THE EFFECTS OF COMPLETE STREETS ON MOBILITY
AT THE ARTERIAL LEVEL

by

Sara E. Patterson

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ABSTRACT

With an increasing desire to design complete streets, it is crucial to determine what constitutes a complete street and how complete streets affect mobility. The general definition of a complete street is one that is safe for all users including drivers, pedestrians, cyclists, and transit riders. This definition is vague and allows the designer to make the decisions about what techniques should be used to create a complete street. To determine what techniques are best for a specific project, first transportation engineers must determine the effect each technique will have on the street, and the tradeoffs that a community may have to live with after construction. Specifically, when working with an existing street, there will be changes in LOS, capacity, delay, and emissions.
Chapter 1

INTRODUCTION

At a recent conference, a speaker stated that it would be more acceptable to have a road with a level of service of D that had a bike lane than to have a road with a level of service C without a bike lane. During a time in American history when global warming is becoming a more important topic, vehicle miles traveled (VMT) is raising at record rates, and obesity is threatening the lifespans of Americans, it is important to ask if bike lanes are the solution to all of these problems. A slightly broader question is equally important: will introducing better facilities for pedestrians, cyclists, and transit riders fix the problems of global warming and obesity in the US and around the world? The answer to this is a very complicated one, but asking the question is crucial to determine the validity of the earlier statement.

Another question that is pertinent to this discussion is how much should drivers be affected by making roads safer and more usable for others? For many decades, the US has been focusing most of its transportation planning on the automobile, often at the expense of other travel modes. This has led to a society that relies heavily on the car not only in daily activities but for longer planning decisions. If the US suddenly changes those policies to focus primarily on other travel modes, what affect will that have on large sections of the population who use their cars for everything?

These background questions lead to the most important questions: what are the tradeoffs associated with designing for all travel modes, and how can roads be
designed that improve usability without seriously affecting mobility for any users?
These questions are the basis for complete streets design which focuses on designingoads that are safe and promote mobility for all users. To determine how to best move
forward with respect to complete streets design, it is necessary to first answer these
questions and decide what is best for a given community. The tradeoffs and road
design will depend substantially on the context that a given road is found in. The
contextual factors that will be most important are the community, the transportation
network, and the density of the surrounding area.
Chapter 2

BACKGROUND AND LITERATURE REVIEW

2.1 Background

There are a significant number of problems related to the current American transportation networks including the obesity epidemic, high gasoline prices, air pollution, and mobility constraints experienced by aging baby boomers[1]. Countries with well-developed urban transit systems and an established bicycle infrastructure are better off than those that depend on cars if there is a downturn in world oil production[1]. The vast majority of trips are taken by car, and urban areas are designed around the ability to drive everywhere. Mobility is determined primarily on the affordability of the automobile because the transportation networks are designed solely for drivers. There is a need for a change at the network level to make streets safer for all users, but concentrating only on changing the transportation network will not fix all of these issues.

It is very difficult to change the status quo and most large social and infrastructural norm changes go through the “four stages”: silly, controversial, progressive, and then obvious[2]. These stages take time, and each large infrastructural change requires a lot of work to convince the end users that the change might improve their mobility in the long term. Because of this, it is important to work with the community during the design process to understand what needs the community has and explain the implications of different design aspects.
Complete street techniques are viewed as the best solution to a long list of current problems that the US faces. Currently, there are many interest groups that are pushing for policy to be adopted at the city and state level that requires agencies to design complete streets. The wording is often vague and allows the designer to decide what determines complete street design. Context Sensitive Solutions and Complete Streets are often used interchangeably to explain the same type of street design: streets that are designed in a specific context that cater to the users of that street within a community. While complete streets techniques focus more on the safety of all road users, the techniques that are used in context sensitive design and complete street design are essentially the same.

Most of the interest in complete streets falls on the policy side of the issue. The goal is to design streets are safe for all users, causing people to switch travel modes (from driving to biking, walking, or riding transit), and this will improve the livability of communities and the health of the residents while reducing emissions and accidents. At the federal level, there are a number of groups that are advocates for complete street design including the Partnership for Sustainable Communities and the National Complete Streets Coalition.

The Interagency Partnership for Sustainable Communities (includes the USDOT, HUD, and EPA) attempts to provide more transportation options and support existing communities through transit-oriented, mixed-use development, and land recycling. This partnership defines complete streets as streets that are safe for all users, are customized to the context, and accommodates the needs and expectations of the travelers in and through the neighborhood, community, or region. The partnership
agrees with the National Complete Streets Coalition list of complete streets elements which includes

“sidewalks, bicycle lanes (or wide, paved shoulders), shared-use paths, designated bus lanes, safe and accessible transit stops, and frequent and safe crossings for pedestrians, including median islands, accessible pedestrian signals, and curb extensions. Certainly, a design for a complete street in a rural area will look quite different from one in an urban or suburban area. For example, a complete street in a rural area could involve providing wide shoulders or a separate multiuse path instead of sidewalks. The common denominator, however, is balancing safety and convenience for everyone using the road.” [3]

The partnership references Safe Routes to School, and Context Sensitive Solutions. At the federal level, there is statute 23 USC 217, which requires State DOTs to use a portion of certain Federal funds to hire a State bicycle and pedestrian coordinator. This position is responsible "for promoting and facilitating the increased use of nonmotorized modes of transportation."[3]

The National Complete Streets Coalition is an organization that is working to improve the safety of streets in the United States through education and promoting policy change in cities and states. According to the National Complete Streets Coalition, the benefits of creating complete streets policies are improving safety of roadways, encouraging walking and bicycling for health, addressing climate change and oil dependence, and fostering stronger communities[4]. Some of these benefits are easier to define and measure than others. For example, safety of the roadways can be measured in pedestrian and cyclist fatalities per year. The effectiveness of individual complete streets techniques can be determined by looking at the difference of fatalities before and after the installation. Encouraging walking and biking could be measured, but would need extensive pedestrian and cyclist counts before and after
installation. There are also other factors that affect the choice to drive or use another mode of transportation, for example distance of trip. Complete streets will only address climate change and oil dependence if a number of users switch transportation modes. Fostering strong communities is the most difficult to measure and define. It is important to look at the needs and wishes of a community during road design, but a complete street alone will not build a strong community without the necessary building blocks already in place.

