Safety and Mobility of Vulnerable Road Users

Transportation in a Sustainable World

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Introduction

Transportation safety problems are a serious concern. A study by Transport Canada estimates the annual cost of collisions at $62.7 billion for the Canadian economy (Transport Canada 2006). Automobile transport impacts such as traffic congestion, pollution and road safety issues will only continue to increase unless safe and convenient sustainable transportation alternatives are available. This report focuses on bicycle transportation because of its energy-efficiency, low-cost and zero-emissions. The safety of cyclists is an important topic because it has a higher per-mile casualty rate than car travel, yet poses minimal risk to other road users. Overall traffic casualty rates are found to decline as walking and cycling increase in a community because drivers are more cautious (Victoria Transportation Institute 2014). In addition, a study by the Ontario Coroner found that the majority of cycling deaths are preventable (Government of Ontario 2012). Bicyclists are an important division of "vulnerable road users," which also consists of pedestrians and motorcyclists.

The purpose of this bicyclist safety study is to achieve a better understanding of the effectiveness of cycling safety treatments and their implications to traffic, pedestrians and bicyclist mobility. There are social and economic consequences of shared space, shown by a tradeoff between motorist mobility and the safety of vulnerable road users. The ultimate goal is to create an environment where all transportation modes are safe and convenient to use. This report seeks to improve the safety of bicyclists by ranking bicycle infrastructure based on costs, substantive safety benefits and perceived safety benefits to determine the optimal bicycle investment. To evaluate the substantive cyclist safety benefits of infrastructure, secondary research through a review of the literature and Collision Modification Factors (CMFs) and Collision Reduction Factors (CRFs) was conducted. A calculated CMF is a multiplicative factor used to show the expected change in safety performance associated with the corresponding change in bicycle infrastructure (Sayed & de Leur 2008). Perceived benefits were assessed through a literature review of published surveys of bicyclists and potential bicyclists preferences. The final deliverable is to determine the most cost-effective and optimal bicycle infrastructure investment that will increase the safety of cycling. The intent of the study is to form recommendations that will be used to shape more sustainable future policy and government spending.

Setting the Stage

Increasing the number of cyclists on roads has many proven benefits for the environment, economy, quality of life and public health. The most effective way to increase the number of bicyclists is to increase road safety. It is important to understand the advantages to society of improving the safety of vulnerable road users.

Environmental Benefits

Increasing the number of pedestrians and cyclists will benefit the environment because non-motorized transport does not contribute to air pollution. In British Columbia, transportation is the leading contributor to greenhouse gas emissions, contributing to 36% in 2006:

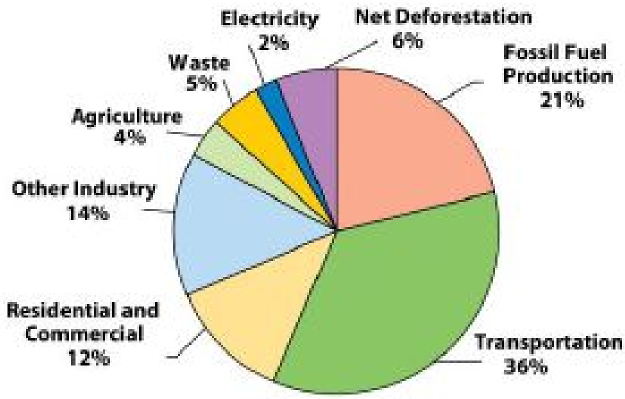

Figure 1: BC Greenhouse Gas Emissions, 2006 (BC Ministry of Transportation 2011)

The same study in British Columbia found passenger vehicles to be the largest contributor to transportation greenhouse gas emissions, at 39% of total transportation emissions (BC Ministry of Transportation 2011):

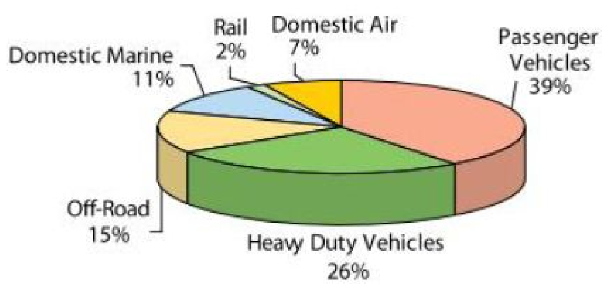

Figure 2: BC Transportation Greenhouse Gas Emissions (BC Ministry of Transportation 2011)

This is an important statistic because increasing the mode share of pedestrians and cyclists is assumed to decrease the amount of people travelling by motorized passenger vehicles, and therefore decrease greenhouse gas emissions. A safe and comfortable environment is critical to encourage cycling trips and will allow municipalities to reduce their carbon footprint, reduce their dependence on fossil fuels and lower greenhouse gas emissions (City of Vancouver 2012).

Economic Benefits

Studies show the economic benefits from bicycling to be substantial. The League of American Bicyclists estimates that bicycling makes up $133 billion of the US economy and funds up to 1.1 million jobs because of cycling's positive effect on tourism, business and environment. Local businesses profit from patrons that bike or walk to local stores, who tend to spend more money than people that drive because of their increased disposable income. For individuals, the cost of owning and operating a bicycle is estimated at only $150 per year, much lower and more accessible than the cost of owning and operating a private vehicle, which is $8,000 per year. For municipalities, it is less expensive to build and maintain bicycle infrastructure: studies show that shifting transportation modes from driving to walking is estimated to provide roadway facility and traffic service cost savings of 5 cents per mile of urban driving. Finally, encouraging bicycling creates livable communities, which increases housing value and attracts the younger creative class, giving cities a competitive edge nationally and diversifying the economic base (British Columbia Ministry of Transportation 2011).

Social Benefits

The ability to safely and conveniently bicycle or walk improves quality of life. This is especially true for people with limited access to a motor vehicle, such as youth, seniors and low-income residents. A bicycle-friendly municipality creates a stronger sense of community through increasing personal interaction, slowing down motorized vehicles and improving social capital (British Columbia Ministry of Transportation 2011). Studies show that cycling facilities contribute to the livability of a city (City of Vancouver 2012). Increasing the opportunities to cycle through building a safe and comfortable bicycling environment will create cities in which people prefer to live.

Public Health Benefits

As a form of exercise, bicycling reduces heart disease, obesity, high blood pressure, type 2 diabetes, osteoporosis and depression. When bicycling is available as a daily travel mode, substantial public health benefits can result, reducing the cost of spending on health care by over $500 per year (British Columbia Ministry of Transportation 2011). The ability to safety access destinations by bicycle, or to cycle for recreation, has implications for public health. The correlation between active transportation and obesity has been seen in countries around the world, with nations that have a greater mode share of pedestrians, cyclists and transit users also having lower obesity rates (Bassett et al 2008):

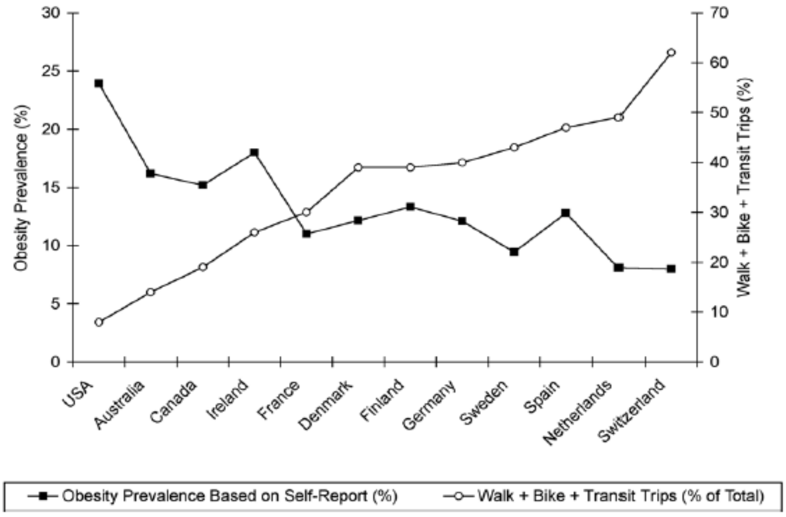

Figure 3: Correlation between active transportation and obesity (Bassett et al 2008)

Because of this correlation, improving the safety of cycling one method to encourage active transportation and improve public health. In fact, it is believed that the substantial health benefits received from cycling can offset the increase in collision risk because longevity is found to increase with active transportation (Victoria Transport Institute 2014). Public health improvements are important to increase both societal quality of life and wellbeing, and to profit from the economic benefits of proactively improving public health before problems occur.

