# Designing for Bicycle Safety

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## Abstract

Bicycle use has been increasing in popularity in North America. This growth and the projected continued growth has made it important for engineers to learn the fundamentals regarding bicycle design and safety. This paper presents an overview of the fundamentals of design that will give the reader a basic understanding of safety guidelines. Several treatments along with their success are presented to allow for evaluation of those new treatments. A new proposal of Lateral Lane Divider Humps (LLDH) is described. LLDH are a new design idea that could potential be very effective in keeping motor vehicles out of bikeways.

## 1.0 INTRODUCTION

Bicycle use has been growing in popularity over the past couple of decades and its popularity is projected to increase in the future due to its many benefits over driving traditional automobiles (Schaller 2006). This has created problems for engineers in dealing with the conflicting road demands of both cyclists and motorists. A balance must be achieved in bikeway design so that the mobility and safety needs of cyclists can be addressed without seriously, negatively affecting the automobile users.

Background information on the requirements for effective bikeways as well as the four bikeway classes has been examined. Factors that affect the safety and usefulness of bikeways have been discussed for new construction and retrofit projects. Examples of two successful retrofit projects in the United States have been discussed. Some of the recent innovations in bikeway treatments have been compared, and finally a new possible type of bikeway treatment has been introduced.

## 2.0 BACKGROUND INFORMATION

There is background information relating to the importance of cycling and the reasons why it is growing in popularity that should be studied because it is important to understand what is required to make a bikeway successful and what types of bikeways currently exist.

### 2.1 Benefits of Cycling Over Traditional Automobiles

There are many benefits that bicycles provide over traditional personal automobiles that municipalities should consider when trying to decide whether or not to invest in designing and retrofitting areas specifically for bicycle use. There are social and health benefits in the exercise that cycling provides. There are environmental benefits with the reduction of automobile emissions. Finally, there are obviously traffic benefits with the reduction in roadway congestion with fewer automobiles on the roadway. All of these benefits work together to make it worthwhile to design for bicycle use.

With obesity and especially childhood obesity on the rise in recent years, there is a lot of support for promoting more physical activity and exercise. Designing safe areas for cyclists to use is a proactive step in encouraging more activity. People can be intimidated by heavy traffic in downtown and core areas of municipalities, but with more money and effort dedicated into building safe bicycling areas, more people will be encouraged to take advantage of such areas and reap the benefits of physical activity.

There has been a lot more attention in the press lately with climate change and more specifically the effects that green-house gasses are having on the long term sustainability of the planet. Personal automobiles are a major contributor to the greenhouse gas emissions in North America, so any reduction in the use of automobiles will result in the benefit of less greenhouse gas emissions being released into the atmosphere. With Canada agreeing to the goals of the Kyoto Accord in 1998 and rectifying the Accord in 2002 (CBC 2007), Canada has committed to the international community that it will take proactive steps in reducing greenhouse gas emissions in order to help achieve a more sustainable way of life. After 5 years, Canada has done little to try and achieve these goals and needs to start coming up with ideas and act on those ideas to get them back on track with their greenhouse gas reduction commitment. Designing for bicycle safety and the resultant drop in automobile use is certainly a step in the right direction when it comes to environmental improvement and any improvement to encourage bicycle use, however small, has the potential to have long-lasting benefits to the planet.

The final and most obvious reason to encourage bicycle use and invest in bicycle safety is the potential reduction in traffic congestion. Traffic congestion is currently plaguing major North American municipalities and the present-day way of thinking seems to be that building more lanes on highways will eventually solve the problem. This results in millions of dollars being spent on highway improvements and expansions without even considering the main reason why there is so much congestion; there are too many automobiles on the roadways. Instead of simply trying to build more capacity to reduce congestion, demand should be reduced by getting automobiles off of the roadway. A great way to get automobiles off of the road is to encourage people to take other methods of transportation including riding a bicycle. Investments in bicycle safety and encouraging bicycle use can be more than paid off by the resulting reduction in congestion.

These preceding benefits of bicycling make the corresponding costs of investing in bicycle safety more than feasible for most communities.

## 2.2 Requirements of a Bike Route

There are four basic requirements for a bicycle route when functionality and safety are being considered. The first is that there must be space to ride. The second is that there must be a smooth surface. Third, a bike route must be able to provide speed control. The fourth is that it must be connected to other bicycle routes (TAC 1999).

