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The Application of Traffic Calming and Related Strategies in an Urban Environment

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THE APPLICATION OF TRAFFIC CALMING AND RELATED STRATEGIES IN AN URBAN ENVIRONMENT

A Thesis Presented

by

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ABSTRACT

THE APPLICATION OF TRAFFIC CALMING AND RELATED STRATEGIES
IN AN URBAN ENVIRONMENT

MAY 2008

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This thesis presents a collection of network optimization strategies aimed at aiding the local practitioner in selecting, implementing, and evaluating appropriate strategies to achieve community goals and objectives in the urban environment. The urban environment is often challenging due to the plethora of activity and variety in mode choice. Growing interest in sustainable transportation practices along with encouragement at the Federal, State, and Local levels to is leading to the growing use of non-motorized modes of transportation such as walking and bicycling. The combination of high population density and mixed land use in the urban environment creates unique safety and operational challenges.

This research presents a synthesis of strategies designed to improve local transportation safety and efficiency by targeting speeding and cut-through volumes as improving pedestrian and bicycle facilities in urban areas such as those found in Western Massachusetts. Additionally, this research evaluates two local network optimization strategies; speed cushions and reverse angle parking. The effectiveness of the speed

cushions in achieving the community's goal of reducing speeds was evaluated and determined to be a recommended strategy for future implementation, especially when couple with enforcement. Reverse angle parking, however, was not determined to be an effective strategy due to the high occurrence of events as well as lower parking volume exhibited during implementation.

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CHAPTER 1

INTRODUCTION

More Americans are utilizing non-motorized modes of transportation such as walking and bicycling, especially in urban environments. Federal and State transportation organizations such as the United States Department of Transportation (DOT) and the Massachusetts Highway Department (MassHighway) are making efforts to increase non-motorized forms of transportation. At the same time, however, populations are still rapidly increasing and so is the number of cars on the road. While pedestrian and bicyclist attitudes and behaviors may be changing, congestion is still increasing on most United States highways. This unique dilemma, where more vehicles are utilizing the roadway than ever before, coupled with a shift in behaviors that may lead to an increase in pedestrians and bicyclists, is creating a unique safety challenge for local practitioners, particularly in urban environments. Traffic calming and related strategies aim at improving safety and efficiency in the busy urban environment.

Traffic calming and related strategies can increase safety through a combination of physical, behavioral and psychological strategies. Traffic calming seeks to maintain flow and circulation through a network while guiding traffic through optimal routes at safe speeds for all users of the network. Through the implementation of mainly physical measures, traffic calming can improve safety in the urban environment by decreasing travel speeds, cut-through traffic and making facilities safer and more accessible to pedestrians and bicyclists. The definition of traffic calming can be limiting and a broader umbrella of strategies should be examined which aim to achieve common goals and objectives. Regardless of the category that a strategy may fall into, objectively examining a spectrum of measures to achieve community goals is an essential and critical component of the research process. Related strategies may target roadway infrastructure, such as signage or pavement markings, to improve clarity and reduce driver confusion or address behavior modification through community action programs.

There is a wide range of improvements that can be made through the implementation of traffic calming or related strategies to improve traffic safety in a community when properly selected and implemented. An incorrect placement of a selected strategy may have a negative effect on safety or result in more dangerous conditions for one or more users of the roadway. Care must be exercised when selecting, implementing and maintaining a chosen urban environment network optimization strategy. Implementation may need to supplemented with other engineering strategies, enforcement, encouragement, or education.

The Institute of Transportation Engineers (ITE) *Traffic Engineering Handbook* and *Traffic Calming: State of the Practice Report* outline some of the recommendations for traffic calming implementation in communities in the US. In Massachusetts, the Massachusetts Highway Department (MassHighway) has a chapter devoted to traffic calming in its *2006 Project Development & Design Guide*. Due to its youth in the United States, there is a need for more guidance on traffic calming selection and implementation, particularly in local urban environments.

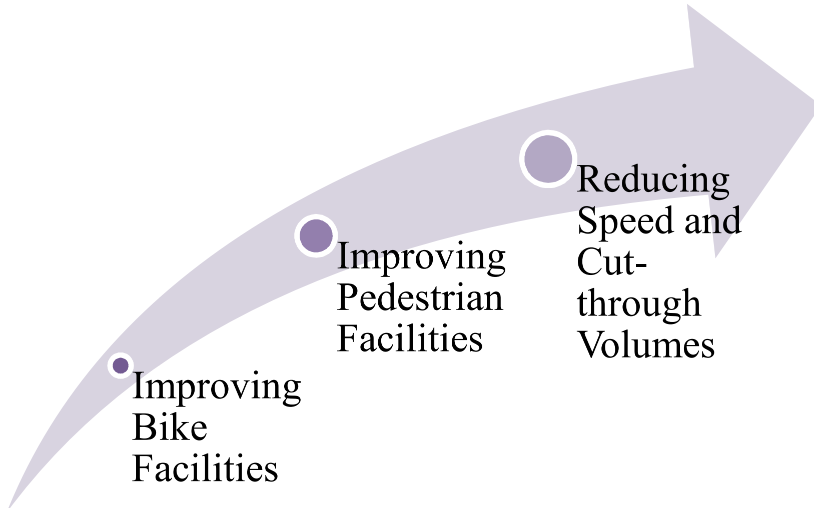


Figure 1 Improving safety and community livability

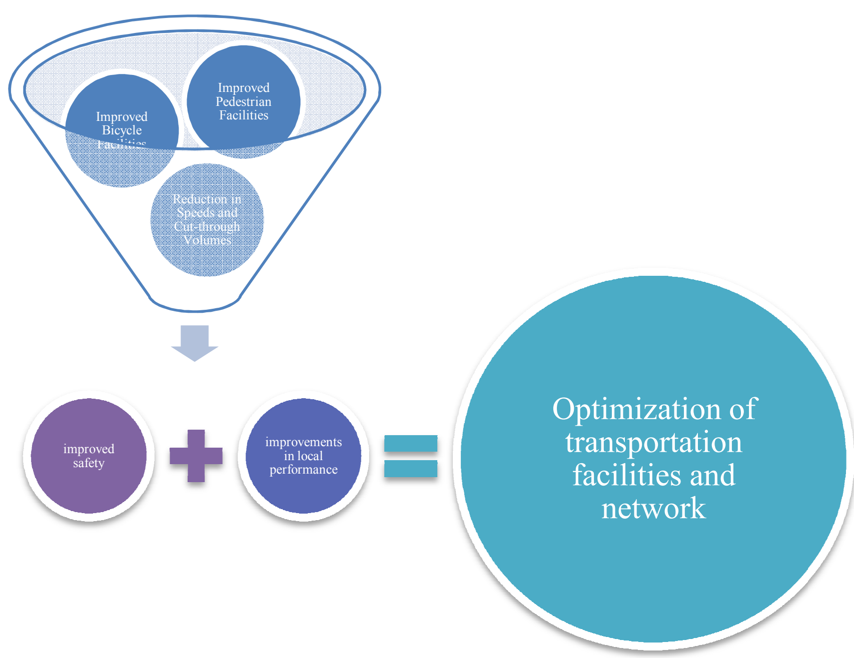


Figure 2 Components of local transportation network optimization

Problem Statement

Urban environments, such as those experienced in Western Massachusetts, are candidate locations for the implementation of traffic calming and other safety strategies. While there is some information about traffic calming and related strategies in the United States, there is limited guidance on device selection and implementation. This approach may not lead to the selection of the optimal traffic calming strategy because it is vague and lacks guidance. A lack of uniformity among the selected traffic calming measures in neighboring communities may lead to driver confusion, which can negatively impact flow. Furthermore, as shown in Figure 1, there is limited signage in the *Manual on Uniform Traffic Control Devices* (MUTCD) designed to supplement traffic calming. Traffic calming in the US lacks uniform national standards and design specifications and this can result in the improper selection or implementation of a wide array of traffic calming strategies, decreasing traffic safety or operations.

Category	Group	Section	Signs	MUTCD Codes
Roadway Related	Changes in Horizontal Alignment	2C.06	Turn, Curve, Reverse Turn, Reverse Curve, Winding Road, Hairpin Curve, 270-Degree Curve	W1-1 through W1-5, W1-11, W1-15
		2C.07	Combination Horizontal Alignment/Advisory Speed	W1-1a, W1-2a
		2C.08	Combination Horizontal Alignment/Intersection	W1-10
		2C.09	Large Arrow (one direction)	W1-6
		2C.10	Chevron Alignment	W1-8
		2C.11	Truck Rollover	W1-13
	Vertical Alignment	2C.12	Hill	W7-1, W7-1a, W7-1b
		2C.13	Truck Escape Ramp	W7-4, W7-4a
		2C.14	Hill Blocks View	W7-6
	Cross Section	2C.15	Road Narrows	W5-1
		2C.16-17	Narrow Bridge, One Lane Bridge	W5-2, W5-3
		2C.18-20	Divided Road, Divided Road Ends, Double Arrow	W6-1, W6-2, W12-1
		2C.21	Dead End, No Outlet	W14-1, W14-1a, W14-2, W14-2a
		2C.22	Low Clearance	W12-2, W12-2p
	Roadway Surface Condition	2C.23-24	Bump, Dip, Speed Hump	W8-1, W8-2, W17-1
		2C.25	Pavement Ends	W8-3
		2C.26	Shoulder	W8-4, W8-9, W8-9a
		2C.27	Slippery When Wet	W8-5
		2C.28	Bridge Ices Before Road	W8-13
Traffic Related	Advance Traffic Control	2C.29-30	Stop Ahead, Yield Ahead, Signal Ahead, Be Prepared To Stop, Speed Reduction	W3-1, W3-2, W3-3, W3-4, W3-5, W3-5a
	Traffic Flow	2C.31-35	Merge, Lane Ends, Added Lane, Two-Way Traffic, Right Lane Ends, Lane Ends Merge Left, No Passing Zone	W4-1, W4-2, W4-3, W4-5, W4-6, W6-3, W9-1, W9-2, W14-3
	Change in Speed	2C.36	Advisory Speed	W13-2, W13-3, W13-5
	Intersections	2C.37	Cross Road, Side Road, T, Y, and Circular Intersection	W2-1 through W2-6
		2C.38	Large Arrow (two directions)	W1-7
		2C.39	Oncoming Extended Green	W25-1, W25-2
	Vehicular Traffic	2C.40	Truck Crossing, Truck (symbol), Emergency Vehicle, Tractor, Bicycle, Golf Cart, Horse-Drawn Vehicle	W8-6, W11-1, W11-5, W11-5a, W11-8, W11-10, W11-11, W11-12p, W11-14
	Nonvehicular	2C.41-42	Pedestrian, Deer, Cattle, Snowmobile, Horse, Wheelchair, Playground	W11-2, W11-3, W11-4, W11-6, W11-7, W11-9, W15-1
Supplemental Plaques	Distance	2C.45	XX Feet, XX Miles, Next XX Feet, Next XX MI	W16-2, W16-3, W16-4, W7-3a
	Speed	2C.46	Advisory Speed	W13-1
	Arrow	2C.47	Advance Arrow, Directional Arrow, Diagonal Arrow	W16-5p, W16-6p, W16-7p
	Hill-Related	2C.48	Trucks Use Low Gear, X% Grade	W7-2, W7-3
	Street Name Plaque	2C.49	Advance Street Name	W16-8
	Intersection	2C.50	Cross Traffic Does Not Stop	W4-4p
	Share The Road	2C.51	Share The Road	W16-1
	HOV	2C.52	High-Occupancy Vehicle	W16-11
	Photo Enforced	2C.53	Photo Enforced	W16-10
	Traffic Circle	2C.37	Traffic Circle	W16-12p

Figure 3 Categories of MUTCD warning signs (1)

Most, if not all, traffic control devices will require supplemental signage to warn of approaching conditions. The *Manual on Uniform Traffic Control Devices* (MUTCD) provides guidance on sign selection and placement for only a few select traffic calming devices as shown in Figure 4. The remainder of traffic calming strategies must design a sign within MUTCD specifications so that uniformity is preserved. Traffic control device uniformity is a critical component of safety and efficiency because it provides roadway users with clear, concise, and consistent messages that lead to faster recognition and understanding, and a reduction in driver perception-reaction time (1). Uniform traffic calming signage is a critical component of the evolution of traffic calming techniques.

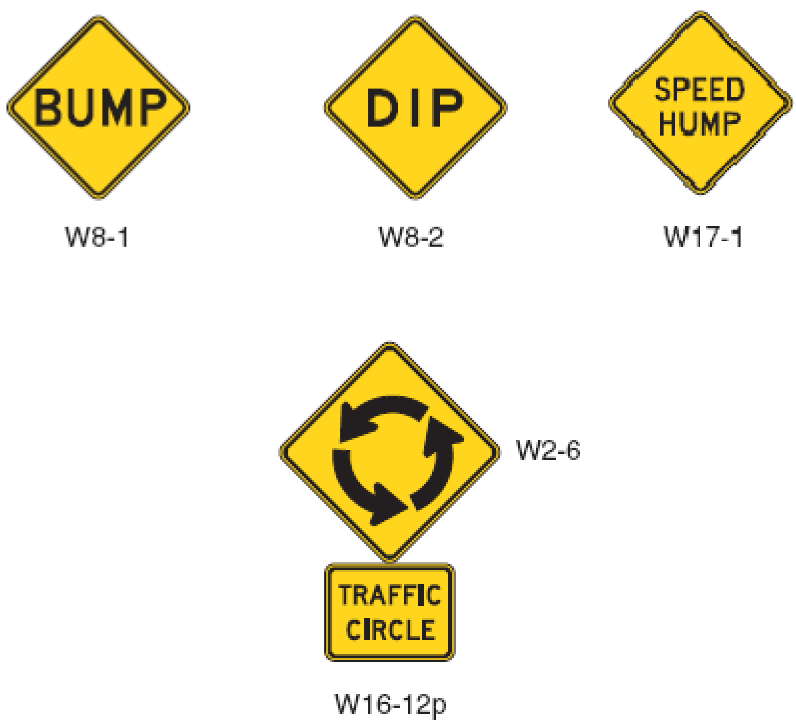


Figure 4 MUTCD signage related to traffic calming (1)

Traffic calming techniques were first implemented in the United States in the 1970's making this a relatively young implementation measure. The long-term benefits and effects of such strategies are just now becoming known and as a result, a plethora of assorted case studies is appearing. The evolution of traffic calming in the United States indicates a growing need as well as growing popularity for this measure and related strategies.

There is support at the Federal and State levels for improving traffic safety in the United States. Recent legislation and campaigns towards improving traffic safety have evolved. Enacted in 2005, the *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users* (SAFETY-LU), focuses on highway safety. The Federal Highway Administration (FHWA) works towards improving highway safety along with numerous other organizations at the Federal, State, and Local levels. Speeding, high-cut through volumes, pedestrian safety and bicycle safety are all important traffic safety components heavily concentrated in the urban environments most often experienced in Western Massachusetts. The design of the roadway network often leads to higher speed arterials traveling through small-town centers, posing a great risk for community residents. Another component of network optimization in Western Massachusetts is a high, seasonal population. With more vehicles on our roadways and more people making an effort to walk or cycle, a unique network optimization challenge is presented.

Lastly, the connection between research and practice can be nonexistent at times, resulting in a significant loss of critical information for local decision-making. While case studies are becoming more prevalent with regards to local urban strategies, there is still a challenge for practitioners and researchers alike to share information with one another. This results in a large mass of lost information that could be centrally synthesized to further broaden the scope and breadth of this field. An attempt will be made in this research to bridge the gap between research and practice.

Research Objectives

The objective of this research was to design an urban environment network optimization strategy toolbox and decision flow chart for the local practitioner as well as evaluate two selected local engineering measures. A range of countermeasures specifically designed for the local practitioner, which target speeding, high cut-through volumes, improving pedestrian and bicycle safety, can be implemented at the local level to aid in the attainment of network optimization. While there are many components of traffic safety, these four variables (speeding, cut-through volumes, pedestrians, bicyclists) are the focus of this research, with the argument that any improvement in any of these variables will have a positive effect on traffic safety in local communities. The more information and resources which can be provided to local practitioners, the more knowledgeable, accurate, precise decisions can be made. This is currently a challenge for some practitioners as a plethora of scattered resources exist. Building upon earlier work in the field of traffic calming and low cost safety improvements, the development of a toolbox of traffic safety countermeasures is to be expanded upon for the local practitioner. Such a toolbox, found herein, contains a variety of resources that can aid the practitioner in the identification, implementation, and evaluation of strategies for local traffic challenges. This compilation of strategies will consist of information on problem identification, needs assessment, countermeasure selection tools, design specification, and implementation considerations.

This research consists of a synthesis of useful traffic calming and related strategies for the local practitioner in urban settings with characteristics similar to those of many of the communities located in Western Massachusetts. This thesis is organized into six sections as shown in Figure 5. The first section consists of an introduction to traffic calming and related strategies, while the second and third sections provide significant background information on various implementation strategies and their need. Section four contains the study design of the two selected strategies, including data collection methodology. Research findings and data analysis results are contained the fifth section. Finally, conclusions and recommendations complete the thesis in section 6.