Safety Benefits

Studies show that concern about safety is the greatest reason people to choose to not commute by bicycle. Real and perceived safety risks have an impact on how people travel, especially for minority population groups (Heinen 2011). There is a common perception that cycling is dangerous, especially in communities with a low cycling mode share. The top priority found in both recreational and commuting bicycle trips was safety (Karsch et al 2012):

Recreational trips (by order of preference)	Commuting trips (by order of preference)
1. Safety	1. Safety
2. Low traffic volume	2. Quick route
3. Smooth pavement	3. Direct route
4. Scenery	4. Smooth pavement
5. Slow traffic	5. Low traffic volume
6. Few stops	6. Slow traffic
7. Few hills	7. Convenient for errands and few hills

Figure 4: Preferences for Recreational and Commuting Trips (Karsch et al 2012)

When looking at statistics from the City of Vancouver, the importance of safety for vulnerable road users is evident. Between 2005 and 2010, vulnerable road users (pedestrians, bicyclists and motorcyclists) accounted for 3% of all reported collisions. During that same time period, vulnerable road users accounted for 59% of all collisions involving fatalities (City of Vancouver 2012):

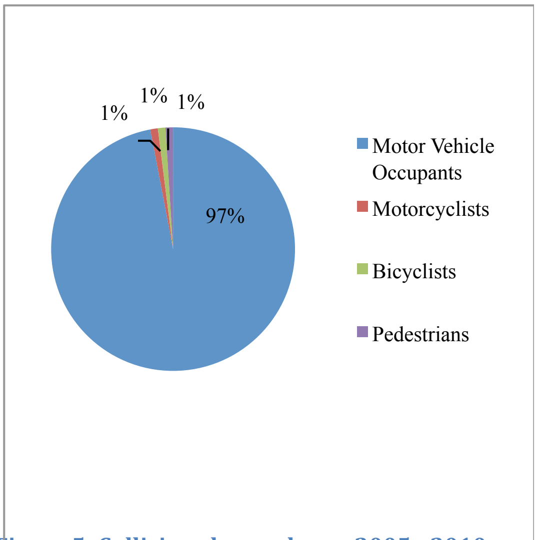

Figure 5: Collisions by road user 2005 - 2010 (City of Vancouver 2012)

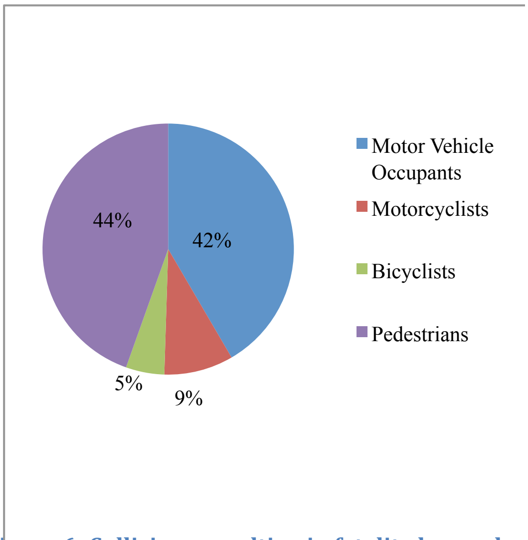

Figure 6: Collisions resulting in fatality by road user 2005 - 2010 (City of Vancouver 2012)

There is a huge discrepancy in how vulnerable road users are affected by road safety, making it clear why road safety is found to be the largest barrier to bicycle use.

The “safety in numbers” phenomenon suggests that bicycle collision rates decline as the proportion of bicyclists increases. Causation is likely to run both ways: safer cycling encourages more bicyclists and more bicyclists encourage greater investment in cycling safety. When plotting cycling fatality rates against bicycle mode share, it shows that cities with higher bicycle mode share also have the least fatalities (Pucher & Buehler 2011):

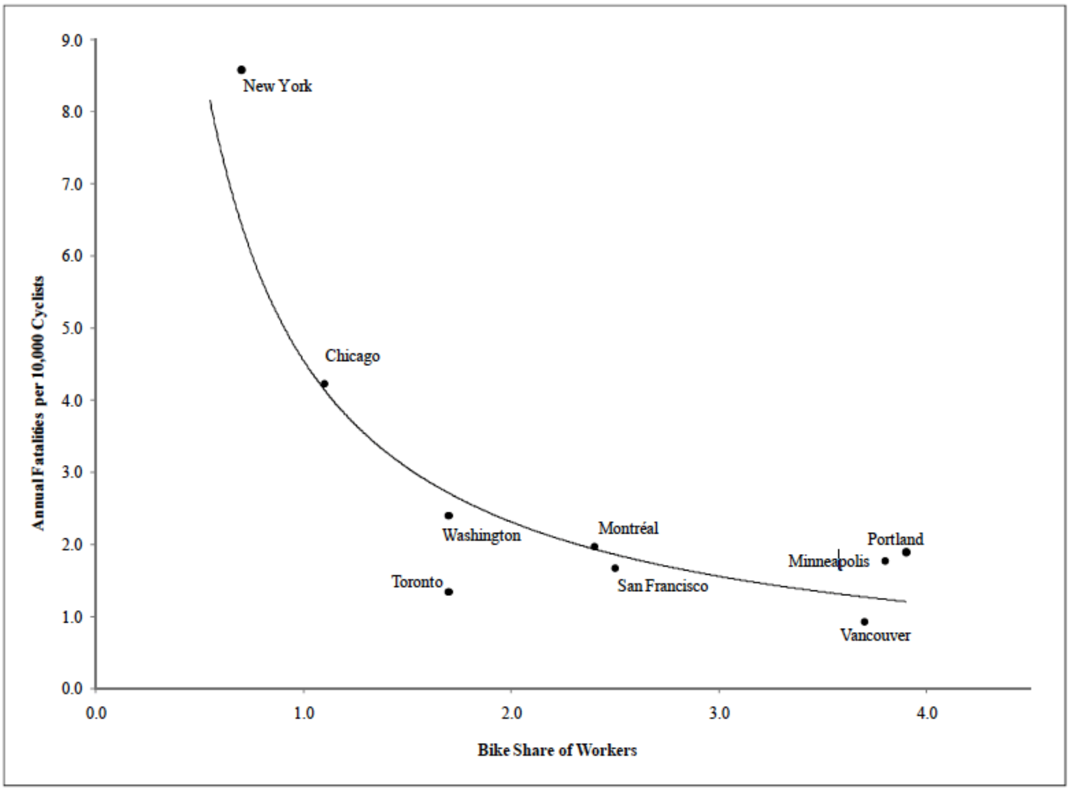

Figure 7: Average annual fatality per 10,000 cyclists v Bike share (Pucher & Buehler 2011)

The “safety in numbers” trend emphasizes the importance of increasing bicycle mode share by encouraging bicycling on bicyclist safety. This means that infrastructure needs to not only be safe, but be perceived as safe by the population to encourage all demographics and skill levels to cycle. Evidence shows safety in numbers from a case study in Portland, Oregon, shown on the next page. As levels of cycling increased, the injury and fatality rates per-trip and per-km travelled decreased (BC Ministry of Transportation 2011).

