ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INISTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

BIKEWAY COMPATIBILITY AND IMPLEMENTATION STUDY ON SELECTED ROUTES OF ADDIS ABABA

BY
GIZAW ESHETU

DECEMBER 2015
ADDIS ABABA, ETHHIOPIA

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A Thesis Submitted To the School of Graduate Studies Of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering (Road and Transport Engineering)

Advisor
Dr. Bikila Teklu

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Declaration

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr Bikila Teklu and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

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Contents

List of Tables

List of Figures

Abstract

Studying suitability and ways of implementation of bikeway for transportation infrastructures found on selected Addis Ababa routes are the main underlying reasons behind why this research is conducted. The degree of these infrastructures ability to accommodate cycle facilities are identified and ways of implementing or providing the cycle facilities to the infrastructures are discussed.

To do these, assessment of different countries practice of bikeway provision methods for road segments, junctions and bridges, and ways of checking the suitability of these infrastructures to bikeways; identification of best methods and approaches based on the assessments made; and implementation study of bikeway to the infrastructures found on the selected routes based on identified best methods and approaches are done.

The analysis results show that almost all studied routes are moderately compatible and topographically suitable for bikeways, but some are more compatible and bikeable than the other. Routes selected from Addis Ababa's East-West are found to be more flat and bikeable than routes selected from North-South of Addis Ababa, and again routes selected from the newly developed areas, which are found at the outskirts of Addis Ababa, are found to be more bikeable than routes selected from the city centers.

CHAPTER 1 Introduction

1.1 Background

Cycling is among the most efficient modes of transport for short trips which cause little danger and inconvenience to others. It has many societal and environmental benefits accounted to its use. Whether it is used for commuting or recreational trip purposes, it can make a significant contribution in solving problems of transportation in any city. It is the transport mode that can be owned within the financial capacity of most people relative to cars. It invites to take pleasant and healthy physical exercise.

As many developed and developing cities of the world are diverging to cycle use, Addis Ababa city should also try to adopt cycling as one of its transport system since it has many advantages for the sustainable development of its transportation system. Addis Ababa city administration should recognize the need to increase the amount of cycling as part of sustainable transport solution. Highway design engineers should give value in including facilities for cyclists considering the right of way, geometric and topographic characteristics of the road to be designed.

Thus, dealing with roads ability to accommodate cycling facilities is the first most valuable step for cities like Addis Ababa where there are many road problems and where there are no cycling paths. This can be made based on other cycle friendly cities bikeway design manuals and best practices that will suit to Addis Ababa’s situation considering geometric, topographic, right of way and environmental characteristics of the roads.

1.2 Statement of the problem

The rising cost of transport with respect to the rise of price of fuel energy, congestions being seen especially on peak hours and lack of places where to make physical exercise are among the many problems the society of Addis Ababa is currently facing. These problems can be somehow addressed by introducing cycling to the city, because cycles do not use fuel energy, the space required for cycle riding is much less than that required for cars, and riding cycle can give a cheap place where to make physical exercise which in turn can contribute to solving environmental problems that comes from usage of motorized traffics. Therefore, to introduce cycling to the city, cycling infrastructures have to be built by considering their accommodating ability of cycling facilities.

Addis Ababa roads ability to accommodate cycling facilities is unknown as there are no works done to assess their accommodating ability. Hence, it is necessary to study or make a research on the ability of the city's roads to accommodate cycling facilities, identify problems associated with them and point out the possible solutions as it will have valuable contribution in solving many problems of the city. It is the time for Addis to consider about the use of cycling as there are many roads and buildings being built nowadays. Once the roads are built without considering cycling facilities, it will be too much costly to include cycling facilities in the future.

The unknown status of selected Addis Ababa routes ability to accommodate cycling facilities and the way cycling facilities can be provided for infrastructures found on the selected routes is thus the main research question that needs apt reply from this research. This can be studied based on assessment of topographic, geometric, environmental and right of way characteristics of the selected routes. The study includes road segments, junctions and bridges.

1.3 Objectives of the thesis

The research has two objectives. These are:

- To assess selected Addis Ababa routes suitability to bikeway facilities, and
- To identify the way cycle facilities can be provided for the selected routes.

1.4 Structure of the thesis

The thesis has six chapters. In this introductory part the background, statement of the problem and objective of the thesis are presented. The second part is the literature review part of the research; literatures are reviewed, best practices and methods are taken and selected on each sub topics. These best practices and methods are then used in the analysis part of the research. For some elements in which it is believed that best practices and methods are not there or not found, analysis methods are summarized based on the findings of the literature review on chapter three section 3.3. Chapter three discusses the research methods that show the way the research will be accomplished, and these research methods are then used for the analyses' made in chapter four. In turn, these analyses resulted in implementation studies made in chapter five, and conclusions and recommendations made in chapter six. The final part of the paper is appendix which contains details of the analysis part. In the analysis part discussions are presented shortly and discussed in detail in the appendices.

CHAPTER 2 Literature review

2.1 Current status of cycling in Addis Ababa

Particularly, no written document has been found regarding to Addis Ababa's bicycle transport specific to this research topic. However, there are some other documents written on Africa and on Ethiopia's bicycle transport. The role of bicycles in urban transport is insignificant in Africa (Mengesha et.al 2002) and bicycle is not considered as mode of transportation in the city (Addis Ababa) due to inconvenient topography (Mintesinot & Takano 2007). Mintesnot Gebeyehu and Shin-ei Takano said such decisive statements without doing topographic study and without citation or referencing to any information or research's done on this ground.

Taxis, city buses and private cars altogether cover 30 percent of the urban mobility in Addis Ababa; that is, 26% buses, 72% taxis and 4% private cars, while 70% of urban mobility is covered on foot (Addis Ababa Transport Authority 2006). Looking to cycling practice of other developed cities of the world: it is up to 40-45% in Amsterdam, Netherland; 35% in Copenhagen, Denmark; 15% in Nagoya, Japan and 8% in Rio, Brazil (Copenhagenize Design Company 2013). Compared to these developed cities, the developing city Addis Ababa has very low cycle use. Even according to many study findings done in Ethiopia, small cities like Hawassa and Bahirdar have better practice of cycling than Addis Ababa (Belew 2012).

2.2 Advantages of cycling

Cycling is advantageous regarding to space saving, pollution reduction, accident reduction, energy consumption reduction, congestion reduction, increasing mobility, income saving…etc. (UNEP 2010). The following are some of the points found regarding to cycling's advantages:-

Space saving: standing car occupies $25m^2$ and $55m^2$ when it is on movement which is opposed to bicycling, $2m^2$ on standing and $5m^2$ on movement (Grava, cited in Belew 2003).

Energy consumption reduction: taking private car as base to be 100 in energy consumption for identical journey with the same number of people per Kilometer, it is 0 for cyclists, 30 for buses and 405 for plane in primary energy consumption (J. Dekoster & U. Schollaert 1999).

Accident reduction: taking private car as base to be 100 in risk of accidents for identical journey with the same number of people per kilometer, it is up to 2 for cyclists, 9 for buses and 12 for planes in risk of accidents (J. Dekoster, & U. Schollaert 1999).

Pollution reduction: North Americans emit 6 tonnes of CO_2 a year traveling an average of 64 km/day mainly by car and plane. Brazilians emit 0.7 tonnes of CO_2 a year traveling an average of 11 km/day by a combination of car and bus. Tanzanians emit 0.1 tonnes of CO_2 a year traveling around 5 km/day mainly on foot, by bus and bicycle. And 1 % of automobile travel replaced by bicycling decreases 2% to 4% of motorized vehicles emission (Kumanoff & Roelof, cited in Belew 2008).

Economical: 1.5 billion People are expected to live in cities with 1 million or more inhabitants by 2050. If a 5% increase in mode share for cycling could be achieved in these cities, and an equal impact were achieved in towns and villages containing another 1.5 billion people, car travel would be cut by around 600 billion km a year worldwide, saving 100 million tonnes of CO2 emissions. And a case study from South Africa shows low income earners spending 25% of income on public transport to and from work; with bicycle purchase, after initial purchase cost, the household cost of transport was reduced to 5% of income after three months (Patricia Kim and Elisa Dumitrescu 2010).

The way forwardness: Cycling is gaining more and more attention with cities like Paris, Mexico City and Hangzhou all starting bicycle renting schemes and cities investing in creating and expanding cycling networks. In Copenhagen (Denmark), 37% of residents' bike to work and the city plans to invest more than USD 200 million in bike facilities between 2006 and 2024 with the goal of 50% of residents biking to work or school by 2015. In Amsterdam (Netherlands), cycling accounts for 55% of journeys to jobs less than 7.5 km (4.7 miles) from point of origin and the government has pledged USD 160 million from 2006 to 2010 to bicycle paths, parking and safety. In London (UK), a record 111 million pounds (2010) is being invested on improving safety for cyclists, cycling training, more secure parking, 6,000-bike rental scheme, and two cycle superhighways. In Freiburg (Germany), a city with 218,000, the government has dedicated roughly USD 1.3 million annually to cycling since 1976, with 70% of local trips being made by bike, foot or public transit (Patricia Kim and Elisa Dumitrescu 2010).

Congestion reduction: Bicyclists need less than a third of the road space that is used by a private vehicle, and a pedestrian needs only a sixth of that space (Patricia Kim and Elisa Dumitrescu 2010).

