Cyclist safety on the Sea to Sky Highway: reducing vulnerability through the identification and mitigation of high-risk areas

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Abstract: The popularity of road cycling has been continually increasing throughout North America and such a trend will persist through the coming decades as petroleum resources are depleted and the cost of private transportation continues to rise. The purpose of this paper is to address cyclist safety on the Sea-to-Sky Highway - the connecting route between Metro Vancouver and Whistler - as it is a favoured training ground for road cyclists in the region and will support much of the growth in the sport as well as tourism. The study used current literature, consultation, and consecutive surveys to assess the route. Analysis discovered a significant lack of appropriate signage, narrow shoulders, poor maintenance, and inadequate shoulder sweeping along the highway, contributing to a hazardous cycling environment. Mitigation recommendations are made, arguing a need for increased signage and sweeping, drainage improvements, and the installation of two cyclist-activated signals.

INTRODUCTION

Cycling has been undergoing a renaissance in North America over the past two decades as ridership levels have increased throughout Canada and the USA, while fatalities have managed to decrease over that same period (Pucher, Buehler & Seinen, 2011). A significant driving force behind the revitalization of cycling has been municipal efforts to promote the use of bicycles as a primary method of transportation. This has been accomplished predominantly through infrastructure and safety improvements, as well as comprehensive cycling promotion and planning programs that include bike sharing and bike-transit integration (Pucher, Buehler & Seinen, 2011). Cycling has become a focus of many cities' planning agendas as it provides numerous social, environmental, health and community benefits (Carlos & Phillips, 2001). It is a carbon-neutral mode of transport that occupies less space per person in comparison to private automobiles. It contributes to a reduction in traffic congestion, air and noise pollution levels and a preservation of outdoor recreational space (de Hartog, Boogaard, Nijland & Hoek, 2010). De Hartog et al.'s (2010) study quantified the benefits of commuter cycling and found that a life

expectancy gain of 3-14 months results from the increased levels of physical activity; additionally, the study concluded the use of automobiles contributes to a loss in life expectancy of up to 40 days due to air pollution and up to an additional loss of 9 days due to motor vehicle accidents.

Often overlooked are the improved health and fitness levels of cyclists, which in turn significantly reduce health care costs, a majority of which, in British Columbia, are government-funded. Health care is a major expense worldwide that consumes a significant portion of regional and federal budgets. In 2010, Canada's total health care expenditures grew to approximately $192 billion; as a share of the overall economy, it accounted for an estimated 11.7% of GDP, the equivalent of $5,614 CDN per person (Health Canada, 2011). Perhaps more significant is the burden health care costs have on provincial budgets: in 2009, among the latest data available, health care represented an average of 39.2% of total provincial and territorial government program spending (Canadian Institute for Health Information, 2010). Studies have found that individuals who bike to work are more likely to lead physically active lives and in turn retain better health and lower morbidity rates (Raynor, Bond, Freedson & Sisson, 2011). Sedentary lifestyles are associated with a higher risk for developing serious medical conditions including diabetes and cardiovascular disease; furthermore, they serve as an independent risk factor for all-cause and cardiovascular-related mortality (Raynor, Bond, Freedson & Sisson, 2012; Grøntved & Hu, 2011). As a result, it is estimated that up to 16 percent of total health care expenditures are attributable to physical inactivity (Shinogle, 2008), and that the lifetime subsidy from others to those with a sedentary lifestyle is $1,900 (Grossman & Mocan, 2011). Portland, pioneering the renaissance of cycling in the United States, serves as an appropriate case study to review the potential benefits: through three cycling initiatives [in Portland], studies concluded a benefit-to-

cost ratio peaking at 3.8 and in all recorded historic cycling investments a long-term net gain has resulted (Gotschi, 2011).

As governments and the populace become increasingly aware of the social, environmental, community and health benefits, it is paramount that safety concerns are not overlooked; despite declining mortality rates, the risk remains significant for cyclists. Cyclists are currently 14 times more probable than car drivers to be involved in a road accident resulting in serious injury or death (Hamilton & Stott, 2004), and per kilometre travelled there are 5.5 times more cyclists killed than motorists (de Hartog, Boogaard, Nijland & Hoek, 2010). On highways, the dangers are even greater: cyclists hit at speeds exceeding 65 km/h have less than a 15% chance of survival (Hamilton & Stott, 2004).