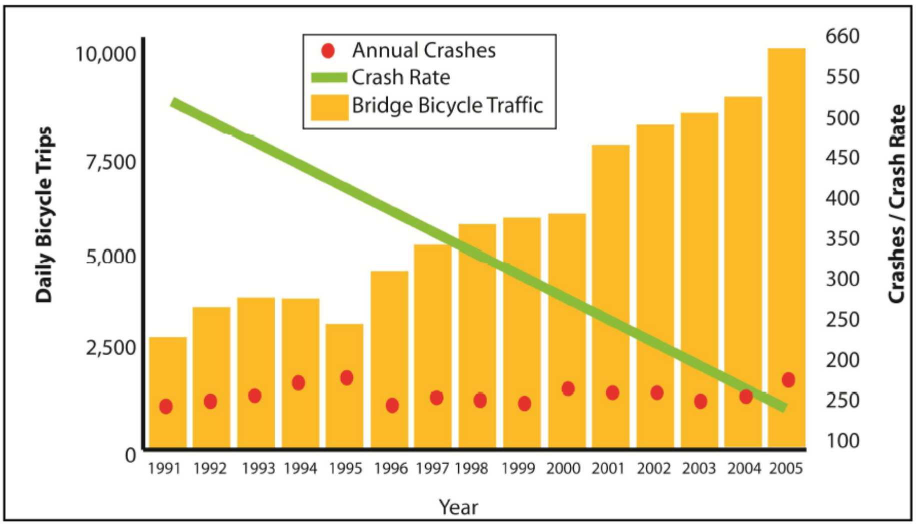

Figure 8: Relationship between cycling traffic levels and crash rates in Portland from 1991 to 2005 (BC Ministry of Transportation 2011)

The explanation for this phenomenon is that as drivers become more accustomed to bicyclists and bicycle infrastructure, they can predict cycling movement. Safety in numbers is justification to invest in bicycle facilities to improve safety, because there is a clear link between investing in bicycle infrastructure and increased bicycle usage. Cities have been successfully in increasing bicycle mode shares by providing safe, attractive and convenient bicycle infrastructure (British Columbia Ministry of Transportation 2011):

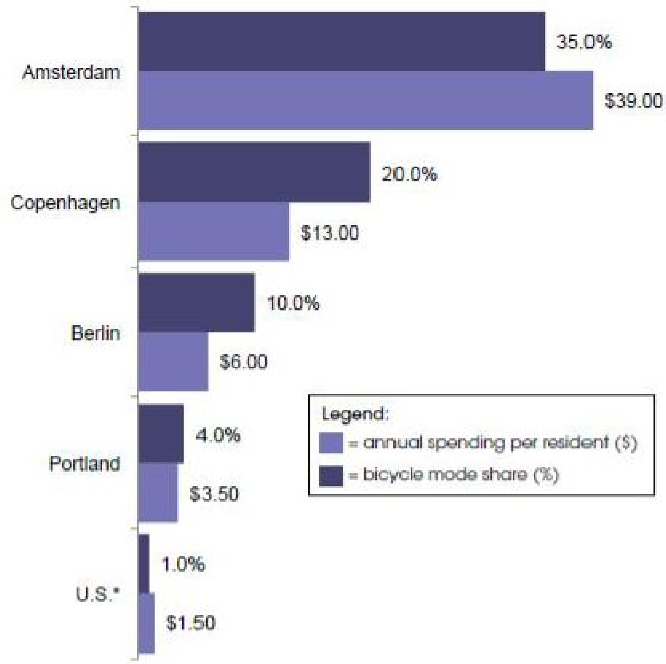

Figure 9: Link between investing in infrastructure and increased bicycle use (British Columbia Ministry of Transportation 2011)

The good news is that as more people cycle and more infrastructure is constructed, cycling has become statistically safer in both Canada and the US over the past twenty years. Bicycle collisions have decreased, while cycling levels have increased (Pucher & Buehler 2011):

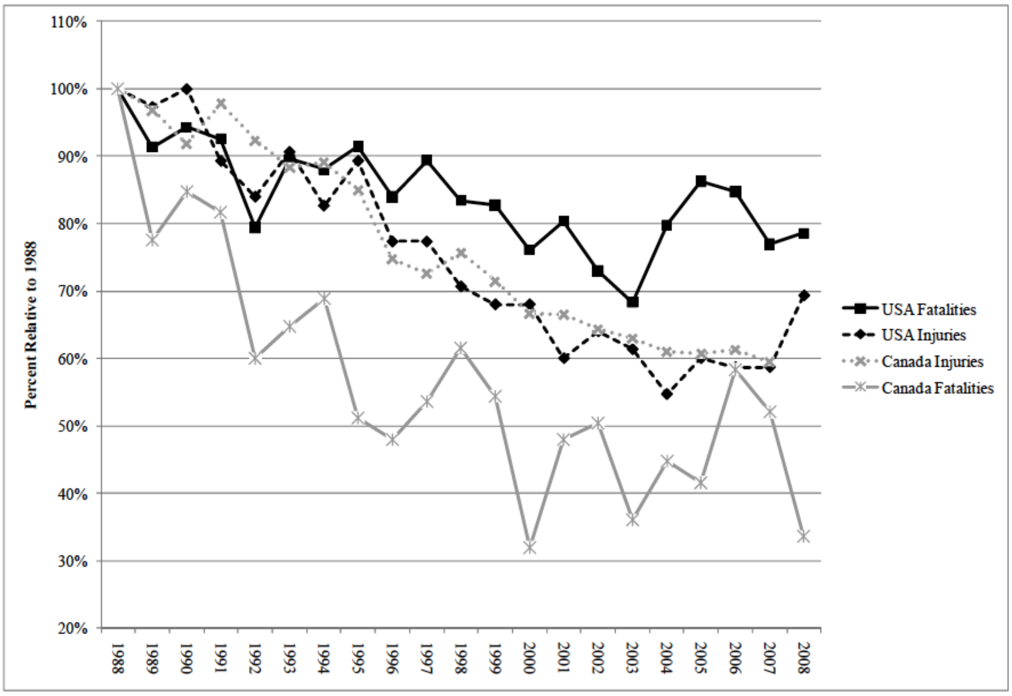

Figure 10: Cycling in Canada and the US has become safer over the past 20 years (Pucher & Buehler 2011)

The best way to improve the safety of bicycling is to improve infrastructure, which will encourage more people to shift their transportation mode to cycling.

Despite improvements, the lack of both substantive safety and perceived safety are still the largest barriers to bicycle use. Substantive safety refers to facility provision and design that will reduce the number of bicyclist injuries and fatalities (BC Ministry of Transportation 2011). Substantive safety is the effectiveness of bicycle infrastructure treatments, and can be determined by calculating Collision Modification Factors (CMFs) and Collision Reduction Factors (CRFs). A CMF is a multiplication factor that reflects the expected change in safety that is associated with the corresponding change in bicycle infrastructure (Sayed & de Leur 2008). A CRF is the reduction of collisions expected from the implementation of the bicycle infrastructure, and is represented by 1 - CMF. For the purpose of this study, CMFs and CRFs were found through a literature review and were used to determine the substantive safety of six alternate types of bicycle infrastructure. Perceived safety measures bicyclists' reported level of comfort and can greatly influence bicycle use.

For the purpose of this study, the perception of safety was considered through the review of a population-based survey of current and potential adult cyclists using a web/mail self-administered questionnaire (Winters & Teschke 2014). Both substantive safety and perceived safety need to be improved to increase bicycle mode share.

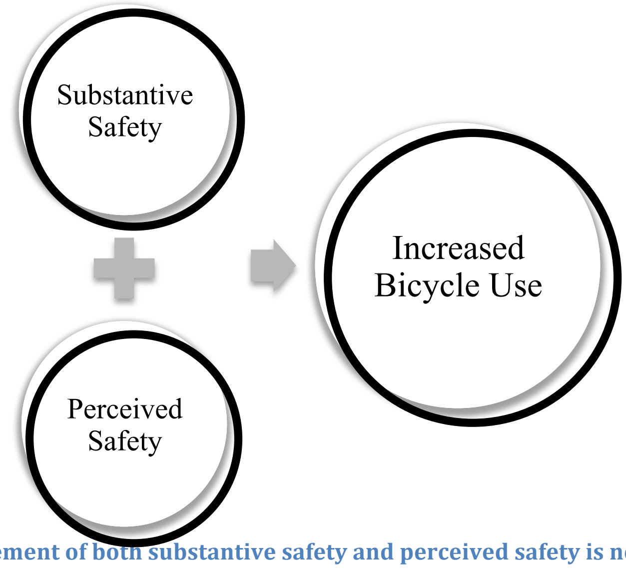

Figure 11: An improvement of both substantive safety and perceived safety is needed to increase bicycle use

Cost of Collisions and Infrastructure

A comprehensive review of the cost-effectiveness of different engineering treatments to improve bicycle safety is important when determining the optimal cycling treatments. In addition, the costs associated with fatalities, injuries and property damage from unsafe transportation environments needs to be considered. The annual cost of collisions in Canada is estimated at $62.7 billion, much higher than the $3.7 billion annual cost of traffic congestion in Canada. The economic and social costs associated with road collisions are greater than other mobility costs because of the pain, grief, property damage, injuries and deaths. The increased mobility over the past century has resulted in huge safety and economic costs. In addition, sustainable modes of travel such as cycling suffer a higher level of collision risks because of higher vulnerability. Approximately 22% of fatal road collisions in Canada and 30% of fatal road collisions in BC involve vulnerable road users (City of Vancouver 2012).