So, according to these statistical information from different literatures, cycling is useful for Addis Ababa city as well as for the country.

2.3 Bikeway compatibility models

There are several Models and indexes developed in the past 20^{+} years to assess roads ability to accommodate cycling, these are:

- Bicycle Safety Index Rating (BSIR), Davis, 1987,
- Bicycle Stress Level (BSL), Sorton and Walsh, 1994,
- Road Condition Index (RCI), Epperson, 1994,
- Interaction Hazard Score (HIS), Landis, 1994,
- Bicycle Suitability Rating (BSR), Davis, 1995,
- Bicycle Level of Service (Botma) (BLOS), Botma, 1995,
- Bicycle Level of Service (Dixon) (BLOS), Dixon, 1996,
- Bicycle Suitability Score (BSS), Turner et al, 1997,
- Bicycle compatibility index (BCI), Harkey et al., 1998,
- Bicycle Suitability Assessment (BSA), Emery and Crump, 2003,
- Bicycle Level of Service (Jensen) (BLOS), Jensen, 2007,
- Bicycle Level of Service (BLOS), Petritsc etal, 2007, and
- Bicycle level of service (BLOS); HCM, 2011.

But some of these are the improvements of earlier methods while some others are developed starting from scratch to come up with different approaches. Among these models, some important & widely used models are discussed as follows.

Bicycle safety index rating (BSIR) model developed by Davis (1987) was the first modeling trial towards cycling. It tried to relate bicycle safety to the physical and operational features of the roadway for both road links and intersections. The overall index for the highway is calculated by summing all of the intersection and link indexes, and dividing by the total number of intersections and links.

Safety index (links) =AADT/2500L + S/35 + (14-W)/2 + PF + LF

Where, AADT-average annual daily traffic, L- number of travel lanes, S- speed limit, W- outside lane width, PF- pavement factor ,LF- location factor.

Safety index (intersections) = (VC + VR)/10,000 + (2VR)/ (VC + VR) + GF + SF

Where, VR- average daily entering volume on route under consideration , VC – average daily entering volume on cross street, SF- signalization factor ,GF- geometric factor

BSIR= (3/n) ($^{n}_{n=1}$ link safety index ratings) + (3/m) ($^{m}_{m=1}$ intersection safety index ratings)

Where, n- number of road segments and m- number of intersection on the road

Table 2-1 BSIR safety classification (Davis 1987)

Index Range	Classification	Description
0 to 4	Excellent	Denotes a roadway extremely favorable for safe bicycle operation.
4 to 5	Good	Refers to roadway conditions still conducive to safe bicycle operation, but not quite as unrestricted as in the excellent case.
5 to 6	Fair	Pertains to roadway conditions of marginal desirability for safe bicycle operation.
6 or above	Poor	Indicates roadway conditions of questionable desirability for bicycle operation.

Note of the author: *indexes are not definitive values, but instead assign general designations to roadways that can be used in determining bicycle routes, preparing bicycle maps, or prioritizing improvements for bicycling.*

But, besides the authors note as indexes are not definitive, it is criticized by earlier models as no specifics were provided regarding how the association of variables within the model was determined and there are other models developed by improving this model. Hence, it is better to use the recent ones.

The roadway condition index (RCI) model developed by Epperson (1994), which is a modification of BSIR, was developed by multiplying the speed limit by the lane width factor, by reducing the speed limit used in the denominator from 35 mi/h to 30 mi/h to increase the weight of the speed factors and by increasing the traffic volume in the denominator from 2500 to 3100 to reduce the weight of the traffic volume factor.

Roadway condition index (RCI) =AADT/3100L + S/30 + (S/30) ((14-W)/2) + PF + LF

But the model was developed only for narrow lanes and high motor vehicle speeds of Hollywood city that is why it tried to put greater weight on those road segments. Hence, it can't be applied in all cases.

The interaction hazard score (IHS) model developed by Landis (1994), was based on the prior models to solve two problems in the previous models: the subjectivity of some variables estimation and the lack of considering the exposure variables. To include some variables in the model he grouped road bicycle interactions into two: *longitudinal roadway environment* (variables that affect cyclists perception of hazard), which include variables such as volume, speed, size of the vehicles sharing the roadway, proximity of cyclists towards this cyclists and pavement condition of the road way; *traverse roadway environment* (variables that represent the uncontrolled vehicular movement), which include variables such as frequency of driveways, and on street parking presence and turnover. He combined these additional and previous variables to form the following model.

$$IHS= \{(ADT/L)\ (14/w)^2\ [a_1(S/30)(1+\%HV)^2 +a_2PF] + a_3LU(CCF)\}/10$$

Where, ADT-average daily traffic, L-total number of through lanes, W-width of the outside lane, HV-percentage of heavy vehicles, a_n's-calibration coefficients, LU-land use adjoining the road, CCF-curb cut or on street parking frequency, S- speed limit and PF-pavement factor

This model was again criticized by recent models as it was not succesful in avoiding subjectivity and increasing consideration of exposure factors like bicycle volumes. And it didn't improve intersection model. But it seems better than previous models in considering more valuable variables and its data requirements are easilly accessible. May be, it can be helpful in link roadway compatibility assessments.

Bicycle compatibility index (BCI) model developed by Harkey (1998), was developed based on variables that express bicycle friendliness of the roadway for adult bicyclists. It has three typical applications which will make it versatile: *Operational evaluation*; existing roadways can be evaluated, Design; new roadways or roadways being redesigned can be assessed, and *Planning*: forecasts can be used to assess bicycle compatibility of roadways in the future. It checks the level of service of roads with respect to the presence of bicycle lane or paved shoulder (BL), bicycle lane or paved shoulder width (BLW), curb lane width (CLW), curb lane volume in one direction (CLV), other same direction lanes volume (LV), 85th percentile speed of traffic (SPD), presence of parking lane with more than 30% occupancy (PKG) and type of road side development (AREA). It adds adjustment factors(AF) for trucks or buses, right turns and parking turnovers at last.

The Index**:** BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW +0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF

Table 2-2 BCI level service grades (Harkey 1998)

LOS	BCI Range	Compatibility Level
A	<1.50	Extremely High
B	1.51 - 2.30	Very High
C	2.31 - 3.40	Moderately High
D	3.41 - 4.40	Moderately Low
E	4.41 - 5.30	Very Low
F	> 5.30	Extremely Low

Bicycle level of service (BLOS) model developed by American highway capacity manual (HCM) (2011). It is developed to be applied for both links and intersections or segment (combination of one link and one intersection), but HCM said there are some limitations with intersection and segment BLOS, and recommends to focus it on link evaluations. The calculation for link BLOS is based on ten attributes: width of outside lane, width of bike lane, width of shoulder, proportion of occupied on street parking, vehicle traffic volume, vehicle speeds, percent heavy vehicles, pavement condition, presence of curb, and number of through lanes. The ten attributes are weighted as adjustment factors and combined as follows:

BLOS score = 0.760 + F_w + F_v + F_s + F_p

Where, F_w – width adjustment factor, F_v – vehicle volume adjustment factor, F_s – Vehicle speed adjustment factor and F_p - pavement condition adjustment factors

$$BLOS = 0.760 + 0.507 \ln\left(\frac{\mathrm{Vol}_{15}}{\mathrm{L}}\right) + 0.199\mathrm{SP_t}\,(1 + 10.38\mathrm{HV})^2 + 7.066\left(\frac{1}{\mathrm{PR_5}}\right)^2 - 0.005(\mathrm{W_e})^2$$

Table 2-3 BLOS level of service extending from excellent (A) to worst (F) (highway capacity manual, America 2011)

BLOS score	BLOS grade
< 2.00	BLOS "A"
2.00 – 2.75	BLOS "B"
2.75 – 3.50	BLOS "C"
3.50 – 4.25	BLOS "D"
4.25 – 5.00	BLOS "E"
>5.00	BLOS "F"

Among these models, bicycle compatibility index (BCI) developed by Harkey et al. (1998) for the Federal Highway Administration of USA at the University of North Carolina Highway Safety Research Center and bicycle level of service (BLOS) developed by HCM (2011), are the most recent, widely accepted, and highly improved (Journal of the Transportation Research Board, USA). The BCI and BLOS models share several common variables: traffic volume, traffic speed, bike lane, curb lane width, a heavy vehicle factor, parking, and adjacent land use. But neither of them requires the use of bicycle volumes, because they claimed to say bicycle facilities rarely approach capacity and bicycle counts are not typically available. Both models require a large amount of information that can increase the difficulty of using them to describe the compatibility of roads in a large network, but the variables are necessary.

Comparing BCI and BLOS models, the former one (BCI) is developed based on cyclists perspectives by showing them videos captured from different segments of roadways and rates the segments by looking at the comfort ability of the geometric and operational conditions of the segments with respect to how comfortable they feel be riding there. But the findings of rated comfort levels were based on visual preference determined from watching films of motor traffic on roads not based on actually riding a bicycle; they used no cyclists rode bicycles to report their level of comfort. This is its shortcoming because the presence of bicyclists in a traffic lane can alter motorists' behavior and the standing camera at the road side when videos are taken can also affect the motorists' behavior. The other shortcomings stated by the model developers themselves are that it doesn't consider the gradient of the roadway and developed intersection model have limitations and weaknesses. They claimed as the grades are not distinguishable on videos and suggest further researches for intersections. Again taking the model to the status quo of Addis Ababa, there is still a shortcoming because it doesn't consider public transport modes like taxis, which are the main transport modes in Addis Ababa that can affect bicyclists by standing here and there. But it may be possible to take taxis as the short time parking of less than 15 min, to take into account in the parking turnover adjustment factor. Its good part unlike that of BLOS is that the data's needed to be used in the BCI are limited and easily accessible from the governmental offices collected for different purposes.