The purpose of this study is to assess cycling safety on a hazardous section of highway located in southwestern British Columbia - a notoriously dangerous cycling route - and to provide economically-feasible mitigation recommendations to ensure the maximization of cyclist safety as ridership increases in the area. There are approximately 1,400 injuries and 10 fatalities involving road cyclists every year in the province, highlighting the need for such analysis (Grossman, 2011). Our focus in this study is the corridor of Highway 99 that connects Vancouver to Whistler, referred to locally as the 'Sea to Sky Highway'. Prior to the two cities hosting the 2010 Winter Olympics, the highway was in need of substantial improvements and was dangerous for motorists and cyclists alike. In 2009 the Sea to Sky Highway received major upgrades meant to improve motor vehicle safety, and attempted to add measures to improve cyclist safety as well. Between 2001 and 2009 the Ministry of Transportation reported an annual average of 209 incidents, a number which was almost halved after the renovations to 111 incidents in 2010 (Duggan & Woo, 2012).

The 120 km route begins and ends in two municipalities which focus on sustainable development and encourage alternative modes of transportation; it is therefore ridden by thousands of cyclists annually. In addition, it hosts the GranFondo bike event each year, which brings several thousand cyclists to the highway in a single day (Mitchell, 2011). The number of cyclists are expected to increase in the coming years due to: trends in health awareness; government promotion of cycling; the rising popularity of the GranFondo event; and the development of appropriate infrastructure. As a result, it is crucial that we attempt to follow Portland's example by maximizing the benefits and reducing the costs associated with improved safety measures and decreased financial burdens, such as reliance on fossil fuels.

Currently, limited studies have assessed cycling safety on highways despite their growing importance in connecting expanding urban areas; furthermore, research is lacking on how municipalities can effectively increase the benefit-cost ratio related to cycling use in urban settings. This study will serve two important purposes: to help fill the void in literature of cycling safety on highways, and to improve cycling safety on the Sea to Sky Highway through an economically-sound proposal of mitigation methods. As with all studies, limitations do exist: research is being conducted in the off-season for cycling, resulting in potentially different hazards and less-than-optimal surveying conditions. Additionally, time is limited thereby constraining the depth of analysis possible for such a major research initiative. To overcome limitations, certain assumptions have been made: cycling hazards that are currently present will remain in all seasons; the route will experience no infrastructure changes during the writing of this report; and cycling rates will follow trend and continue to rise in coming years.

DATA

The study gathered primary and secondary data through a variety of methods to ensure the final research findings are of acceptable accuracy and relevance for future policy implementation and discussion. Current literature was used as background to the study to provide a working knowledge of cycling hazards on road networks as well as to review a variety of economically-feasible mitigation methods. Previous research conducted on the issue of cycling safety is expansive; as a result, there are a number of potential hazards that were known prior to surveying the study area. Although a substantial proportion of current literature focuses on cycling safety in an urban setting (i.e. on streets with speed limits under 65 km/h), much of the scholarly journals acquired were adequate for identifying common cycling risks and hazards.

In the Lower Mainland and Sea to Sky corridor, a variety of stakeholders exist: cycling coalitions, road users, municipalities, and provincial and federal governments. Each of these stakeholders will be affected by the study and any change that is to occur as a result of it. Consultation with these various stakeholders constituted a considerable portion of data acquisition for the study. Information on local cyclists' concerns of the highway was acquired through meetings with various groups, such as the North Shore Vancouver Area Cycling Coalition (NSVACC), as well as community members. The group members, and residents from Whistler, North and West Vancouver, provided input on what they felt were recurring safety hazards or general concerns. Nearly all community members, who contacted the group through email or during public meetings and events throughout February and March 2012, described themselves as experienced cyclists who frequently cycle on the Sea to Sky Highway. Their input identified specific sections, which were felt to be dangerous due to debris, design, or insufficient maintenance. Other concerns included cyclist recognition by motorists as well as cyclist-motorist

behavior and interaction. Many of these respondents also noted sections of the highway they particularly liked to cycle on and felt safe from most hazards. Consultation with the various stakeholders was vital for guiding our analysis and establishing focal points in the study region.