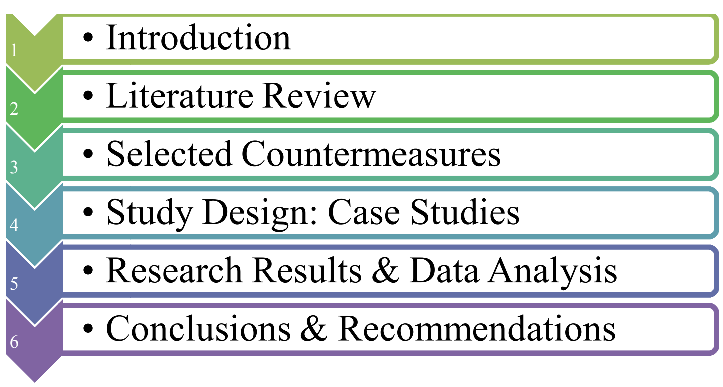


Figure 5 Thesis organization

Scope

The scope of this research was limited to engineering strategies utilized in the United States specifically addressing speeding, cut-through volumes, pedestrians and bicyclists. Furthermore, an attempt will be made to focus on research which has been performed in communities with characteristics resembling local urban communities in Western Massachusetts. It is important to recognize that a great number of strategies being implemented today were originally developed in Europe. The urban environment network optimization strategy toolbox included in this research contains some design specification resources for selected strategies. These resources will consist of design specifications from reputable agencies and associations, such as the Institute of Transportation Engineers (ITE), Massachusetts Highway Department (MHD), American Association of State Highway and Transportation Officials (AASHTO) and Federal Highway Administration (FHWA), that the cities and towns in Western Massachusetts use for guidelines.

Additional strategies which may target specific populations, such as school children or older drivers, were considered but not included in this analysis. Enforcement, encouragement, and education strategies were also beyond the scope of this research. Lastly, numerous strategies are being implemented in International communities that have not been included in this research but may provide contributions to the development of local strategies in the United States.

CHAPTER 2

LITERATURE REVIEW

The Need for Safety Improvements

Increasing trends in population, vehicle miles traveled and vehicle ownership are leading to more congestion and concerns about traffic safety. Driver demand is increasing, challenging networks which may be constrained by limited space, funding, and recent global warming awareness issues. An inefficient transportation network can be financially costly and emotionally taxing on its users. As congestion on major roads increases, drivers shift to alternate routes, often cutting through residential neighborhoods. Local roads are experiencing increases in volume, at higher speeds, which is causing many safety related concerns. Furthermore, motor vehicle crashes are the leading cause of death in children from the age of 3 to 14 (2). Increased volume on local roads can present a community with many potential conflict areas and can be very unsafe.

Urban environments contain many challenges for the local practitioner due to the abundance of multimodal traffic contained within a (generally) small region. This combination coupled with high volume and steady demand poses unique challenges to improving safety and efficiency; where a tradeoff is usually exhibited. Furthermore, many urban environments continually experience increasing population trends along with an increase in vehicle ownership. A myriad of traffic calming and other strategies exist as potential solutions to local traffic problems, but if chosen or implemented incorrectly, can lead to worsened conditions.

The state of traffic safety in the United States has a lot of room for improvement and is very concerning. In 2006 there was an estimated 42,642 fatalities and 2.6 million reported injuries (3). Interestingly, as the National fatality rate has steadily decreased, the number of fatalities has remained stable as shown in Figure 6. A combination of factors is guilty of contributing to this ghastly figure. Of the more obvious problems are increasing population trends, limited funding and resources, land use constraints, aggressive or erratic driver behavior and human factors.

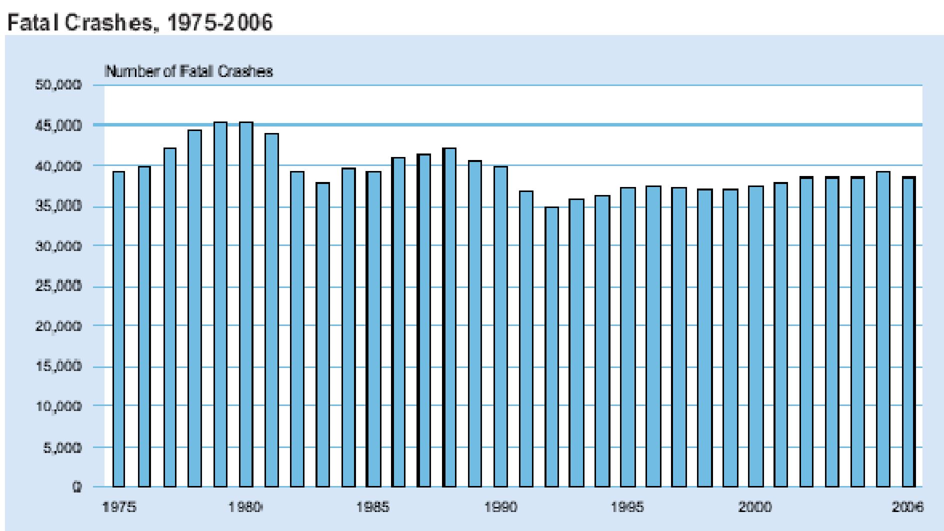


Figure 6 Number of fatal crashes, nationally, 1976-2006 (4)

The majority (70%) of fatalities occurring in the US in 2006 involved occupants of motor vehicles, while 4% involved motorcyclist riders, 3% involved pedestrians, and 2% involved bicyclists as shown in Figure 7. The breakdown of injuries resulting from traffic crashes in 2006 is as follows: 92% involved motor vehicle occupants, 3.5% involved motorcycle riders, 2.5% involved pedestrians, and 2% involved bicyclists as shown in Figure 8 (4).

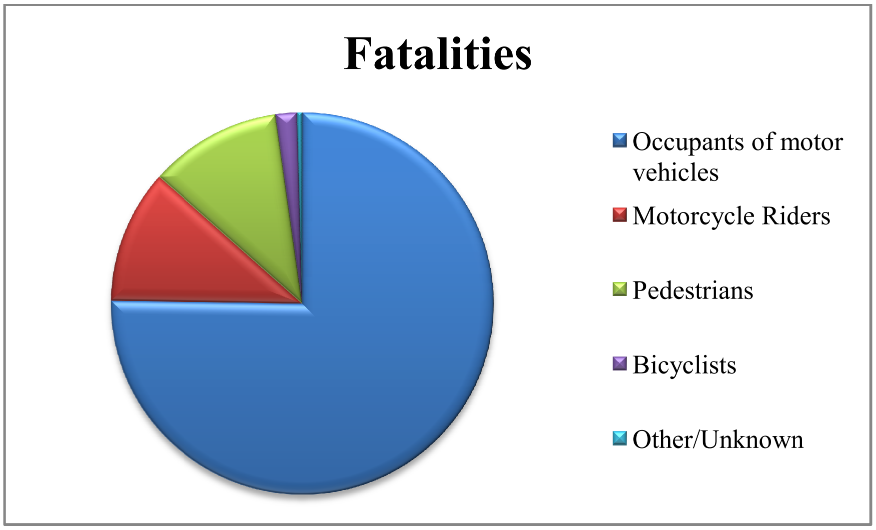


Figure 7 Breakdown of 2006 traffic related fatalities by user type

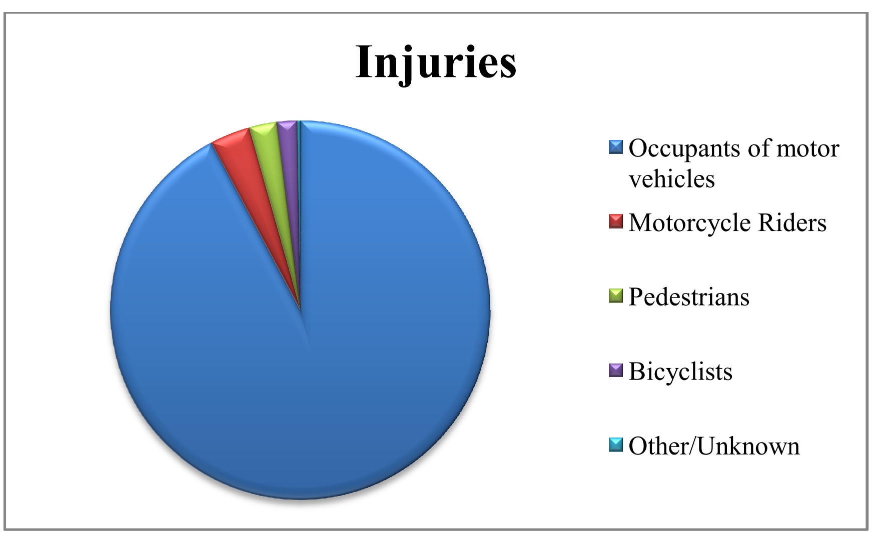


Figure 8 Breakdown of 2006 traffic related injuries by user type

The causes of crashes are vast and complex, but speeding is often a significant contributor in many crashes and results in huge economic consequences, tallying up $40.4 billion in 2006. In 2006 alone, 13,543 people lost their lives in speeding-related crashes (5). As shown in Figure 9, speeding-related crash frequency remains approximately stable over time Nationwide. Interestingly, the majority of fatal crashes involving speed did not occur on Interstates, but rather on non-Interstate roadways, as shown in Figure 10. Speeding related fatalities account for 30% of all fatal crashes, with the predominant roadway being identified as a non-Interstate; making speeding a prime target for engineering, education and enforcement changes in the small town urban environment (2). By decreasing the occurrence of speeding as well as decreasing the speed differential, crash frequency can be decreased (6). When speeding is examined in conjunction with pedestrian safety it is clear to see why speeding and pedestrians do not mix well. It has been shown that a "pedestrian hit at 40 mph has an 85 percent change of being killed; at 30 mph, the likelihood goes down to 45%, whereas at 20 mph, the fatality rate is only five percent" (7).

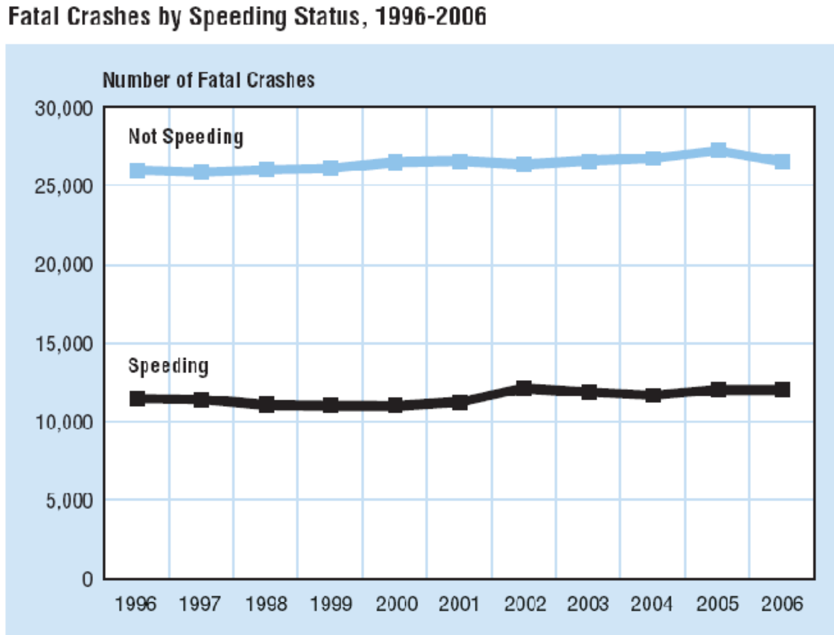


Figure 9 Fatal crashes where speeding was a factor, 1996-2006 (3)

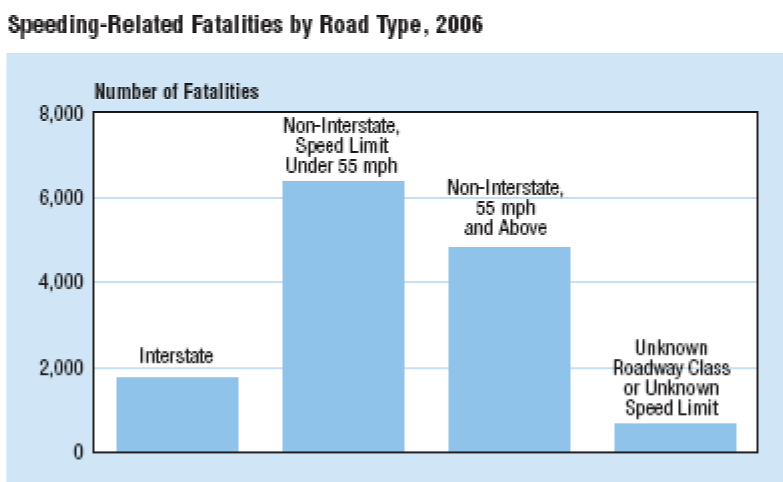


Figure 10 Breakdown of speeding related fatal crashes by roadway type, 2006 (5)

Unfortunately, traffic safety cannot be completely isolated from its counterpart, efficiency, so measures are often considered with both goals in mind (7). An inefficient network can be costly in numerous ways. As congestion on major roads increases, drivers shift to alternate routes, often diverting through residential neighborhoods at great risk. Increased volume of local roads serving as cut-through roads can present a community with many potential conflict areas and can be very unsafe. An unsafe network or link along a network can significantly decrease efficiency. Increased delay and congestion commonly results from a traffic incident, as well as enormous social and financial losses (3). Motor vehicle crashes occurring in 2000 cost an estimated $230.6 billion. Improving traffic safety will not only have measureable social gains, but also significant economic benefits as well.

Pedestrian safety also deserves much attention as attitudes towards walking are changing; becoming more favorable. As shown in Figure 11, pedestrian fatalities resulting from motor vehicle crashes account for 11% of all traffic related fatalities in 2006, registering 4,784 fatalities. Well above the national average, Massachusetts' pedestrian fatalities resulting from traffic crashes accounted for 14.2% of all traffic related fatalities. The 61,000 pedestrian injuries occurring nationwide in 2006 account for approximately 2% of all traffic related injuries. A great risk especially to children, nearly 20% of fatalities for children aged 5 – 9 occurred where the child played the role of the pedestrian (8). The majority (60%) of pedestrian injuries occurring from traffic crashes occur at non-intersection locations, while the remaining 40% of injuries occur at intersections (9).

Total Pedestrian Fatalities by Year 1996-2006

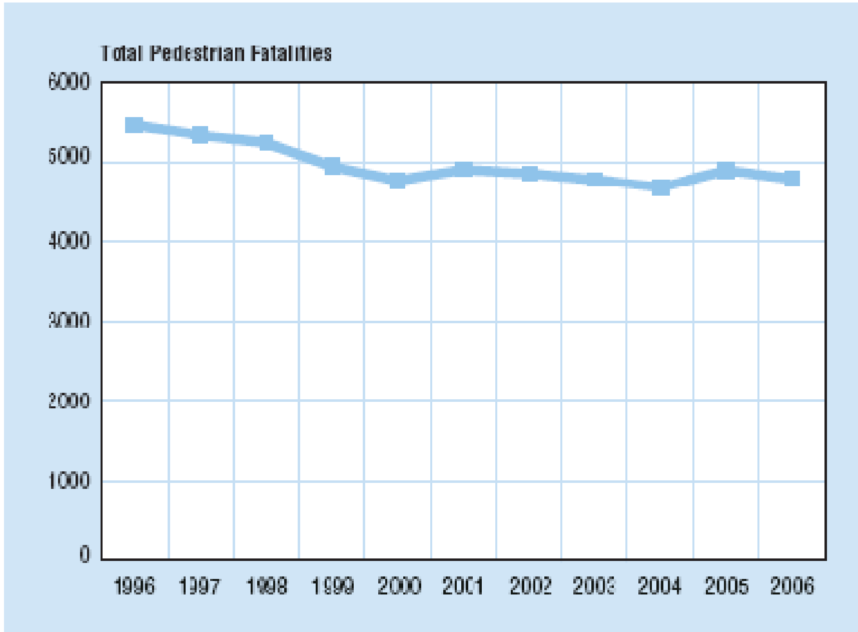


Figure 11 Fatal crashes involving pedestrians, 1996-2006 (8)

Bicyclists, including any "cycle" solely powered by pedals, had a total of 44,000 injuries in 2006 resulting from traffic related injuries. Nationwide in 2006, the 773 fatalities accounted for approximately 2% of all traffic fatalities, shown in Figure 12. Of those bicyclists killed, 14% were between the ages of 5 and 15. Massachusetts, in 2006, had 1.4% of its total traffic related fatalities involving bicyclists (10).