The latter one (BLOS) is the most recent method claimed to be based on earlier studies and it is developed based on bicyclists rode bicycle on a specified route, and rated the safety of each link at checkpoints along the route unlike that of BCI. However; it requires the acquisition of more detailed land use data, like trip generation intensity of the land use adjoining the road segment and pavement condition information like pavement surface condition rating, both are rarely accessible. Like that of BCI again this one didn't consider public transport modes like taxis. But it is better than BCI in intersection BLOS which shall be seen later on intersection assessments.

Finally, the former one BCI is better for link assessments because of the accessibility of its data requirements and its possibility to take taxis as the short time parking of less than 15 min to take into account in the parking turnover adjustment factor. And thus, BCI and BLOS are preferred for link roadway assessments.

2.4 Comparisons of different design manuals

The two most recent bikeway design manuals are the Americans NACTO (2013) and the Netherlands CROW (2011). The NACTO Urban Bikeway Design Guide is said to be based on the experience of the best cycling cities in the world. It is based on three levels of guidance, which helps it to fit with the standards of different kind of road conditions and road quality levels. These are: required, recommended and optional elements. *Required:* elements for which there is a strong consensus that the treatment cannot be implemented without. *Recommended:* elements for which there is a strong consensus of added value. *Optional:* elements that vary across cities and may add value depending on the situation. These will make NACTO design manual applicable and working in every city of the world better than Dutch's design manual.

But, still there are some points which will not fit to Addis Ababa's living and roadway standards. The first is that it suggests reinventing the wheel; reinventing the wheel is a huge waste of time, money and resources, and the second one is that it suggests 3'=0.9m bike lane next to parked design vehicle's door zone, which will not guarantee cyclists safety, because it will expose cyclists to danger in the bike lane. But this is not found in the Dutch's CROW. The Netherlands are more experienced and their CROW guide is always updated within short time intervals.

From junctions point of view the Netherlands CROW seems to be better with regard to safety. For example; in the intersection designs, NACTO suggests a two stage turn queuing boxes. The queuing boxes lead cyclists to delay and make them exist in a very dangerous position in the middle of the junction, which will discourage cycle users for cities like Addis Ababa where cycle use is very low, where cyclists have to wait while motorized traffic passes on all sides. But this is not found in the Netherlands design guide. The Netherlands use space gap between intersection roadways and cycle tracks in which cyclists don't enter to the intersection and revolve the intersection as in the roundabout. Again on turn lanes at junctions, conflicts with cyclists going straight and on turning right are minimized because of their long time practice with many different kind of turn lanes trial. This makes the Netherlands CROW design guide better in junctions.

Focusing at road segments, the NACTO design guide recommends 5 feet=1.5m desired width for a cycle track and 7 feet=2.1m in areas with high bicyclist volumes or uphill sections. This is very narrow according to Netherlands design guide, because the standard width for one way cycle paths in the Netherlands is a minimum of 2.5m (8‘) and for bidirectional use the minimum is 3.5 m (11‘), but most modern cycle paths in the Netherlands are 4m (13‘) or more. When we come to Addis Ababa road situations, the Netherlands CROW guide gives very wide lane widths, which may be impossible to use because of observed constrained road situations in Addis Ababa, and therefore NACTO design guide is better with segment roadways.

According to Netherlands CROW (2011) from traffic flow and speed perspectives, there are six suggested different ideas to decide on when and where bicycle lanes should be built for different types of bicycle lanes. These are:

- Slow Lane for Bikes- when the Speed Limit is over 30 MPH goes the whole length of the road

- Wide hill climbing lane for bikes- like the first one, but ends at the top of the hill.
- Acceleration Lane for Bicycles- in case of mixed traffic, to give the bike a chance to get up to speed, when entering road from a side street, then merges with the existing traffic.
- Express Lane for Bicycles- When traffic is at a standstill bicycles can fly past the gridlock. It is an ideal bike lane for urban areas, which can give fast lane for bikes when the motorized traffic is very slow, this is because the traffic conditions are so different from one location to the next.
- Bike only bikeways- when traffic volume and speed on the main road is too high, and when land use necessitates and has enough space. It may be costly.
- Bike lane segregated from traffic- when traffic volume and speed on the main road is very high. It may be costly and needs wide space for implementation.

From these points, Netherlands CROW guide has better practice than the recently published NACTO guide, but the NACTO guide also has better guidance at some points.

Generally, both guides are better over the other at different points. Hence, during assessment of specific bikeway structural features, the better shall be used without throwing away the other. In addition to these two design guides better practices from other guides should also be used.

2.5 Topographic features

2.5.1 Climbing hills

Franz (2010) considers several factors that need to be taken into account to identify the maximum rideable grade for bikes in hill climbing. He considered maximum grade, average grade, total distance and total elevation. If one knows the distance of the climb and the total elevation, the average grade and the grade at any point are easy to calculate as they can be calculated by basic mathematical calculations. But it is difficult to calculate the distance that one can bike along the uphill (distance of the climb), because some can climb over a very steep short section and fade with a long climb while some others have difficulty with a short and steep grade but can climb over long climb. So the impacts of these factors (climbing distance & maximum rideable grade) over cyclists are personal as it is related to cyclists' power, endurance, and strength (Allain 2013). Hence he failed to calculate the climb distance for differently abled humans.

Factors to be considered on hill climbing include power, gradient, gearing, adherence (tire pressure), and position on the bike (center of gravity ahead of rear wheel) (ebike 2013). According to this site a fit human able to put out 200 watts riding a bike on flat ground, can go about 20 mph, and can maintain this speed for an hour. But, international human powered vehicle association (cited in Allain 2013) showed that average folks are only good for about 40-60 watts of effort for only a relatively short time. With the base of these statistics, the gears motor and a modest 50 watt contribution from the human, a bike would need about 150 watts at the wheel to go 20 mph on flat land.

There are also some who tries to identify the feelings of the cyclists riding up a grade. Cycling news.com (n.d.) provided the feelings of different grades as follows:

- 0%: A flat road
- 1-3%: Slightly uphill but not particularly challenging. A bit like riding into the wind.
- 4-6%: A manageable gradient that can cause fatigue over long periods.
- 7-9%: Starting to become uncomfortable for seasoned riders, and very challenging for new climbers.
- 10%-15%: A painful gradient, especially if maintained for any length of time
- 16%+: Very challenging for riders of all abilities. Maintaining this sort of incline for any length of time is very painful.

But it failed to consider climbing distance for each classification as the climbing distance has a great impact on the power of cyclists.

Mid-Ohio Regional Planning Commission (2006) announces that grades less than 5% are suitable for cycling for any length. But, grades greater than 5 percent are undesirable as they are hard for bicyclists to climb and may cause riders to travel downhill at a speed where they cannot control their bicycles.

Therefore, some tried to classify gradients based on comfort level while some others tried to point out maximum powers that average human can produce. But still, what is the minimum distance we should use to calculate the maximum grade? Is the main question that they could not answer and it is the most important one to calculate the rideable maximum gradient. With this regard Allain (2013) has provided better approach; he used different information’s from different sites. He used a graph of human power limits and a graph of speed, power and gradient relationships for his analysis.