To calculate the cost of collisions, both market and non-market costs are typically considered. Market costs include medical care, administrative costs, lost earning and productivity and lost productivity from injury. Non-market costs are more difficult to estimate because it is difficult to put a dollar value on human life, disability from injury, suffering or grief. Non-market costs are commonly determined through willingness to pay, reflected by people's willingness to pay for increased safety and a reduction in collision risk. This method is currently used by most road agencies to evaluate road safety programs to evaluate the true cost to society of collisions. A report published by the Transportation Association of Canada attempts to measure the non-market costs such as the cost of death, injury and disability (City of Vancouver 2012):

Type of effect	Value by type of effect by scenario:		
	Upper bound	Lower bound	Mean value
Death	$19.7 million	$7.5 million	$13.6 million
Activity day used for short-term disabling injury below	$2,885	$577	$1,730
Per major injury	$215,510	$43,102	$129,231
Per minor injury	$43,275	$8,655	$25,950
Per minimal injury	$2,308	$462	$1,384
Partial disability	$1,201,977	$240,395	$721,186
Total disability	$2,403,954	$480,790	$1,442,372

Figure 12: Non-market costs of collisions (City of Vancouver 2012)

It is important to understand the importance of the cost of collisions because policy and infrastructure improvement decisions that involve tradeoffs between monetary costs and safety risks need to be made by governments. This study did not calculate the cost of collisions associated with each separate bicycle infrastructure treatment due to a lack of data. However, the importance of cost of collisions and safety was shown in the analysis by giving treatment effectiveness a heavier weight than the cost of infrastructure.

Estimating the typical infrastructure costs associated with non-motorized transportation is much easier to calculate from a literature and policy review. Comparing the cost of collisions to the relatively low cost of infrastructure, it is evident that there is a large benefit from investing in bicycle infrastructure. Looking only at infrastructure costs, shifting transportation modes from car to active transportation is expected to produce cost savings in roadway infrastructure and traffic services of 3 cents/km for urban driving and 2 cents/km for rural driving

(Transport Canada 2011). The following table estimates the average costs of bicycle infrastructure:

Table 1 Estimated Average Cost of Bicycle Infrastructure

	Cost	Source
Off-Street Pathway	Boardwalk US$ 3,570,000/km; Paved US$ 774,000/km; Unpaved US$ 195,000/km	Bushell et al 2013
Cycle Tracks	US$ 870,000/km	Bushell et al 2013
Bicycle Lanes	US$ 18,000/km if no road widening necessary	Transport Canada 2011
Neighbourhood Bikeways	Traffic circle US$ 85,000 each; Speed bump US$ 1,550 each	Bushell et al 2013
Marked Curb Lanes	Bicycle marking cost: US$ 180 each	Bushell et al 2013
Shoulder Bikeways	US$ 6,400/km	Bushell et al 2013
Signage	US$ 300 each	Bushell et al 2013

These costs were used to determine the relative cost score for each different type of bicycle infrastructure in the next section.

Infrastructure Analysis

To calculate the optimal investment for cycling infrastructure, the relative cost was combined with the safety effectiveness of each type of infrastructure treatment. The investment scores were calculated for the most common bicycle infrastructure treatments in North America: off-street pathways, cycle tracks, neighbourhood bikeways, marked curb lanes and shoulder bikeways. The investment scores were used to rank the bicycle infrastructure to determine the optimal investment based its substantive safety and costs.

Figure 13: Infrastructure Analysis

For the purpose of this project, the relative effectiveness and relative cost of each bicycle infrastructure treatment was given a score, which was used to rank the infrastructure and find the optimal bicycle infrastructure investment. The infrastructure cost score was determined based on a literature review of the average costs of bicycle infrastructure, and the infrastructure effectiveness score was specified based on the observed Collision Modification Factors (CMFs) and Collision Reduction Factors (CRFs) found in the literature. A CMF demonstrates the expected change in safety performance associated with the corresponding change in bicycle infrastructure (Sayed & de Leur 2008), while a CRF is the expected reduction in collisions, or 1 – CMF. The perceived safety found to be associated with each infrastructure treatment was also considered as an important factor, but was not calculated as part of the analysis because it is difficult to quantify. Finally, the investment score for each bicycle infrastructure treatment was calculated through a benefit cost ratio and the infrastructure treatments were ranked based on their scores.

To determine the cost-effectiveness score, the costs of each bicycle infrastructure was calculated for a potential case study using the infrastructure costs found in the literature. The data was converted into US dollars per kilometer, and the cost of each type of bicycle infrastructure treatment was calculated for a distance of 1 km. Signage was also added to each section, using an assumption of 24 signs per kilometer (one sign per block, 12 blocks per kilometer and signs in each direction of travel). The cost was then given a score from one to ten, with each infrastructure given a score proportionally to the highest cost, which was automatically scored 10 (see Table 2). The square root of the cost was also taken when converting the costs into scores, to give the relative cost score less power in the final investment score. The rational for taking the square root in the quantitative analysis is to give the safety effectiveness of the infrastructure more weight in the scoring system. The reasons for this were: the study was unable to calculate the cost of bicycle collisions and factor it into the analysis due to lack of data; and, when choosing the optimal bicycle infrastructure, safety should be much more heavily weighted than infrastructure cost to prevent future collisions their related future costs.

For calculating the relative effectiveness score, the study focused on the hard data of Collision Reduction Factors (CRFs) and excluded perceived safety from the ranking analysis. It is difficult to rank based on perceived safety, so instead the potential for bicycle collision reduction through CRFs found in the literature were used. For neighbourhood bikeways, marked curb lanes and shoulder bikeways, there were no CMFs or CRFs existing in the literature, so they were logically assigned smaller collision reduction scores based on their perceived safety. Neighbourhood bikeways were given a CRF score of a 10% reduction in collisions because traffic calming measures result in bicyclists perceiving this infrastructure as safe but bicyclists still have to share the road with local low-volume traffic. Marked curb lanes and shoulder bikeways were given the lowest score (CRF score of a 1% reduction in collisions) because even though signage may increase the visibility of bicyclists, they are still required to share the road with high-volume traffic. This study identified the need for further studies on the substantive safety and potential for collision reduction of these types of infrastructure.

Finally, an investment score was calculated for each type of bicycle infrastructure treatment by taking a benefit cost ratio. The relative effectiveness score was multiplied by a factor of 10 to give the score (and safety) more importance, and then divided by the relative cost score. The resulting investment scores showed the most optimal investment to be bike lanes due to their low cost and high effectiveness. The quantitative analysis and scoring system is shown in the table below. The following sections go into further depth about the different infrastructure types and the ranking analysis.

Table 2: Results of infrastructure analysis to calculate the optimal bicycle infrastructure treatment

	Infrastructure	**Cost for 1 km (US$)**	**Relative Cost Score**	**CRF**	**Relative Effectiveness Score**	**Investment Score**
1	Bike Lanes	25,200	1.69	0.35	5.56	**32.78**
2	Paved Off-Street Pathway	78,1200	9.44	0.63	10.00	**10.60**
3	Cycle Tracks	877,200	10.00	0.13	2.06	**2.06**
4	Neighbourhood Bikeways	545,100	7.88	0.1	1.59	**2.01**
5	Shoulder Bikeways	13,600	1.25	0.01	0.16	**1.27**
6	Marked Curb Lanes	15,840	1.34	0.01	0.16	**1.18**

Off-Street Pathways

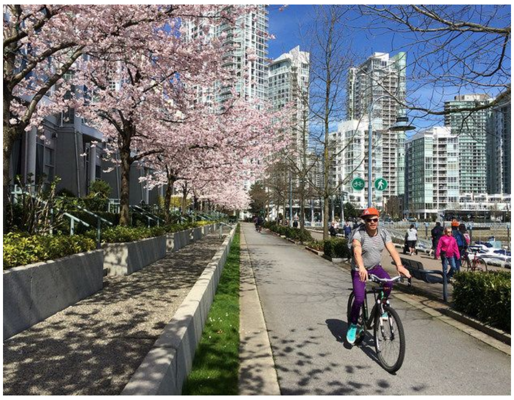


Figure 14: Off-street pathways

Off-street pathways are physically separated from motor vehicles and provide sufficient width and supporting facilities to be used by pedestrians, cyclists and other non-motorized users. They can be reserved exclusively for the use of cyclists or can accommodate multiple users. Off-street pathways include boardwalks, paved and unpaved paths, and their costs vary based on existing site conditions. This type of infrastructure is typically found along an existing corridor or natural feature. Since the corridor is separated form motor vehicles, they increase user safety and comfort and have no impact on road operations (BC Ministry of Transportation 2011).