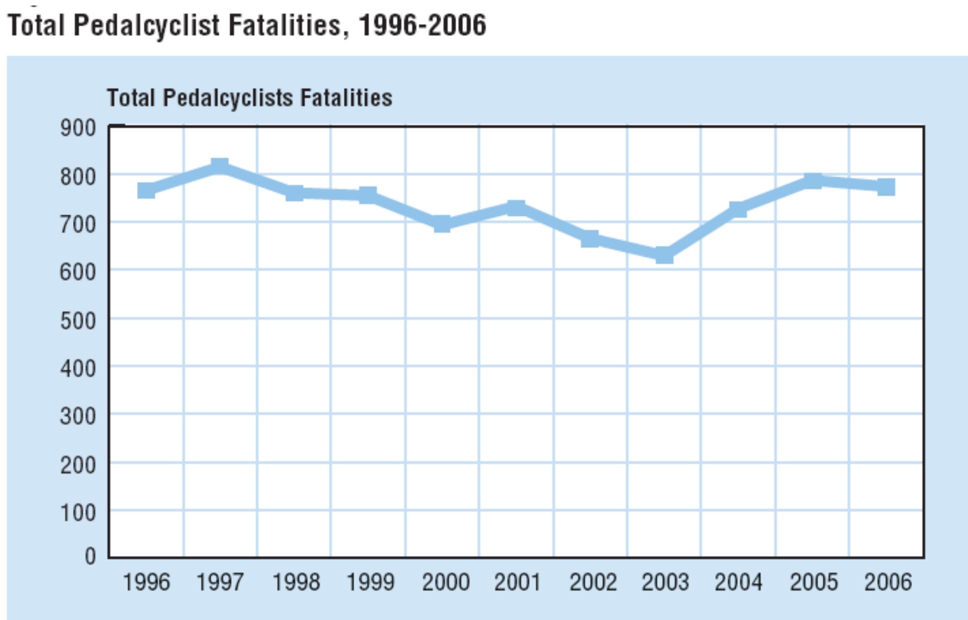


Figure 12 Fatal crashes involving bicyclist, 1996-2006 (10)

The approximate breakdown of causes associated with fatal bicycle crashes is presented in Figure 13. The majority of bicycle fatalities result from failure to yield the right of way, followed by riding, playing or working in roadway, and finally with improper crossing of roadway or intersection (7).

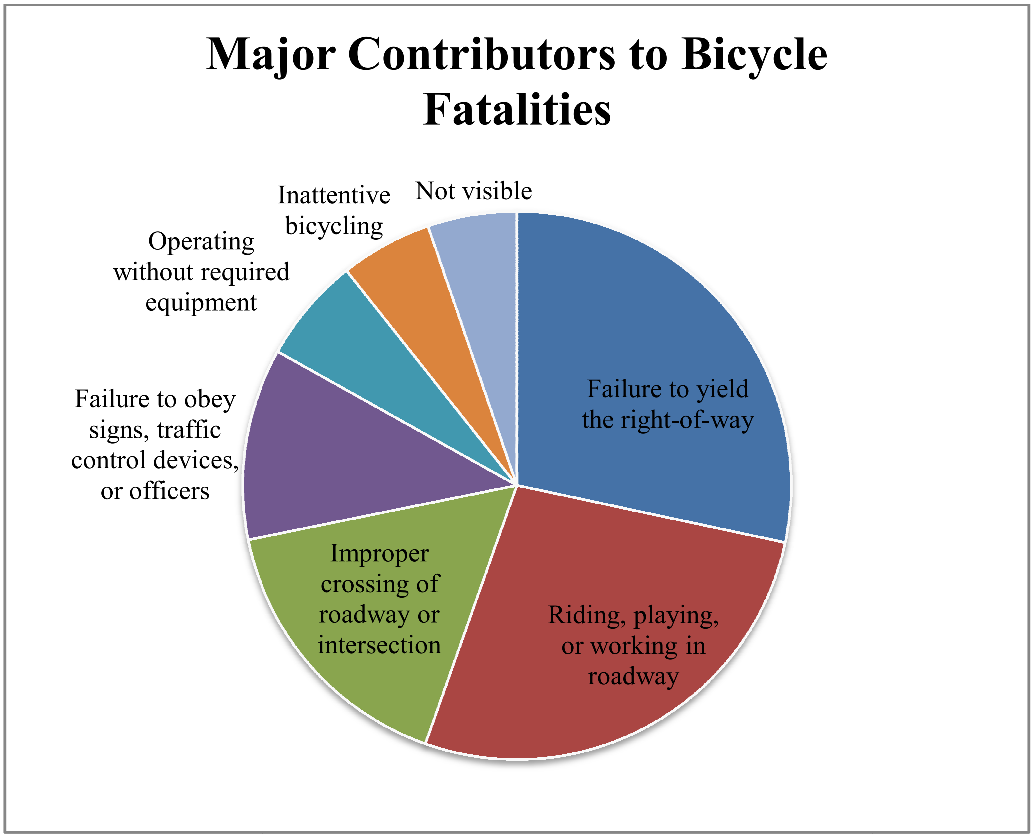


Figure 13 Breakdown of major contributors of bicycle fatalities (1997)

In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) was passed governing the restructuring of transportation departments' attention. Specifically, this piece of legislation required each state to allocate time and resources to improving traffic safety with the goal of reducing the number and severity of traffic crashes (11). Perhaps the most influential piece of recent legislation has been the *Safe, Accountable, Flexible, Efficient Transportation Equity Act* (SAFETEA-LU) passed in August of 2005. This critical piece of legislation opened up an array of opportunity for the improvement and expansion of surface level transportation in the United States for the years 2005 to 2009 (12). This means that a significant source of funding is being directed towards programs for highways, highway safety and transit operations and maintenance. This is providing many communities with the opportunity to make small and large-scale changes with regards to the transportation network; including building upon goals such as maximizing safety and efficiency.

Five years after the initiation of ISTEA the American Association of State Highway and Transportation Officials Standing Committee for Highway Traffic Safety developed a congregate of national safety experts to "develop a strategic plan for highway safety that would impact the nation's present and predicted statistics on vehicle-related deaths and injuries" (6). The birth of the Strategic Highway Safety Plan (SHSP) ensued with the primary goal aiming at "reduc[ing] the number of annual highway deaths by 5,000 to 7,000 and to do so effectively and in a manner acceptable to the general public" (6). More specifically, three of the twenty-two top strategies are directly applicable to the more general topics addressed in the local urban environment and are:

- *Goal 4: Curbing aggressive driving;*
- *Goal 9: Making walking and street crossing safer;*
- *Goal 10: Ensure safer bicycle travel.*

Furthermore, "Pedestrian Bicycle Safety" and "Speed Management" are two of the four primary topics addressed in ITE's *Safety Mega Issue* Publication (6). The development of these goals along with the attention and resources provided by SAFETEA-LU create a strong and supportive environment along with opportunity for local practitioners to improve traffic safety in their communities. In Massachusetts, the Massachusetts Highway Department (MassHighway) governs traffic and transportation engineering projects receiving state or federal funding. MassHighway, also concerned with community livability and preservation, aims to "provide a transportation infrastructure that provides access for all, a real choice of modes, and safety in equal measure for each mode of travel" (13). Not only is there is support and funding at the government and state levels but there is also a significant source of guidance and support, in Massachusetts, at the local level for local practitioners.

One popular approach to addressing issues of speeding, high cut-through volumes, pedestrian safety and bicycle safety is through the implementation of traffic calming measures. Traffic calming is a design implementation measure aimed at improving traffic safety by reducing vehicle speeds and potentially reducing cut-through traffic volumes by altering the physical characteristics of the roadway. They can provide safer facilities for pedestrians and bicyclists and improve community livability and aesthetics. Traffic calming measures are also thought to be incredibly efficient, with the sole cost beyond installation being low maintenance costs. Traffic calming implementation can have many benefits for a community when the appropriate measure is chosen and properly implemented. Many traffic calming techniques have been shown to have positive effects on the environment, community livability, traffic safety, aesthetics, and can be financially efficient. A poorly chosen or incorrectly implemented traffic calming measure can have many negative effects and care must be exercised to fit the measure to the problem.

Local Safety Challenges

Western Massachusetts is a unique geographic area with limited principal arterial roadways. Principal arterial roadways, Interstate 91 and Interstate 90 (MassPike), only reach limited sections of this study area. The resulting effect is a large reliance on minor arterials that commonly travel through town centers (14). This high volume of traffic poses safety concerns for communities filled with high pedestrian and/or bicycle activity. Furthermore, this traffic often experiences higher speeds on stretches of roadway which travel through the rural settings between towns, and lower speed in the more urban settings. The resulting effect may be speeding through the urban, highly populated, residential town centers.

The size of the towns also leads to a limited network within each community where high cut-through volumes are commonly exhibited due to congestion and delay exhibited on main roads. Due to this congestion, these networks have been observed to operate over capacity during peak hours, often forcing drivers to seek alternate routes beyond the primary local roads. Both speeding and increase cut-through volumes pose several concerns related to traffic safety, particularly for pedestrians and bicyclists. Furthermore, the improvement of pedestrian and bicycle facilities in urban settings can have a positive effect on traffic safety and help accommodate for predicted increases in pedestrian and bicyclist volumes.

Speeding

Driving in excess of the posted speed limit technically defines speeding. Speeding in urban environments can pose many safety challenges due to the abundance of activity in these settings. The effect of speeding is an increase in the distance needed to react to a stimulus and stop a vehicle, as well as a reduction of a driver's ability to steer safely around obstacles in the roadway (5). High speeds are not appropriate for such an area which may be inhabited by school zones, frequent bus stops, high pedestrian activity and the presence of commuting or recreational bicyclists. It is therefore critical that the appropriate design speed be selected for roadways in the urban environment. Residential streets in particular should not have high design speeds, but this may also apply to urban arterials depending on surrounding land use and pedestrian activity (15). Some contributors to speeding may include incorrect design speed, perceived environmental conditions and driver behavior.

The speed limit designation process must be performed in accordance with the Manual on Uniform Traffic Control Devices (MUTCD) and any state regulations. The design speed is based on the 85^{th} percentile speed obtained from an engineering study and in most cases, is within 5 mph of the 85^{th} percentile speed of the roadway. Other roadway factors, such as geometry, leave room for engineering judgment to be exercised (1). Depending on design elements, typical design speeds for local urban roadways range from 20 to 30 mph and are typically higher than or equal to 30 mph for collector streets (16). An engineering study should be performed at any location to determine the best appropriate speed for a section of roadway. Since it is common for a minor arterial roadway in Western Massachusetts to pass through a town, often through the town center, it is important to also pay particular attention to gradually decreasing and increasing speed limits. A higher design speed on a minor arterial roadway will feed into a smaller design speed for a local road, and this difference in speeds must be appropriately addressed. According to the Institute of Transportation Engineers (ITE) a "well-designed highway should produce natural driving behavior that results in modest speed changes between highway segments" (15). Adequate space must be left between the lowering of posted speed as a vehicle approaches an urban environment and the physical act of the vehicle entering into that environment to allow the driver to react to the presented stimulus and slow the vehicle down. A lower speed limit, when placed too close to town center, may result in speeding because the driver does not have adequate time or distance to decrease their speed.

Speeding occurring on roadways with accurate design speeds may also be a result of driver behavior. Assuming the posted speed is suitable for that roadway, one must look at other factors influencing driver behavior and choice. There may be many causes of speeding behavior but alterations in enforcement, education, environment and surrounding landscape may all influence driver behavior. Driver perception of road elements such as lane width, shoulder width, lateral clearance and clear zone may alter driver behaviors. Typically, the wider the road element, the less perceived danger to the driver and therefore, increased speeds. A road with a proper balance of roadway and roadside elements can help decrease operating speeds as will be shown later.

High Cut-Through Volumes

Traffic diverting to residential roadways from arterials pose many safety threats to occupants of residential neighborhoods. This traffic seeks to take a “short-cut” through a residential neighborhood to decrease travel time and delay that would otherwise be experienced on the larger arterial roadway. Poor level of service (LOS) occurring on the arterial roadways forces impatient drivers to re-route, often traveling on roads that are not designed for higher speeds or increased capacity. Residential neighborhoods, lined with pedestrian activity (many including children), become very unsafe when higher volumes of traffic utilize the roadway. Furthermore, the traffic traveling on those roadways in an attempt to “cut-through” may represent a more aggressive niche of drivers, some of which who may be still operating at the higher speeds exhibited on arterial roadways (17). The combination of speeding and the presence of pedestrians that may occur as a result of cut-through traffic is especially troubling since a speeding car is less likely see and react to a pedestrian with enough time to avoid the interaction (7). An efficient transportation network can decrease this potential conflict by making the freely flowing arterial roadways more attractive than using residential roadways or physical measures are installed on the roadway to alter driver behavior.

In some communities, such as many urban environments in Western Massachusetts, local traffic may determine that residential roadways have less delay than the larger arterial roadways. Local traffic patterns may display popular cut-through routes for any time of day, not just the peak hours. Such a pattern of travel behavior may be an indicator of an inefficient network design. In the event that the popular cut-through route is determined to be a critical link in the roadway network then changes in road geometry or surrounding environment may need to be made to accommodate for this change and ensure safety.

For example, take a scenario where a new residential neighborhood is built. Motorists determine that this new neighborhood has a great cut-through road and begin using it regularly. The road was not designed for such a high volume of traffic. Therefore, it must either be altered to accommodate for that or some measure must be taken to divert traffic away from this road; such as the implementation of a traffic calming strategy. If the same scenario becomes altered only by the addition of a school in the area, the choice becomes clearer, divert the traffic away from the hazards of the school.

Pedestrians

Study areas such as these, small urban environments, can potentially house a plethora of pedestrian activity when facilities are safe and efficient. Many of these environments in Western Massachusetts particularly, have some proportion of pedestrian population from a local college or University, representing a somewhat seasonal effect and also representing pedestrians who may be unfamiliar with local roads and regulations. Due to this increased volume, it is not surprising that the majority of pedestrian crashes occur in urban areas (17).

According to AASHTO, there are many factors influencing a person's decision to walk, including: distance, perceived route safety, convenience and availability of alternative modes with distance being the most influential (16). Popular social movements addressing issues such as sustainability are encouraging more people to start walk as a form of transportation. The extent to which people walk, however, is partially determined by the attractiveness of available pedestrian facilities. Pedestrians are more likely to be attracted if security, comfort, convenience, efficiency, affordability and the sense of invitation are positive (18). A nationwide survey conducted in 2002 supports these results, stating that Americans would like to walk more if communities were designed better to decrease speeding and there were better facilities to improve convenience as shown in Figure 14. Furthermore, this survey found that there is plenty of interest and public support for improved pedestrian a facilities; particularly for designing communities for slower traffic speeds and improving walking routes to schools for children (19). This survey found some of the following results regarding Americans' attitudes towards walking:

- More than half (55%) say they would like to walk rather than drive more throughout the day either for exercise or to get to specific places.
- Large majorities of Americans support policies to ensure the safety of walkers and to make their communities more walkable. The most popular policies focus on reducing speeding – tougher enforcement of the speed limit and designing streets with more sidewalks and safe crossings to reduce speeding.
    - It was also found that majorities favor making it easier for children to walk to school, improving public transportation, and increasing federal spending on pedestrian safety.

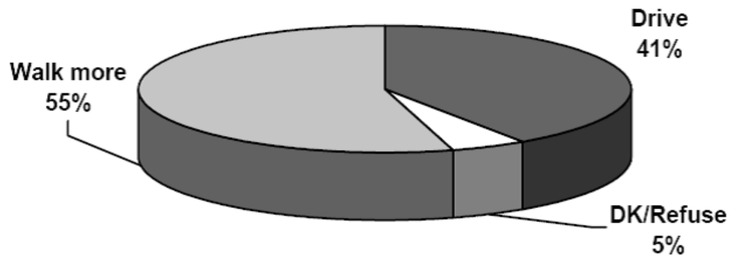
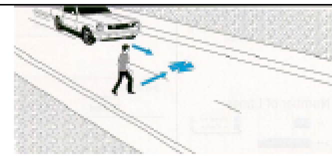
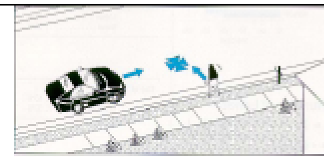
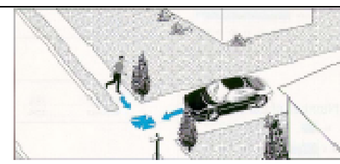
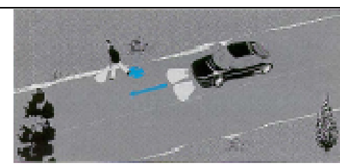
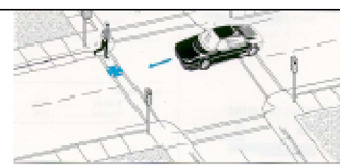
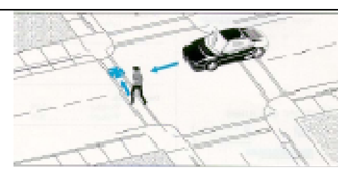
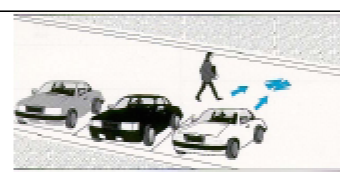


Figure 14 Americans' desire to walk more (19)

Pedestrian to vehicle conflicts may arise for many reasons including: limited pedestrian facilities, speeding, limited sight distance, limited visibility, driver confusion, as well as both pedestrian and driver attitudes. In Massachusetts, the pedestrian has the right of way, which is unique. This can create an aggressive movement behavior and a false sense of security for the pedestrian in an urban setting, causing them (at one extreme) to just walk out into traffic regardless of location (crosswalk or no indicated crossing). Table 1 provides an overview of the most common pedestrian-vehicle conflicts, with the majority of incidents occurring at non-intersections. An understanding of the conflicts most often experience between pedestrians and vehicles can lead to a better understanding of the needs of a community during the planning process.