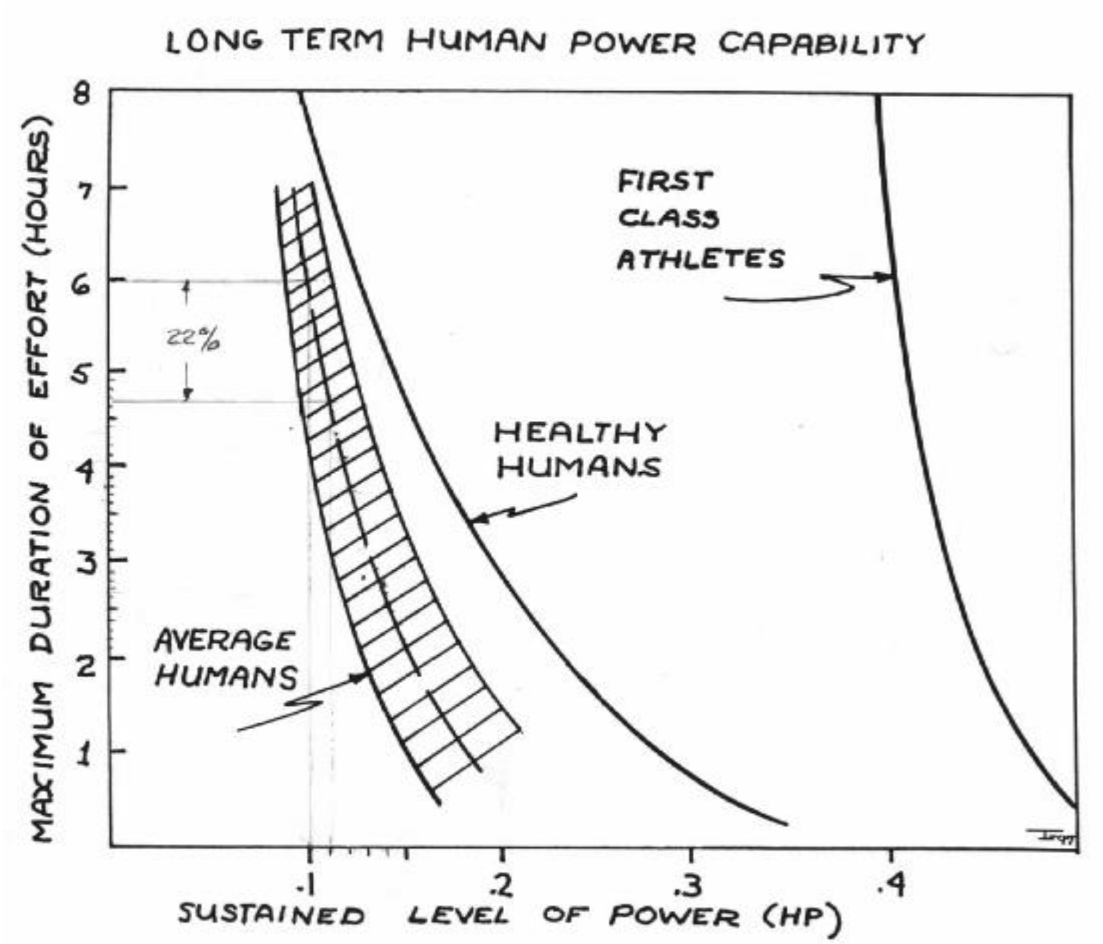

Figure 2-1 long term human power capability (international human powered vehicle association, cited in Allain 2013)

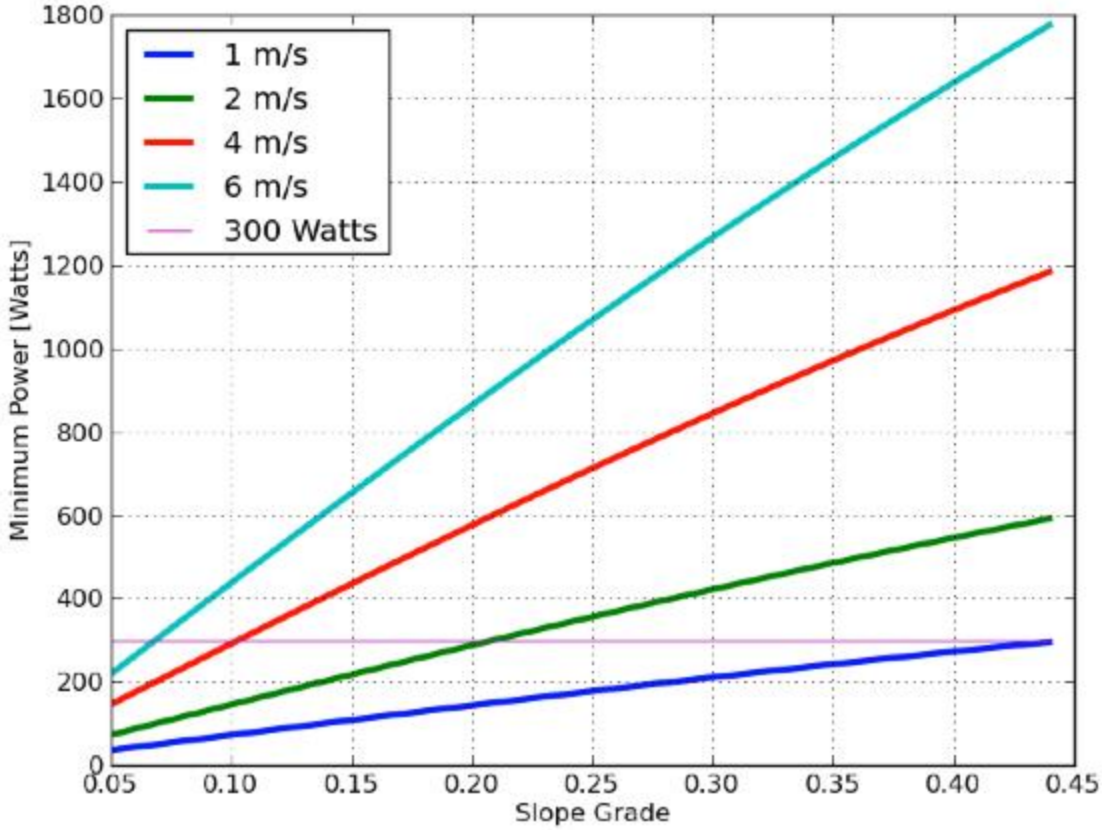

Figure 2-2 minimum power requirement for road slopes (Allain 2013)

He has produced the following relationships from the Figure 2-1 & Figure 2-2. From Figure 2-1 a top athlete could produce 0.4 horsepower which equals to 300 watts and from Figure 2-2 a minimum speed of 1 m/s=3.6 km/hr with slope of 40% grade would take a minimum of 300 watts; for an average speed of 2 m/s=7.2km/hr with slope of 20% grade a maximum power of 300 watts (it suggested this as maximum grade (20%) with an average speed of 2m/s); for a speed of 4m/s=14.4km/hr with slope of 10% grade a maximum power of 300watts and for a speed of 6m/s=21.6km/hr with slope of around 7% grade a maximum power of 300watts.

But for an athlete 2m/s speed may be too slow and 20% grade may be too steep as it takes the maximum power of 300watt to climb it, because study shows that average speed of cyclists is 2.87m/s (Garber & Hoel 2009). Let’s take a speed of 3 m/s=10.8km/hr as an average speed, it will lead us to around 12% grade for 300watt power. Friction helps not to slide down, air and grade resistance discourages not to speed up, and Centre of gravity could be hard to handle as gradient gets steep for the bicyclist riding uphill. So, 2.5m/s=9km/hr could be the average speed and 13% grade could be the maximum limit. This means an athlete can ride for 9km uphill distance in an hour with 13% grade.

Healthy man can produce a minimum of 0.1 horsepower which equals to 75 watts at a speed of 1m/s with slope of around 11% and at a speed of 2m/s with slope of around 7%. And average humans can produce 0.08 horsepower which equals to 60 watts at a speed of 1m/s= 3.6km/hr with slope of 6% (with this gradient, they can't ride more than 1m/s speed with 60 watts as it can be seen from Figure 2-1 & Figure 2-2). Therefore; these average humans are the right target population as the research's concern is for usage of cycling for transportation that includes children and elders.

Here power and speed are the main element of analysis rather than climbing distances to calculate the maximum gradients for differently able folks. Thus, from this analysis, it can be seen that different individuals have different ability to ride bicycle at different uphill gradient. And gradient cannot be demarcated without power limit demarcation, because one can ride with different gradient and speed at that power limit. For example, it has been seen when mountain trail athletes climbed a very short & steep uphill with high speed. So what matters is the speed (imagine if this athletes can climb a 1:1 slope with 1m/s speed, it is impossible but possible with high speed). It all depends on the speed used that comes from the capability of the individual.

Generally, concluding from this particular approach, the maximum bikeable gradient for athletes is 13% and for averages is 6%. But, because contributive & resistive forces are not considered during the analysis, it cannot be precise and confidential. Therefore, analysis should be made by considering all necessary contributive & resistive forces.