Some techniques are easier to implement than others without affecting an existing road. Audible pedestrian signals do not have an effect on the existing road design and could greatly improve safety for blind pedestrians. Making crosswalks more visible is another way to improve the safety of existing crosswalks. This can be done by adding signs and a blinking light to warn drivers of a possible pedestrian. Adjusting signal timing to allow for the slower pedestrians to clear the intersection also does not affect the existing road design, but may have an effect on traffic because the red light would be longer. Increasing the number of crossing opportunities could affect the road design minimally if they are added at all existing intersections[4].

In addition to the national groups discussed above, there are a number of programs that were started in individual cities to promote the use of complete streets techniques in the design process. They deal primarily with the policy side of the issue instead of the design implementation. Programs include The Partnership for Active Communities in Sacramento CA and Active Seattle. In Sacramento the project continued over five years and supports increased walking and biking through in school programs, land-use development, and transportation infrastructure while focusing on safety of all street users[5]. The Active Seattle program set up a five year plan to
increase the physical activity in Seattle. The program looked at four core areas: planning and partnership, mapping program, physical infrastructure, and health promotion. The program focuses on adopting policy changes at the higher levels of government in Seattle while initiating interest at the neighborhood level[6]. In Hawaii, a comprehensive multilevel social ecological approach was used in the complete streets policy, which worked in conjunction with a Safe Routes to School policy. The approach counted on the collaboration of multiple stakeholders, and it focused on education, capacity building, and networking efforts[7]. None of these initiatives focus only on street design, but also on education and other programs that promote multi-modal use.

2.2 What Makes a Complete Street?

Burden and Litman define complete streets policy with a number of requirements including encouraging street connectivity and creating a comprehensive, integrated, connected network for all nodes, and state that complete streets’ solutions are context specific. A number of things need to be done to reduce the negative effects associated with driving (including emissions, death, and obesity). Along with complete streets techniques, proper land development patterns and proper street design must be used together to create complete streets[8]. Complete Streets and Context Specific Solutions should be seen as complementary, not competitive. Complete streets’ techniques should be introduced into the very beginning of the design project to make streets that are safe for everyone without adding costs at the end of the project to change designs to accommodate all users. A number of techniques can be used to improve safety for pedestrians and cyclists including road diet, raised medians, curb bulb-outs, and street parking[9].
One goal of complete streets is to make transportation more sustainable. To achieve this, complete streets endeavor to reduce vehicle emissions, reduce vehicle miles traveled, and use intelligent transportation systems (ITS) and traffic engineering applications that support sustainability. Roundabouts should be used instead of signaled intersections to improve safety and reduce emissions. To achieve transportation sustainability, changes would have to include designing systems to provide modal choices and working with land use planners to create connected street systems that reduce urban sprawl[10].

Another aspect of making streets more sustainable is to address the issues related to storm water management. Streets are often comprised of large areas of impervious surfaces which cause problems with storm water runoff. Low-impact development storm water designs are shown to effectively reduce contaminant loads from impervious surfaces. Porous asphalt is one option which improves wet pavement frictional assistance, reduced hydroplaning, and reduced pavement delay[11]. Porous concrete can also be used beneficially in similar applications. Along with using pervious road and sidewalk surfaces, street landscaping can be used to help manage storm water issues. Bioswales, planters, and rain gardens can be used to help curb storm water runoff in addition to making the street more visually interesting and comfortable. Some complete street techniques- chicanes, islands, and curb extensions- are places where street landscaping can be introduced into the existing design[12]. These storm water management techniques have a range of costs and maintenance requirements, but they are simple ways to improve existing streets without changing them too much.
While street design is the focus of complete streets policies, often other initiatives are required to promote the use of these streets. The initiatives that should be used in conjunction with complete streets policies are ones that educate the public about the importance of using different travel modes, increase the availability and promote the use of public transportation, and reduce urban sprawl (or at least the distance that people travel between home, work, and play). Without also addressing these issues, complete street design will not be used effectively and would waste money spent on providing for users who don’t exist and will not be created.

2.3 Safety

Safety is the primary concern of complete streets advocates. If the roads are safe for all users, people will want to use them for other activities, not just driving. Depending on the users and the context, making a road safe could mean a number of different things. There is a big difference between the safety measures that should be implemented on an urban road with a lot of pedestrians and speeds of 25 mph or less and a rural road that carries large amount of horse and buggy traffic. In general, safety will focus on the most vulnerable user groups. Cyclists and pedestrians are more vulnerable than drivers, but among cyclists and pedestrians, there are individual groups that are especially vulnerable including the young, the elderly, and the disabled. While it is important to cater to the needs of all of these groups on all roads, it is crucial to focus on these groups in areas that have a large portion of vulnerable pedestrians (for example, areas surrounding a retirement community).