There is a bicycle design envelope that the Transportation Association of Canada (TAC) Geometric Design Guide recommends using to help provide a starting point for designs. The envelope has a width of 1.0m, a height of 2.2m and a length of 1.75m simply to compensate for the fact that cyclists are not able to maneuver in an exactly straight line and that both the size of bicycles and height of riders will vary. TAC also recommends a minimum distance to a travel lane of 1.5m for a 100km/h design speed, 1.0m for an 80km/h design speed, and 0.5m for a 60km/h design speed. Finally, there should be a 0.2-0.5m clearance to any wall, fence, or fixed barrier, and a minimum 1m clearance to an unfenced drop-off such as a river or embankment (TAC 1999).

There is an obvious need for a travel surface to be smooth to be both safe and functional for cyclists. Bicycles tend to have very narrow tires under very high pressure and rarely have very good suspension systems. TAC recommends that no structure as part of the route be more than 5mm off of the existing grade of the route. Anything that extrudes or depresses more than 5mm off the route (such as manhole covers, edgings or driveways) can become serious safety concerns for cyclists (TAC 1999).

Cyclists must be able to maintain a relatively constant speed for routes to be functional. It is very physically demanding and impractical to expect cyclists to continuously slow down and stop, then have to speed back up again. Routes should be designed to allow uninterrupted riding wherever possible and should try and avoid: steep gradients, rough surfaces, sharp corners, and intersections of roadways. All of those situations result in the need for abrupt speed changes, which will compromise the safety of cyclists (TAC 1999).

Finally, a bicycle route will not be very practical if it is not connected to other routes in the area. If a route is not connected to other bicycle friendly areas, it will not provide safe access for any type of meaningful trip and will be rendered useless. It will also force cyclists who use that certain part of the route, to traverse other areas not designed for bicycles putting them in more danger. If bicycle routes are not effectively connected in a municipality, they will not allow for safe and efficient travel (TAC 1999).

## 2.3 Bikeway Classification

There are 4 different classifications of bikeways that exist. These include: Class I bikeways, Class II bikeways, Class III bikeways, and Class IV bikeways or shared roadways. Each bikeway class requires different techniques to enable safe passage by cyclists (RTAC 1983).

Class I bikeways are routes that are totally dedicated to bicycles and automobiles are prohibited from use on them. These routes commonly are more for recreation, but can also provide a route for high-speed bicycle commuting. Class I bikeways should keep street crossings at a minimum, because they result in dangerous conflict points with vehicles and will force the cyclist to significantly lower their speed, reducing the effectiveness of a high-speed route (RTAC 1983).

Class II bikeways run parallel with existing vehicular roadways and are separated from the roadways by either a painted strip or a physical barrier. The bikeways are intended to assign right-of-way between bicycles and vehicles. Problems can arise with class II bikeways when vehicles want to make right turns, as a right turn results in an encroachment on the bikeway and creates a hazard for cyclists. Confusion on who has the right-of-way at intersections also causes problems. Class II bikeways are appropriate for areas of heavy bicycle use or areas where there have been a lot of accidents between cyclists and motorists trying to share the same space. Class II bikeways are the most common type of bikeway that municipalities build so they have been discussed in further detail later on (RTAC 1983).

Class III bikeways are roadways that are designated as bikeways, but the cyclist is expected to share the same roadway with motorists. These areas tend to be in low-speed urban environments so that the cyclist can travel at the speed of motorists. These routes are marked by signs for two purposes. The first purpose is to alert the driver to watch out for cyclists who might be sharing the facility. The second purpose is to identify the route for a cyclist as the best option for route selection. A class III bikeway serves two purposes: it connects two other bikeway facilities and it designates a recommended route for cyclists where no higher bikeway designation exists (RTAC 1983).

Class IV bikeways or shared roadways are nothing more than unmarked shared lanes. There is no visual warning or identifying signs for either the motorist or the cyclist. The vast majority of streets at this time are unmarked and undesignated due to the effort and cost of doing such for municipalities. Class IV bikeways are roadways that cyclists find they are able to safely operate on with motorists present (RTAC 1983).