2.5.1.1 Analytical approach towards identification of maximum bikeable gradient

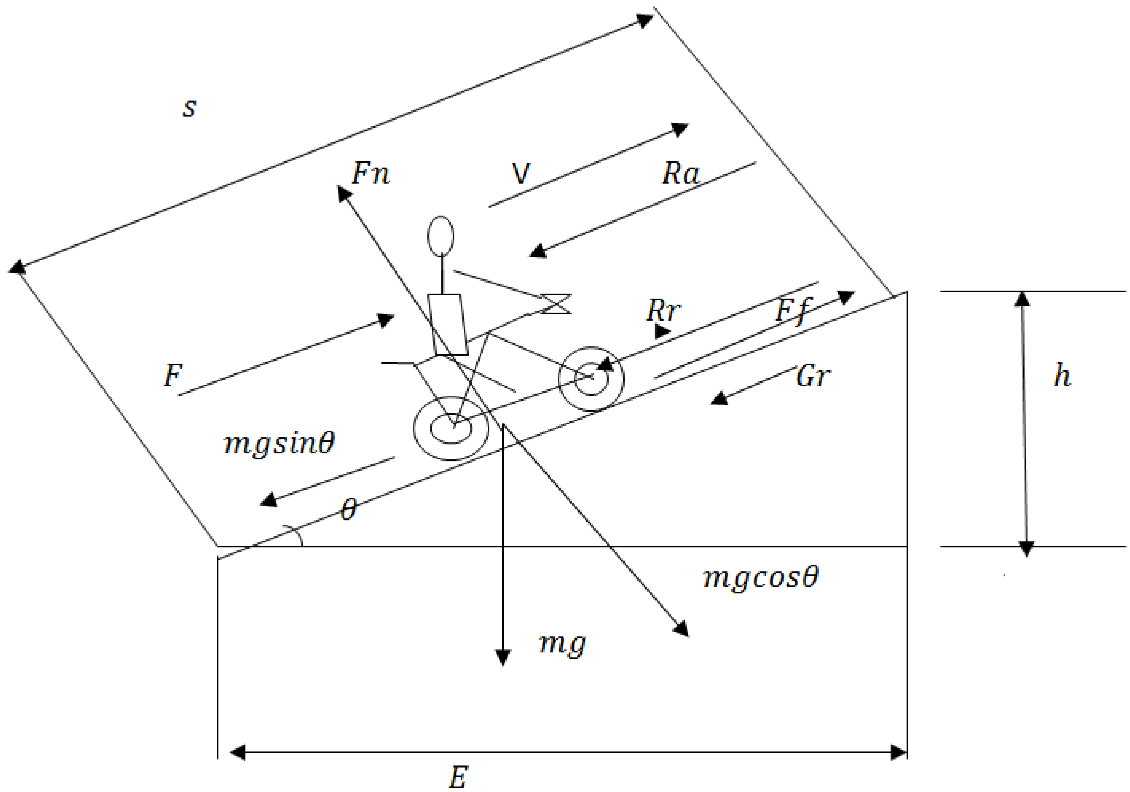

Figure 2-3 forces on cyclists moving up a grade

As it can be seen from fig. 2.3, there are many forces that act on a bicycle and bicycle rider moving up a grade. These are; force that move the bike forward (F), gravitational forces ($mgsin\theta$ *and* $mgcos\theta$), frictional force (F_f), air resistance (Ra), grade resistance (Gr), rolling resistance (Rr), normal force (Fn), and curve resistance (bicycle Wikipedia n.d.).

- Force that move the bike forward (F=F4)

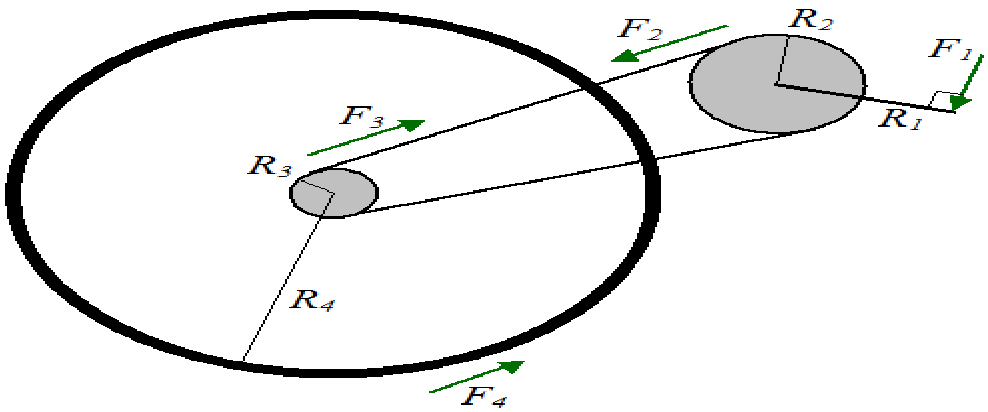

Figure 2-4 forces and radial dimensions (bicycle Wikipedia n.d.)

Figure 2-4 shows that F1 is force applied to the pedal by the rider, R1 is the pedal radius, F2 is force that act on the crank due to chain contact, R2 is the crank radius, F3 is the force that act on the rear gear due to chain contact, R3 is the radius of the rear gear, F4 is the force that act on the rear wheel due to contact with the ground and R4 is the rear wheel radius (bicycle Wikipedia n.d.).

For static equilibrium assumptions, F1R1= F2R, F3R3=F4R4 and F2=F3, combining the equations F4=F=F1* R1R3/R2R4, which is the force that moves the bicycle forward by disseminating the resisting forces, and the frictional force should help this force for the bicycle not to slip (Meijaard et al. 2007).

- Gravitational forces ($mgsin\theta$ and $mgcos\theta$)

Gravitational force is the force that resists the bicycle not to move forward on upgrade.

- Frictional force

In bicycle, pedaling is done on rear wheel. This means that we try to rotate the rear wheel to move forward. The rear wheel pushes the ground backwards and gets the forward frictional force which pushes the bicycle forward. The front wheel is being pushed forward (through the connecting rod between the rear and front wheels) which results in the backward frictional force on its tire which rotate it in the same direction as the rear wheel. The static frictional force which acts on both the wheels is a friendly force that helps the bicycle move without loss of energy (Meijaard et.al. 2007).

So, frictional force has the positive effect on the bicycle that moves up a grade, it helps the bicycle not to slip and not to slide down, along with F4. Frictional force helps to the rider's advantage working between the tires and the road. It gives grip that makes the bike easier to control, especially on wet days. It can be expressed as $F_f \leq \mu_s Fn$ (Meijaard et.al. 2007).

- Grade resistance

Grade resistance is the force that resists the bike not to move forward, which is $Gr = \frac{r}{100} * mg$ (Meijaard et.al. 2007).

- Rolling resistance

This is the resistance that will always be there as the bicycle is ridden, whether it is on upgrade and downgrade or on the flat ground. It is the force that pushes and pulls the tire in all directions, and it will increase as the riders body mass increases. Narrow and smooth tires will have higher rolling resistance than wide and fatter tires. It can be expressed as $Rr = C_r * mgcos\theta$. Where C_r is the coefficient of rolling resistance (Meijaard et.al. 2007).

- Air resistance

It is the force that will resist the forward movement as the bicycle is ridden upgrade or on flat ground. It increases as the riding speed increases, and as the area of rider and the bike perpendicular to the direction of velocity increases. Cyclist's body creates twice as much drag as their bicycle. It can be reduced by wearing tight neoprene clothing and pointed helmets, and by minimizing the space between arms. Wide and fatter tires will have higher air resistance than narrow and smoother tires. It can be expressed as $Ra = \frac{1}{2} * \rho C_d A V^2$, where C_d is drag coefficient (Meijaard et.al. 2007).

- Normal force

It is the force that will act opposite to the gravitational force due to ground contact and it can be expressed as $Fn = mgcos\theta$ (Meijaard et.al. 2007).

- Curve resistance

It is the external force that acts on the front wheel of the bicycle, especially on turning at curves, which will retard the bicycle. It can be expressed as $\mathrm{R_c} = \frac{1}{2}\mathrm{W}\frac{\mathrm{V^2}}{\mathrm{Rg}}$

Therefore; in flying up the hill power limit of the rider is the critical factor to withstand the resistances that comes from the above explicitly expressed forces.

As we have seen from the above graph, which is from international human powered vehicle association's website, athletic humans have a power limit of 300watts, healthy humans have a power limit of 75watts and average folks have a power limit of 60watts.

In order for the bicycle to move forward F=F4 (force that is applied to the rear wheel due to the riders applied force on the front wheels pedal) should be equaled (constant velocity or no acceleration) or greater (accelerates) than the forces opposing the motion (Meijaard et.al. 2007).

$$F + F_f = F_{gx} + Rr + \mathrm{Ra} + \mathrm{Gr} + \mathrm{Rc}$$

$$F + F_f = mgsin\theta + C_r\, mgcos\theta + \frac{1}{2}C_d\rho AV^2 + \frac{r}{100}mg + \frac{1}{2}W\frac{V^2}{Rg}$$

$$Gr = \frac{r}{100} * mg,\ and\ \ tan\theta = \frac{r}{100} = \frac{h}{E},\ then\ Gr = tan\theta\ * mg$$

- μ_s is the static coefficient of friction

It is the static coefficient of friction between the rubber tire and asphalt. Values for μ_s vary depending on the material that the ground or road surface is made of, whether the ground is wet or dry, the smoothness or roughness of the ground, the firmness or looseness of the ground, and the speed of the bicycle (Wong 1993). Coefficient of static friction between dry asphalt and rubber is in the range of 0.5-0.8, for wet asphalt and rubber 0.25-0.75, for dry tire and dry road 1, and for wet tire and wet road 0.2 (Wong 1993; the engineering toolbox n.d.). Therefore, as it has been discussed earlier frictional force is the contributing factor for the bicycle to move forward and hence coefficient of static friction between the bike tire and asphalt road should be large enough to grip the bicycle forward along with force applied by rider on the back wheel. Therefore; to be safe let's use the lower bound of the coefficient of friction values given for the wet condition, i.e. 0.25.

- ρ is Addis Ababa's air density

Mean relative humidity of Addis Ababa is 72%, mean air temperature 16.2℃ and mean altitude above sea level 2450m (Ethiopia television agency; Ethiopian national meteorology agency n.d). So, using air density calculator, mean air density of Addis Ababa is 1.211kg/m3.

- C_d is the drag coefficient

Table 2-4cyclists drag coefficient (Wilson 2004; Kyle 1991)

Cyclists C_d	
Cyclist (Tops)	1.15
Cyclist(Hoods)	1.0
Cyclist (Drops)	0.88
Cyclist (Aero Bars)	0.70

- A=average front area of rider and bike in m^2,which equals to

Table 2-5 Cyclists frontal area (Wilson 2004; Kyle 1991)

Cyclists' Frontal area A	
Tops	0.632 m^2
Hoods	0.40 m^2
Drops	0.32 m^2

Therefore, drag coefficient and frontal area multiplied will have these values according to different estimation methods: $C_dA=C_d*A$, triathlon's have C_dA = (0.25 to 0.33), bell curves have C_dA =(0.28-0.31), and most folks' have C_dA >0.33 (Jeukendrup 2002).