Policy-makers will be presented the final findings of the study and are the catalyst for cycling infrastructure and safety improvements in the region; therefore, ongoing dialogue throughout the study with British Columbia's Ministry of Transportation and Infrastructure was necessary to coordinate mutual goals and establish a definitive target for the research. Approximate mitigation and upgrade costs were also acquired through the Ministry of Transportation and Infrastructure to ensure numbers used in the analysis are both accurate and up-to-date.

METHODOLOGY

To assess the route, ground-truthing proved to be the most viable and appropriate method. Although satellite imagery was used to visually display the high-risk segments of the route, along with the suggested mitigation methods for improving the safety of cyclists, the spatial resolution was insufficient to identify such hazards and serve as a means of research. Knowledge acquired from literature and consultation was used as a preliminary survey of the study region to reduce the possibility of gross errors and their overall impact on results. Community consultation allowed prior identification of hot-spots (areas of focus) to improve efficiency and thoroughness during ground-truthing. Ground-truthing was conducted via three separate visits to the study region. The first visit was based on documenting basic information such as general inconsistencies versus methods of safeguards. Prior to the second and third visits, additional private meetings and community feedback sessions were conducted; this permitted a more thorough examination of the highway. On the second visit various measurements,

photographs, and detailed notes were taken to permit an accurate analysis of the route. The third visit to the study region was conducted via bicycle to provide a first-person experience of the highway. Cycling the route proved difficult and dangerous, but was valuable in the identification of hazards highlighted through community consultation with local cyclists.

All measurements, photographs, and notes taken during ground-truthing were compiled into a single database to be assessed against cycling safety literature and case-studies. Analysis revealed trends in the data, such as variations in signage placement as well as shoulder widths.

RESULTS

The upgrades of the Sea to Sky Highway in 2009 included wider shoulders for cyclists and disabled cars. Unfortunately, lack of foresight on the increasing use of the highway as a major cycling route has brought to light many safety concerns, as the 'shared shoulder' is not a designated bicycle lane (Sea to Sky Highway Improvement Project, 2010). Observations along the route took note of the frequency of cars and emergency vehicles using the shoulder, which creates another obstacle in the cyclists' path, while also not providing an alternate route around the vehicles as cyclists are not permitted on the road. As well, since the 'shared shoulder' is not a designated bicycle lane, standards for the width are compromised. While the Ministry of Transportation and Infrastructure has guidelines for highway shoulder widths, each section of the upgrade was constructed on a case-by-case basis as a result of the local topographies and geographic settings. While this does not alter a motorist's route, it drastically compromises the amount of the shoulder a cyclist can use, which is further reduced by the presence of drains, debris, and rumble strips.

Parkin and Meyers (2010) conducted a study in the U.K to gauge motorists' behaviour in the presence and absence of a cycle/shoulder lane (i.e. the painted line). They discovered that