There are many factors that help determine what class of bikeway should be built or retrofitted. The higher the class of bikeway that is built, the higher the level of safety for cyclists using the facility. Motorists will also experience less congestion and fewer accidents with cyclists on the higher class bikeways. With a higher class of bikeway though, comes a higher cost and unless there is significant bicycle usage or there is a high projected usage, the cost of building a high class bikeway may not be warranted. Therefore demand must be weighed against cost and increased safety before any decisions are made to go ahead and construct new bikeways (RTAC 1983).

# 3.0 CONSTRUCTION GUIDELINES

There are basic construction guidelines that should be followed when constructing bikeways either for new construction or for retrofit projects. It is much easier to design bikeways with no design restrictions and simply follow the design guidelines presented by the American Association of State Highway and Transportation Officials (AASHTO) if there is land available. The more common practice of retrofitting a bikeway to an existing road is more difficult, but suggestions on how this can be done are presented.

## 3.1 New Construction

Most new bikeway construction will consist of class II bikeways that are being constructed alongside new roadway. The majority of effort in this report is focused on retrofit projects to existing roads because that is where most of the work is done; in comparison with retrofit projects, there are few new roads being built with a bikeway in the design.

That being said, AASHTO has set-out design standards that should be followed to ensure that bikeways are safe and efficient for cyclists. The class II bikeway is the most popular as it is relatively cost-effective compared to class I and it is much safer when compared to class III or class IV. The class II involves a dedicated bike lane on the outside of the vehicle travel lanes of the roadways. On-street parking is not recommended on bikeway routes, but if it is required, it is to be parallel parking that takes place between the bike lane and the curb to provide the safest operation for cyclists. The recommended minimum width of a bike lane is 5 feet if it is marked and it should not be accessible to vehicle traffic. Where parking is permitted, it is recommended that the width of the bike lane and parking stalls be at least 11 feet. Where the cyclist is expected to share an outside lane with motorists, no bike lane is marked, the minimum recommended width should be 14 feet and 15 feet where the cyclists is expected to require more maneuvering space, on hills for example (AASHTO 1999).

## 3.2 Retrofit Construction

The majority of projects involving the creation of bikeways are retrofit projects; this is because most roadways that are chosen for bikeways are not built or rebuilt from scratch. The roadways chosen are on main transportation routes that provide direct access to popular destinations.  Many of these roadways are in dense urban areas where the cost or the availability of land may make it very difficult and impractical to widen a roadway for the sole purpose of adding bike lanes. Most projects currently on the go or expected to be preformed in the near future involve squeezing roadways together to allow for a bike lane to be fitted onto the outside of the travel lanes (Hallett *et al.* 2006).

There are only 3 characteristics of a roadway that can be changed to allocate space for bikeways if the overall curb to curb width of a roadway is to remain the same. If there is a median between travel directions, the median could either be shrunk or removed completely.  A lane or lanes could be removed from the existing traffic configuration if the roadway is not near capacity or not expected to become near capacity in the future. The most common approach for squeezing bikeways into a fixed width roadway is to narrow the width of existing lanes. Often urban streets are wider than required and the narrowing of streets to allow for bikeways will have little or no effect on the congestion or safety of motorists.  It has been shown that there is a smaller negative effect on traffic safety and congestion by narrowing lanes, then to remove left turning lanes. Existing left-turn lanes, especially where there is only one through lane, are crucial to keep congestion down and drivers comfortable (Hallett *et al.* 2006).

Once it has been decided that a roadway will be retrofitted to include bike lanes in both directions, the next step is to decide whether or not to paint the bike lanes or to just have an extra wide outside lane.  Obviously there is added cost in painting the extra stripe for the bike lane and possibly a symbol in that lane designating it as such. The following examples will show that there are a lot of benefits of having the bike lane stripe to help ensure that drivers recognize the presence of a bike lane. The research suggests that cyclists are more apt to obey traffic laws as well as drivers were much less likely to encroach, cross into, the bike lanes when they were marked. Passing maneuvers by vehicles overtaking cyclists were made much more comfortably and safely as drivers were able to stay in their own lane knowing the lateral extent that a cyclist would go off of the curb. Drivers were much more likely to cross into adjacent vehicle lanes in areas where the bike lane was not marked. The driver would be unaware of how far the cyclist may move off of the curb and will be forced to give the cyclist more of a buffer zone to avoid collisions.