Areas near schools, playgrounds, and other places that attract large numbers of young people should be designed to accommodate the specific needs of young cyclists and pedestrians. The Walk to School movement has potential benefits that include
reducing childhood obesity and early onset diabetes[1]. Safe Routes to School is a program that focuses on making streets safer for children so more are able to walk and bike to school. This program focuses solely on the factors that affect the safety of children travelling to school including the fact that children walk and cycle slower than adults and require pedestrian signals that give them enough time to cross the street. Traffic volume has a negative effect on a child’s ability to cross a street safely because they become impatient waiting for an acceptable break in heavy traffic. It becomes more difficult for children to wait for a find an appropriate time to cross the street [13]. Patience is not the only issue that children face. Mid-block collisions more often involved young pedestrians as compared to intersection collisions[14].

Another vulnerable user group, seniors, requires different infrastructure than children: smooth sidewalk surfaces and curb cuts to reduce falls, sidewalks that are wide enough to accommodate a walker, and benches for resting. Brisk walking is adequate for seniors to achieve positive health results and is correlated with neighborhood design [15]. To give seniors the ability to add brisk walking into their daily routines, the sidewalks need to be designed to accommodate their movements and the neighborhood needs to be designed in such a way that there are nearby destinations or public transit options. This allows seniors to have access to neighborhood resources without having to drive.

Disabled pedestrians and cyclists are the final vulnerable group that has specific needs. Disabled pedestrians that use wheelchairs or walkers have similar needs to senior pedestrians (wide, smooth sidewalks that slope down to the street). Blind pedestrians have different needs than pedestrians using walkers and wheelchairs, however. Many cities are designing “shared spaces” in their downtown areas which
are meant to slow down drivers because the road is shared between pedestrians and drivers. This puts blind and partially sighted people at a disadvantage because there is no delineation between safe pedestrian areas and areas that are shared with drivers. “Shared space” designers do not want to include traditional 120 mm curbs because they separate the pedestrian vehicle areas too much. Thomas found that a curb height of at least 60 mm is required to define the difference between the two areas. Along with the 60 mm curb height, dropped curb crossings and tactile paving should be used to mark the edge of the footpath for vulnerable pedestrians[16].

All pedestrians and cyclists are vulnerable groups when sharing the road with cars and the safety of all pedestrians and cyclists needs to be taken into account. Reducing accidents is the focus of many who are trying to improve the safety of pedestrians and cyclists. There have been a number of studies done that determine the factors that lead to accident involving vehicles and pedestrians or cyclists. The factors associated with a vehicle-pedestrian or vehicle-cyclist accidents are largely the same as those of vehicle-vehicle accidents: traffic conflicts and high vehicle speeds. The built environment has a large effect on driver error instead of the widely held belief that driver error is random and road design should reflect this belief (which leads to road design that is forgiving of driver error instead of trying to correct it)[17]. Pedestrian crashes are more common in business districts and in more densely settled residential neighborhoods with a large and less affluent population. The majority of accidents resulted from human error on the part of the pedestrian or the driver[14].

Human error is not something that can be eliminated, but there are a number of techniques that help reduce the impact of human error. Counter measures for improving safety of intersections include more visible pedestrian crossings, adding
pedestrian refuge islands and turn lanes, adding traffic lights instead of other signals, and lowering the speed limit[18]. For six-lane divided highways with high traffic volumes, implementation of the right turn/U-turn concept leads to a 26.4% reduction in crash rate as compared to direct left turns[19]. There are two factors that often determine crash severity and they are speed and sight lines. In loops and lollipops, vehicles are driving slower, but there are shorter sight lines, so there are more crashes, but they are less fatal[20].

The best way to reduce injuries in cyclists and pedestrians is to have facilities for these users that are separate from motorized traffic. Sidewalks and refuge islands are the most effective facilities for pedestrians, and on-road bike routes or off-road bike paths are the most effective facilities for cyclists. They are best placed in city centers, between contiguous neighborhoods, and along major arterial streets because this is where accidents are most likely to occur. Adding street lighting to areas that have poor visibility is also effective in improving safety for pedestrians and cyclists[21]. The most effective pedestrian safety measures include refuges, median openings, ice tracks, ramp for wheelchairs, zebra crossings, signal timing, flashing yellow lights at crossings, and better visibility for vehicles. Pedestrian safety measures are most effective if they are the result of comprehensive policy rather than piecemeal, isolated improvements[22]. There are a variety of low-cost signing and striping technologies or higher-cost geometric features (curb extensions and refuge islands) that can be used to improve safety. The use of marked crosswalks at uncontrolled locations on high-volume, multilane roads can lead to higher pedestrian-related collisions. To improve safety at these crossings, more notice to drivers is necessary by using a combination of signs, signals, and geometric features[23].
In studying an increase in lane width, installation of median barriers, vertical and horizontal improvements in the road alignment, and installation of guide rails on roads with a speed limit of 45 mph or less, all treatments reduced crash rates except the installation of guide rails. Vertical and horizontal alignment had the largest effect, followed by increased lane widths, and then median barriers[24]. While increasing lane widths may reduce the number of crashes, they may also increase speed. It is important to determine if the context requires wider lanes depending on how many crashes occur in the area and how fast people drive on the road and how fast people should be driving on the road.

In any accident involving a cyclist and a driver, one party has the right of way, and the other party is at fault. Type 1 crashes occurred when the cyclist had the right of way, and type 2 crashes when the motorist had the right of way. Type 1 crashes were more likely to occur at intersections with two-way bicycle tracks, well-marked, and reddish colored bicycle crossings. Type 1 crashes were negatively correlated to the presence of a raised bicycle crossing and other speed reducing strategies. Both well marked bike lanes and raised bike crossings have an effect on the cyclists’ behavior, but only the raised bicycle crossing has an effect on the motorists’ behavior[25].