motorists drive in reference to the painted lines, and not to the cyclist. Such behaviour exhibited by motor vehicle drivers puts road cyclists at significant risk for an accident; driving in reference to the painted line results in less buffer distance given - on average - from the shoulder. This decreased buffer distance results from a primary concern to remain on the road, rather than to ensure the safety of possible shoulder users such as cyclists. Driving behaviour such as this becomes problematic if cyclists are forced to exit the shoulder and enter the main lane when confronted with an obstacle. As part of an effort to increase cyclist safety and minimize such driving behaviour, new U.K regulations were enacted that suggest a 2 metre wide cycle lane in areas with speed limits exceeding 65 km/h. As a majority of the Sea to Sky Highway consists of speed limits greater than 65 km/h, this suggested standard is suitable for comparison - especially given the constant turns of the road. Measurements of the shoulder width along the Sea to Sky Highway were taken at numerous locations and revealed a gross negligence in the construction of ample shoulder width for cyclists. Inconsistent shoulder widths, along with the addition of rumble strips, drains, and debris within them, provide cyclists with little effective (i.e. usable) cycling space. Shoulder width has a significant range along the highway, reaching a minimum of 38 centimetres in sections of Porteau Cove - an area consisting of blind turns due to near-vertical cliffs lining the northbound lane - and a maximum shoulder width of 153 centimeters. These measurements are of the effective shoulder; that is, the usable width of the shoulder excluding any obstructions such as rumble strips. Average shoulder width of the highway was found to be 100.01 centimeters; a width that falls considerably short of the suggested 2 meter standard. The average width was calculated from 8 individual measurements of shoulder width at various locations of the highway - in both northbound and southbound directions - in areas that encapsulated the approximate variation in width (Figure 1).

Measurement Number	Shoulder Width (centimeters)
1	152.40
2	93.98
3	38.10
4	88.90
5	139.70
6	35.56
7	109.22
8	142.24

Figure 1: Shoulder width measurements along the Sea to Sky Highway

The average width of 100.01 centimeters is generous: the widest shoulder width measurements occurred in populated municipalities where speed limits are considerably slower and cycling is generally safer. For example, 'Measurement 1' was taken in the municipality of Lions Bay where the speed limit is 60 km/h and therefore below the minimum speed-limit threshold for the UK proposed 2 metre standard. These measurements indicate a substantial shortcoming of providing an appropriate shoulder for cyclists to use on the Sea to Sky Highway.

Analysis of the highway also indicated a severe deprivation of appropriate signage to make motor vehicle drivers aware of possible cyclists riding on the shoulder. Intervals between major bike signs informing motorists of cyclist usage on the highway were recorded on a southbound section of the highway from Squamish (north end) to West Vancouver (south end). The 50 kilometre stretch of highway is equipped with only 7 bike signs (Figure 2); similar to the shoulder width, a disproportionate number of them are in the residential areas where cycling is less dangerous.

Bike Signs	Kilometres From First Sign
1	- -
2	2.3
3	10.0
4	20.5
5	31.8
6	33.6
7	48.1

Figure 2: Documented bike signs and their distances apart - southbound between Squamish and West Vancouver

The Sea to Sky Highway is located in an area susceptible to severe weathering and debris accumulation. Running at the base of the Pacific Ranges where they meet the Pacific Ocean, poor weather conditions and heavy precipitation prevail for much of the fall, winter, and spring months. Northern sections of the highway experience snow accumulation through the winter, and snow melt in spring causes the deposition of rocks and other materials on the road. Subsequent surveys of the highway in snow-free areas reveal considerable debris on the shoulders, ranging from fallen branches to large rocks sometimes exceeding 10 centimetres in diameter. Areas such as Lions Bay, during one of the surveys, had unusable shoulders resulting from the accumulation of such debris. Rather than a prompt cleanup of the highway, debris was moved to the shoulder and marked with cones, further disabling the use of the shoulder. While peak usage during the summer months may experience less material accumulation, many still cycle the route regularly in the spring for both transportation and recreation, as well as training for the GranFondo event. Painting maintenance appears insufficient as well, with paint marking the highway shoulders disappearing almost entirely in the most dangerous areas. Shoulder paint on the southbound lane in Porteau Cove was particularly poor, likely the result of substantial interaction with automobile tires from motorists straying right due to the area's narrow lanes and blind corners.

Both the placement and choice of drainage on the highway is one of the most problematic hazards for cyclists. Highway gullies - drainage pits covered by open metal grating located on

the road edge - are of primary concern to cyclists' safety. Often located on the shoulder of the highway, they remain a direct obstacle; furthermore, poor design decisions increase their danger. The metal grating of highway gullies on the route often run in the same, or similar, direction of bicycle tires rather than perpendicular; paired with spacing between the grates exceeding the common bike tire width, there exists a high probability of tires catching the grates while traversing the gullies. When placed in shoulders where rumble strips are present, as is common on most of the highway, effective shoulder width is severely reduced. In areas where highway gullies were located on the shoulders, paint indicating the hazard was often severely worn or hidden in the slope towards the gully, and all but two lacked signs highlighting the obstacle. From the angle of view a cyclist has of the road, highway gullies are often only visible from very short distances. Scuppers - openings in the concrete barriers to drain water - are found along the highway as well and pose no threat to cyclists; their use over highway gullies should be standard except where road conditions and regulations do not permit their use.