### 3.2.1 Retrofit Example on Valencia Street in San Francisco

A bicycle lane retrofit proved very effective in San Francisco. Valencia Street was chosen as a candidate for bicycle lanes due to various factors including its street width, grade, location, and current route of choice for cyclists. Prior to the retrofit, the street consisted of a 4-lane arterial with 2 lanes in both directions; there was also a 5-foot wide painted median between directions. Finally, there was space for parking on both sides of the roadway. A traffic study was preformed which concluded that there was sufficient capacity to cut the number of through lanes down to 2 and that there was sufficient capacity on surrounding streets for vehicles who may change their route due to any changes on Valencia Street (Sallaberry 2000).

The new proposed design of Valencia Street consisted of 1 through lane in each direction with a shared left turn lane running down the middle of the street. There would still be parking on the far outside of each direction. Finally, there would be one marked and signed bike lane between the outside travel lane and the on-street parking on each side of the roadway (Sallaberry 2000).

After 1 year of operation in this manner, a study was done to determine if the desired effects of the changes in street geometry were realized. The project was considered very successful. There was a dramatic increase in the amount of people using the street for cycling with no statistically significant increase in accidents. There were a few minor problems observed with people using the bike lane to double park on the street, but that was supposedly a problem prior to adding the bike lanes and that is expected to be solved by more stringent enforcement (Sallaberry 2000).

Valencia Street in San Francisco is a very successful example of what can be done when there is excess capacity on a roadway and demand for a class II bikeway.

### 3.2.2 Florida Example of Lane Narrowing

Research was preformed in Florida where a 14 foot shared lane was converted to an 11 foot travel lane and a 3 foot bike lane to see what effects if any the painted line separating the modes of transportation would have. The marked bikeway resulted in cyclists riding further off of the curb and drivers not encroaching on adjacent automobile lanes in passing manoeuvres. Both of those results make sense in the ideology that the painted line will result in cyclists being more confident that drivers will not encroach over the bikeway line and cause harm to them and drivers will be confident that cyclists will not encroach over the line because that causes safety concerns when drivers are making a pass. There was an average reduction in encroachments over the line of between 15-40% in areas where the new stripe was added. (Hunter *et al.* 2005)

# 4.0 EFFECTIVENESS OF NEW BIKEWAY TREATMENTS

These examples are of new technologies or bikeway treatments. Each treatment will be looked at to see how effective it was at keeping both motorists and cyclists safe.

## 4.1 Extra Wide White Painted Line

Traditionally, a four-inch wide stripe is used to separate the outside travel lane from a bike lane. Some municipalities have tried using an eight-inch wide stripe just to differentiate for the drivers more that they are not to be crossing or encroaching over that line. There is limited research on the use of the wider lane marker, but it seems to be more effective in areas where there is an exceptionally wide bike lane. Some bike lanes, especially in areas where vehicle lanes have been removed, are in excess of 6 feet and can start to look like an additional vehicle lane to drivers if not appropriately marked. An extra wide lane marker could be helpful in reaffirming to the driver that they should not cross into the wide bike lane (Zegeer 2002).

## 4.2 Bicycle Friendly Rumble Strips

Rumble strips on the sides of roadways have been shown to be very effective in keeping drowsy drivers off of the shoulder and on the roadway. They can be very effective in reducing run off the road (ROTR) accidents and their installation costs are relatively low. Problems have arisen however in areas where rumble strips are used with bike lanes. The standard milled shoulder rumble strips (MSRS) are too aggressive for most cyclists to handle potentially causing a cyclist to lose control and fall into a travel lane. The idea of having rumble strips on the outside of travel lanes is effective in keeping vehicles out of the bike lane, but until recently they were not safe for cyclists who hit them inadvertently.

Research in Pennsylvania was geared at developing a rumble strip pattern that was bicycle friendly yet was still effective in alerting inattentive drivers that they were outside of the travel lane. The research involved testing various different geometric designs of rumble strips with the goal of a maximum audible alert to drivers while keeping the acceleration on the body of cyclists at a minimum. Table 1 shows the results of the research; by decreasing the depth and width of the grooves while increasing the flat portions between grooves, the desired goals were achieved (Torbic *et al.* 2001).

