) showed that drivers are in fact more likely to yield at a marked crosswalk; however, pedestrian behavior observed at marked crosswalks suggests that pedestrians are less vigilant than at unmarked crosswalks. This suggests that pedestrians assume that marked crosswalks are inherently safe, an assumption that may reduce their attention while crossing. To help mitigate this situation, Zegeer (*12*) recommended that marked crosswalks on multilane roads with heavy traffic be combined with other features such as medians. Similar evaluations of what Leonard Evans calls "human behavior feedback" (*14*) should be conducted for other countermeasures to assure optimal design and implementation and to avoid causing dangerous behavior by pedestrians.

Hazard perception depends not only on expectations, but also on visibility. For example, the rate of vehicle-pedestrian injury increases sharply with darkness. The highest frequency of pedestrian fatality collisions occurs during twilight and the first hour of darkness (*15*). This period of risk can be addressed by improvements in lighting where vehicle-pedestrian collisions have occurred during twilight or darkness (*16*). Increasing visibility of pedestrians through use of lights or clothing is effective in increasing drivers' awareness of their presence (*17,18*). Although the use of reflective clothing is not a roadway feature, this strategy can be encouraged on a local, regional, or global basis.

Reducing vehicle speed is the single most important factor in reducing the severity of vehicle-pedestrian and vehicle-bicyclist collisions. Additionally, reducing speed may also reduce the probability of collisions occurring in the first place (*19*). Roadway and urban design strategies for reducing speed are discussed in Strategy #3.

Alter Pedestrian and Bicyclist Behavior

While it is important that drivers be optimally aware of the presence of pedestrians and bicyclists, it is equally essential that pedestrians and bicyclists be aware of the presence of vehicles, i.e., there should be “mutual awareness.” Infrastructure features that might be used for this purpose include signs indicating travel patterns of vehicles (e.g., right turn on red not allowed and signs indicating areas of heavy traffic). If, as recommended earlier, such risk zones are reduced in size (through countermeasures described in Strategy #1), signs warning pedestrians to increase awareness could direct their attention to conflict zone areas in which they should pay heightened attention. Pedestrian or bicycle Level of Service (LOS) measures typically include levels of pedestrian or bicyclist comfort (*20*). Care should be taken to ensure that pedestrian and bicyclist “comfort“ correlates with actual and not merely perceived levels of safety, a critical distinction that is often not made.

While countermeasures such as vehicle technologies (i.e., pedestrian detection and cameras), and reducing drunk driving are among other effective approaches to implementing Strategy #2, they are outside the scope of this paper’s focus on roadway and infrastructure design.

Strategy #3: Reducing P(I|C), or Reducing the Probability of an Injury Given a Collision

There are two primary approaches for reducing injury given a collision involving vehicles and pedestrians or bicyclists. The first, and most important, is reducing vehicle speed. The second, applicable primarily in the case of pedestrians, is to alter front-end vehicle design to reduce the severity of injury in the event of a collision. Because this paper focuses on roadway and urban infrastructure design factors, this latter approach is not discussed in detail.

Reducing Vehicle Speed

Strictly speaking, speed is an element of exposure in that it reflects the level of potential harm to which a person is exposed. However, it functions differently than distance or duration of exposure in terms of risk decomposition, and is addressed separately in this paper.

The critical observation is that speed is highly related to injury (*21*). In one recent study, fatality risk at 50 km/h was twice the risk that it was at 40 km/h, and five times the risk that it was at 30 km/h. This study reflects the general finding of much of the earlier research that speed is exponentially related to injury (*22*). There is also substantial evidence that reducing vehicle speeds results in decreased pedestrian fatalities. This may be due to both (i) reduction in the probability of crash—which is part of strategy #2, and (ii) reduction in severity in the event of a crash (*3,4,2*).

There are numerous promising countermeasures to reduce vehicle speed, including: speed bumps, narrowed lanes, radar speed signs, automated speed enforcement, and lowering speed limits (2,23). From a roadway design and engineering standpoint, it is relatively easy to reduce speed via roadway and urban design. One of the barriers to doing so is the public perception that these measures will decrease vehicle capacity. However, a review by Archer et al. (24) concludes that reduction in average travel speed through speed reduction methods has only a minor impact on drivers’ travel time. Effective speed reduction strategies involve design, education, and enforcement. It appears feasible to reduce speed limits in corridors or across the board with minimal impact on vehicle capacity (*25*), although additional research is needed.

Improved emergency response, while not reducing the probability of injury, could reduce the potential outcome of an injury given a collision, but this is outside the scope of this paper’s focus on roadway and infrastructure design.

TRADE-OFFS AMONG MODES

The discussion so far has focused on the impact of the three broad strategies on pedestrian and bicyclist safety. We assert below that it is also likely that each of the strategies will have an impact on increasing walking and bicycling through increased convenience and comfort.