Relative Cost Score: High (9.44)

Table 3: Off-Street Pathway Infrastructure Costs

Infrastructure	Cost
Boardwalk	US$ 3,570,000/km
Paved Off-street Pathway	**US$ 774,000/km**
Unpaved Off-street Pathway	US$ 195,000/km
Signage	**US$ 300 each**

To calculate the relative cost score for the purpose of this analysis, the paved off-street pathway cost was used from Table 3 because it was the median value of US$ 774,000 per km. In addition, 24 signs were added into this value, with the assumption that there would be about 12 signs per km in each direction (with one sign per typical 80 meter street block). The cost of a paved off-street pathway for one kilometer was found to be US$ 781,200, which was then converted to a relative cost score of 9.44, using a ten-point scale and taking a square root of the cost to lower its power over the final investment score (see Table 2).

Relative Effectiveness Score: High (10)

Substantive Safety

Installing a bicycle boulevard was found to have a Collision Modification Factor (CMF) of 0.37, and a Collision Reduction Factor (CRF) of 63% (Minikel 2011). The relative effectiveness score was taken using the CRF of 63% and converting it to a ten-point scale (see Table 2). Since it was the highest CRF, the relative effectiveness score of 10 was automatically assigned.

Perceived Safety

A published population-based survey of current and potential adult cyclists found that 82% of surveyed participants were likely to choose paved off-street cycle paths for bicycle only, 78% were likely to choose paved multi-use paths and 69% were likely to choose unpaved multi-use paths (Winters & Teschke 2014). This information is important to take into account when choosing the optimal bicycle infrastructure, but was not used in the analysis.

Investment Score: 10.60

To calculate the investment score, a benefit cost ratio of the relative effectiveness score over the relative cost score was calculated. The effectiveness score was multiplied by a factor of ten to give it more importance in the analysis, as explained above (see Table 2). Paved off-street bike pathways were found to have an investment score of 10.60 due to their high potential for collision reduction, putting them second on the ranking scale.

Cycle Tracks

 

Figure 15: Cycle tracks

Cycle tracks are physically separated from motor vehicles and located within the road right of way. This infrastructure combines the separated experience of an off-street pathway with the on-street utility of a conventional bicycle lane. The separation from traffic increases safety and ridership if the cycle tracks are properly designed, and are safe and comfortable for all skill levels. Cycle tracks have limited impact on road operations (except for at driveways and intersections) and they require separate maintenance (BC Ministry of Transportation 2011).

Relative Cost Score: High (10)

Table 4: Cycle Tracks Infrastructure Costs

Infrastructure	Cost
Cycle Track	US$ 870,000/km
Signage	US$ 300 each

To calculate the relative cost score for this analysis, the cost of cycle track per kilometer from Table 4 was added to 24 signs, with the assumption that there would be about 12 signs per km in each direction (with one sign per typical 80 meter street block). The cost of a cycle track for one kilometer was found to be US$ 877,200, which was then converted to a relative cost score of 10.00, using a ten-point scale and taking a square root of the cost to lower its power over the final investment score (see Table 2). Since it was the highest cost of infrastructure, the relative cost score of 10 was automatically assigned.

Relative Effectiveness Score: Medium-Low (2.06)

Substantive Safety

Installing cycle tracks in urban areas was found to have a CMF of 0.87, with a CRF of 13% (Jenson 2008). Two-way cycle tracks were found to produce a 28% reduction in injury risk by Lusk (2011). The relative effectiveness score was taken using the CRF of 13%, for a one-way cycle track, and converting it to a ten-point scale (see Table 2), resulting in a medium-low relative effectiveness score of 2.06.

Perceived Safety

A published population-based survey of current and potential adult cyclists found that 68% of surveyed participants were likely to choose cycle paths by major streets separated by barriers (Winters & Teschke 2014). This information is important to consider when choosing the optimal bicycle infrastructure, but was not used in the analysis.

Investment Score: 2.06

To calculate the investment score, a benefit cost ratio of the relative effectiveness score over the relative cost score was calculated. The effectiveness score was multiplied by a factor of ten to give it more importance in the analysis, as explained above (see Table 2). Cycle tracks were found to have an investment score of 2.06 despite their high costs due to their high potential for collision reduction, putting them third on the ranking scale.

Bicycle Lanes

Figure 16: Bike lanes

Bike lanes are separate lanes that are designed exclusively for bicycle travel through pavement markings. They are typically used on streets with higher traffic volume and speeds, thus indicating the need for greater separation. Bike lanes require little right-of-way, increase cyclist visibility and are relatively low cost to build and maintain. They are the most suitable for commuters and experienced cyclists because they are not separated but provide direct routes to destinations (BC Ministry of Transportation 2011).

Relative Cost Score: Low (1.69)

Table 5: Bike Lanes Infrastructure Costs

Infrastructure	Cost
Bicycle Lane	US$ 18,000/km if no road widening necessary
Signage	US$ 300 each

To calculate the relative cost score for this analysis, the cost of bicycle lane per kilometer from Table 5 was added to 24 signs, with the assumption that there would be about 12 signs per km in each direction (with one sign per typical 80 meter street block). The cost of a bicycle lane for one kilometer was found to be US$ 25,200, which was then converted to a relative cost score of 1.69, using a ten-point scale and taking a square root of the cost to lower its power over the final investment score (see Table 2).

Relative Effectiveness Score: Medium-High (5.56)

Substantive Safety

Providing bicycle lanes were found to have a CMF of 0.65 and a CRF of 35% by Rodergerdts et al. (2004). A comparison of collision frequency on roads with and without bike lanes, adjusting for neutral collisions, estimated that bike lanes reduced collision frequency by 53% (Reynolds et al. 2009). The relative effectiveness score was taken using the CRF of 35%, for a one-way cycle track, and converting it to a ten-point scale (see Table 2), resulting in a moderate relative effectiveness score of 5.56.

Perceived Safety

A published population-based survey of current and potential adult cyclists found that 52% of surveyed participants were likely to choose major streets with bike lanes and no parked cars and 40% were likely to choose major city streets with bike lanes and parked cars (Winters & Teschke 2014). This information is important to take into account when considering bicycle infrastructure, but was not used in the analysis.

Investment Score: 32.78

To calculate the investment score, a benefit cost ratio of the relative effectiveness score over the relative cost score was calculated. The effectiveness score was multiplied by a factor of ten to give it more importance in the analysis, as explained above (see Table 2). Bike lanes had the largest investment score of 32.78, due to their low costs and high potential to reduce collisions.

Neighbourhood Bikeways

Figure 17: Neighbourhood bikeway

Neighbourhood bikeways are routes that are traffic calmed to have low vehicle speeds and volumes, and are ideal for local streets. This type of facility includes a range of treatments, such as traffic calming, pavement markings and signage. The treatments improve the safety for cyclists and all other road users, and can also improve aesthetics in a neighbourhood. Cost for this type of bicycle infrastructure can vary depending on the quantity and intensity of the treatment. The safety benefits are dependent on motor vehicles complying with traffic calming, since bicyclists are integrated with the local motor vehicle traffic. Neighbourhood bikeways are appealing to most cyclists regardless of their cycling level (BC Ministry of Transportation 2011).