Compliance rates are very low when pedestrians have to wait in the median for another signal because crossing time was lengthened significantly. One suggestion is to set signal times to allow the majority of pedestrians to cross in one stage, but place a pedestrian detector at the median to accommodate pedestrians that require two stages to cross. The compliance rate dropped significantly during cold and inclement
weather. During these times, pedestrians used unsafe behavior, which coupled with unsafe road conditions can lead to more pedestrian injuries and fatalities[26].

In a case study done of Queens Boulevard in New York City, the main issues were excessively long crosswalks, inadequate pedestrian reservoir space, excessive vehicular speeds, high number of pedestrian/auto accidents, long distances between signalized crossings, and inadequate pedestrian design elements. Another issue is that the medians do not extend to the far edge of the crosswalk so pedestrians do not have an adequate refuge area. The recommendations include more visible crosswalks, curb cuts and ramps, longer pedestrian signal times, refuge islands, new midblock pedestrian signals, and curb bulb-outs[27].

2.4 Bicycle Facilities

Bike facilities are an important aspect of road design when trying to design a complete street. To insure that cyclists use the provided bike facilities, there are a few issues that need to be addressed. Above all else, cyclists need to feel safe and comfortable. Depending on the cyclist’s age and ability, this means different things. The top motivators among cyclists to ride were the availability of routes away from traffic noise and pollution, routes with beautiful scenery, and paths separated from traffic. The factors that are most likely to influence the likelihood of cycling were safety, ease of cycling, weather conditions, route conditions, and interactions with motor vehicles. Due to the little difference between the motivators and deterrents for potential and regular riders, the same improvements can increase ridership in both groups[28].

One major issue with bicycle facilities is that they typically take up space on an existing street which is a very controversial planning decision. The space that is
taken up could be travel lanes or parking lanes which are highly coveted in some high-traffic areas. New York is the scene of one of the more public and explosive controversies over a bike lane in the last few years. New York City is currently implementing a policy to calm and decrease automotive traffic by closing areas of the vehicular traffic in Times Square and by improving the facilities for cyclists and pedestrians. While one poll suggests that 59% of all New Yorkers (not just cyclists) approve of the bike lane program, some individual bike lanes are fiercely contested. One bike lane was installed in a neighborhood in Brooklyn near the residence of the city’s former transportation commissioner, Iris Weinshall, who demanded the removal of the lane and took the case to the state supreme court where she eventually lost[2].

At intersections there are a few bike lane discontinuities that cause the most discomfort for cyclists: lanes switching sides of the street (right to left) after an intersection, introducing parking after the intersection, long distances across intersections, and width of curb lane. Other factors that affect the safety of cyclists included speed of traffic, a change in the number of traffic lanes, and the direction of the adjacent traffic[29]. A distance of 2 and 5 m between the side of the arterial road and the cycle track is safest for cyclists because cyclists are not riding in the motorists’ blind spots and there is more time for turning vehicles to notice cyclists[25].

Current and potential cyclists are interested in bike lane designs that achieve separation from motor vehicle traffic. A separated bike lane can increase ridership by 18 to 20% as opposed to the 5 to 7% increase caused by a regular on-street bike lane[30]. Wide curb lanes and bike lanes should be used to improve riding conditions for cyclists, however if adequate space exists for a bike lane it should be installed
because of the cyclist comfort level is increased and may increase the amount of

cycling on that roadway[31].

When designing a bike lane, it is important to understand the risks associated
with different types of infrastructure and different contexts. For example, it is
reasonable for cyclists to mix with traffic in a small roundabout. Larger roundabouts,
however, will require a bike lane for safety[32]. Sidewalks and multi-use trails pose
higher risks to cyclists, major roads are more hazardous than minor roads, and bicycle
facilities (on and off-road bike lanes) create the lowest risk for cyclists[33]. If a crash
occurs on a bike lane and one-way street, it is most likely a door crash[34].

More cyclists ride on cycle tracks (separated bike lanes) than on the streets.
The relative risk of injury on cycle tracks was 0.72 compared with bicycling on the
street. Since the relative risk is noticeable smaller for cycle tracks, the construction of
cycle tracks should not be discouraged in the US. This paper looks at the number of
riders in the Netherlands given their large network of cycle tracks[35].

There has been a lot of discussion about how adding bike facilities will affect
ridership and vehicular traffic. When bike facilities are introduced, ridership has been
found to increase. However, ridership only increased on roads with bike lanes while
general ridership remained the same over the two year period of the study. The bike
lanes had a minimal effect on vehicular traffic if any effect at all, but on average, bike
traffic increased by 23%. Original bike traffic levels ranged from 550 to 1,500 and
went up to between 570 and 1,900 cyclists[36].

After the integration of a bike lane on a street in New Orleans, numbers of
bicycle riders and found an increase from 90 to 142.5 riders per day on the street.
There was a 133% increase in the number of women riders and a 44% increase in the
number of male riders. While the numbers of cyclists riding illegally on the sidewalk did not change, the percentage of cyclists riding in the correct direction (with traffic) increased from 73.3% to 81.8%. This was also during a time when the price of gasoline decreased, which may have had an effect on the results[37].