Table 2-6 cyclists' frontal area (Jeukendrup 2002)

Cyclists frontal area	
Cyclist riding on the tops	0.727
Cyclist riding on the hoods	0.40
Cyclist riding on the drops	0.28

But from wind tunnel (better in accuracy) estimation, C_dA for tops is 0.4080, for hoods is 0.3240, for drops is 0.3070 and for aero bars clip on is 0.2914 (Jeukendrup 2002).

Estimating drag coefficient is a bit difficult task, since different sources suggest different C_dA values, but considering the average height of Ethiopians (1.69m) and assuming the road users as they don’t use helmets and aero bars, let’s take 0.3240 suggested by Jeukendrup (2002) for hood riders, for this calculation purpose.

- V is the relative speed of the bicycle relative to air.

Mean velocity of bicycle (V_b) is assumed to be 2.87m/s (Garber 2009) and mean wind speed in Addis Ababa (V_a) is 3.02m/s (BBC weather report), and relative speed is expressed as $V=V_b-V_a$=2.87m/s-(-3.02 m/s)=5.89 m/s if the velocity is for headwind and V=2.87m/s-3.02 m/s=-0.15 m/s if the velocity is for tailwind.

- C_r is the coefficient of rolling resistance.

The coefficient of rolling resistance ranges from 0.0022 to 0.007 (Ashbum 2007). C_r=0.004 for bicycle tire on asphalt road (engineeringtoolbox.com n.d.). Therefore, the average value of 0.004 shall be used.

- m is the average mass of the rider and the bicycle.

According to Garabed (2007) & Quetelet (1796–1874) body mass index is given as; $(body\ mass\ index)BMI = \frac{m_h(mass(\ kg))}{\{height(m)\}^2}$. Ethiopians have generally average BMI of 20.46 and average height of 66.6in (1.69m) (World Health Organization 2006). Hence,$m_h = BMI * (height)^2 = 20.46 * 1.69^2 = 58.44kg$ is the average body mass.

And according to the ‘Devine Formula’, males Ideal Body Weight (W_{male}) = 50kg + 2.3kg * (Height (in) - 60) and Female Ideal Body Weight (W_{female})= 45.5kg + 2.3kg *(Height (in) - 60). So, W_{male} =50+2.3(69.4-60) =71.62kg and W_{female}=45.5kg + 2.3kg *(63.8 - 60)=54.24kg. Then, averaging these two m_h=62.93kg.

Weight of bikes differs as their purpose, quality and manufacturing date. Mountain bikes are between 15Ib=7kg and 40Ib=18kg; road cycles are between 15Ib=7kg and 25Ib=11kg; old cycles are in between 35Ib=16kg and 40Ib=18kg; and racing bikes have minimum weight of 15Ib=7kg (bicycle Wikipedia). Averaging these values, average mass of bikes m_b=12 kg. Therefore; average body mass of the rider and the bike together is $m = m_h + m_b = 58 + 12 = 70kg$.

- F is the force exerted by the rider and can be calculated as F=P/v.

It can be estimated as F=P/V, For athletes power limit is 300watt and F is 104.53N, for healthy humans the power limit is 75 watt and F is 26.13N, and for average humans the power limit is 60watt and F is 20.9N (International Human Powered Vehicle Association, cited in Allain 2013).

Having all the required values, it is possible to start calculating for θ without considering the resistive forces except gravity;

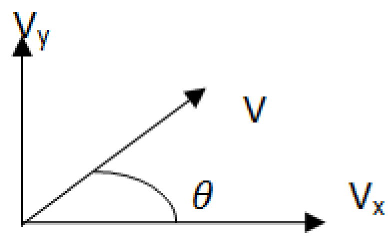

Figure 2-5 x-and y-components of velocity for cyclists moving up a grade

$$p = \frac{\Delta E}{\Delta t} = \frac{mgh}{\Delta t}$$

$$sin\theta = \frac{V\gamma}{V} = \frac{h}{s}$$

$$V\gamma = Vsin\theta = \frac{h}{\Delta t} = \frac{Vh}{s}$$

$$\Delta t = \frac{h}{Vsin\theta}$$

$$p = mgVsin\theta$$

$$tan\theta = \frac{r}{100} = \frac{h}{E}$$

$$r = \frac{h}{E} * 100$$

For athletic humans

Given that power(p)=300watts for athletes, p=75watts for healthy humans, p=60watts for average humans, g=9.81m/s2, average mass of bike user and bike m≈ 70kg, and average speed of bicyclists as V_b= 2.87 m/s=10.34 km/hr, it is possible to estimate for θ using equation p=mgVsinθ.

$$300watts = 70\ kg * 9.81\frac{m}{s2} * 2.87\frac{m}{s} * sin\theta,\ \gg\ sin\theta = 0.15222\ \ \gg\ \ \theta\ = \sin^{-1}(0.15222\ )$$

$$\theta = 8.76°$$

$$tan\theta = \frac{r}{100} = \frac{h}{E} = tan8.76° = 0.154015$$

$$r = 0.154015 * 100$$

r=15.401% is therefore the maximum slope for athletic humans without considering resistive forces.

For healthy humans

75=70*9.81*2.87sinθ ≫ sin$\theta = 0.038055$ ≫ $\theta = 2.1809°$ and tan2.1809°=0.03808 ≫

r=3.808% is therefore the maximum slope for healthy humans without considering resistive forces.

For average humans

60=70*9.81*2.87sinθ ≫ sin$\theta = 0.030444$ ≫ $\theta = 1.7446°$ and tan1.7446°= 0.03046 ≫

r=3.046% is therefore the maximum slope for healthy humans without considering resistive forces.

Calculating for maximum bikeable gradient by considering the resistive forces, the more precise values can be obtained.

For athletic humans

Assumptions

- Neglecting curve resistance, because it only happens at curves.
- Assuming headwind velocity, because it is discouraging unlike tailwind

Then, substituting the estimated values into $F + F_f = mgsin\theta + C_r\,mgcos\theta + \frac{1}{2}C_d\rho AV^2 + \frac{r}{100}mg + \frac{1}{2}W\frac{V^2}{Rg}$

$$104.53 + F_f = 70 * 9.81 sin\theta + 0.004 * 70 * 9.81 cos\theta + 0.5 * 0.3240 * 1.211 * 5.89^2 + tan\theta * 70 * 9.81$$

$$F_f = 686.7 sin\theta + 2.747 cos\theta + 6.806 + 686.7 tan\theta - 104.53$$

$$F_f = 686.7 sin\theta + 2.747 cos\theta + 686.7 tan\theta - 97.724$$

From this equation one can see that the positive contribution of frictional force is highly significant on upgrade riding; i.e. the back wheel's contributing frictional force is greater than the fore wheel's discouraging frictional force. And on the flat ground the frictional force on the back wheel turns to negative contribution or discourage the bike not to move forward (one can check this by setting the angle value to zero in the above equation).

From equation $Fn = mgcos\theta$

$Fn = 70 * 9.81 cos\theta = 686.7 cos\theta$

Then from equation $\mathrm{F_f} \leq \mu_s \mathrm{Fn}$

$(686.7 sin\theta + 2.747 cos\theta + 686.7 tan\theta - 97.724) \leq 0.25 * (686.7 cos\theta)$

$$686.7 sin\theta + 686.7 tan\theta - 168.928 cos\theta \leq 97.724$$

$$sin\theta + tan\theta - 0.246 cos\theta \leq 0.1423$$

Then θ value can be found by trial and error as follows;

Table 2-7 trial and error θ value detail

Value of sinθ+tanθ-0.246cosθ	θ values
0.134994	8.9
0.161941	8.95
Details	
0.134994	8.9
0.140812	8.91
0.141949	***8.912***
0.142514	8.913

Therefore; $\theta\ is$ 8.912° and $\tan 8.912° = 0.1568$, $\gg r$=15.68%, which is greater than the previous value (15.401%) calculated without consideration of resisting forces except gravity, this is because frictional force's positive contribution is greater than the opposing resistive forces.