MITIGATION

Despite the obvious pitfalls in planning for cyclist safety and the major hazards that exist along the highway, certain mitigation options are more feasible and appropriate. It is important to determine those that should be implemented based on their cost, effectiveness, and the resulting long-term return on investment. Although shoulder widening would be an ideal upgrade to the route, it is one of the least cost-effective mitigation methods. Many areas along the route, beyond just the Porteau Cove area, would benefit from shoulder widening; however, with single lane paving costs often averaging $100,000 per km (Ministry of Transportation and Infrastructure, 2011), it remains a poor option for future upgrades. The difficult terrain bordering the highway would likely increase construction costs; similarly, many areas such as Porteau Cove have

natural barriers (i.e. cliffs) that provide little-to-no room for widening. It was noted, however, that a lack of maintenance caused parts of the shoulder in Porteau Cove to diminish entirely as a result of weathering. Repaving small sections in this part of the route at more regular intervals to preserve the already minimal shoulder width should be a priority.

The study finds that the most appropriate mitigation methods to pursue are increased signage to improve driver awareness of cyclists, more regular shoulder-sweeping, as well as sufficient hazard marking to alert cyclists of upcoming obstacles. The lack of proper signage on the highway is severe, and increasing the number and appropriate placement of signs is recommended as a required upgrade to improve cyclist safety. To highlight this deficiency, our surveys discovered that signs for wildlife (i.e. deer) along the Sea to Sky Highway far outnumber those of cyclists, despite the lack of frequency of wildlife crossing the highway and the increasing number of cyclists regularly riding the route. Additionally, few mitigation methods come at such a low cost: at under $500 per sign - including installation - this remains the most economically-feasible area for improvement. An increase in signage would improve driver awareness of sharing the road, and could have a potentially significant impact on the prevention of future accidents involving cyclists. For less than $15,000 a total of 30 bike signs could be added to the highway (from West Vancouver to Whistler and return) at an average spacing of less than 8 kilometres apart. Minimal-to-no annual maintenance would be required, providing only an initial upfront cost. A no-cost option that should be pursued in addition to increased signage is the reconfiguration of notices on the electronic highway message boards. Currently, these boards are typically used to notify drivers of road conditions; however, when conditions are acceptable it would be beneficial to post messages relating to sharing the road and watch for cyclists.

At present, highway sweeping is carried out only once per annum (Ministry of Transportation, personal communication, February 17, 2012). For an area susceptible to such regular weathering and debris accumulation, this annual sweep is insufficient. Cost to sweep the shoulder averages $100/hour: at a pace of 10km/h, the Sea to Sky Highway could be swept (north and southbound shoulders) for approximately $2400. The study recommends expanding sweeping to be done on a monthly basis from April to July, for an estimated annual cost of $9600. Such sweepers are capable of clearing widths greater than the shoulder; therefore, both drivers and cyclists would benefit from reduced debris and as a result limit the number of avoidance maneuvers on the highway and potentially reduce motor vehicle collisions.