The impact on vehicle capacity is not as clear. Traffic engineers have traditionally focused on vehicle capacity when designing roadway networks, and there is understandably some concern that features that separate travel modes will reduce that capacity. One example is a road diet, which consists of reducing the number of vehicle travel lanes and reallocating the space saved to bicycle lanes, pedestrian facilities, parking, or landscaping (*26*). It is generally assumed that this constitutes a kind of "zero sum" game in which the gain of one mode is a loss for the other. However, very little of the increasing body of research on roadway features that increase pedestrian bicyclist safety and mobility has addressed how to balance pedestrian and bicycle needs with the needs of motor vehicles and other road users. In fact, there are relatively few studies on the simultaneous impacts of countermeasures described above on safety and capacity for multiple modes. It is extremely important that empirical studies be conducted and network models be developed to evaluate impacts on safety and capacity across modes. With such information, trade-offs can be evaluated and optimal roadway configurations for accommodating multiple transportation modes can be explored (*26,27,28,29*).

CO-BENEFITS

Increased Walking and Bicycling

In this paper we have focused on the safety impact of three broad strategies for roadway and urban design on pedestrian and bicyclist safety. Application of these strategies in a sustained and vigorous manner should result in a substantial reduction in pedestrian and bicyclist injury without—pending further research—an excessive reduction in vehicle capacity. These strategies are also very likely to facilitate increases in walking and bicycling. While neighborhood and environmental characteristics such as population density, increased land use mix, and, connectivity are likely the largest factors contributing to walking and bicycling (*30*), a number of studies have also shown that perceptions of safety and comfort are also significant predictors of these activities (*31,32*). Increasing safety and comfort for pedestrians and bicyclists—through means such as those included in the three strategies described in this paper—increases the likelihood that they will engage in these modes of transportation.

There are very significant benefits to walking and bicycling. Walking and bicycling offer great opportunities for physical activity, which is associated with numerous health benefits including decreased rates of cardiovascular disease, depression and diabetes (*33*). Lack of physical activity can contribute to obesity, while remaining physically active can help prevent falls and reduce depression among older adults (*34*). Pedestrian or bicycle level of service (LOS) measures typically include levels of pedestrian or bicyclist comfort (*20*). Walking also offers social benefits since large numbers of people out walking tend to indicate that an area is interesting and safe. A vibrant pedestrian street life is an indicator of a vital urban neighborhood (*35*).

Implementation of the three strategies discussed in this paper would have a significant impact on the perception by pedestrians and bicyclists of safety in an urban environment. Reducing the "conflict domain," increasing driver awareness of pedestrians and bicyclists, and increasing pedestrian and bicyclist awareness of vehicles should increase pedestrian and bicyclist confidence and vigilance. The end result is improvements in both actual and perceived safety, which will encourage these active modes of transportation.

Improvements in Overall Traffic Safety

Roadway features within each of the three strategies may also have an impact on safety and capacity for other modes, e.g., vehicles. Many of the roadway features described above in relation to the three primary strategies will also have a positive impact on safety in terms of crashes between vehicles. Reducing conflict space within the existing roadway system (part of Strategy #1) by expanding space and time for pedestrians and bicyclists will have the impact of reducing vehicle speed, and may have a positive impact on vehicle safety (*36,37*). Increasing awareness of pedestrians and bicyclists on the part of drivers (part of Strategy #2) may have an impact on overall driver awareness in relation to vehicle-vehicle crashes. Reducing vehicle speed (part of Strategy #3) will lessen both the probability of vehicle-vehicle crashes and the severity of such crashes in the event of their occurrence (*38*).

RELATIONSHIP TO CURRENT APPROACHES

Many of the elements discussed in our three primary strategies are currently incorporated in other approaches to address risk to vulnerable road users, while some approaches differ in important ways.

Complete Streets

Complete Streets are designed to enable safe access for all users: pedestrians, bicyclists, motorists, and transit riders of all ages and abilities (*39*). According to the complete streets concept, streets should be designed and built to accommodate all road users. The goal is to view the roadway as a public space, and make design decisions about how it should be organized for the benefit of all different modes. Most features of Complete Streets involve one or more of the principles from the strategies described in this paper.

Context Sensitive Design

Context Sensitive Design (CSD, also known as Context Sensitive Solutions or CSS) refers to roadway standards and development practices that are flexible and sensitive to community values, leading to roadway design decisions that address economic, social, and environmental objectives (*40*). The Federal Highway Administration (FHWA) defines CSS as: "a collaborative, interdisciplinary approach that involves all stakeholders in providing a transportation facility that fits its setting. It is an approach that leads to preserving and enhancing scenic, aesthetic, historic, community, and environmental resources, while improving or maintaining safety, mobility, and infrastructure conditions." Most of the specific features described as part of context sensitive design are consistent with the principles described in this paper.

Naked Streets

Officially known as Shared Space, this concept originated in the Netherlands and involves the removal of traffic lights, signs, crosswalks, lane markers, and curbs so that pedestrians, motorists, and bicyclists are integrated and negotiate their way through streets by communicating with, and reacting to, one another (41). The theory is that if you remove all traditional countermeasures, vehicle speed will be greatly reduced, and different mode users will negotiate the time and space. While this is an intriguing approach, it is clear that it is viable only in special circumstances, i.e., when vehicle speeds are kept low by road design features and where mass and speed of various modes are not drastically different.