For healthy humans

Considering frictional force which will highly depend on the speed of the cyclist, relatively less speed from that of athletic humans to fit with this folks should be used. As the speed decreases frictional force should increase to move the bike forward and hence coefficient of friction increases. So, using 1.5m/s speed=75/1.5=50N and 0.5 coefficient of friction and substituting in to equation $F + F_f = mgsin\theta + C_r\, mgcos\theta + \frac{1}{2}C_d\rho AV^2 \; + \frac{r}{100}mg + \frac{1}{2}W\,\frac{V^2}{Rg}$, the result will be;

$$F_f = 686.7sin\theta + 2.747cos\theta + 3.3097 + 686.7tan\theta - 50$$

$$F_f = 686.7sin\theta + 2.747cos\theta + 686.7tan\theta - 46.6903$$

From equation $Fn = mgcos\theta$

$Fn = 70 * 9.81cos\theta = 686.7cos\theta$

Then from equation {5}

$(686.7sin\theta + 2.747cos\theta + 686.7tan\theta - 46.6903) \leq 0.5 *(686.7cos\theta)$

$$686.7sin\theta + 686.7tan\theta - 340.603cos\theta \leq 46.6903$$

$$sin\theta + tan\theta - 0.496cos\theta \leq 0.067992$$

Then θ value can be found by trial and error as follows;

Table 2-8 trial and error θ value detail

Value of sinθ+tanθ-0.496cosθ }	θ values
0.06405	2.36
0.065672	2.361
0.067289	***2.362***
0.068901	2.363

Therefore; $\theta\ is\ \mathbf{2.362}°$ and tan$\mathbf{2.362}° = 0.04125$, ≫ r=4.125%

For average humans

By the same logic, increasing coefficient of friction to 0.6, speed to 1.3m/s and F=60/1.3=46.15N; and substituting into equation $F + F_f = mgsin\theta + C_r\, mgcos\theta + \frac{1}{2}C_d\rho AV^2 \; + \frac{r}{100}mg + \frac{1}{2}W\,\frac{V^2}{Rg}$, the result will be;

$$sin\theta + tan\theta - 0.5956cos\theta \leq 0.0628028$$

Table 2-9 trial and error θ value detail

Value of sinθ+tanθ-0.5956cosθ	θ values
0.062727	***2.32***
0.066537	2.322

Therefore; $\theta\ is\ 2.32°$ and tan$2.32° = 0.040514, \gg r$=4.05%

Concluding from this particular analytical approach; while applied force is varied significantly without varying coefficient of friction and speed, the difference in gradient is not that much significant, this is because frictional force has more effect than applied forces in riding up a grade. As the bikes speed decreases frictional force on the back wheel increases, but it becomes less than the discouraging friction force on the fore wheel as the rider continue to decrease his speed; i.e. why mountain bikers use high speed as they approach the hill climb to disseminate the high resistive force that comes from the fore wheel and others. And as speed increases the contribution of friction force decreases because the rider has enough power to disseminate resistive forces.

Coming out of physics and focusing on the road and road users' characteristics, which is the main purpose of this calculation, it can be concluded that the maximum bikeable gradient for athletic humans is 15%, and for healthy and average humans is 4%. Therefore, provision of isolated bikeway facilities as well as roadway bikeway facilities with gradient of up to 4% grade is possible.

Developed method of topographic analysis:

Concluding by merging together the above particular conclusions from different analytical approach; the maximum bikeable slope for athletes is 15% grade, for healthy humans' 4%-6% grade and for average humans 3%. Therefore, provision of isolated bikeway facilities as well as roadway bikeway facilities with gradient of up to 3% grade is possible for any length, up to 4% grade is not frequently possible and up to 6% grade should be only for connectivity matters. More than 6% there should not be bikeway.

However, AASHTO offers the following suggested lengths for certain grades greater than 5%:

- 5-6% is acceptable for up to 800 feet=243.84m
- 7% is acceptable for up to 400 feet=121.92m
- 8% is acceptable for up to 300 feet=91.44m
- 9% is acceptable for up to 200 feet=60.96m
- 10% is acceptable for up to 100 feet=30.48m

Therefore, the combined usage of the developed method of topographic analysis with AASHTO recommendations along with the feeling of different gradients provided by cyclingnes.com will be used in this research paper.

2.5.2 Descending hills

In descending hills comfort level and riding ability is the main concern rather than gradient of the road. But it is better to provide the slopes suggested on ascending hills as it is ascending for bikes flying on the opposite direction so that riders can keep center of gravity of themselves and their bikes on their own body, and be able to control themselves Mid-Ohio Regional Planning Commission (2006).

Bikes tire, brake application and balancing are the main issues related to comfort and riding ability in the downhill. Bikes tire traction depends on the type of roads top surfacing whether it is asphalt or sand/ gravel. Availability of debris is also a concern during riding down the hill and one can skip it by looking forward (Grant n.d.).

2.6 Environmental impacts

2.6.1 Cold weather biking

Factors to be considered during winter biking are rain, snow, formation of ice, high winds, drifting snow, dry powdery snow, gusting winds and clouds. Winter bike riding possess several challenges higher than summer biking. In the winter, snow is plowed to the side of the road, which often covers the shoulder of the road and makes the available road surface narrower. As a result, cars and bicycles have less space to share on the road. To maintain control of a bike on icy roads, cyclists need a different riding style than they would use in summer (Grant n.d.).

But some of these factors are outsider to Addis Ababa, only high rains, high winds, and clouds that may deny visibility need to be considered. Snow plowed to the side of the road occurs sometimes in Addis Ababa in the winter season, but they melt faster and flow to the side ditches (Ethiopian National Meteorology Agency n.d). High rains, high winds, and clouds occurred in Addis Ababa occasionally. But since they are short lasting according to the national meteorology agency this may not bother too much. Sometimes it may rain for long period of time slightly and the delay from this can be reduced by clothing and riding within it since it can't deny riding.

2.6.2 Hot weather biking

Biking in summer season may be difficult due to high temperature that comes from the environment and cyclists' body during riding. Biking in a very hot weather may be fatal if cares will not be taken (Fisher 2011). But Addis temperature fluctuates between minimum 10 degree Celsius and maximum 27 degree Celsius most of the time(national metrology agency and daily news), which is normal and even suitable to ride.

Generally it can be said that Addis Ababa has suitable environmental conditions to ride bicycle, except that long lasting rains that may occur sometimes in the winter season.

2.7 Bikeway facilities

In this section bikeway infrastructure/facility types of different cities and countries will be discussed.

AASHTO (1999) divides bikeway facilities into two major groups: on-road bikeway facilities and off-road bikeway facilities.

On road bikeway facilities:- are segregated bikeways provided for moderate to low speed roads with some intersections and entrances. There are sub classifications;

- Bike Lane: Bike lanes are portions of the roadway designated for bicyclist use.
- Bike Route: Bike routes are specially designated shared roadways that are preferred for bicycle travel for certain recreation or transportation purposes
- Shared Bike/Parking Lane: Bike/parking lanes are recommended on streets with low parking occupancy
- Share the Road: cyclists share the road with motorists.
- Shared Lane Marking: used to indicate correct straight ahead bicycle position at intersections with turn lanes and at intersections where bike lanes are temporarily discontinued due to turn lanes or other factors.
- Refuge Island: it allows bicyclists to cross one direction of traffic at a time at intersections.

Off road bikeway facilities:- are non-segregated bikeways which offer significant separation from other vehicle traffic.

- Shared-Use Path (Trail): are physically separated from motor vehicle traffic, except at road crossings, which include road users like pedestrians, bicyclists, and others, for both recreation and transportation purposes. Its subunits are Side path and Rails-to-Trails; Side paths are shared use paths running immediately parallel to a roadway similar to a sidewalk and Rails-to-Trails are constructed over removed rail track along a rail corridor.
- University Bike Paths: are off-street paths with a striped dashed centerline, facilitating bi-directional travel.

AASHTO (1999) tried to include on road and off road facilities but seems vague when it comes to further classifications of the two major groups. For example; separated bikeway facilities can be physical separation adjacent to the travel lane and it can also be the exclusive or total separation from the roadway. The other inexplicit point is it mixes segment bikeway facilities with intersection bikeway facilities (Refugee Island). It used some vague terms like university bike path; it may lead to a question, is it the facility to be provided in universities only or somewhere else?

Caltrans Highway Design Manual (2008) categorizes bikeway facilities as class I, class II and class III:-

- Class I (Bike Path): Provides a completely separated right of way for the exclusive use of bicycles and pedestrians with cross flow minimized.
- Class II (Bike Lane): Provides a striped lane for one-way bike travel on a street or highway for the exclusive use of bicycles.
- Class III (Bike Route): Provides for shared use with pedestrian or motor vehicle traffic for low volume residential roads that have no need for bike lanes to arterials with heavy traffic volumes where widening to provide bike lanes would be infeasible.
- Class III-Arterial roadway: are used where bike lanes or wide shoulders would be preferable but are politically or economically infeasible due to right-of-way or topographical constraints.
- Class III-Arterial roadway with wider shoulders: in rural areas, whose shoulders have been widened to at least four feet and
- Class III Bikeway-Local Roadways and Bicycle Boulevards: Local residential roads that are recommended for bike routes make excellent bikeways because traffic volumes are low and speeds are slow.

Here the mix use of roadway classification words (arterial) with bikeway classifications will make the guide users somewhat confused.

NACTO bikeway design guide (2013) classifies bikeway facilities as bike lanes and cycle tracks with sub classifications under both of them.

Bike lanes:- are part of roadway designated for the preferential or exclusive use of cyclists and further classified as conventional bike lanes, buffered bike lanes, contra flow bike lanes and left side bike lanes.

- Conventional bike lanes: are bike lanes adjacent to motor vehicle travel lanes and flows in the same direction of motor vehicle traffic and located on the right side of the street between the adjacent travel lane and curb, road edge, or parking lane.
- Buffered bike lanes: Buffered bike lanes are conventional bicycle lanes paired with a designated buffer space separating the bicycle lane from the adjacent motor vehicle travel lane and/or parking lane.