Hazard marking and appropriate choice of drainage should be addressed to ensure cyclist safety as ridership on the highway increases. Krista Falkner, a traffic engineer, explains that drainage location is dependent on a variety of factors: slope, cross-section of the highway, and so forth (personal communication, March 15, 2012). Thus, it is not possible in many circumstances to avoid placing highway gullies in the shoulder; however, choice in drainage system can be altered. Scuppers can be added at a cost of $110 per meter (Ministry of Transportation and Infrastructure, 2011), and are therefore a cheap alternative to highway gullies where regulations permit. Additionally, 'Bicycle Safe' grates can be used to replace any conventional highway gully as they meet regulations, while contain design specifications that ensures bicycles can traverse them. During the highway improvement project, Kiewit installed 28 grates on a 7km stretch of the highway costing approximately $18,260 in materials and $18,650 in equipment - one Cat 320 Hoe and one F-150 Pickup 4x4 - and labour - an operator, general foreman, and four labourers working ten hours per catch basin (M. O'Connor, personal communication, March 16, 2012). Replacement of the highway gullies with bicycle safe grates would require less labour

than the original installation; a piece of equipment, one labourer, and an operator would be able to replace the grates in a fraction of the time. As for materials, bike safe grates cost roughly $250 USD a piece (Hampton Concrete Products, Inc. 2012). The entire replacement process would be expected to cost $900 per grate. For $45,000, fifty of the most dangerous grates could be replaced.

Maintenance of the road markings alerting cyclists of upcoming drainage grates are necessary to ensure identification of upcoming hazards. The perimeter of each gully is measured as approximately 1.8 metres. The cost for line painting is $487 per kilometre (Ministry of Transportation and Infrastructure, 2011); assuming the price is for labour and materials (i.e. excluding the varying difficulties of painting different lines), painting 50 gullies with a 1.8 metre perimeter would equal less than 100 metres, costing less than $1500 (due to added labour time resulting from distances between gullies). As noted, the highway is subject to much wear and debris deposition in the winter and spring, so annual painting in April to ensure adequate quality during summer months is recommended.

As the section of highway in Porteau Cove is the most dangerous for cyclists, it is critical to address appropriate mitigation methods specific to the area. As discussed, shoulder widening is not a feasible mitigation method due to cost and topographic circumstances; therefore, it is recommended that cyclist-activated signals are installed at each end of Porteau Cove for the respective directions. Such signals can be automatically activated - through the use of detection loops - by cyclists when passing the sensors. Upon activation, the signals will function as a beacon to notify motorists of the cyclist(s) on the shoulder; the signal will flash repeatedly for a preconfigured length of time before returning to a standby state. When cyclists are not present in the area, the signal will remain deactivated and have no impedance on the flow of traffic. To

purchase and install two cyclist-activated signals, there is an approximate total cost of $45,000 (California Department of Transportation, 2002; Edwards, 2009; Gardener & Kortegast, 2010). The approximate cost includes two loop detectors; this expense can be significantly reduced if button-activated signals are installed in lieu of automatic detectors (Figure 3).