Relative Cost Score: Medium-High (7.88)

Table 6: Neighbourhood Bikeway Infrastructure Costs

Infrastructure	Cost
Traffic Circle	US$ 85,000 each
Speed bump	US$ 1,550 each
Signage	US$ 300 each

To calculate the relative cost score for this analysis, the cost of a neighbourhood bikeway per kilometer was calculated by adding 24 signs, with the assumption that there would be about 12 signs per km in each direction (with one sign per typical 80 meter street block); 6 traffic circles, with the assumption that there would be about one traffic circle for per every two typical 80 meter street blocks; and 18 speed bumps, with the assumption that there would be about three speed bumps for six blocks on average. The cost of a neighbourhood bikeway for one kilometer was found to be US$ 545,100, which was then converted to a relative cost score of 7.88 using a ten-point scale and taking a square root of the cost to lower its power over the final investment score (see Table 2).

Relative Effectiveness Score: Medium-Low (1.59)

Substantive Safety

An installation of a speed reducing measure on a main road was found to have a CMF of 1.28 and a CRF of -28& (Schepers et al. 2011), however this study did not look at low traffic volume roads and therefore was not an accurate representation. There are currently gaps in the literature to determine the effectiveness of neighbourhood bikeways. The relative effectiveness score was taken using an estimated CRF of 10%, and converting it to a ten-point scale (see Table 2), resulting in a moderate to low relative effectiveness score of 1.59. Neighbourhood bikeways were given a CRF score of a 10% potential reduction in collisions because research of perceived safety shows that traffic calming caused bicyclists to perceive this infrastructure as safe, but bicyclists still had to share the road with local low-volume traffic.

Perceived Safety

A published population-based survey of current and potential adult cyclists found that 66% of surveyed participants were likely to choose residential bike routes with traffic calming (Winters & Teschke 2014). This information is important to take into account when considering bicycle infrastructure, because there were no studies analyzing the substantive safety of neighbourhood bikeways.

Investment Score: 2.01

To calculate the investment score, a benefit cost ratio of the relative effectiveness score over the relative cost score was calculated. The effectiveness score was multiplied by a factor of ten to give it more importance in the analysis, as explained above (see Table 2). Neighbourhood bikeways were found to have an investment score of 2.01 despite their high costs due to their high observed perceived safety value, putting them fourth on the ranking scale.

Marked Curb Lanes

Figure 18: Marked curb lane

Marked curb lanes, sometimes referred to as "sharrows," provide direct routes for experience cyclists along the outer lane of a roadway. They are low cost to implement and maintain, since the only infrastructure required is signage and pavement markings. Marked curb lanes are ideal for arterial streets that have limited right of way. This bicycle infrastructure is most suitable for commuters and experienced riders, and can be uncomfortable for inexperienced cyclists that do not feel safe riding in motor vehicle traffic (BC Ministry of Transportation 2011).

Relative Cost Score: Low (1.34)

Table 7: Marked Curb Lane Infrastructure Costs

Infrastructure	Cost
Bicycle Marking Cost	US$ 180 each
Signage	US$ 300 each

To calculate the relative cost score for this analysis, the cost of a marked curb lane per kilometer was calculated by adding 24 signs, with the assumption that there would be about 12 signs per km in each direction (with one sign per typical 80 meter street block); and 48 bicycle markings, with the assumption that there would be about four bicycle markings per typical 80 meter street block. The cost of a marked curb lane for one kilometer was found to be US$ 15,840, which was then converted to a relative cost score of 1.34 using a ten-point scale and taking a square root of the cost to lower its power over the final investment score (see Table 2).

Relative Effectiveness Score: Low (0.16)

Substantive Safety

“Sharrows” are not fully studied and there is no research their CMFs, however it is accepted in practice that they do reduce collisions (Oregon Department of Transportation 2012). Marked curb lanes need to be studied further, because they are widely used but there are currently gaps in the literature to determine their effectiveness. The relative effectiveness score was taken using an estimated CRF of 1%, and converting it to a ten-point scale (see Table 2), resulting in a low relative effectiveness score of 0.16. Marked curb lanes were given a CRF score of a 1% reduction in collisions because even though signage may increase the visibility of bicyclists, research of perceived safety showed that bicyclists do not find this type of bicycle infrastructure safe, as they are still required to share the road with high-volume traffic.

Perceived Safety

A published population-based survey of current and potential adult cyclists found that 47% of surveyed participants were likely to choose major city streets with bike symbols and no parked cars and 35% were likely to choose paved major city streets with bike symbols and parked cars (Winters & Teschke 2014). This information is important to take into account when considering bicycle infrastructure, because there were no studies analyzing the substantive safety of marked curb lanes.

Investment Score: 1.18

To calculate the investment score, a benefit cost ratio of the relative effectiveness score over the relative cost score was calculated. The effectiveness score was multiplied by a factor of ten to give it more importance in the analysis, as explained above (see Table 2). Marked curb lanes were found to have an investment score of 1.18 due to their low observed perceived safety value, putting them sixth and last on the ranking scale.

Shoulder Bikeways

Figure 19: Shoulder bikeway

Shoulder bikeways can typically be found on streets without curbs and gutters with shoulders wide enough for bicycle travel. Shoulder bikeways increase the visibility of bicyclists because they often include signage alerting motorists to expect bicycle travel along the roadway. This infrastructure treatment is low cost to build and maintain, requires little right of way and is ideal for use along rural collectors and arterial streets. Shoulder bikeways are suitable for commuters and more experienced cyclists because they increase visibility and provide direct routes. However, beginner cyclists will feel unsafe and uncomfortable on this type of road.

Relative Cost Score: Low (1.25)

Table 8: Shoulder Bikeway Infrastructure Costs

Infrastructure	Cost
Curb	US$ 6,400/km
Signage	US$ 300 each

To calculate the relative cost score for this analysis, the cost of shoulder bikeway per kilometer from Table 8 was added to 24 signs, with the assumption that there would be about 12 signs per km in each direction (with one sign per typical 80 meter street block). The cost of a shoulder bikeway for one kilometer was found to be US$ 13,600, which was then converted to a relative cost score of 1.25, using a ten-point scale and taking a square root of the cost to lower its power over the final investment score (see Table 2).

Relative Effectiveness Score: Low (0.16)

Substantive Safety

Shoulder bikeways are not fully studied and there are no existing CMFs for this type of infrastructure, however the increased visibility of bicyclists through signage reduces collisions. Shoulder bikeways need to be studied further, because there are currently gaps in the literature to determine their effectiveness. The relative effectiveness score was taken using an estimated CRF of 1%, and converting it to a ten-point scale (see Table 2), resulting in a low relative effectiveness score of 0.16. Shoulder bikeways were given a CRF score of a 1% reduction in collisions because even though signage may increase the visibility of bicyclists, research of perceived safety showed that bicyclists do not find this type of bicycle infrastructure safe, as they are still required to share the road with high-volume traffic.

Perceived Safety

A published population-based survey of current and potential adult cyclists found that 31% of surveyed participants were likely to choose rural roads with paved shoulders (Winters & Teschke 2014). This information is important to take into account when considering bicycle infrastructure, because there were no studies analyzing the substantive safety of shoulder bikeways.

Investment Score: 1.27

To calculate the investment score, a benefit cost ratio of the relative effectiveness score over the relative cost score was calculated. The effectiveness score was multiplied by a factor of ten to give it more importance in the analysis, as explained above (see Table 2). Shoulder bikeways were found to have an investment score of 1.27 due to their low observed perceived safety value, putting them fifth on the ranking scale.

Conclusions and Action Plan

Table 9: Final Ranking of Bicycle Infrastructure

Rank	Infrastructure	Relative Cost	Relative Effectiveness	Investment Score
1	**Bicycle Lanes**	Low (1.69)	Medium-High (5.56)	**32.78**
2	**Paved Off-Street Pathway**	High (9.44)	High (10.00)	**10.60**
3	**Cycle Tracks**	High (10.00)	Medium-Low (2.06)	**2.06**
4	**Neighbourhood Bikeways**	Medium-High (7.88)	Medium-Low (1.59)	**2.01**
5	**Shoulder Bikeways**	Low (1.25)	Low (0.16)	**1.27**
6	**Marked Curb Lane**	Low (1.34)	Low (0.16)	**1.18**

The results show the ranking of cycling treatments from the most cost-effective to the least taking into account the safety treatment effectiveness. The highest ranked infrastructure, bike lanes, had medium to high treatment effectiveness and lower costs. In this ranking method the relative effectiveness was given a higher power than the relative cost by multiplying it by a factor of ten before calculating the benefit cost ratio of the relative effectiveness score over the relative cost score. This was important to the analysis, because the safety of infrastructure should have more weight than the cost due to the importance of reducing collisions and the high cost associated with potential collisions. Since all scores are above one, all the treatments were found to be cost-effective in increasing bicycle safety. It is important to note that there are large differences observed throughout the top scores.