Table 1 Eight Most Common Pedestrian to Vehicle Crash Types (20)

Crash Type	Description	Picture
Midblock-Other	The crash occurred at midblock, but does not conform to any of the specified crash types	
Vehicle Turn/Merge	The pedestrian and vehicle collided while the vehicle was preparing to turn, in the process of turning, or had just completed a turn (or merge).	
Midblock Dash	At midblock location, the pedestrian was struck while running and the motorist's view of the pedestrian was not obstructed.	
Not In Roadway	The pedestrian was struck when not in the roadway. Areas included parking lots, driveways, private roads, sidewalks, services stations, yards, etc.	
Walking Along Road	The pedestrian was struck while walking (or running) along a road without sidewalks.	
Intersection Dash	The pedestrian was struck while running through an intersection and/or the motorist's view of the pedestrian was blocked until an instant before impact.	
Intersection-Other	The crash occurred at an intersection but does not conform to any of the specified crash types.	
Backing Vehicle	The pedestrian was stuck by a vehicle that was backing.	

Specifications for planning and design purposes provide general guidelines but care must be exercised to design for the specific needs and goals of each community. The MUTCD defines a default pedestrian walking speed used in traffic signal pedestrian clearance calculations as 4.0 ft/sec for the average person (1). Pedestrians with disabilities or older persons, for example, may require more crossing time. Pedestrian signal phase timing is determined by this default walking speed and the distance the pedestrian must cross. Safe timing allocations are important to allow pedestrians sufficient time to enter the crossing area, perform the crossing maneuver, and complete the crossing maneuver. Pedestrian timing is merely one aspect of pedestrian safety at intersections. Ensuring that the phase is clear to all roadway users is also critical. Lastly, making facilities accessible to all individuals is an important piece of pedestrian facility design.

Pedestrians vary greatly in abilities and behaviors so it is important to design facilities for users of all ages and abilities. Designing for individuals with disabilities is critical to the users' safety, accessibility and comfort; especially since 20% of the population has some form of disability (13). The Americans with Disabilities Act (ADA) of 1990, which prohibits discrimination and ensures equal opportunity and access for persons with disabilities, aims at ensuring pedestrian facilities can accommodate all users. Measuring the performance of pedestrian facilities can be measured using pedestrian level of service (LOS) calculations found in the Highway Capacity Manual. Figure 15 shows the general spatial requirements of a single pedestrian and a person using a wheelchair. Tables 2 - 4 show the general spatial requirements and recommended design guidelines for designing pedestrian facilities. While the spatial requirements of users vary it is important to ensure that community facilities provide access for all users. In addition to ensuring the physical spatial dimension requirements are met, there are a plethora of other techniques that can help accommodate for users of all ages and abilities and will be addresses in the strategies section.

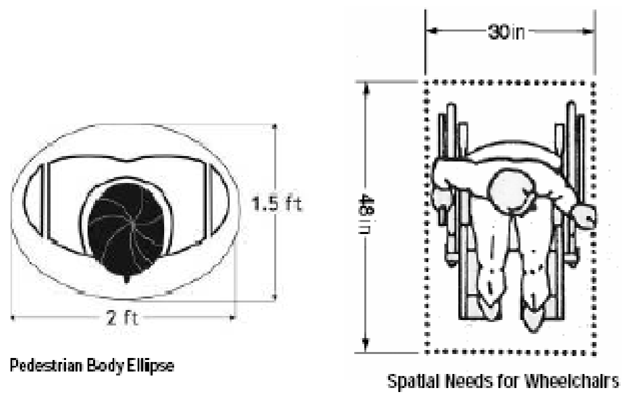


Figure 15 General spatial requirements of pedestrian facility users (13)

Table 2 General Spatial Requirements of Pedestrian Facility Users (13)

Facility User	**Spatial Requirement; width (ft)**	**Spatial Requirement; depth (ft)**
Single Pedestrian Standing	2	1.5
Person Sitting in Stationary Wheelchair	2.5	1.5
Person Using Scooter or Power Chair	≥2.5	≥4
Person Using Crutches, Service Animal, or Walker	3	≥1.5

Table 3 Design Buffer Zone Requirements for Pedestrian Facility Users (13)

Facility User	Total Area (ft^2)
Single Pedestrian	8
Person Using Cane or Wheelchair	~16

Table 4 Walkway Width Requirements for Pedestrian Facility Users (13)

Facility Desired	Width Requirement (ft)
Single File Pedestrian Flow in One Direction	≥3
Pedestrian Flow with Free Passing	≥5
Two People Walking or Riding in Chair Abreast	≥6

It is critical to design for all users of the roadway and ensure access, mobility and safety through design. Creating safer and accessible pedestrian facilities as well as improving existing facilities can have a positive effect on the overall transportation network and the environment. Reducing the reliance upon the automobile will not only help alleviate congestion on our roadways, but will also help distribute the demand over various modes, creating a more balanced and efficient network. Lastly, there are many supplemental benefits to increasing the number of people walking which include but are not limited to reduced pollution, smaller ecological footprint, fuel and cost savings, as well as improved health and wellness.

Bicyclists

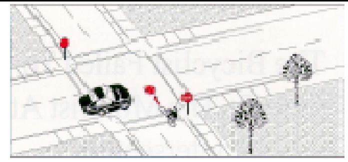
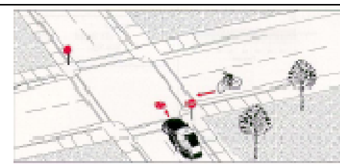
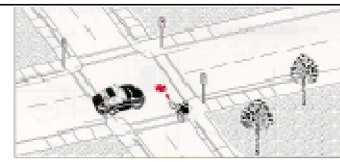
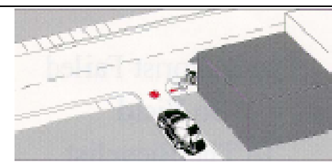
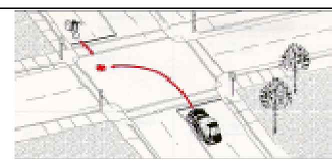
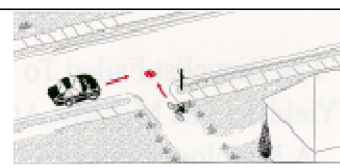
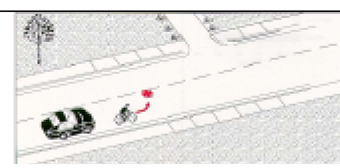
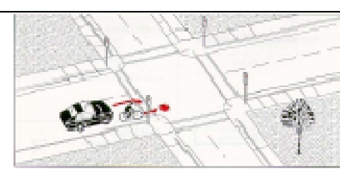
Cycling can be a popular mode of transportation and exercise in the busy urban environment. There are many hazards in this environment, however, which can drastically affect the safety and attractiveness of biking. A safe and efficient bicycle network can effectively encourage more people to utilize bicycles as a mode of transportation. A challenge exists to accommodate for a wide range of abilities such as beginners, professionals, and recreational bicyclists. Additionally, new types of bicycles such as recumbent and three-wheeled cycles are hitting the roads, posing new challenges to local practitioners.

Due to urban sprawl, more people are commuting a greater distance to work each day. This results in a significant dependence upon the automobile in today's society. In urban centers and smaller communities, however, more people may have the option of commuting via bicycle due to the shorter distance between work (or other destinations) and home. Most viable in the urban center, bicycling is becoming a more popular mode choice but there may not always be adequate facilities for such a shift. Research shows that people are more likely to bicycle when there are adequate facilities but many roadways are not designed to safely accommodate bicyclists or pedestrians (20).

There are many factors which influence a person's decision to select cycling as their mode of transportation. Primarily, eight factors have been identified to have the most influence over this decision and include: public attitude and cultural differences, public image, city size and density, cost of car use and public transport, income, climate, danger, and cycling infrastructure (21). Climate cannot be easily modified by local practitioners to increase the attractiveness of cycling, however, each of the other variables can, to some extent, be modified to make cycling more attractive. City-wide cycling awareness campaigns, fee reductions and other monetary based rewards programs and improved facilities can all have significant positive impact on increasing cycling in a community.

Bicycle to vehicle conflicts can arise due to visibility, site distance and road geometry issues as well as driver and rider behaviors. Unless given a designated path, cyclists should use the roadway and not the sidewalk for travel. In doing so, cyclists are subject to the same motor vehicle laws with minor exceptions (13). When adequate space is not provided, cyclists may be forced to occupy an entire lane of traffic, ride on the shoulder or share a lane of the roadway, creating many opportunities for conflict and dangerous situations. Another high conflict area can be at intersections where the bike or vehicle have the right of way but the proper right of way is not exercised. Lastly, parking lots and other areas where visibility and sight distance are compromised can be just as treacherous. Table 5 provides a summary of the either most common bike to vehicle crash types.

Table 5 Eight Most Common Cyclist to Vehicle Crash Types (20)

Crash Type	Description	Picture
Ride Out at Stop Sign	The crash occurred at an intersection at which the bicyclist was facing a stop sign or flashing red light.	
Drive Out at Stop Sign	The crash occurred at an intersection which the motorist was facing a stop sign.	
Ride Out at Intersection- Other	The crash occurred at an intersection, signalized or uncontrolled, at which the bicyclist failed to yield.	
Drive Out at Midblock	The motorist was entering the roadway from a driveway or alley.	
Motorist Left Turn- Facing Bicyclist	The motorist made a left turn while facing the approaching bicyclist.	
Ride Out at Residential Driveway	The bicyclist entered the roadway from a residential driveway or alley.	
Bicyclist Left Turn in Front of Traffic	The bicyclist made a left turn in front of traffic traveling in the same direction.	
Motorist Right Turn	The motorist was making a right turn and the bicyclist was riding in either the same or opposing direction.	

In addition to the potential for cyclist to vehicle conflicts, the cyclist must also watch for other hazards. Pedestrians crossing, debris in the roadway, poor lighting and drainage grates can also pose significant safety challenges to the cyclist. Many of these obstacles can be easily and quickly improved through low cost safety fixes which may include adding paved shoulders, wider traffic lanes in the absence of a shoulder, bicycle-safe drainage grates, and maintaining a smooth, clean riding surface (16). Figure 16 provides an example of a common roadway hazard for cyclists in which opening car door can result in serious injury.

Figure 16 The hazards of cycling in the urban environment (22)

The spatial requirements of cyclists will vary according to user type, cycle type, experience, and operating characteristics which consist of width, angle of lean, sight distance and clear zones (13). The minimum bicycle operating space to be used in designating space for cyclists should be a minimum of 40 inches wide and 100 inches tall as shown in Figure 17. Those cyclists who require extra space because of trailers or bicycle type (tricycles) should have a minimum of 48 inches of width. Bicycle lanes should be a minimum of 4 feet wide per lane with extra spatial requirements if added comfort or safety (e.g. higher speeds) are desired. This can result in bike lanes with widths of 5 to 6 feet. This requirement is also applicable on roadways with adjacent on street parking to avoid hazards such as those seen in Figure 16. Lastly, debris and obstructions can pose conflicts when they interact with the surface of the tire (13).

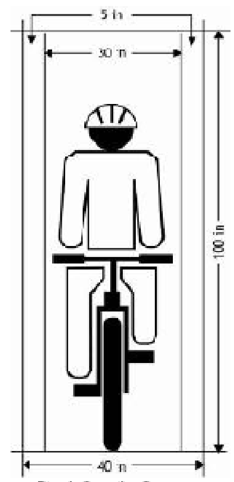


Figure 17 Spatial requirements of the typical bicyclist (13)

In summary, designing facilities that encourage and promote safe and efficient cycling for a variety of users is a challenge to the local practitioner. A higher percentage of users using non-motorized modes of transportation is more probable in the urban center due to the proximity of home to shopping, work and other destinations. Limited space and resources can make creating such facilities challenging, however, there are many ideas contained later in this thesis to assist the local practitioner in selecting appropriate safety and efficiency improvement measures. More users utilizing non-motorized forms of transportation may reduce congestion, improve community livability and decrease pollution in the urban center.

Local Urban Engineering Strategies

There are multiple approaches that can be taken in an attempt to improve safety and efficiency of the local urban transportation network. Traditional approaches to transportation problem solving include the three “E” approach consisting of education, enforcement and engineering. In recent years, however, a fourth “E” has been added, encouragement. A successful program should make an attempt to incorporate each of the four “E’s” into the planning process in order to maximize positive impacts, community involvement, efficiency and safety.

Education

Often grouped with community action, education can be an effective and inexpensive way of addressing local urban transportation issues. Education will be likely supplement to any strategy and may also be one of the first approaches taken to address such issues due to its affordability as well as availability of resources. Education can be targeted towards residents and community members about transportation issues and problems while others are aimed at educating roadway users as to the conditions or laws of the roadway (23). Some examples of education may include neighborhood meetings, signage, speed trailers and pace car programs. Behavioral based programs rely on the example behavior displayed by citizens of a community. Pace car programs, such as Northampton’s, flag model cars which set the example of driving in a safe and responsible manner and within the posted speed limits.

Enforcement

Enforcement can be a useful approach or component to addressing local urban transportation issues. One challenge with utilizing enforcement may be the availability of resources and the costs associated with this service. For issues on residential roadways with smaller volumes, utilizing law enforcement may detract from higher priorities. Furthermore, the use of law enforcement can become quickly costly. Only when there is a consistent and continued presence of enforcement has it been found to be a useful approach. Enforcement may be a good option where there is a specific problem at a recurring time period, such as at the dismissal of school or an event (7). The use of a penalty, traffic tickets or fines, may not be well received by communities, including residents.

Encouragement

If enforcement is at one end of the spectrum, encouragement is at the other. Instead of penalizing poor driving behavior, encouragement rewards positive behaviors. Such programs may originate at the workplace, from the town or in other arenas and offer positive rewards and incentives for 'good' behavior (20). Some techniques may consist of companies offering incentives which reward their employees with discounts on public transportation or encourage the walking or bicycling. Providing adequate facilities for bicyclists include safe and secure bicycle racks and storage spaces and can significantly contribute to a person's decision to utilize alternative modes of transportation. Working in conjunction with law enforcement, many insurance companies provide reduced rates for "good driver" behaviors.

Engineering

When education, enforcement and encouragement do not sufficiently address local issues another approach, engineering, must be taken. Engineering may consist of modifications or additions of roadway design elements, roadside elements or a combination of approaches. The Institute of Transportation Engineers (ITE) explicitly defines traffic calming measures as self-enforcing measures as opposed to regulatory controls which require enforcement. A similar definition, provided by the Massachusetts Highway Department (Mass Highway) describes traffic calming as "physical road design elements intended to reduce vehicle speeds and improve driver attentiveness" (7). There are a variety of definitions of traffic calming, but all have the same core values which are improving community livability and safety. Traffic calming devices require no regulation although some initial education may be suggested. Furthermore, traffic calming measures have a wide range of implementation costs but have relatively low annual maintenance costs and can be considered self-sustaining. Lastly, when implemented well, traffic calming measures provide the user with no alternatives to slowing down and guide the user towards a safer path. According to the Traffic Engineering Handbook, traffic calming encompasses a wide range of strategies that aim

> "at reducing the physical and social impacts of traffic on urban life, principally through the reduction of traffic speeds and volumes. In principle, traffic calming may be directed at the neighborhood street, corridor, or citywide levels. Programs may involve direct intervention using physical devices or other management techniques, or they may involve more fundamental social changes that result in different travel choices and driver behavior" (15).

While most traffic calming projects result in physical alterations of the roadway or roadside environment, there are many supplemental strategies which can be used to improve local urban transportation safety and efficiency. Selected traffic calming and related strategies are contained in the toolbox section of this thesis.

History

Traffic calming is the result of community action against speeding traffic on community streets on the Netherlands in the 1960's. In order to tame the traffic, residents created difficult to traverse streets by using physical measures (tables, etc.) in the roadways. In addition to slowing traffic down, the streets also became more livable and soon this practice was adopted throughout parts of Europe (24). Some early traffic calming measures, street closures and traffic diverters, were used in the United States as early as the late 1940's. The first citywide adoption of traffic calming took place in Seattle, WA in the early 1970's. It was not until 1980 that the first comprehensive study of traffic calming in the United States was performed (25). Traffic calming is gaining popularity due to its positive impact on safety and sustainability.

There are many positive outcomes of traffic calming implementation. Traffic calming measures, as previously mentioned, have relatively low maintenance costs and can improve safety dramatically by controlling speeds and guiding drivers. This may be achieved by the use of physical roadway furniture that forces the driver to slow down. Traffic calming can improve street or community livability by reducing cut through traffic and making roadsides safer through speed control. There is opportunity to improve a sense of community and livability through improved aesthetics. The reduction of cut through traffic and speeding can also lead to reduced noise and air pollution, creating a cleaner environment. Traffic calming techniques are also gaining popularity due their sustainability.