While there are a number of important factors that determine whether or not people choose to ride over other modes, there seems to be one that has an enormous effect. Creating a network of bike facilities seems increase ridership substantially because people are able to travel from their origin to their destination without leaving a bike facility. Between 1991 and 2004 ridership in Portland increased by 210% and the miles of bikeways increased by 215% (from 65 to 230 miles). Hawthorne Bridge has the largest number of cyclists because of its facilities and proximity to downtown. While ridership had been increasing over time, it jumped 20% when another bridge opened which created a recreational loop within the city. Ridership increased significantly because of the combination of the quantity of facilities with the high quality of the facilities. A bikeway network must be well connected and provide continuous or mostly continuous service. This approach only works when the bike lanes are constructed to the highest standard and the trip distances are relatively short[38].

2.5 Changing Travel Behavior

According to Marchetti, throughout time and around the world humans have always been willing to travel for one hour per day on average regardless of the mode of travel[39]. This means that humans are willing to spend 30 minutes traveling to their destination, and thirty minutes returning. This time will be used to determine what distance is reasonable to commute on foot or bike. There are other factors that
affect an individual’s choice to walk or bike versus drive to work and need to be accounted for.

The Federal Highway Administration completed a study in 1992 focusing on why individuals choose one travel mode over another (specifically why individuals choose driving over walking and bicycling for the vast majority of trips). The primary reason that people walk or bike is for exercise and enjoyment. The key findings for bicycles are that the primary individual factor for not cycling is age. The main environmental factor that increases bicycle use is the presence of a university. Other environmental factors that have an effect are commute distance, primary bicycle facilities (for example, parking), and a high ratio of bikeways to road mileage. High density areas have a higher number of cyclists, but having a network of bike facilities was required. Safety was also a primary concern of cyclists; increased bike facilities helped with the feeling of safety. The key findings for walking are that people walk when it is more convenient than other travel modes. Distance is the primary reason why people don’t walk more often; other reasons are the hassle of carrying things, time limitations, and fear of crime. It is possible to increase the amount of walking because most short trips are not walked. It is important to make these trips more feasible and pleasant by adding sidewalks, crosswalks, greenery, and landscaping[40].

One of the interesting findings is that there is a discrepancy between the numbers of people who say they are interested in cycling more and the actual number of regular cyclists. The data gathered from surveys may not be as reliable as assumed because while people would be willing to drive, it is much more difficult to actually change behavior because of a number of factors[40].
This article stresses the importance of Active Living by Design (ALbD) projects and the 5Ps: preparation, promotion, programs, policy, and physical projects. These 5Ps work together to create a more successful project instead of using a “build it and they will come” model. This article recognizes the need for broad partnerships, community engagement, and context specific responses to address the issues in each community[41].

An increase in commute distance corresponds with a decrease in the value of attitudes toward other characteristics of bicycling. The characteristics that show a significant decrease from groups commuting less than 5 km to groups travelling more than 10 km are comfort, time-saving, flexible, cheap, pleasant, and suits lifestyle. The study also found that individuals who bike for a number of other purposes are more likely to commute by bicycle over all distances[42].

2.6 Effect of Street Design on Driving Behavior

Driving behavior is affected by the following street environment factors: occurrence and density of junctions controlled by traffic lights, speed limit, street function, and type of neighborhood. There are pronounced negative environmental effects due to regulating junctions with traffic lights. From an environmental point of view, roundabouts may be a better traffic solution than traffic lights[43].

Data shows that the reduction in free-flow speed due to narrow lanes in work zones was higher than reductions given in the Highway Capacity Manual. Speed reductions of 10, 7, 4.4, and 2.1 mph should be used for lane widths of 10, 10.5, 11, and 11.5 ft, respectively. The speed reduction for a 12 ft lane without a shoulder was found to be 5.6 mph numbers based on 55 mph work zone speed limit and a 65 mph
regular speed limit (without a work zone). Heavy vehicles reduced their speed more than passenger cars[44].

This study focused on the effects of narrowing a road from 10.8 ft to 9.8 ft with a one ft shoulder. The study found that speeds were not affected by lane narrowing, but drivers drove more to the center of the lane after the narrowing (when they drove more to the left before narrowing). Drivers also shifted more to the right when there was an oncoming vehicle after the lane narrowing[45].

The Highway Capacity Manual (2000) has a lane width factor for determining the speed change based on lane width based on a standard width of 12 feet. The factor equation is

$$f_w = 1 + \frac{(W - 12)}{30}$$

The result of this equation is then multiplied by the speed found using a 12 foot lane to determine the change[46].

2.7 Road Diet Treatments

A 6 block section of an arterial street (West Avenue) in Ocean City, NJ was used to test the efficacy of a road diet design. Four traffic lanes were reduced to three, and pedestrian refuge islands and bike lanes were introduced. The results were that the traffic volumes were unchanged, there was a modest reduction in speed, and the speed reduction was welcome but not as large as anticipated. Ocean City deemed the trial as successful- the new facilities were being utilized and there was not a noticeable increase in delay. The city has decided to extend the project 10 blocks south and is also evaluating the feasibility of extending the project to the north[47].

Crash frequency was reduced by six percent after a road diet treatment was implemented. Crash rate remained the same, however, when comparing the road diet
and comparison sites. Crash severity also remained unchanged. The reason for the reduction in the crash frequency is unknown[48].

This report replaces the previous one done in 2005 (Evaluation of Lane Reduction “Road Diet” Measures and Their Effects on Crashes and Injuries). The new research determined that there is an average 29% reduction in total crashes after a road diet plan is implemented. In small urban areas a 47% reduction was found, and in more suburban areas outside a major city a 19% reduction was found. These differences are most likely due to original AADT and 85th percentile speed of vehicles[49].
Chapter 3

METHODOLOGY

While there are many complete streets’ techniques, all of them fall into one of the following categories that can affect traffic: lane width change, volume shifts, and delay due to pedestrians.