Table 1: Results of the testing for cyclist friendly rumble strips (Torbic *et al.* 2001)

| Type of Strip | Groove Width (mm) | Flat Portion Between Cuts (mm) | Depth (mm) |
|---|---|---|---|
| Standard | 178 | 127 | 13 |
| High Operating Vehicle Speed Bikeway | 127 | 178 | 10 |
| Low Operating Vehicle Speed Bikeway | 127 | 152 | 10 |

## 4.3 Effectiveness of a Painted Bikeway

Intersections and interchanges are often trouble spots, as it is more likely that there will be conflicts between motorists and cyclists. The city of Portland, Oregon researched what effect if any signing and painting recommended pathways through conflict areas would have on both drivers and cyclists. Portland painted a recommend path completely in blue through selected trouble intersections and signed the intersections explaining to motorists that they were supposed to yield to cyclists within the blue path. The results were very promising as the number of conflicts between motorists and cyclists reduced by almost 40%. Both drivers and cyclists were surveyed after the installation of signs and paint and both parties acknowledged that they felt more comfortable. The drivers were more comfortable because they expected the cyclists to stay in the painted lanes and the cyclists were more comfortable as drivers were yielding to them more often. Painting the recommended route through a high-conflict area seems to be an effective treatment and increases bicycle safety (Hunter *et al.* 2000).

## 5.0 NEW DESIGN TREATMENT: LATERAL LANE DIVIDER HUMPS

There seems to be very little in the way of recent investment in the development of new safety measures to make cycling safer. With the lack of new research, it is proposed that a new effective way to keep vehicles out of the bikeway and cyclists out of the travel lane should be developed. What is proposed are lateral lane divider humps (LLDH).

The design would be similar to a speed hump but instead of going perpendicular across a roadway to slow down traffic, it would run parallel to the roadway between the automobile lane and the bikeway. If a driver was to come in contact with the hump, the gentleness of the curve of the hump would simply guide them back into the travel lane. Likewise, if a cyclist was to come into contact with the hump, they would be guided back into the bikeway. It would also be gentle enough that vehicles could crossover it in an emergency to pull onto the shoulder or if a bicyclist needed to cross the street.

There are many limitations that must be looked at prior to such a treatment being installed. First, it would be difficult for snowplows, so its use outside the southern United States would be limited, but the majority of cyclist use is in the southern United States where the weather is warm and traffic congestion tends to be a larger problem. It also causes issues for drainage off of the roadway; catch basins would probably have to be built into the design to keep water from ponding up along the side of the humps. Another solution would be to have holes underneath the LLDH close enough together to allow the water to flow under. Finally of course, research would have to be done into finding the most effective width and height of such a barrier as to provide enough of a jolt to cyclists and motorists to be effective, but not enough to cause users of the roadway to lose control of their bicycles or vehicles. Such a treatment may also be problematic on sharp horizontal curves, especially for large trucks. The hump must be gentle enough as to not put a truck into a dangerous roll-over situation.

One final consideration for LLDH are that they probably will have to be painted in order to be visible at night. Perhaps white would be a good colour; white is traditionally used to divide lanes of the same direction of travel and LLDH are not designed to be used in snow conditions, so lack of contrast against snow would not be a concern. Reflectors on the sides of the humps might also be a solution to a potential visibility problem at night.

If such a treatments proves successful, temporary lateral lane divider humps could be created, out of rubber for example, similar to temporary speed humps that could be installed for the summer months in more northern areas where plowing takes place in the winter months. Bicycle use is more popular in the summer so the majority of the cycling demand would be met while not compromising the plows ability to remove snow in the winter months.

## 6.0 CONCLUTIONS

Increased bicycle use should be continued to be encouraged throughout North America. It has many benefits including: exercise, pollution reduction, and congestion reduction. In order for cycling to be considered a safe alternative to driving though, designers have to invest time and municipalities have to invest money into determining appropriate retrofit practices for converting roadways into multiuse facilities. The best option for municipalities seems to be investing in class II bikeways. They visually separate traffic and cyclists with painted lines or an entire painted bikeway and they are much cheaper than building completely separate roads specifically and exclusively for cyclists (class I bikeway).

Development of lateral lane divider humps may be a step in the right direction for a new treatment for bike lanes. Although this type of design shows a lot of promise in a conceptual stage, it has a lot of limitations that would have to be further researched prior to it being put into use on a trial basis. More effort should be put into development of new treatments and a LLDH or a similar adaptation of a LLDH is a very possible new treatment that would likely be very effective.

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