Speeding can be effectively reduced via traffic calming measures because of the introduction of physical barriers. One of the primary goals of traffic calming is to "reinforce the desired operating speed through design of the facility, thereby self-enforcing the desired speed" (13). Driver attentiveness can be increased through the effective selection and implementation of traffic calming measures. Traffic calming is effective in this way as its grasps driver attentiveness by reducing operating speeds, drawing attention to and highlighting other users of the roadway, providing a shift in conditions, and preventing dangerous behaviors (13). Traffic calming techniques have been shown as effective tools in speed reduction in a number of case studies (24).

Traffic calming measures are not only aimed at curbing speeding in a community but are also aimed at reducing traffic volumes on a roadway (13). This application of traffic calming in Northampton will most likely be seen in the residents' desires to reduce cut through traffic on local roads. This cut-through traffic that is often times diverted off of roads with more capacity due to congestion or operational issues, can pose safety hazards and stress the capacity of a roadway. Through the innovative use of traffic calming measures, cut-through traffic volumes can also be reduced.

The reduction of operating speeds to match design speeds on a roadway can greatly increase traffic safety by providing the user with more time to react to obstacles and challenges in the system. The severity of a crash is directly related to the vehicle speed at time of impact and it has been shown that the risk of severe injury or death increases with speed (26). In addition to decreasing crash severity through promotion of operating speeds mirroring design speeds, crash severity can also be reduced indirectly as a result of reduced speeds as drivers will have greater stopping distances, potential conflict points may be decreased and more reaction time may be available (13).

Safety for pedestrians is often a concern in cities with multimodal transportation centers. Northampton has a plethora of pedestrians who are aggressive and inattentive. Traffic calming has the ability to decrease severity of non-motorist crashes by reducing the number of conflict points, creating short crossing distances, providing pedestrians with refuge islands, placing the pedestrian in high visibility areas and forcing the pedestrian to actively look into traffic before crossing (13). The effect of each measure will be discussed in the "Toolbox" which shall accompany the final report.

While there are many different traffic calming techniques, there are three general design measures outlined by Mass Highway including: roadway narrowing, path deflection, and vertical path alteration (13). Roadway narrowing is the actual narrowing of the roadway, but it can also include a perceived roadway narrowing. This is effective because it is known that vehicle operators drive at slower speeds when there is less perceived lateral clearance. Furthermore, it can also lead motorists to slow down due to a perceived calmer environment. Some examples of roadway narrowing techniques are: chokers, neck-downs, and mid-block islands (27). Path deflection techniques are designed guide the driver through route alteration. Some examples of such techniques include: roundabouts, mini-circles and diagonal diverters. Finally, vertical path alteration consists of the addition (mostly) or subtraction of roadway such that a change in the vertical path of the roadway aids in traffic calming. Some examples of this might include speed humps, bumps or tables.

Design Considerations

When selecting a traffic calming implementation measure more must be considered beyond need, cost and availability of resources. Often times there are direct and indirect consequences of traffic calming implementation which must be predicted to the best extent possible beforehand. If a measure has been chosen incorrectly or improperly implemented, it can have dire consequences on the safety, sustainability and/or efficiency of the network. It is important to take community needs and limitations into consideration. Flexibility in both implementation and design are critical as it may take more than one attempt to alteration to achieve the desired outcome. Some negative side effects of traffic calming implementation may include increase noise or air pollution, an increase in cut through or diverted traffic, drainage issues and maintenance responsibility issues (27). It is important to investigate all potential side effects of each traffic calming mechanism and weigh its costs with its benefits.

Emergency vehicles can have difficulty maneuvering through or over certain traffic calming measures. It is important that the location of the roadway segment or intersection be carefully studied in this respect. A cost-benefit analysis may need to be performed to determine if the safety benefits of a traffic calming measure are more beneficial than a slower emergency vehicle response time where applicable (7). An area under review which is a critical link in a community's emergency response system may have a different traffic calming selection library than another area.

Another consideration to take into account is climate. Communities such as those located in Western Massachusetts which have heavy snowfall in the winters may want to consider utilizing temporary structures which can be removed to allow for snow plows and other such vehicles. When permanent structures are chosen in such an environment, supplemental indicators may need to be placed near the device to warn plows and other vehicles of their presence in inclement weather. Some materials are more robust to winter weather and wear and tear and this should also be examined in the selection and implementation procedures.

CHAPTER 3

COUNTERMEASURES

A thorough traffic engineering study should be performed at each location to determine the extent of the problem(s) facing a community, an inventory of existing conditions and infrastructure and determination of the right of way (ROW). Furthermore, the influence on traffic calming implementation on emergency vehicle response paths needs to be carefully examined. Once this study has been performed and it is determined that safety countermeasures need to be implemented the task to select the most appropriate countermeasure(s) begins. Often, the implementation of one countermeasure aimed at addressing a particular problem may have added positive effects on another problem. However, the implementation of a countermeasure may also come with added unforeseen negative consequences so the selection of any countermeasure must be done with adequate planning and research. It is usually not sufficient to solely implement a countermeasure without supplemental education and enforcement, if not for the entire life of the selected strategy, then for the initial stages on implementation. Lastly, any measure should be periodically monitored for performance, which may unexpectedly change due to alterations in environmental, social or other conditions.

Dynamic Speed Monitoring Displays (DSMD) and Dynamic Speed Display Signs (DSDS)

Dynamic Speed Monitoring Displays (DSMD) and Dynamic Speed Display Signs (DSDS) are radar based interactive speed displays. They operate by using radar to detect a vehicle's traveling speed and displaying it for the motorist to view via immediate feedback as shown in Figures 18 and 19. It is expected that motorists will slow down upon viewing their excessive speed (28). DSMD and DSDS will usually be implemented in combination with a regulatory speed sign such that relevant information is immediately provided to the operator and an assessment of their performance relative to that feedback is given and may be either temporary or permanent (29). Such strategies have been proven to be effective in areas such as urban settings in both the short and long term (30). DSMD and DSDS measures can utilize solar power to operate the device daily.

The dimensions of variable display signs can vary but most will be the approximate size of the adjoining speed regulation sign as outlined in the Manual on Uniform Traffic Control Devices (1). Variable message signs will have no impact on emergency vehicle response times or comfort. Variable message signs may results in an occasional operator testing the limits of the sign and trying to "race" the sign, resulting in significantly higher speeds. Permanent variable speed signs alone can range anywhere from $2500 to $6000 (14).

Figure 18 Permanent dynamic speed monitoring display (30)

Figure 19 Temporary speed trailer (31)

<u>Speed Humps</u>

Speed humps are physical measures installed in the roadway to reduce vehicle travel speeds by providing a raised surface traversing across the roadway to control speeds. Designed to allow vehicles to travel with little discomfort at the posted operating speed, speed humps result in increasing discomfort when traversed at higher speeds. Speed humps have been shown to be an effective speed calming measure resulting in a net effect of speeds that are only slightly higher than the posted speed and are more effective than all way stops (32; 13). Speed humps differ from speed bumps in that they allow higher operating speeds than speed bumps, which have been shown to require vehicles to slow to a near stop to pass over comfortably. Speed humps typically allow for speeds ranging from 15 – 20 mph when spaced appropriately and are appropriate for minor collectors and local roads (32; 13). Such measures are useful for residential roadways or roadways where lower speeds are critical and may result in the additional benefit of reduced cut-through volumes.

MassHighway provides design guidelines for speed humps in the Project Development and Design Guide. Typical speed humps are 12-14 feet in length, and rise to a height of 3-4 inches, with a parabolic crown profile, shown in Figure 20. Speed humps can be permanent or removable as shown in Figures 21 and 22, respectively. Permanent speed humps are typically constructed with asphalt, textured or colored asphalt, poured or stamped concrete while temporary speed humps may be constructed from rubber or recycled rubber materials (13; 33). Spacing may be left between the end of the hump and the curb to accommodate for drainage and/or bicycles. Speed humps are typically placed in a series of 300 – 600 feet apart depending on the environment (34).

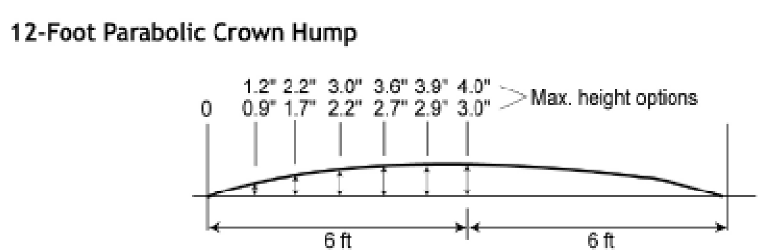


Figure 20 12-Foot parabolic crown hump (13)

Emergency vehicles utilizing a route with speed humps will have a decreased response time because they will be forced to operate at lower speeds. Therefore, this strategy is not suggested for routes heavily traveled by emergency vehicles. Accelerating and decelerating vehicles traversing over the speed humps may produce some noise pollution in a community. An appropriate traffic calming implementation strategy should be prepared to provide noise pollution mitigation. The speed humps should be strategically placed so as to reduce the effects of noise pollution on communities (13). Speed humps can range in price from $1000-$2000 with no or relative low maintenance costs (34; 33)

Figure 21 Temporary speed hump constructed of recycled rubber (35)

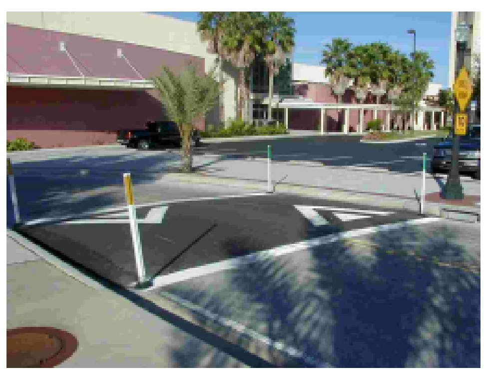


Figure 22 Permanent speed hump (36)

Speed Tables and Raised Crosswalks

Speed tables, similar to speed humps, are physical measures installed in the roadway to reduce vehicle travel speeds by providing a raised surface traversing across the roadway to control speeds. Designed to allow vehicles to travel with little discomfort at the posted operating speed, speed humps result in increasing discomfort when traversed at higher speeds. Such measures are useful for residential roadways or roadways where lower speeds are critical and may result in the additional benefit of reduced cut-through volumes. Speed tables have a flat top where speed humps have a parabolic profile. As a result of this flat top design, speed tables can accommodate a crosswalk in the middle of the design creating a raised crosswalk, allowing for a more visible and safer pedestrian crossing zone (34). Speed tables are more comfortable to traverse for larger vehicle than are the speed humps (37).

MassHighway provides design guidelines for speed humps in the Project Development and Design Guide. Typical speed tables are approximately 22 feet in length, and rise to a height of 3 inches, with either a parabolic crown profile or straight ramp profile as shown in Figures 23 and 24. Speed tables can be permanent or removable as shown in Figures 25 and 26, respectively. Permanent speed tables are typically constructed with asphalt, textured or colored asphalt, poured or stamped concrete while temporary speed humps may be constructed from rubber or recycled rubber materials (13; 33). Spacing may be left between the end of the hump and the curb to accommodate for drainage and/or bicycles.

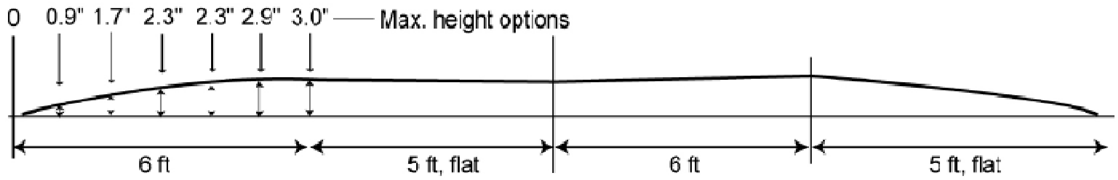


Figure 23 22-Foot parabolic ramp speed table (13)

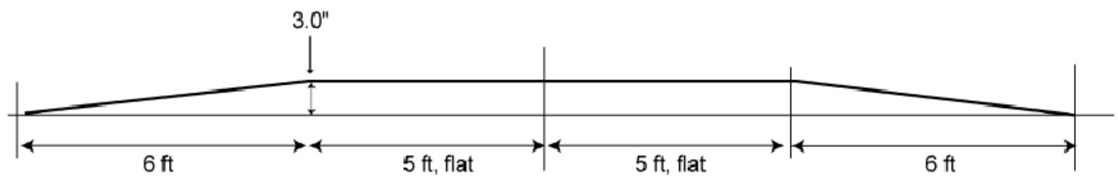


Figure 24 22-Foot straight ramp speed table (13)

Speed tables are more comfortable for larger vehicles, such as emergency vehicles, than are speed humps. Speed tables can be tolerated by emergency vehicles with less increase in response time when compared to speed humps. As a results of more frequent acceleration and deceleration of speeds, as well as the noises emitted as a vehicle traverses over the table, noise and air pollution may increase slightly. Speed tables can range in price from $2000-$2500 with no or relative low maintenance costs (34; 37).

Figure 25 Speed table constructed from rubber (25)

Figure 26 Permanent speed table/raised crosswalk (38)

Speed Cushions

Speed cushions are similar to speed humps because they also have a flat-topped hump, but differ in that they do not fully extend across the roadway. A set of three speed cushions will be placed side by side in the cross section of the roadway with adequate spacing. This spacing allows larger vehicles to maneuver the roadway unaffected by the speed cushions. Speed cushions are designed so that one (or both) sides of the vehicle pass over the cushion. Speed cushions may be chosen over speed humps where drainage and bicycle lanes are being considered. Furthermore, the break in the speed cushion allows for emergency vehicles and larger vehicles to straddle middle cushions depending on lane configurations and set-up. The width of the two cushions closest to the roadway edge are 6.0’ while the middle cushion is 4.5’ which is designed to specifically allow emergency vehicles to pass over a section of roadway uninterrupted as shown in Figure 27. Speed cushion dimensions will vary depending on roadway geometry, drainage and shared usage requirements.

Speed cushions, like speed humps, target a reduction in speeds but can also result in a decrease in cut-through volumes. When compared to speed humps, speed cushions are more affordable because they require less material (25). Similar to speed humps, noise and vehicle emissions may be increased due to frequent slowing down and passing over the cushions. Speed cushions may be permanent or temporary based on a community’s needs as shown in Figures 28 and 29, respectively.

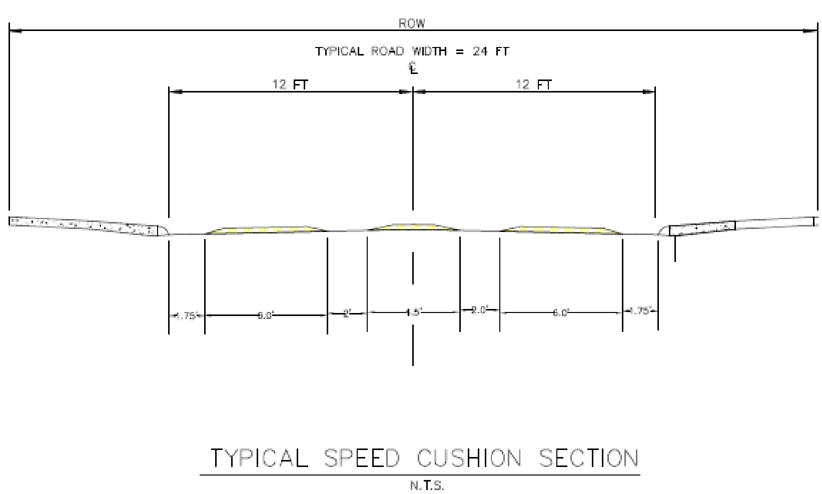


Figure 27 Typical speed cushion cross-section (39)

Figure 28 Permanent speed cushions (25)

Figure 29 Temporary speed cushions

Roundabouts

Roundabouts can be effective tools in managing speeds and cut through volumes as well as providing opportunities for improved aesthetics through landscaping. Furthermore, roundabouts can aid in the improvement of pedestrian facilities. Roundabouts have been proven to be effective in improving traffic safety in the United States. One reason is because of their low operating speeds. Roundabouts also change the crash types experienced at intersections, altering them away from angle crashes and towards less severe sideswipe crashes (7). Roundabouts also offer pedestrian crossing islands which decrease the distance a pedestrian must cross in one section and add to visibility. Some critics argue that roundabouts pose challenges for bicycles, however, when the appropriate signage and speeds are chosen, this concern can be calmed. Roundabouts are also popular because of their relatively low maintenance costs. While expensive initially to implement, roundabouts are incredibly efficient and self-sustaining. An example of a roundabout can be seen in Figure 30.

Figure 30 Example roundabout (40)

There are some basic elements that comprise a roundabout and include: a circulating roadway, a central island, and splitter islands as shown in Figure 31 (15). The recommended entry design speeds for roundabouts vary with type (i.e. size and shape) but range from 15 to 30 mph (41). Roundabouts can be challenging for emergency vehicles and other large vehicles depending on size so they are not recommended for heavily traveled emergency vehicle routes.