3.1 Lane Width Changes

Lane width changes occur when there is an existing road that has a set width, and different techniques are applied that were not accounted for in the original width of the road. Standard lane width is 12 ft, and widths of 10, 10.5, 11, and 11.5 ft are reasonable widths of road depending on the speed of the vehicles.

There are a number of sources that discuss the effects of changing lane width. Some describe the effects on capacity, while others focus on the effects on speed. With respect to speed, there are three sources that will be focused on in this study and they are a study on the effect of reducing lane width in a work zone, and the two most recent versions of the Highway Capacity Manual (2000 and 2010). In the 2000 manual, lane width was considered to have an impact on speed, but in 2010, the new Highway Capacity Manual changed the effect of lane width on speed. The current standard states that speed does not change for lane widths of 10 feet to 12.9 feet. If the lane width is between 8 and 10 feet, the factor that the free flow speed is multiplied by is 0.96[50]. Although the speed does not change, the capacity does change.
Table 3.1:  Speed based on lane width with a free flow speed of 25 mph

<table>
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<tr>
<th>Width (ft)</th>
<th>13</th>
<th>12</th>
<th>11.5</th>
<th>11</th>
<th>10.5</th>
<th>10</th>
<th>9.5</th>
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<td>25.0</td>
<td>25.0</td>
<td>25.0</td>
<td>24.0</td>
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<tr>
<td>HCM 2000[46]</td>
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<td>23.4</td>
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<tr>
<td>Work Zone[44]</td>
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<td>24.0</td>
<td>23.0</td>
<td>21.8</td>
<td>20.5</td>
<td>N/A</td>
</tr>
</tbody>
</table>

By adding refuge islands, curb bulb-outs, bike lanes, and sidewalks, space is taken away from each lane to accommodate other users without widening the road. There are a number of different ways that an existing road can be changed to make it safer for all users without acquiring the necessary right-of-way to widen the road. For example, a road with two 12-foot travel lanes in each direction and parking lanes on both side can be changed in a number of different ways (Figure 3.1).
Figure 3.1: Different lane configurations based on 76 ft right-of-way
The original street design is meant to be indicative of many streets in urbanized areas across the country. This street design requires a pedestrian to cross 64 feet in one cycle which could be difficult for some pedestrians. It does not allow any separate space for cyclists and does not have any additional facilities for transit users. Using the original right-of-way area, many solutions are possible by reducing the lane width, reducing the number of travel lanes, and taking out one or both of the parking lanes.

Solution A reduces the distance that pedestrians have to cross by adding curb bulb-outs at pedestrian crossings while leaving in the parking lane where there is not a crossing. Curb bulb-outs are also used to increase the visibility of the pedestrians, so drivers see them before they walk into traffic. A median was also added, but the median cannot act as a refuge island because they must be a minimum size of six feet to accommodate pedestrians with disabilities. Solution A and B with two and four-foot islands are not sufficient, but they do create a potential for street vegetation and storm water systems. This is done by reducing each of the travel lanes to 11 feet wide instead of 12 feet.

Solution B reduces the lane width to 10 feet and introduces a median and one bike lane that can accommodate bike traffic in one direction only. The bike lane is protected from traffic by the parking lane. This makes cyclists feel more comfortable because of the separation and reduces the risk of door crashes because the travel lane is not next to the driver-side door. This solution keeps the curb bulb-outs on both sides, but it does accommodate the bike lane on one side.

Solution C has a 10 foot travel lane, and it takes away one parking lane to add a protected, two-direction, bike lane on the other side. It also adds a pedestrian refuge
island that is wide enough to accommodate pedestrians with disabilities. It significantly reduces the distance that a pedestrian has to cross, which changes the amount of time that is required to allow pedestrians to clear the intersection because they only need to make it to the refuge island.

Solution D removes one of the travel lanes in each direction and allows for a turning lane in the center. This is a road diet solution because travel lanes are taken out and replaced by a turning lane and other facilities. This solution keeps both parking lanes and allows for a bike lane on each side and for a slightly wider sidewalk. This option could have refuge islands instead of turning lanes at the intersections. Each of the solutions dramatically reduces the distance a pedestrian has to cross in one light cycle, and also makes pedestrians more visible to drivers using curb bulb-outs. Depending on the available space for a bike lane, there could be a bike lane on each side of the street that moves along with traffic (As shown in solution D), or there could be a two-way bike lane on one side or in the middle of the street (as in solution C).

To determine which techniques are best for a specific project, it is necessary to design based on the context. If the road has a large number of vulnerable pedestrians, the best solution would have short crossing distances. If there are a lot of cyclists in the area, the best solution would have adequate bike lanes to accommodate the users. This plan would require a large network of bike lanes which would take more time than just one project. If the road is near a school, the best solution would allow for young pedestrians and cyclists to travel safely alone or with a parent. These solutions would include different signal timing at intersections, very visible and more frequent crossing opportunities, and bike lanes that are protected from traffic.
Context specific solutions are necessary because each decision made will affect the traffic of the area in some way. Reducing capacity of the street will affect all of the drivers in the area. This may be a determining factor in whether to proceed with a project or not. If everyone in the community is trying to reduce the number of cars in their household, creating infrastructure to accommodate new types of users would be appropriate for the neighborhood. If, however, the community is not interested in reducing the number of cars per household, or if it is not close enough to a central business district, than reducing road capacity by adding in sidewalks is much less appropriate. This could result in an increase in delay and emissions for infrastructure that will go mostly unused.