CHALLENGES/RECOMMENDATIONS

The three broad strategies, (i) reducing exposure, (ii) reducing the probability of a collision given exposure, and (iii) reducing the probability of injury given a collision, are widely used in road safety in general, and, together, can account for virtually all road safety approaches. Their application for improving safety for pedestrians and bicyclists is proposed here as a means of conceptualizing the possible approaches for rural and urban environments globally. Applying these strategies could have substantial impacts in terms of reducing pedestrian and bicyclist injury and fatalities around the world, and create environments that encourage walking and bicycling with a number of beneficial consequences.

We see several challenges—and offer the following recommendations to planners and traffic engineers—for the immediate future and longer term.

Need for a Comprehensive Informational Data Base on Roadway/Urban Design for Implementing the Three Primary Strategies

There are numerous reviews and several informational databases including roadway and urban infrastructure design. However, these are incomplete and there are new studies appearing with increasing frequency.

Recommendation #1

Conduct a comprehensive review of roadway and urban infrastructure design features used to implement the three strategies outlined above to improve pedestrian and bicyclist safety. This would include the following steps:

a. Update information provided in the FHWA Clearinghouse and Guidebook and other reviews
b. Identify gaps in the existing body of research
c. Evaluate the degree to which the various countermeasures are applicable outside the countries/settings in which they were evaluated
d. Collate the information collected in a web-based repository available globally

Need for Additional and More Rigorous Research on Roadway and Urban Infrastructure Design

While enough evidence is available to make choices about roadway and infrastructure design, a great deal of information can be obtained with additional and much more rigorous studies.

Recommendation #2

Conduct large-scale studies of design features to increase statistical power and control confounding variables:

a. Execute pre-post studies with control sites
b. Use Bayesian methods to help account for regression to the mean
c. Assess impacts other than safety for pedestrians and bicyclists
d. Assess safety and mobility impacts for modes other than walking and bicycling

e. Develop network models to conduct optimization of safety and mobility for multiple modes

Need to Enhance Training for Traffic Engineers and Planners around the World

There is now sufficient information about roadway features and infrastructure design to help reduce pedestrian and bicyclist injury in mixed-mode environments. It is crucial that this information be imparted to current (through continuing education) and future (through training) traffic engineers, planners, and other professionals involved in running our transportation systems:

Recommendation #3

Develop and deliver comprehensive curriculum for education (including continuing education) for engineers and planners worldwide:

a. Provide funding to develop and conduct workshops and courses
b. Provide funding to initiate web-based delivery of courses, workshops, webinars, etc.

Need to Facilitate Implementation of Countermeasures and Other Approaches Representing the Three Main Strategies

In established roadway environments, the issue is one of the inertia inherent in already built systems with established patterns of travel. Where roadway systems are being rapidly developed, the issue is incorporating safety-related infrastructures into the plans of roadways systems currently planned or in development.

Recommendation #4

Develop strategies that can be used by those building or managing road systems for incorporating safety features:

a. In existing roadways, develop strategies for "retrofitting" pedestrian and bicycle safety features
b. In new roadway projects, develop strategies to incorporate needs of all users at every level of development, from planning to implementation

Need for Improved Roadway and Urban Data Systems Worldwide

Despite the large number of fatalities and injuries, relatively few (if any) large roadway data systems include variables most relevant for assessing and preventing non-vehicle related fatalities and injuries. Systems such as this are relatively complete in countries that have been motorized for an extended time, while countries that have more recently experienced motorization have less well-developed systems. And, in virtually all cases the systems are almost exclusively focused on vehicle-related features of the roadway, i.e., infrastructure, volumes, and collisions related to vehicles.

Recommendation #5

Develop methods to establish and maintain roadway and urban design data systems:

a. Develop strategies and funding to establish and upgrade road safety data systems that include information such as relevant roadway and urban design features, pedestrian/bicyclist injury, and pedestrian/bicyclist volume
b. Develop methods for efficient and accurate data gathering
c. Develop statistical methods to model various types of data related to road safety, with the aim of enhancing existing data
d. Conduct studies of policy or political barriers to the collection or use of data systems for reducing injuries and fatalities

Need to Develop Estimates of the Benefits of Shift in Travel Model from Vehicle Travel to Pedestrian/Bicyclist Travel

A shift from vehicle-based transportation to walking and bicycling offers a number of potential benefits, including increased health and reduced environmental impacts: More precise information about these potential benefits can provide strong motivation providing institutional incentives for mode shift.

Recommendation #6

Develop methods, including statistical models, for predicting the impact of mode shifts from vehicles to walking and bicycling:

a. Calculate impact of active transportation on increased physical activity and subsequent health, local pollution and subsequent health outcomes, green house gases, and energy conservation
b. Calculate costs of active transportation
c. Develop models to evaluate the net benefit of active transportation

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