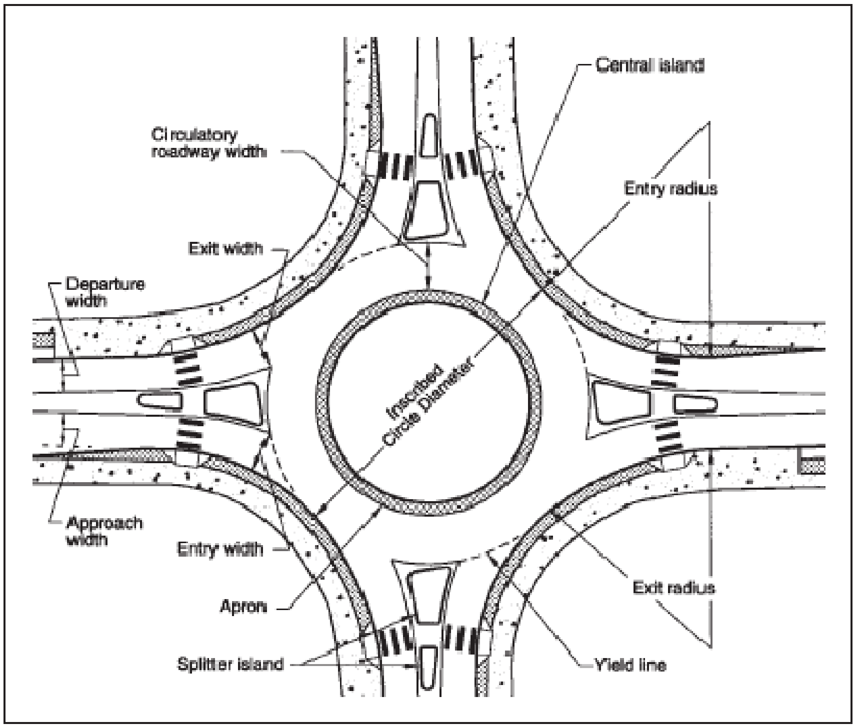


Figure 31 Basic elements of a roundabout (41)

<u>Lane Reduction</u>

Lane and width reductions have been shown to result in a decrease in crash rates (42). Reductions in the number of lanes or lane widths can decrease travel speeds along the roadway. Furthermore, this can also result in improved pedestrian or bicycle facilities if bike lanes are added, pedestrian sidewalks widened, or landscaping is added. The addition of a bicycle lane as well as adding landscaping can help separate the travel way from the pedestrian travel way, thus increasing safety (7). The effect of reducing the number of lanes as shown in Figure 32 and Figure 33 can result in lower operating speeds due to the decrease perspective of space. The reduction of lane width achieves the same effect, creating a more confined environment for drivers in which they are no longer operating at higher speeds.

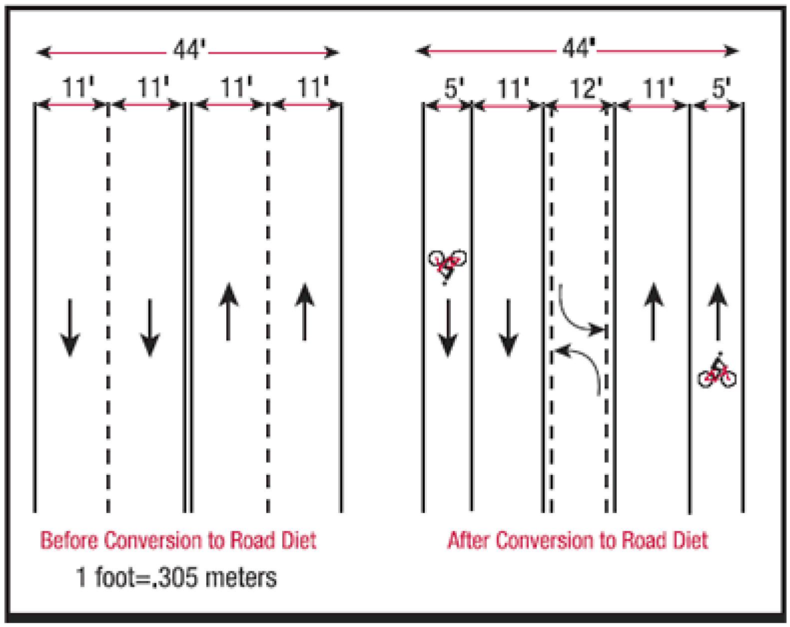


Figure 32 Sample lane reduction plan (42)

The reduction in the number of lanes can also be beneficial to pedestrians as the crossing distance can be decreased for pedestrians. The result is not only a shorter crossing distance but also a decrease in the amount of time the pedestrian spends in the roadway. A traffic study should be performed to determine if the number of lanes on the roadway is suitable (43). The reduction in the number of lanes can also have an added benefit to the community, making it safer and more livable.

The costs of reducing the number of lanes will vary according to the desired outcomes. Reconfiguring pavements marking is a relatively inexpensive solution, while adding raised medians, widening sidewalks and adding bicycle lanes all add to the costs.

Figure 33 A converted four-lane roadway to three-lane roadway (44)

Textured Pavement in Pedestrian Crosswalks

Enhancing crosswalks may include textured or colored pavement as shown in Figure 34 and Figure 35 to help enhance the path of the crosswalk. Enhancing crosswalks can accomplish many goals. First, bringing attention to the pedestrian crossing path may benefit both pedestrians and drivers. A clear path for pedestrians may encourage the use of the path and result in fewer midblock crossings not occurring at crosswalks. Another benefit may be that the drivers' attention is directed to the pedestrian crossing path, making drivers more aware of crossing pedestrians (45).

Textured pavement and colored pavement may also help highlight the intersection of a crosswalk or pedestrian crossing path with the roadway, warning pedestrians of the changing roadway conditions. Textured pavement especially, may aid pedestrians in delineating the roadway, especially those with a disability. Lastly, textured pavement can also add to the charm and aesthetics of a community.

Figure 34 Textured pedestrian crosswalk (46)

Figure 35 Stamped concrete pedestrian crossing (44)

<u>Bulbouts and Sidewalk/Curb Extensions</u>

Bulbouts and curb extensions can improve traffic safety at intersections or areas with pedestrian crossing. They can be used at either intersections (as shown in Figure 36 and Figure 37) or at midblock locations. Curb extensions and bulbouts can improve traffic safety by decreasing the crossing distance for pedestrians (resulting in a short amount of time the pedestrian spends in the roadway), decreasing travel speeds (due to smaller lane widths), and improving visibility for both motorists and pedestrians alike (44). Furthermore, bulbouts and neckdowns can also prevent the situation where a pedestrian is struck in the crosswalk by a motorist attempting to pass a vehicle in front of it which had stopped for someone in the crosswalk. They can result is lower turning speeds and encourage pedestrians to utilize designated crossing areas. There are many safety challenges that bulbouts and neckdowns address. In addition to those safety benefits, this strategy can also improve aesthetics in a community. Curb extensions can be coupled with textured or colored pavement to maximize the benefits to both roadway users and pedestrians alike.

Figure 36 Curb extensions at an intersection (44)

Figure 37 Intersection bulbouts at an intersection (44)

Pedestrian Crossing Island

Pedestrian crossing islands, such as the one shown in Figure 38, can improve traffic safety by providing refuge for a crossing pedestrian, decrease the pedestrian crossing distance, and decrease the amount of time the pedestrian spends in the roadway. Pedestrian crossing islands are usually located on roadways with a median separating opposing traffic streams. This strategy may also be useful in communities with much variation in pedestrian walking speeds. Pedestrian crossing islands provide pedestrians with a refuge and can also improve visibility. An angled pedestrian crossing island as shown in Figure 39 guides the pedestrian so that he/she faces the traffic stream they are about to cross, making them both more visible and more aware of approaching vehicles. This can be useful at locations where pedestrians do not exhibit care in crossing.

Figure 38 Pedestrian crossing island (44)

Figure 39 Pedestrian crossing island with angled crosswalk (44)

Chicanes & Chokers

Chicanes and chokers are a series of horizontal deflections (as seen in Figure 40) in the roadway to force drivers to weave through the roadway, resulting in decreased operating speeds when properly implemented. Chicanes are also preferred by many emergency personnel to speed humps (34). Chicanes may also have a significant impact on reducing cut-through volumes on roadways. The placement of chicanes should be at midblock locations. Where two chicanes are place in a midblock location directly across from each other, a choker is formed. A choker is similar to lane narrowing but only involves a small cross section of roadway. Chokers may be an ideal countermeasure to speeding where there is a change in the posted speed limit or for routes heavily traveled by emergency vehicles. A midblock pedestrian crossing utilizing a bulbout may also work as a traffic choker. A poorly designed chicane may have little effect on decreasing speeds as vehicles may be observed to travel in a straight path regardless.

Figure 40 Sample chicane (47)

CHAPTER 4

STUDY DESIGN: CASE STUDIES

Two strategies recently implemented in local urban environments in Western Massachusetts, speed cushions and reverse angle parking, were evaluated as part of this research. Temporary speed cushions were installed on Lincoln Avenue in Amherst, Massachusetts in an attempt to curb speeding and lower cut-through traffic volumes on this residential roadway. A reverse angle parking pilot program was implemented on Main Street in downtown Northampton, Massachusetts in an attempt to improve the safety and efficiency of the City's parking. This analysis contains an evaluation of each strategy.

Temporary Speed Cushions

Background Information

The Town of Amherst is located in scenic Western Massachusetts, 23 miles North of Springfield in Hampshire County. Home to 35,000 residents, Amherst is a diverse community surrounded by three colleges and universities; Amherst College, Hampshire College, and the University of Massachusetts at Amherst. Lincoln Avenue is a bidirectional two-lane local roadway which travels in a north/south direction through a highly residential neighborhood. The enforceable speed limit is 30 mph. Lincoln Avenue is a popular connector roadway highly traveled by the student population at the University of Massachusetts traveling to or from Amherst town center.

The Town of Amherst conducted numerous traffic counts and intersection movement studies within the study area to determine the extent of speeding and cut-through traffic volumes. The study found that the actual annual average daily traffic (AADT) for Lincoln Avenue significantly exceeds the expected volumes by almost 3,000 trips a day. Furthermore, the 85th percentile speeds observed on Lincoln Avenue exceeded the enforceable speed limit (48). After growing concern amongst the residents, which was validated with roadway data collected by the Town, several traffic calming measures were considered along Lincoln Avenue in Amherst, Massachusetts and this process is outlined in Figure 41. The resulting decision was to install temporary speed cushions as shown in Figure 42, discussed in the previous chapter, at multiple locations along Lincoln Avenue. A before and after study was conducted to determine the effectiveness of the temporary speed cushions in reducing vehicle travel speeds and cut-through volumes.

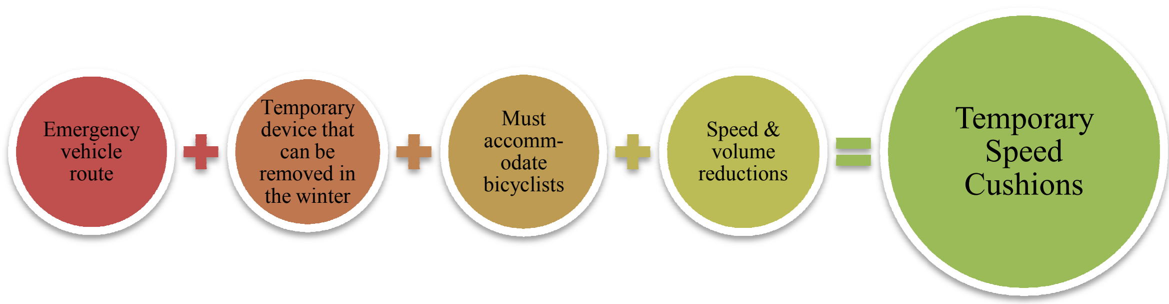


Figure 41 Speed cushion selection considerations

Figure 42 Speed cushions on Lincoln Avenue

Data Collection Methods

Speed and volume data was collected by the University of Massachusetts Transportation Engineering Research Team in the Fall of 2007 and supplemented with data provided by the town of Amherst. At the time of data collection, the University of Massachusetts was in session. The study area consisted of three locations on Lincoln Avenue and one location on Sunset Avenue, a parallel roadway with no speed cushions which was used as a control as shown in Figure 43.

Automatic traffic recorders (ATR) were placed at each location to collect speed and volume data. Data was collected from September 7, 2007 to November 24, 2007 and sorted into three categories: 4.5’ speed cushions, 6.0’ speed cushions and After (no speed cushions present) as is outline in Figure 44. Such categorization allows for easy comparison between the different conditions. An additional category, “Before”, was added to this data which contains data previously collected in the study location by the Town of Amherst.

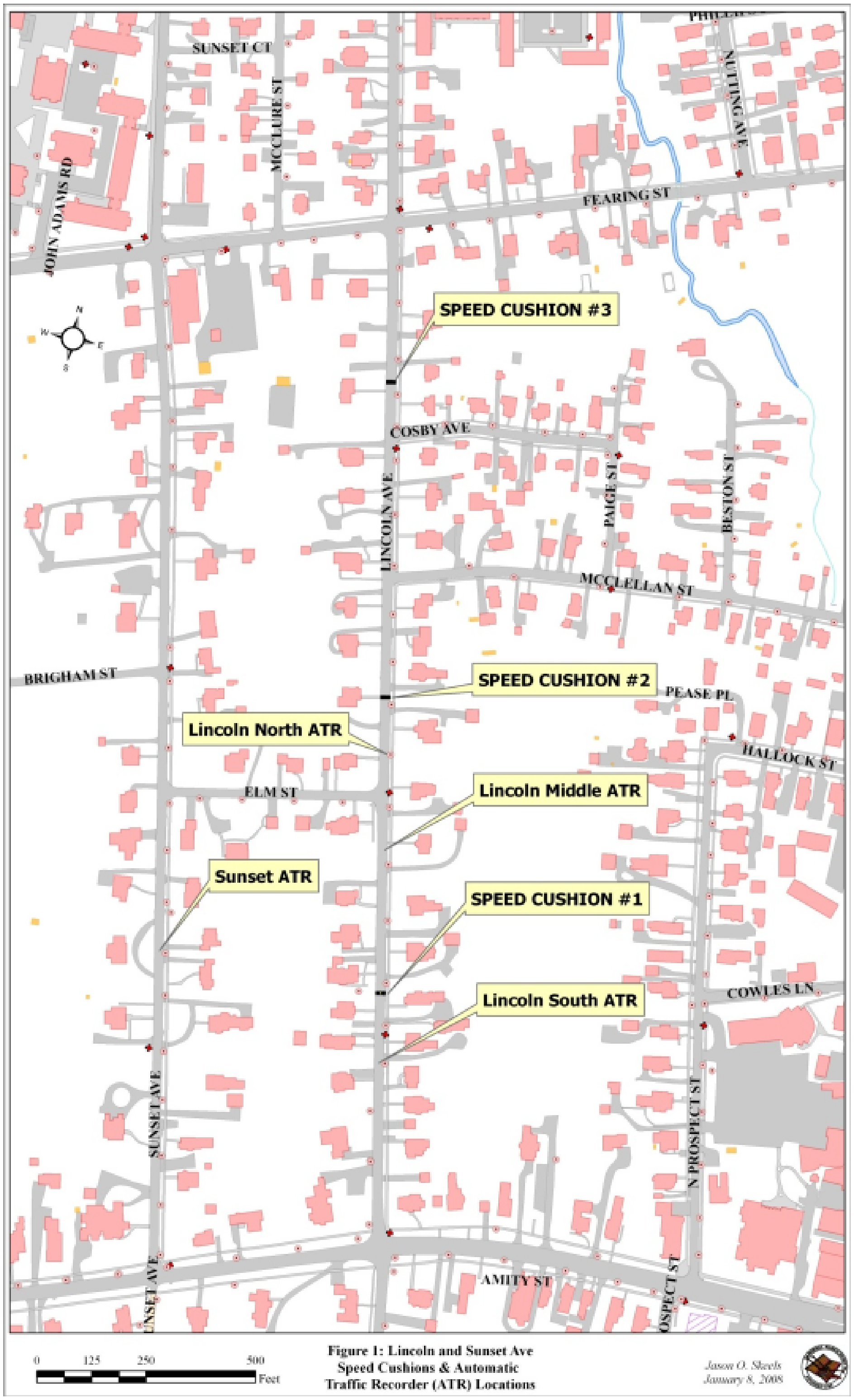


Figure 43 Amherst data collection locations

Figure 44 Amherst speed cushion timeline

Descriptive statistics which included: mean speed, 85th percentile speed, 95th percentile speed, median, mode, range, variance, standard deviation, 95% confidence interval for mean, and coefficient of variance were calculated for each study location. Average daily traffic (ADT) and 85th percentile speed plots were made for each location.

Time Period Selection

Data collection efforts were organized to be consistent with data previously obtained by the Town of Amherst. A two month period was used to ensure adequate sample size. Data collection efforts were performed in the Fall of 2007 when both the speed cushions were present as well as during their absence as a basis for comparison. At the time of data collection, similar to the previous study, the University of Massachusetts was in session.

Reverse Angle Parking

Reverse angle parking is an innovative design strategy aimed at improving the safety of angled parking on crowded roadways. Reverse angle parking is similar to tradition angle parking but the angle is reversed so that the vehicle must back into the space. The end result is a vehicle facing in the direction of travel and facing the travel way. The object of reverse angle parking is to maximize the safety and operational benefits through increased visibility when exiting the parking space. This not only gives exiting vehicles better visibility with which to re-enter the traffic stream, but also gives them a better opportunity to see approaching cyclists and pedestrians. This strategy was first developed and implemented on the West Coast, particularly in communities in Washington and Oregon.