The most significant impact that needs to be addressed is the change in capacity based on lane width change. To determine capacity change, Highway Capacity Software was used. Their software, Art Plan 2009, was used to simulate the effects of lane width change based on a street in a large urbanized area with two thru lanes in each direction and a free flow speed of 35 mph. A baseline service volume was determined based on the service volumes for this street with 12 foot lanes. The change in service volumes (based on level of service) was determined by using 11, 10, and 9 foot lanes. These service volumes can be used to determine what lane width is necessary for a certain street based on current and projected hourly volumes and the techniques that are desired for a given context.

### 3.2 Delay Changes

Delay caused by pedestrians can be caused either by changing the signal timing of existing crosswalks, or by adding additional, mid-block, crosswalks. Delay depends heavily on how many pedestrians there are and how compliant those
pedestrians are to the traffic laws. This can be affected by the volume shift if a significant number of users choose to walk instead of drive when using a certain road.

At intersections, signal timing needs to accommodate for the distance pedestrians have to travel using a 3.5 foot per second speed. Assuming pedestrians follow the laws and there is enough time for them to cross, there will be no additional delay. If there are long distances to cross, it is possible that some pedestrians would be left in the crosswalk after the signal has changed, and that could cause some delay.

Midblock crossings, on the other hand, do cause delay. Depending on the type of crossing and number of pedestrians, there could be substantial delay. The cost of each of the options differs depending on what safety features are included. The options range from adding pavement markings at midblock crossing to adding pedestrian signals (Hawks, Pelicans, or Puffins, for example). Midblock signals can be very expensive to install, but they are meant to improve safety for pedestrians. The difference between a signalized and an un-signalized midblock crossing is how the traffic is stopped. In some signalized midblock crossings, the pedestrian pushes a button which creates a red light for the driver and the pedestrian is allowed to cross. In an un-signalized crossing, the pedestrian has the right-of-way and walks out in to the crossing without any warning. Un-signalized crossings in highly-travelled areas can cause problems because there is a constant stream of pedestrians walking through the crossing. If the crossing is signalized, there are breaks in the stream of pedestrians which allow drivers to pass.

To determine the delay caused by pedestrians crossing at a midblock crossing, a simulation was done in VISSIM. This simulation focused on a section of road with two travel lanes in each direction and a midblock crossing. Simulations were done to
determine the travel times for vehicles using different vehicular and pedestrian volumes. Vehicular volumes of 500, 1000, 1500, 2000, and 2500 vehicles per hours were tested. Each vehicular volume was tested using a range of pedestrian volumes: 0 (to establish a travel time without a midblock crossing), 10, 50, 100, 150, 200, and 400 pedestrians per hour. These ranges were used to compare roads that have a low vehicular and pedestrian volume to roads that have a very high vehicular and pedestrian volume and everything in between. Once the travel times were found, the delay was determined by using the difference in travel time between each of the scenarios and the base case (with no midblock crossing). The results can be used as a decision tool for planning organizations to determine if increasing the delay for drivers is a reasonable tradeoff to give pedestrians an extra road crossing.

3.3 Volume Shifts

Volume shifts may occur because people choose to use a different mode of travel based on the current facilities. Drivers may also choose alternate routes because of delay that is caused or a perception that there may be increased delay due to the change in design. It is very difficult to determine what sort of effect this will have on the daily traffic volume. Instead of trying to determine how many drivers will switch modes based on a new road design, it is more important to determine how many drivers have to switch modes so the level of service does not change significantly. This number is based on the techniques chosen for a certain road and are affected by lane width and delay caused by pedestrians.
Results

4.1 Lane Width Changes

There is a marked difference between the service volumes of a street with 12 foot lanes and those with narrower lanes. Depending on the level of service, the service volume drops a certain amount each time a lane gets narrower. While this seems like common sense, it is important to understand the difference between choosing a 10 foot lane versus an 11 foot lane. Below shows the percentage drop in service volumes based on lane width.

Figure 4.1: Service volume change based on lane width
As figure 4.1 shows, reducing the lane width by 3 feet can reduce the service volume by 10% depending on the level of service. However, a 1 foot reduction only reduces service volumes by 2-3%. This Service volume differs from capacity in that it focuses on a certain set of conditions and a given level of service. This data helps planners understand how much lane width can be reduced based on a target level of service and traffic forecasts for an area.

4.2 Delay Changes

Introducing additional pedestrian facilities at un-signalized intersections causes delay. The amount of delay for drivers depends on the number of vehicles and the number of pedestrians. As the number of pedestrians and vehicles increases, the delay increases substantially.
Figure 4.2: Delay based on pedestrian and vehicular volumes

Planners can use this information to determine if the number of vehicles and pedestrians warrants an un-signalized midblock crossing, or if no crossing or a signalized intersection is more appropriate for the context.

4.3 Volume Shifts

Volume shifts are required based on the results for delay changes and lane width changes. For lane width reductions, the volume shift would have to be equal to
the service volume reduction to maintain the same level of service. A road that originally accommodated an annual average daily traffic of 12,400 at a level of service D would only be able to accommodate an AADT of 12,000 if the lane were reduced to 11 feet. To maintain this level of service, 400 (3%) drivers would have to choose a different mode or different route every day. 900 (7%) drivers would have to switch modes or routes with a 10 foot lane, and 1,300 (10%) drivers would have to switch with a 9 foot lane. In all cases, a significant number of drivers would have to switch modes or routes to maintain the level of service.