This simple ranking method has some limitations. There was a lack of data in the literature for the potential for collision reduction associated with neighbourhood bikeways, shoulder bikeways and marked curb lanes, so further study is needed to create a more robust analysis. In addition, it was difficult to complete an accurate analysis without first calculating the cost of collisions associated with each type of bicycle infrastructure treatment, and inputting that into the relative cost score. This was corrected through giving the treatment effectiveness score a higher weight in the analysis, but calculating the cost of collisions would help create more accurate results.

In reality, the optimal bicycle infrastructure treatment should be most dependent on the type of bicycle rider targeted (beginner or commuter) and the existing built environment. Whether a bike lane or paved off-street pathway, the two top-ranked infrastructure types, is considered, the optimal bicycle infrastructure investment will depend on the built environment, amount of traffic flow and level of cyclist. Therefore, choosing the most appropriate cycling infrastructure should be a site-specific and objective process.

In this study, the rankings were completed through primarily looking at the substantive and perceived bicyclist safety and the costs of bicycle infrastructure. Further considerations for facility selection should include:

- Motor vehicle speed and volume, as different types of facilities are appropriate for different roadway settings.
- Roadway width, since it is most cost-effective to not widen roads the available right of way will influence the type of bicycle facility that can be considered.
- The skills, needs and preferences of bicycle users.
- The turnover and density of on street parking, which can affect bicycle safety.
- Truck and bus traffic can cause unique problems for cyclists.
- Specific conflict points, such as intersections, need to be given special attention because high percentages of collisions typically occur in these areas.
- Aesthetics is an important consideration, particularly for recreational facilities.
- Funding availability can limit infrastructure alternatives, but a lack of funds should not result in a poorly designed or constructed facility.

- Designs that facilitate and simplify maintenance will improve the safety and use of a facility.
- The existing land use and urban context in an area will influence the best infrastructure alternative (BC Ministry of Transportation 2011).

An example of planning for specific sites is a guide from Denmark, which outlines the best bicycle facility for different levels of traffic volume and traffic speed (OECD International Transport Forum 2013):

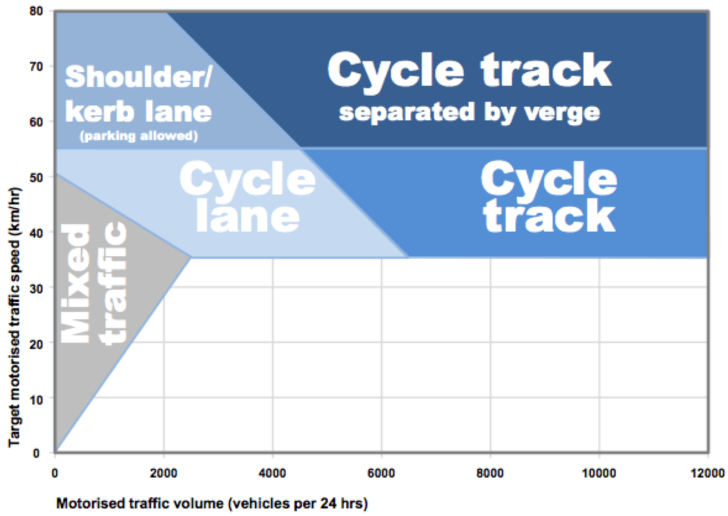

Figure 20: Site specific planning of bicycle facilities (OECD International Transport Forum 2013)

To encourage a shift in mode share towards cycling, there must be an understanding of what type of bicycle infrastructure the public would like to use. Surveys have found that there is currently a disconnection between the bicycle infrastructure being built and what bicyclists want or perceive as safe and are likely to choose (Winters & Teschke 2014):

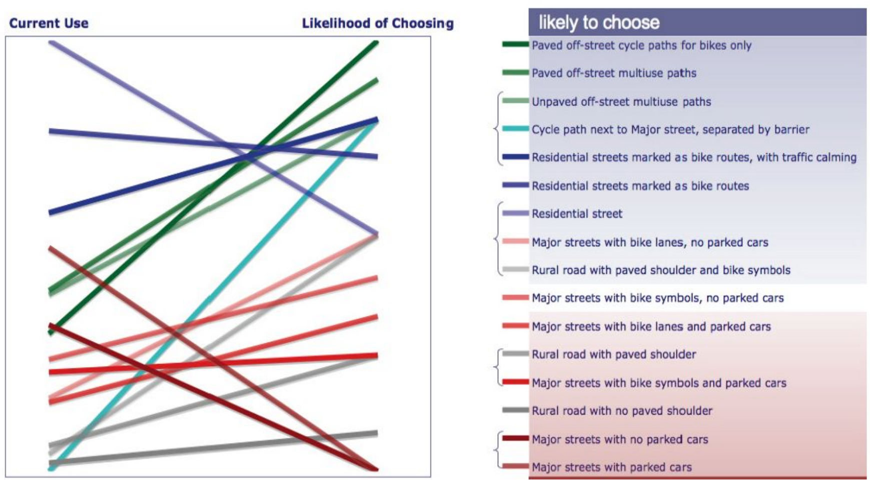

Figure 21: The current construction of infrastructure compared to the likelihood of choosing infrastructure (Winters & Teschke 2014)

The type of bicycle infrastructure is important for encouraging cycling and improving the perception of safety. The top motivators and deterrents for cycling were found to be within the "Engineering" and "Environment" categories. "Education" and "Encouragement" were moderate motivators, and "Enforcement" factors were found to have neutral influence, from 73 different factors:

- Engineering (n=32)
- Education (n=5)
- Enforcement (n=4)
- Encouragement (n=12)
- Environment (n=20)

The type of bicycle user also matters, as regular, occasional and potential cyclists were found to have different preferences and likelihoods of choosing a particular infrastructure type, although the relationship is linear (Winters & Teschke 2014):