Background Information

Reverse angle parking was implemented in Northampton, Massachusetts on a small section of parking space located on Main Street as shown in Figure 45. Beginning on August 5, 2007, the City of Northampton implemented reverse angle parking on eight metered spots along Main Street between Center Street and Gothic Street. The reverse angle parking spaces were in place for 45 days, after which time they were painted back to traditional angled parking spaces. Northampton center is a busy local urban center with much multimodal and tourist activity. The concentration of bicyclists and pedestrians in Northampton lead the transportation and parking commission to consider reverse angle parking because of its theoretical safety and operational benefits for bicyclists.

Figure 45 Reverse angle parking in Northampton center

Data Collection Methods

Reverse angle parking data was collected using a video camera mounted to a light post so that it captures the entire row of reverse angle parking spaces located on the southbound side of Main Street between Center Street and Gothic Street as shown in Figure 47. The camera was attached to a tripod which was mounted to a city light post located near 96 Main Street on the eastbound side of Main Street. The field of vision of the camera captured the entire row of spaces under review. Authorization to collect video data of the test site was granted by the Chief of Police at the Northampton Police Department and by the Northampton Parking Director. Prior to each date of video data collection, the aforementioned individuals were notified of the proposed dates and times of observation.

Figure 46 Reverse angle parking data collection efforts

Data collection efforts resulted in 12 hours of real time data per each data collection date, except for one day (Friday, August 17) where filming was terminated early due to weather. Table 6 contains the dates and times of data collection. There were three stages of data collection: before, immediately after and long after. For each stage of data collection a Wednesday and a Friday weekday were analyzed. The camera operated from 9 am to 9 pm, weather permitting. A tape change occurred every four hours thus breaking the video footage into three time blocks; 9 am to 1 pm, 1 pm to 5 pm, and 5 pm to 9 pm, as shown in Figure 46. In addition to video data collection, photographs were also taken documenting the signage and inappropriate and appropriate uses of the parking spaces.

Table 6 Reverse Angle Parking Data Collection Schedule

	Day	Date	Start Time	End Time
Before	W	1-Aug	9:00 AM	1:00 PM
	W	1-Aug	1:00 PM	5:00 PM
	W	1-Aug	5:00 PM	9:00 PM
	F	3-Aug	9:00 AM	1:00 PM
	F	3-Aug	1:00 PM	5:00 PM
	F	3-Aug	5:00 PM	9:00 PM
August 5-7 Parking Spaces Painted				
Immediately After	W	15-Aug	9:00 AM	1:00 PM
	W	15-Aug	1:00 PM	5:00 PM
	W	15-Aug	5:00 PM	9:00 PM
	F	17-Aug	9:00 AM	1:00 PM
	F	17-Aug	1:00 PM	5:00 PM
	F	17-Aug	5:00 PM	7:30 PM*
After	W	5-Sep	9:00 AM	1:00 PM
	W	5-Sep	1:00 PM	5:00 PM
	W	5-Sep	5:00 PM	9:00 PM
	F	7-Sep	9:00 AM	1:00 PM
	F	7-Sep	1:00 PM	5:00 PM
	F	7-Sep	5:00 PM	9:00 PM

*Shorter data collection time due to weather.

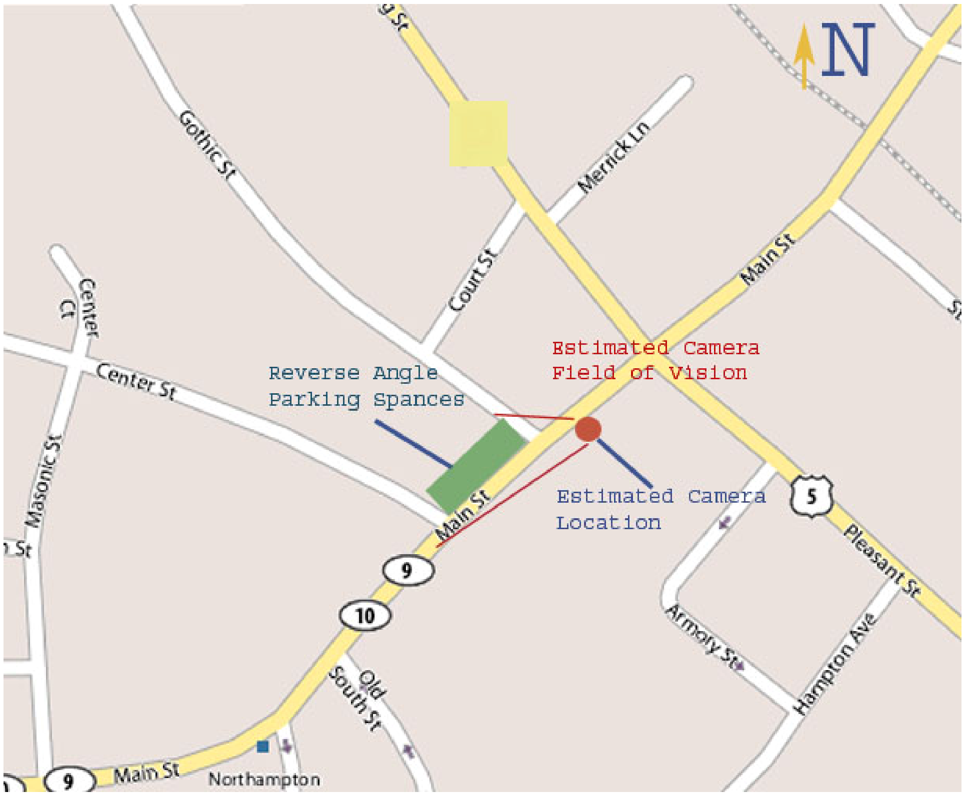


Figure 47 Reverse angle parking site location

Location Selection

The location of the reverse angle parking pilot program was chosen by the City of Northampton Transportation and Parking Commission with authorization from the City Council (49). The location of the data collection video recorder was chosen based on visibility of the entire row of spaces, access to space and security of the video equipment. A street light was chosen because of its height and viewpoint. Permission was granted from the City of Northampton as well as the Northampton Police Department.

Time Period Selection

Two weekdays (Wednesday and Friday) were selected as sample time periods for data capture. Wednesday is often chosen as a typical weekday that reflects many of the daily activities of commuters and residents. Friday was chosen to represent both local populations as well as a mixture of some tourists. Typically, Friday represents a day with more congestion than the typical weekday, but with some commuting behaviors not seen on the weekends.

The analysis extended over three days in an attempt to capture 72 hours worth of data to ensure a sufficient sample size to achieve accuracy. Due to weather and technical difficulties, 5.5 hours of data were unable to be used, resulting in 66.5 hours of data used in this analysis. A twelve-hour period was chosen to capture the range of parking space uses and driver behaviors. This period began at 9 AM which was mostly dictated by the small parking loads exhibited before 9 AM and limitation with data collection after 9 PM due to lighting issues.

CHAPTER 5

RESULTS AND ANALYSIS

The results of the development of a traffic calming or related strategy selection flow chart as well as the results of the evaluation of temporary speed cushions and reverse angle parking are contained below. The flow chart is designed to aid the local practitioner in utilizing the critical questions to help select an appropriate traffic calming or related strategy while the cycle is to be used to demonstrate the relationship between research and practice. The two case studies are designed for both the communities where implementation occurred as well as assist other communities from these experiences. The goal is to add to the library traffic calming measures and help the industry develop standards through the lessons learned in case studies, such as these.

Traffic Calming Selection Flow Chart

The urban environment network optimization strategies flow chart is designed much like a medical diagnosis guide. The first step is identify the primary goal of the measure; whether it be to address speeding, cut-through volumes, unsafe pedestrian facilities, or unsafe bicycle facilities. There may be more than desired outcome of the selected strategy, however, this interrelationship between strategies is also shown on the chart. The second step is to consider the primary challenge (if one exists) and follow that link to a list of recommended strategies. It should be noted, however, that this chart is used to be as a supplement to undergoing a thorough selection and review process. This diagram is shown in Figure 48.

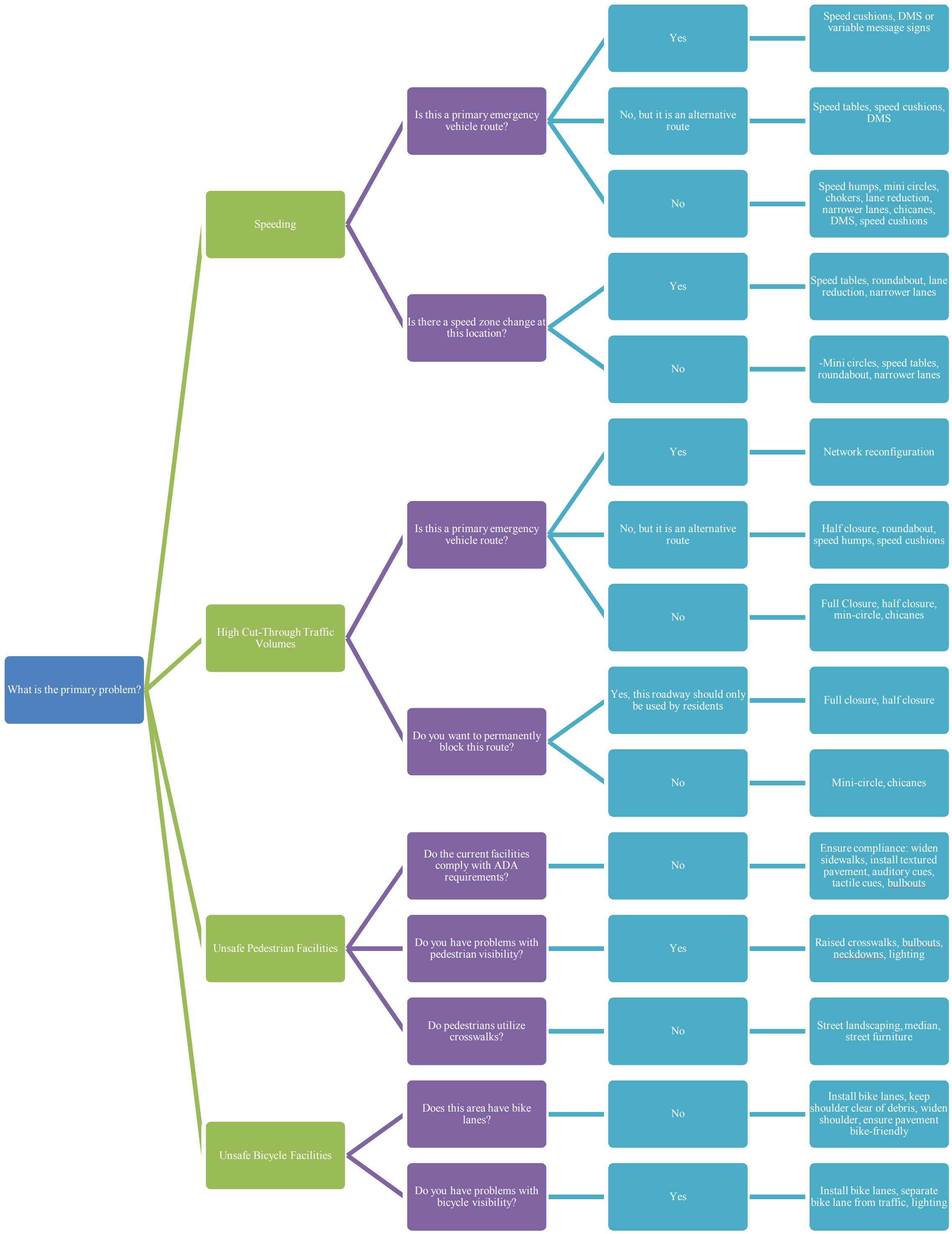


Figure 48 Urban environment network optimization flow chart

The relationship between research and practice in transportation engineering is a critical link in the evolution of the field. Unfortunately, gaining an understanding of this relationship can be challenging and can result in a lack of shared information between the two realms. Bridging this gap, however, can quickly open up an array of resources and information that can aid the local practitioner in selecting and implementing appropriate strategies. As shown in Figure 49, once a strategy is selected and implemented there is constant need for evaluation of any selected strategy. Taking this one step further, however, in order for other professionals to benefit from that information, the results of the evaluation must be shared. Furthermore, the results must be shared in a way that provides access to a range of users who must then take that information and utilize it effectively. This brings us back to the top with the selection of another strategy or the continued use of an existing strategy.

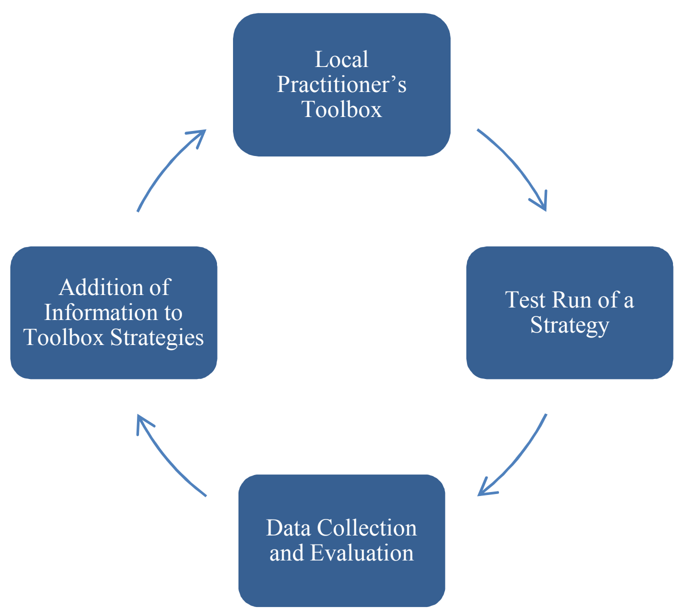


Figure 49 The cyclic relationship between research and practice

Speed Cushion Evaluation

Temporary speed cushions were installed on Lincoln Avenue in the town of Amherst, Massachusetts in an attempt to reduce vehicle travel speeds and cut-through traffic volumes. This study aimed at determining the effectiveness of those traffic calming treatments on achieving the town's goals and objectives.

Research demonstrates that the speed cushions were an effective treatment in reducing vehicle volumes and speeds on Lincoln Avenue. Caution must be exercised, however, as concerns arose about compliance. Some vehicles were observed to straddle the centerline, potentially creating more hazardous roadway conditions. The flexibility in design that allowed the Town of Amherst to recognize that the 4.5 foot speed cushions were easily straddled as shown in Figure 50, allowed them to modify their design for optimal performance as shown in Figure 51. As a result, speeds were significantly reduced and there is some evidence to suggest that volumes may also have decreased. Coupled with compliance monitoring, this strategy is determined to have been an effective tool in achieving the Town's goals.

Figure 50 Vehicle straddling the smaller speed cushions

Figure 51 Vehicle forced to decrease speed due to speed cushions

Speed

The results of speed data is shown in Table 7 and in Figure 52 as well as in Figure 53. The previous study cites 30 mph as the enforceable speed limit. The 85th percentile speeds determined in this study range from 28 mph to 39 mph. Two locations (in both directions of travel) with 6.0’ wide speed cushions demonstrated 85th percentile speeds at or below the speed limit. When compared to control conditions, Lincoln Avenue experienced a decrease in vehicle speeds when speed cushions were present. While speed cushions result in lower speeds near the cushions, drivers found to speed up between the cushions. The net result, however, is that the midpoint speeds are still lower than control conditions where speed cushions are not present.