Delay caused by pedestrians is more complicated. If a substantial number of drivers switched to pedestrians, delay could change if the midblock crossing is used by more people. The important thing to note about the delay change results is that doubling the number of vehicles has a much larger effect on delay than doubling the number of pedestrians.
Chapter 5

CONCLUSION

5.1 Tradeoffs

There is one essential question that all planners need to ask themselves: what techniques are appropriate for this context and this community? The answer to this question is going to vary widely from place to place. The context plays the largest part in determining the answer. Some techniques are only appropriate in dense urban areas, other techniques are appropriate for less dense areas. The primary goal of a complete street design is to increase the safety of all users. To meet this goal, it is important to understand who the users are, what the community wants, and what the community needs.

Difficult decisions are required to determine which techniques are the best to implement in a given area. In a densely populated area, the community may want a sidewalk, a bike lane, and street landscaping/storm water management. In a rural area, the community may want a good drainage system and a wide shoulder for walking and biking. These techniques might be appropriate for each community, but both solutions take up space that may be used currently as a vehicular travel or parking lane, or they might require more right-of-way. These changes could greatly affect the traffic in the area by increasing delay or reducing service volume.

The results shown give planners the opportunity to understand the tradeoffs that need to be part of the discussion. It may be appropriate to reduce the service volume to put in a bike lane if the community wants a bike lane, and the bike lane will
be used enough to warrant affecting traffic. This could cause the community to become divided over the issue, and there will have to be a discussion about whose needs will be met and where compromises need to be made. Compromises could be to add a bike lane only on one side of the road and leaving the parking on the other side.

These results allow planners to determine how much the lane width could be reduced to continue to meet the needs of the current drivers while implementing complete streets techniques that will address the needs of the other road users. As discussed earlier, it is possible to choose different techniques that fit in the current width of the street while not reducing the lane width dramatically. This is a problem that is especially difficult in areas where the areas along the street are developed and there is no additional space to increase the width of the road to accommodate all users. Increasing the width of the road does not meet the sustainability goals of complete street design, but it may be a compromise so all of the safety goals are met.

Deciding whether to add a midblock crossing has similar tradeoffs to deciding whether to reduce the lane width. Midblock crossings are useful in areas where there is a long distance between signalized intersections and have a number of pedestrians that have to go out of their way to get to a signalized intersection. If there are not a lot of pedestrians, a midblock crossing is not going to have a large effect on the drivers in the area, so the planners need to concern themselves only with what type of crossing they will be putting in and how much money they want to spend. If there is a large pedestrian population and fewer drivers, a midblock crossing is appropriate to accommodate many users. If there is a large pedestrian population and a lot of drivers, it is important to weigh the tradeoffs between accommodating the drivers and accommodating the pedestrians. One possible solution in this case could be to put in a
signalized crossing so more pedestrians cross in groups instead of a steady stream. This also lets the drivers and pedestrians know exactly when it is safe to go. Adding in a signalized crossing is much more expensive than adding an un-signalized crossing, but the pedestrian and driver populations might warrant a signalized crossing.

5.2 Future Work

Transportation planning occurs at different levels because individual roads are designed at different times, but all of these roads along with the public transit network all work together as a larger transportation network that impacts a region. This study focused only on the effects of complete streets techniques at the street/arterial level. Now that the impacts of lane width reduction and delay changes have been determined at a more detailed level, it is important to understand the impacts on the larger transportation network.

In 2010, the Highway Safety Manual was introduced which focuses on the safety of road users. Since the primary goal of designing complete streets, it is important to determine if there will be changes in safety based on the different techniques that are implemented. Planners need to determine if it is safer to introduce more pedestrians on a street versus keeping them in cars. If it is not safer to introduce pedestrians on that street, it is necessary to determine how the street could be designed to make it safer. Sometimes this could be difficult because the context makes streets more dangerous for pedestrians, but if there is something that can be done during design, focusing on the safety of all users is necessary to meet the goals of complete street design.
REFERENCES


Appendix A

LANE WIDTH CHANGE DATA

A.1 Highway Capacity Manual 2000

Table A.1: Speed changes based on lane width changes from HCM 2000

<table>
<thead>
<tr>
<th>Speed (mph)</th>
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<th>12</th>
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## A.2 Work Zone Study

Table A.2: Speed changes based on lane width changes from Work Zone Study

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Appendix B

DATA COLLECTION

B.1 Midblock crossing:

Table B.1: Travel Time in seconds based on number of pedestrians and vehicles at midblock crossing

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Table B.2: Delay in seconds based on number of pedestrians and vehicles at midblock crossing

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B.2 Service Volume Changes:

B.2.1 2 Lanes:

Table B.3: Service Volumes based on lane width in AADT for a two lane road

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<td>3000</td>
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Table B.4: Percent change of service volumes for a two lane road

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<td>100%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>94%</td>
<td>97%</td>
<td>97%</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>88%</td>
<td>93%</td>
<td>94%</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>88%</td>
<td>90%</td>
<td>90%</td>
<td></td>
</tr>
</tbody>
</table>

**B.2.2 4 Lanes:**

Table B.5: Service Volumes based on lane width in AADT for a four lane road

<table>
<thead>
<tr>
<th>Lane Width</th>
<th>LOS</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>7500</td>
<td>27600</td>
<td>31000</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>7400</td>
<td>26700</td>
<td>29900</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>7200</td>
<td>25700</td>
<td>28700</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>7000</td>
<td>24800</td>
<td>27600</td>
<td></td>
</tr>
</tbody>
</table>

Table B.6: Percent change of service volumes for a four lane road

<table>
<thead>
<tr>
<th>Lane Width</th>
<th>LOS</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>99%</td>
<td>97%</td>
<td>96%</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>96%</td>
<td>93%</td>
<td>93%</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>93%</td>
<td>90%</td>
<td>89%</td>
<td></td>
</tr>
</tbody>
</table>