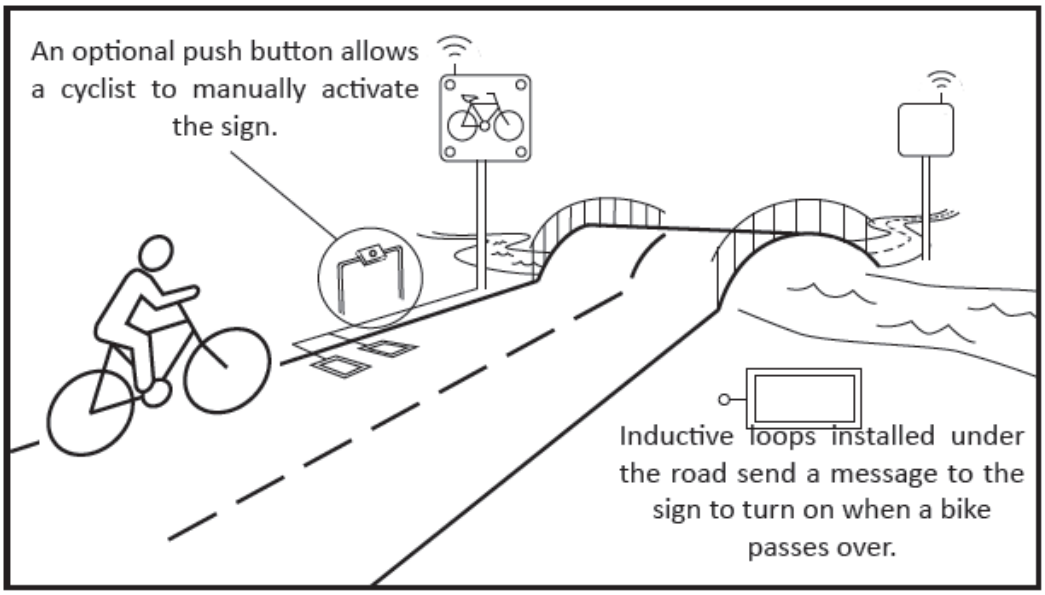

Figure 3: Sketch of Cyclist-Activated Warning Signs (HMI Technologies, 2012)

In total, the suggested mitigation upgrades to improve cyclist safety on the Sea to Sky Highway will cost approximately $116,000.

DISCUSSION

In comparison to other work done in British Columbia by the Ministry of Transportation and Infrastructure, pursuing upgrades on the Sea to Sky Highway for cycling safety should be a concern moving forward; its low-cost and potential to reduce accidents in the region should not be overlooked. As there are approximately 1,400 injuries and 10 fatalities involving road cyclists every year in the province (Grossman, 2011), a reduction of just one fatality on the Sea to Sky Highway at any point in the future would likely offset the cost to British Columbians of the suggested upgrades. The long-term savings, however, are likely to be much greater: in Alberta,

20,000 injuries and 400 fatalities resulting from accidents occur annually, costing Albertans $3.5 billion - an average of approximately $171,500 per accident (Chakravorty, 1998). The provincial government and insurance authorities enacted awareness promotion based on its overall effectiveness and benefit-cost ratio (Chakravorty, 1998); using Alberta's numbers, for each single reduction of a cyclist-involved accident resulting in serious injury or death, the savings would offset the total cost for such improvements. In addition, increased cyclist safety will promote the use of bicycles in the region and improve the physical health of those who participate. The potential rise of physical activity levels will assist in the reduction of avoidable health care spending on sedentary-related illness, currently consuming an estimated 16% of health expenditures in Canada (Canadian Institute for Health Information, 2010). Ensuring cyclist safety through these upgrades will further solidify the Sea to Sky Highway's status as a world-renown cycling destination for tourists. Emphasis must be placed on the low-cost of the proposed mitigation methods and the need to pursue improvements of cycling safety; Figure 4 compares such costs to past projects in the province.

Projects	**Total Cost**
Cariboo District (2011): pavement resurfacing (24.47 km)	$3,221,952.61 contract
Highway 3A (2011): rumble strip and reflectors	$161,166.00 contract
Highway 31 (2011): replacement of two stacked rock walls with concrete walls	$960,000.00 contract
Mission area - Side roads (2011): pavement repair and asphalt resurfacing	$446,981.00 contract
Highway 1 (2012): 3m high, 270m long noise barrier	$355,380.00 contract
Sea to Sky Highway proposed upgrades: signage, sweeping, bike-activated signals, drainage replacement	**Estimated cost: ~$116,000**

Figure 4: Cost comparison of projects undertaken in British Columbia and the proposed cyclist-safety upgrades (Ministry of Transportation and Infrastructure, 2012)

The broken-down costs to improve cycling safety along the Sea to Sky Highway can be seen below (Figure 5). As noted, these provide a low-cost alternative to widening the shoulders, while increased signage will further instill in motor vehicle drivers the "Share the Road" ideal. Debris and drainage was noted to cause the most hazardous cycling environment; the simple suggested measures could reduce this danger greatly. Lastly, as Porteau Cove is the most dangerous section of the route, cyclist-activated warning signs have been suggested. These electronic signs will ensure that at all times when there is a cyclist present, motorists will be aware and able to maintain a proper speed and distance to ensure a safe environment for both road users.