Table 7 Speed Cushion Summary Speed Data

Direction	Condition	Lincoln, N Elm	Lincoln, S Elm	Sunset	Midpoint, Lincoln
NB	Before, no speed cushion	NA	39	36	35
	4.5' Width	30	31	33	NA
	6.0' Width	28	30	34	32
	After, no speed cushion	35	34	36	36
SB	Before, no speed cushion	NA	39	35	33
	4.5' Width	29	30	34	NA
	6.0' Width	27	28	35	32
	After, no speed cushion	36	34	37	35

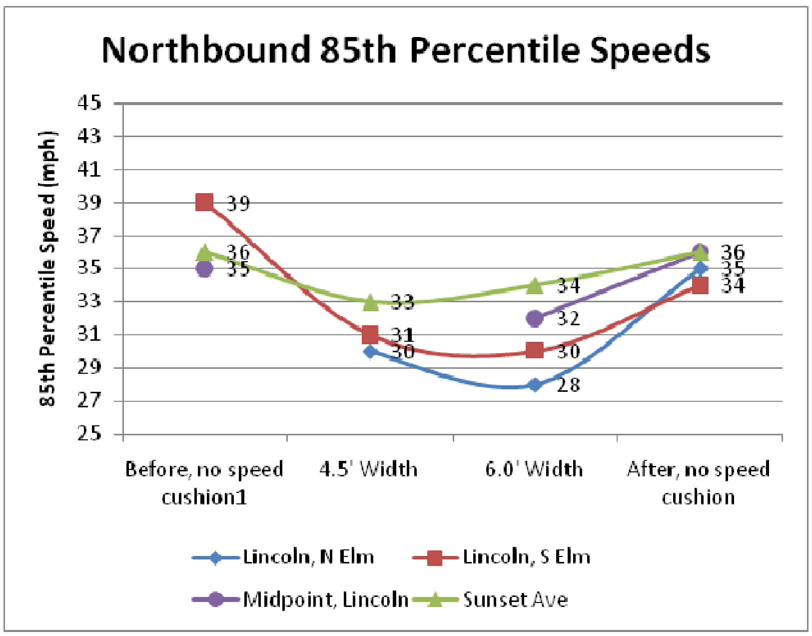


Figure 52 Speed cushion NB 85th percentile speeds

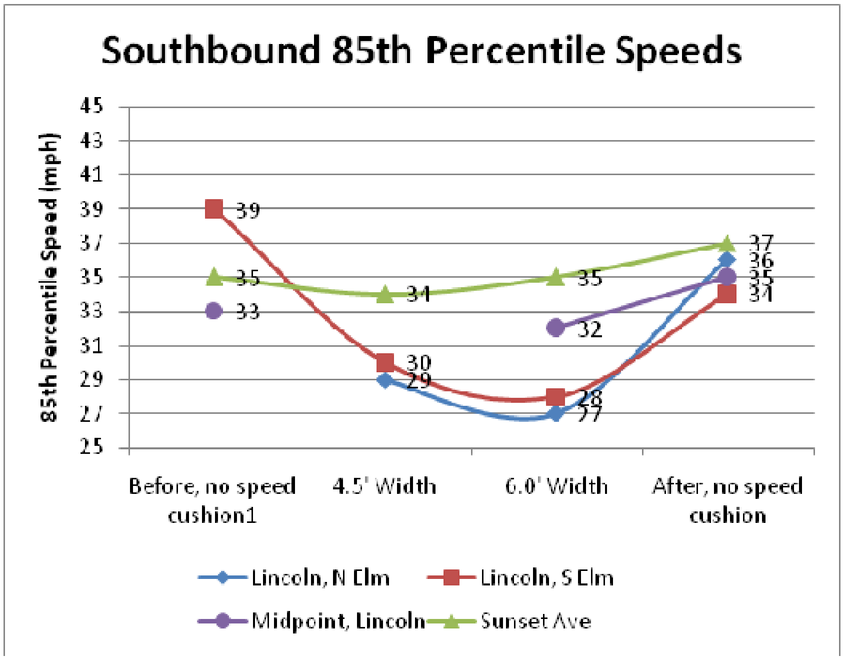


Figure 53 Speed cushion SB 85th percentile speeds

A 95% confidence interval was constructed to determine the significance of speed findings. There is sufficient evidence, at the 0.05 level, to conclude that the average speeds at each location differ significantly for each condition. A 95% confidence interval was constructed to determine the significance of speed findings as shown in Table 8. There is sufficient evidence, at the 0.05 level, to conclude that the average speeds between speed cushions differ significantly from speeds near the speed cushions as shown in Table 9. Speeds were significantly reduced in the presence of speed cushions, when control conditions remained relatively constant.

Table 8 Confidence Intervals for Each Location, per Direction

Location	CI (NB)	CI (SB)	Sig?
After vs 4.5'			
Lincoln Ave; N of Elm	(5.04, 5.28)	(7.32, 7.62)	Y
Lincoln Ave; Mid	NA	NA	
Lincoln Ave; S of Elm	(3.37, 3.59)	(-3.09, -2.65)	Y
After vs 6.0'			
Lincoln Ave; N of Elm	(6.17, 6.35)	(9.37, 9.59)	Y
Lincoln Ave; Mid	(-3.81, -3.43)	(-3.09, -2.65)	Y
Lincoln Ave; S of Elm	(3.12, 3.28)	(5.69, 5.97)	Y
4.5' vs 6.0'			
Lincoln Ave; N of Elm	(1.00, 1.19)	(1.89, 2.13)	Y
Lincoln Ave; Mid	NA	NA	
Lincoln Ave; S of Elm	(-.35, -.21)	(1.33, 1.59)	Y

Table 9 Confidence Intervals for Midpoint Location

Comparison	CI (NB)	CI (SB)	Sig?
6.0’ Midpoint location versus Lincoln Ave, N of Elm	(3.35, 3.61)	(5.89, 6.21)	Y
6.0’ Midpoint location versus Lincoln Ave, S of Elm	(.68, .94)	(4.03, 4.39)	Y

Volume

Evaluation of the volume data demonstrates that both sets of speed cushions may influence traffic volumes on Lincoln Avenue. The results of the volume analysis are shown in Figure 54 as well as in Figure 55. The 6.0’ speed cushions may have the greatest effect. Furthermore, volumes may have decreased as a result of the removal of speed cushions but more research needs to be conducted. The alternate routes exhibited by traffic potentially diverted from Lincoln Avenue as a result of the speed cushions were not examined in this study. The speed cushions had little or no effect on cut through traffic volumes diverting to Sunset Avenue.

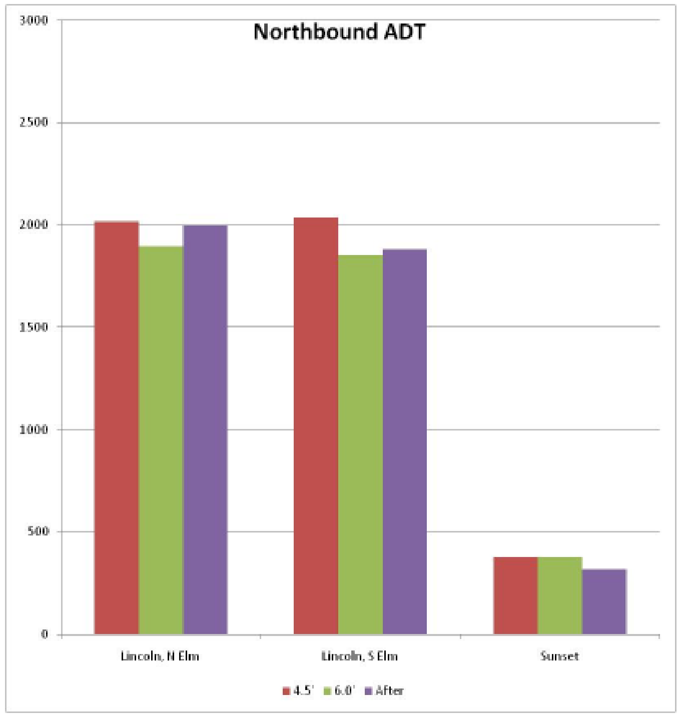


Figure 54 Northbound ADT data

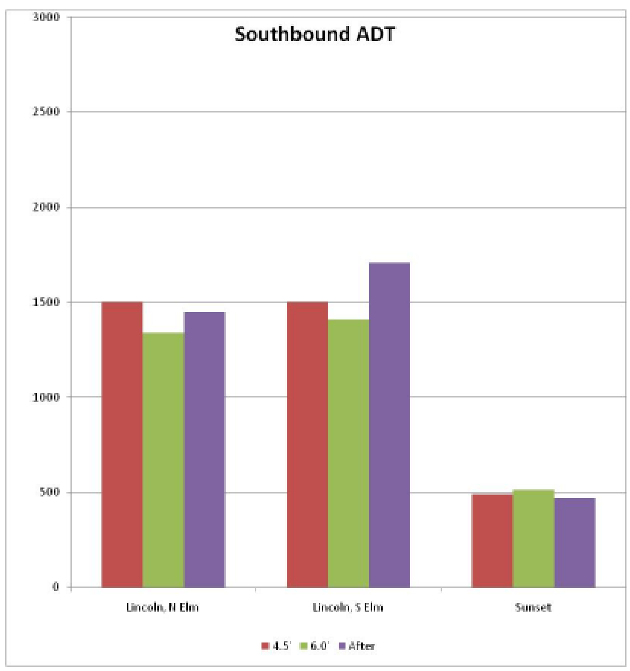


Figure 55 Southbound ADT data

Conclusions

The temporary speed cushions installed on Lincoln Avenue had a positive effect on reducing vehicle speeds and may have resulted in lower volumes. The 6.0' speed cushions were most effective as the 4.5' speed cushions were easily avoided or 'straddled' by most vehicles. It is recommended that compliance be monitored with possible enforcement as it was noted through field observations that some drivers avoided the 6.0' speed cushions by travelling down the centerline. While drivers did speed up between cushions, the 85th percentile speeds were still lower than 85th percentile speeds in the absence of the speed cushions

Reverse Angle Parking Evaluation

Data Analysis

Data collected via video data collection efforts were manually transcribed from video tape into an EXCEL spreadsheet. Three dates were selected for critical examination of parking maneuver times and consisted of each Wednesday 12-hour period. This data was transcribed from video into a spreadsheet by recording the variables shown in Table 10. The variables shown in Table 10 were selected as performance indicators for the evaluation of the operations of the reverse angle parking.

Table 10 Reverse Angle Parking Data Analysis Variables

Parking Space Number	*Ended Parking Maneuver*	*Number Spaces Occupied*
Event A	*Entering Maneuver Time*	*Number Correctly Occupied*
Event B	*Began Departing Space*	*Correct Immediately Left*
Flag Event A	*Departed Space*	*Correct Immediately Right*
Flag Event B	*Exiting Maneuver Time*	*Number Alignment Adjustments*
Flag No Events	*Total Maneuver Time*	
Began Parking Maneuver	*Total Space Occupancy Time*	

An event was defined as any action, maneuver or conflict that occurred during or as a result of the parking maneuver. The most common events are shown below in Table 11. Some of the events shown in Table 11 are only applicable to reverse angle parking configuration or to the traditional angle parking configuration. The remaining Friday data collection dates were also analyzed for events. The events occurring on each day were recorded in 15-minute intervals according to those events defined in Table 11.

Table 11 Reverse Angle Parking Scoring Events

Pulled straight in from other direction	*Pulled head in from proper travel way*
Pulled straight in from other direction and then backed in	*Made u-turn from other direction to backed in*
Pulled straight out across centerline	*Backed out and went opposite direction*
Parking movement conflicted with car behind	*Made u-turn to pull head first into space*
Parking movement conflicted with bicycles	*Parked head in from proper travel way and then backed in*

Events

The results of the reverse angle parking data analysis are shown in Table 12. There were more events for all scenarios recorded on Fridays than were on Wednesdays. This is most likely due to the added congestion of traffic associated with Fridays in general. There were significantly fewer events when the configuration was for traditional angle parking versus reverse angle parking. There were more events on Wednesdays closer to the change from tradition diagonal parking to reverse angle parking than from reverse angle parking occurring after more time elapsed between its inception. This may be due to drivers becoming more familiar with reverse angle parking than during the immediate aftermath of the change. The highest rate of events occurred immediately after the transition and on a Friday. Furthermore, the lowest rate of events occurred on a Wednesday while the configuration of parking spaces reflected traditional angle parking. Lastly, the majority of events across all categories occurred during off-peak hours when there was less congestion on the roadway as shown in the data found in Appendix A. This is most likely due to the more space that is required for many maneuvers or events that are substantially more difficult to perform during congested conditions, simply because congested conditions do not allow any room for crossing the centerline.

The most common event occurring during traditional diagonal parking was a vehicle pulling straight into a parking space from the opposite travel way, thus crossing the centerline. The most common event occurring when reverse angle parking was implemented was vehicles departing their spots (after parking correctly) and crossing over the centerline to enter into the opposing traffic stream. The second most common event occurring during reverse angle parking implementation was vehicles which pulled head in from the other direction of travel, thus crossing the centerline. Overall, crossing the centerline was the most common ‘event’ across all categories. It was also observed that there were many pedestrians crossing Main Street at a midblock location within the study area, but not at a crosswalk. Furthermore, a number of vehicles were also observed to make u-turns in the travel way in within the study area.

Table 12 Reverse Angle Parking Results: Rate of Events

Event	**W** **Aug1**	**F** **Aug3**	**W** **Aug15**	**F** **Aug17**	**W** **Sept5**	**F** **Sept7**
Pulled straight in from other direction	.75	.75	.42	.57	.63	.58
Pulled straight in from other direction and then backed in	0	0	.17	.19	.38	.25
Pulled straight out across centerline	0	0	1.6	2.2	1.5	1.9
Parking movement conflicted with car behind	0	0	.17	.38	.19	.08
Parking movement conflicted with bicycles	.08	0	.08	0	.19	.08
Pulled head in from proper travel way	0	0	.08	.38	0	.58
Made u-turn from other direction to backed in	0	0	.25	.1	.19	.08
Backed out and went opposite direction	.08	.75	0	0	0	.17
Made u-turn to pull head first into space	0	.08	0	0	0	0
Parked head in from proper travel way and then backed in	0	0	0	.48	0	0
Total Rate of Conflicts Per Hour	**.92**	**1.6**	**2.8**	**4.3**	**3.3**	**3.8**

Maneuver Time

Maneuver time was also extracted as a performance indicator. Entering, exiting and total parking maneuver time was examined for vehicles which had no events and the results are shown below in Table 13. Vehicles with events were extracted from this sample because of the influence each event may have on parking maneuver times. As anticipated, the reverse angle parking resulted in a smaller exiting maneuver time, but higher entering maneuver time when compared to traditional diagonal angle parking. The overall parking maneuver time was less for traditional angle parking than for reverse angle parking for both scenarios. Furthermore, the results demonstrate that the parking volume is higher for traditional diagonal parking than for either reverse angle parking scenario.

Average occupancy times were comparable for both traditional diagonal parking as well as reverse angle parking immediately after implementation, but reverse angle parking long after implementation shows a much lower occupancy time. This may be due to the sample that was analyze because on this day, only 8 hours of data was eligible for transcription. The resulting occupancy time may be skewed by the existing data when compared to the other two scenarios. Therefore, no conclusions can be drawn comparing this occupancy time. There were no recorded alignment adjustments with the traditional angle parking. Reverse angle parking, however, had alignment adjustment rates of 0.2 and 0.3 for the immediately after and long after scenarios, respectively.

Table 13 Reverse Angle Parking Summary Results

Date	Parking volume (vehicles per hour)	Average entering time (sec)	Average exiting time (sec)	Average total maneuver time (sec)	Average occupancy time (min:sec)	Alignment adjustment rate (adjustments per vehicle)
August 1	9.2	6	15	21	48:48	0
August 15	7.9	19	8	26	51:36	0.2
September 5	7.0	24	7	27	27:49	0.3

Note: Maneuver times were taken only from vehicles with no events

Conclusions

Reverse angle parking was an innovative strategy implemented in downtown Northampton to improve traffic safety and operations. The theory behind reverse angle parking is that is both more safe and efficient due to the increased visibility resulting from 'heading out'. Results of this study indicate, however, that with the current roadway configuration, community culture, enforcement practices and attitudes, reverse angle parking creates more conflicts and results in a decrease parking volume for those spots on Main Street analyzed in this study. The increased rate of events, most of which involve crossing over the centerline, should create concern about increased safety challenges as a result of implementation. The decreased parking volumes also indicate that the spots are utilized less and are generating less revenue for the town. This may result in added congestion to other parking areas nearby and redistribute traffic negatively around this town center.

With mediation and supplemental measures, reverse angle parking could be an effective tool for improving safety and operations at this location in the future. One recommendation is to install a median barrier down Main Street to address the many occurrences of vehicles crossing the centerline, making midblock u-turn movements as well as pedestrians crossing at a non-crosswalk midblock location. While this trial indicated that with the existing conditions diagonal angle parking results in fewer events and a higher parking load, it does not mean that reverse angle parking may never be an effective strategy.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The local urban environment, similar to many of those found in communities in Western Massachusetts, has many traffic safety and operations challenges. Often times these challenges arise from the centrifugation of a large number of people and vehicles within a limited space. The popularity of multimodal forms of transportation in this environment poses many unique challenges for the local practitioner. Lastly, designing and remediating design for all users of the transportation network is another aspect that must not be overlooked.

Network optimization strategies for the urban environment include traffic calming and related strategies designed to improve traffic safety and operations in the local urban environment while also promoting community livability. The net effect of properly selected and implemented strategies is an overall improvement in the community through increased safety, efficiency and appeal. The strategies presented in this research merely touch on a wide range of strategies that can be effectively implemented in many communities to achieve goals. The urban environment network optimization strategy selection flow chart is intended to be used as a starting point for local practitioners and supplemented with a thorough engineering study and the cycle is to be used to demonstrate the relationship between research and practice.

The two case studies presented herein are intended to add to the growing field of literature and case studies on topics related to addressing safety and efficiency in similar environments. This research evaluated the effectiveness of temporary speed cushions in achieving a community's goal of reducing speeds and cut-through volumes on a residential roadway. While the speed cushions were significantly effective in reducing speeds, there is not enough evidence to conclude that they were effective in reducing cut-through volumes. When coupled with enforcement, however, the temporary speed cushions are a recommended strategy for this community. An evaluation of the reverse angle parking trial indicated that reverse angle parking resulted in a lower parking volume and a significantly higher number of events, thus creating concern regarding safety. At the time of this evaluation and given present conditions, the reverse angle parking is not a recommended strategy because of its negative impact on safety and efficiency.

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