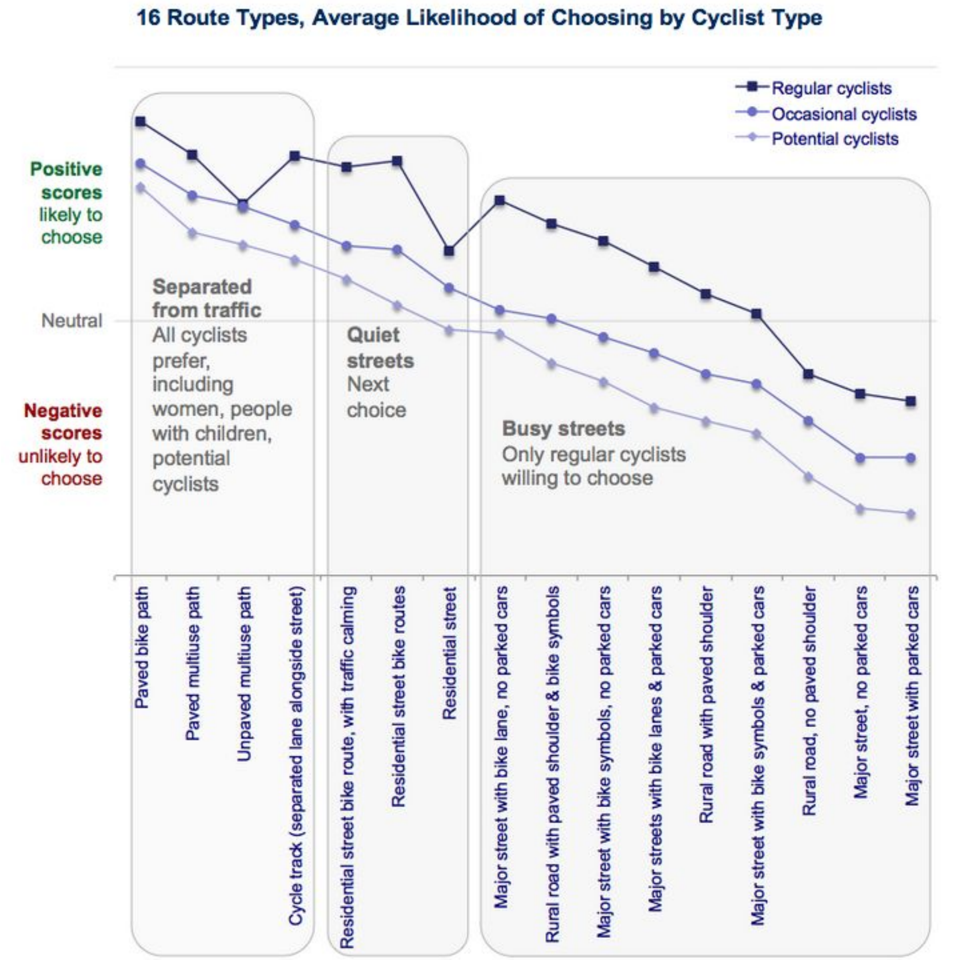

Figure 22: Average likelihood of choosing by cyclists type (Winters & Teschke 2014)

The perception of bicycle safety is closely tied to the severity of consequence, explaining why bicyclists are found to have much higher risk perception for on-street facilities and lower risk perception for multi-use paths away from traffic. A comparison shows the difference between observed relative risk and perceived risk of specific infrastructure (Winters et al 2012):

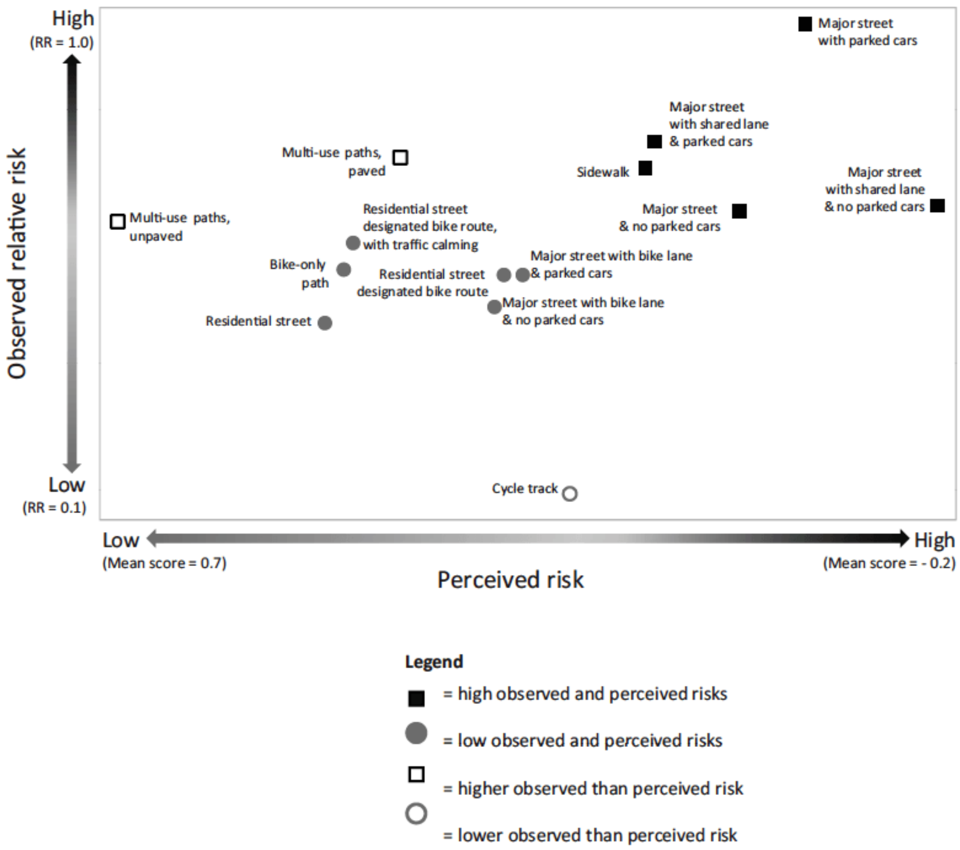

Figure 23: Observed relative risk v. perceived risk for different bicycle facilities (Winters et al. 2012)

It is interesting to note the high perceived risk of cycle tracks compared to their actual relative risk, since they are often found on high-volume roads. It is necessary to improve bicyclist knowledge about the comparative risk of infrastructure types.

In conclusion, the improvement of cyclist safety requires the cooperation, involvement and coordination of a large number of agencies involved in cyclist infrastructure, services, operations and enforcement. Policies, programs and facilities will ultimately make a community bicycle friendly. Practitioners need to consider the following to create a comprehensive and safe bicycle plan:

- Engineering: the design, implementation and maintenance of bicycle facilities and how they fit into the broader transportation system.
- Education: the teaching and training programs for cyclists and motorists.
- Encouragement: the promotion of cycling through participatory events.
- Enforcement: the regulatory laws in regards to bicycle and vehicle road use and sharing the road.

- Evaluation: the confirmation that policies, programs and facilities meet the intended outcomes.

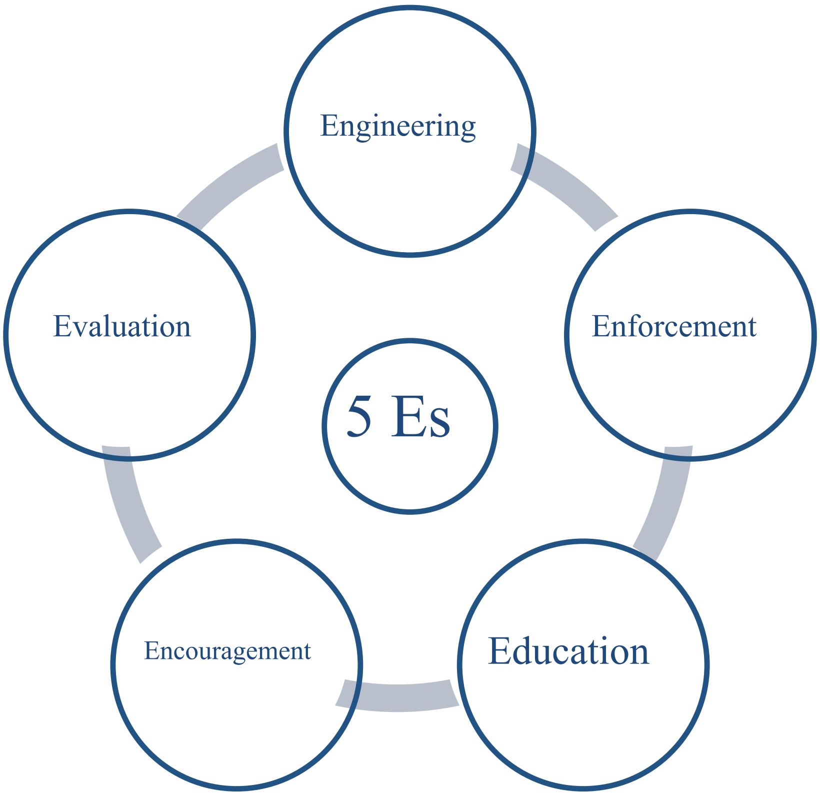

Figure 24: Five E's for a comprehensive bicycle planning framework

This study focuses on the “Engineering” factor to improve the design and maintenance of bicycle infrastructure to improve safety, which is an essential piece of the larger puzzle. Building a system that meets the needs of current and future bicycle users is important to achieve a safe, efficient, economic and sustainably driven transportation network. An effective network of safe, attractive and connected facilities is a crucial step in creating a bicycle friendly city. To encourage bicycle use, it is important to focus on the improvement of bicycle safety through determining the most effective bicycle infrastructure treatments and administering proper engineering and design. This bicyclist safety study will be used to inform decision making for planners and engineers on improving sustainable bicycle infrastructure and policy. The study provides information on the optimal bicycle infrastructure investments based on their substantive safety and costs. There are gaps identified in the literature on the potential of collision reduction for some infrastructure types, and further study is needed to create a more robust analysis.

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