Recommended Mitigation Upgrades	**Cost**	**Details**
Increased Signage	$15,000	30 bike signs at an average spacing of less than 8 kilometers
Altered notification on electronic message boards	$0	When road conditions are acceptable, display share the road notifications
Increased Sweeping	$9,600	Sweep highway an additional four times per annum - once per month (April - July)
Drainage Improvements	$46,500	Fifty of the most dangerous drain grates replaced with bicycle safe grates and perimeter re-painted once per annum
Cyclist-Activated Signals	$45,000	Two cyclist-activated signals using loop detectors, installed at each end of Porteau Cove
	Total Cost: $116,100	

Figure 5: Broken-down costs of Sea to Sky Highway cycling safety upgrades

Limitations existed in this study that may have influenced the overall findings. Minimal surveying of the route was conducted via bicycle, which is necessary for cycling-oriented

project. More than one visit by bicycle is preferred to experience the highway in a range of different scenarios. Highway cycling is a dynamic environment with many variables to encounter: cycling the route more than once would have benefited the study since changes in weather, traffic volumes, and obstacles (such as debris) change daily. Systematically conducting a majority of surveying through the confines of a vehicle effectively caused the identification of hazards to be biased towards one vantage point, which may have caused some hazards to be misrepresented or over-exaggerated. By including a vast array of input from the community regarding the location of known hazards, it was hoped this would reduce the bias and ensure all hazards and remediation measures were included. Directly influencing the ability to cycle the route more than once were the time and weather constraints. The scope of the study created a hurdle to overcome in ensuring the analysis and results were as thorough as possible, while still being completed before the deadline. As well, the winter season caused much of the northern section of the route to be unobservable due to snow accumulation, while severe rain and wind during these months further hindered data collection. The limited literature available on highway cycling reduced the overall quality of background review; much of the acquired cycling safety information was based on urban settings. While the use of such literature should not have a significant influence on the findings, it may instill bias toward certain mitigation methods or the danger of particular hazards.

CONCLUSION

This study served two purposes: to fill the gap in academic literature concerning cycling safety on highways, and to recommend mitigation methods on the Sea to Sky Highway. The study argued that cycling safety on the highway could be drastically improved by the five mitigation techniques suggested in this paper. Ultimately, the mitigation techniques would save

the government money by decreasing injuries on the route, lowering medical costs and limiting resulting highway closures. Enhanced safety along the Sea to Sky Highway has the potential to further increase ridership, contribute to cycling tourism, improve local health culture, reduce traffic congestion and lower both air and noise pollution. In addition, the popularity of the GranFondo has brought tremendous exposure to the Sea to Sky Highway in recent years. From 4000 participants in the first race in 2010 to having 7000 registered participants from 14 different countries in the second race in 2011 (GranFondo Whistler, 2012), this highway continues to be advertised to the world as an epic route to cycle. However, the increase in ridership for the GranFondo and the anticipated increase for future races is concerning in one key aspect. Like many races, the GranFondo closes one entire lane of the Sea to Sky Highway as a safeguard to manage a large influx of cyclists; but for training rides leading up to race day there are no lane closures. A full 52% of participants made a training ride in the Sea to Sky corridor leading up to the event, including 18% of the out-of-province participants (GranFondo Whistler, 2012). Direct and indirect expenditures generated by the 2011 event totaled $8.2 million, which is a 49% increase from the previous year (Canadian Sport Tourism Alliance, 2011). To ensure the economic prosperity that the GranFondo brings to the province each year there must be safety measures along the route before, during, and long after the official race commences. The underlying assumption made by all participants and future participants is that the route is safe. Race planners and highway engineers alike must confirm this assumption because it is the participants themselves that contribute an exorbitant amount of economic benefits, and who lead a healthy active lifestyle brought on by pleasurable race experiences, and who value environmental integrity at the hands of a bicycle. If safety is compromised, it is unknown how many will withdraw from cycling, but it is certain that some will.

In the future, it is recommended that further research is undertaken that investigates unsafe areas beyond the route that was assessed in this study. When the Sea to Sky Highway was renovated for the 2010 Winter Olympics, improvements were stopped in Whistler although the highway continues on to Pemberton, BC. An investigation of cycling safety along this additional portion of the highway could be performed to extend the route by an additional 30km for added duration as well as bringing tourists into the Pemberton region.

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