- Contra flow bike lanes**:** Contra-flow bicycle lanes are bicycle lanes designed to allow bicyclists to ride in the opposite direction of motor vehicle traffic.
- Left side bike lanes: Left-side bike lanes are conventional bike lanes placed on the left side of one way streets or two way median divided streets. Left-side bike lanes offer advantages along streets with heavy delivery or transit use, frequent parking turnover on the right side, or other potential conflicts that could be associated with right side bicycle lanes.

Cycle tracks:- are physically separated from motor traffic and distinct from the sidewalk, which further classified as one way protected cycle tracks, raised cycle tracks and two way cycle tracks.

- One way protected cycle tracks: are at street level and use a variety of methods for physical protection from passing traffic.
- Raised cycle tracks: are bicycle facilities that are vertically separated from motor vehicle traffic.
- Two way cycle tracks: are physically separated cycle tracks that allow bicycle movement in both directions on one side of the road.

The NACTO design guide didn't include non-segregated or isolated facilities. NACTO and most other American guides do not support non segregated exclusive bikeway facilities generally. The other point is that it lacks the treatments for median bikeways which will be possible to apply in case of available wide medians, and emphasizes in case of high volume of parking and short curb lane width in the right of way of roads.

UK bikeway design guide classifies bikeway facilities as on road and off road bikeway facilities.

On road bikeway facilities:- further classified as cycle lanes and cycle tracks.

- Cycle lanes: are traffic lanes marked on an existing roadway or carriageway and generally restricted to cycle traffic.
- Cycle tracks: are roadway constructed specifically for use by cyclists, but not by any other vehicles.

Off road cycle way facilities:- further classified as shoulder and shared use foot ways.

- Shoulders: are used by bicyclists when other bicycle specific facilities are absent.
- Shared use foot ways: are for use by both cyclists and pedestrians and will usually be built to a lower standard than a cycle track.

UK bikeway design guide lacks further detailed classifications. For example, cycle lanes can be further classified specifically as shared lane, separate lane….etc.

CROW Netherlands design guide classify bikeway facilities as follows;

- Solitary/isolated cycle tracks: two way facilities solely intended for cyclists with alignments independent of any roads.
- Separate cycle tracks: a cycle path parallel to but physically separated from an adjacent roadway minimizing passing conflicts between motorists and cyclists.
- Cycle Street: major cycle routes that are deliberately removed from busy mobility-oriented roads because they are neither safe nor attractive for cyclists. They are generally provided on parallel routes through residential communities.
- Cycle lane: a delineated space for cyclists on the roadway characterized by sufficient width, a red color, and the bicycle symbol. Buffered if there is a requirement to maintain parking.
- Suggestion lane: similar to a cycle lane, except not painted red in color. They are preferably accompanied by parking bans but allow periodic loading and unloading.
- Parallel road: parallel roads next to arterial roads and freeways are often residential local roads appropriate for cycle lanes or suggestion lanes.
- Combined traffic: roads which carry both motorists and cyclists with no separation or delineation between modes. Generally these are found on low speed residential streets.

It includes all types of bikeway facilities without the detailed classifications like buffered, unbuffered, boulevards provision…etc. and it emphasizes on residential area bikeway facilities.

The Danish Road Directorate's Collection of Cycle (2010) Concepts has the following form of bicycle classification

- Mixed traffic: At low car speeds and low volumes of motor vehicles, separation rarely results in safety benefits for cyclists.
- Cycle lane: With speeds of 50 km/h and less, and moderate traffic volumes, cycle lanes may be a solution.
- Cycle track: A physical barrier between cars and bicycles is beneficial even at moderate speeds and traffic volumes.

- Cycle track with dividing verge: On roads with high speeds, distances between intersections are often greater and improved comfort and less perceived risk can be attained by providing a cycle track with a dividing verge.
- Paved shoulders: If it is necessary to widen the road in order to establish paved shoulders, the construction of cycle tracks should be considered.

It lacks detailed classifications and non-segregated bicycle facility types are not included, but it is clear and explicit.

Generally, from the above classifications and definitions of bikeway facilities on different design guides, the NACTO bikeway design guide seems to be better and inclusive of all particularly regardless of non-segregated bikeway facilities and CROW Netherlands bikeway design guide is also inclusive of all generally regardless of specific further classifications. Median bikeway facility is the lack of both design guides. Combining these two may lead to good inclusive bikeway facility provision. NACTO is the most recent one, published in 2013, rather than others and it is also claimed to be based on the world's most bike friendly cities design guides. And CROW is experienced because Netherland is the most bike friendly country in the world with up to 50% of mode share; even in some cities it may exceed this figure. These may be the reasons for their inclusiveness of all facility types.

But as it has been seen above, the guides are written within their countries context, for example; NACTO didn't include non-segregated facilities except where it is appropriate, to connect specific locations, and if space permits. And CROW emphasizes provision of cycle facilities in residential area streets; this may be because of the character of their land use. This can tell that Addis Ababa's cycle facilities should be prepared, classified and provided based on the city's status with detailed studies.

Based on the above discussions, generally bicycle facility types can be divided into three major categories with sub classifications under each.

Shared roadway:- bicyclists share the road with other motorized traffic without any signage and markings.

- With regular lane width: Bicyclists share the road with motorized traffic.

- Wide curb lane: Bicyclists share a wide outside lane or curb lane with motorized traffic.

Adjoining Bike lanes:- bike lanes adjacent to but separated from motorized traffic lanes and it has two sub groups with further classification as follows;

- Right side adjoining bike lanes- flows in the same direction with motorized traffic.
  - Free right side adjoining bike lane: with one thick line separation from motorized traffic and curb on the other side.
  - Free with gutter right side adjoining bike lane: with one thick line separation from traffic and gutter on the other side.
  - Parking right side adjoining bike lane: with one thick line between motorized traffic and bike lane, and one thick line between parked vehicles and bike lane.
  - Door zone parking right side adjoining bike lane: with door zone provision between parked vehicles and bike lane, and buffered or thick line separation on the other side.
  - Buffered parking right side adjoining bike lane: with buffer provision between the parked vehicles and bike lane, and buffered or thick line separation on the other side.
  - Buffered right side adjoining bike lane: with buffer provision between the motorized traffic and bike lane, and the other side without gutter.
  - Buffered and gutter right side adjoining bike lane: with buffer provision between motorized traffic and bike lane, and gutter on the other side.
  - Boulevard right side adjoining bike lane: with boulevard provision between motorized traffic and bike lane. This can be one way or two way bike lane.
  - Vertically separated right side adjoining bike lane: with vertical physical separation between motorized traffic and bike lane. Physical separation can be up and down.

- Left side adjoining bike lanes – located on the left side of the roadway
  - One Way Street left side adjoining bike lane: provided on the one way streets left side. This can be two way divided bicycle lane on the left side totally or one lane with motorized traffic flow on the right side and the other lane on the left side opposite to the motorized traffic flow.
  - Median left side adjoining bike lanes: provided on the wide median on the left side of the motorized traffic flow, it is two way divided bicycle lane.

- Buffered median lane left side adjoining bike lanes: provided on the most interior travel lane with buffer. This can't be provided without buffer.

Isolated bike lanes:- bicycle lanes with significant or absolute separation from other motorized traffic roadways.

- Shared isolated bike lanes: bicycle lanes with absolute separation from motorized traffic but shared with pedestrians.
- Bike only isolated bike lanes: bicycle lanes with absolute separation from motorized traffic but without pedestrian share.
- Rail trail isolated bike lanes: bicycle lanes constructed on the removed old railway tracks.

Explicitly, identifying and writing down all possible bicycle facility types will be helpful to give good pictures or to give wide view about bicycle facility types to the readers and users, not to ignore the necessary facility types during designing and selecting facilities, and to widen the options in developing bikeway design guides as well as in developing bicycle facility selection guidelines.

2.8 Facility selection

In this section how different guidelines select appropriate bikeway facility type; especially CROW Netherlands bikeway design guide, AASHTO bikeway design guide and Michael king's ways of selecting particular facility types will be seen in detail. When to apply shared lanes, adjoining lanes, isolated lanes…etc. are the main problem and concerns of this section. Even though different guides provide ways of selecting facility types, there is still considerable debate over the appropriate choice of bicycle facility type in any given set of circumstances (Federal Highway Administration, USA 2006).

Most design guides classify bikeway facilities into four basic bicycle facility types to help them use in the facility selection tools. These are:

- Shared roadway with regular lane width: Bicyclists share the existing road with other vehicle traffic.
- Wide curb lane: Bicyclists share a wide outside (curb) lane with other vehicle traffic.
- Bike lane: Bicyclists have dedicated road space that is adjacent to but separated from other vehicle traffic lanes.

- Separated path or lane: Bicyclists have dedicated paths and trails (or sometimes very wide lanes) that offer significant separation from other vehicle traffic.

CROW Netherlands bikeway design guide

The Netherlands are successful in every aspects related to cycling. Bicycle transportation takes up to 50% of modal share and everybody can ride bicycle in the Netherlands be it children or elders. Their successes, besides the flatness of their country, are based on the tireless efforts of their scholars in modifying and updating their guides, and demonstrations of bicyclists in need of better bicycling facilities (Ottawa bikeway facility selection tool 2014). A nonprofit organization with collection of scholars named ‘the national information and technology center of transport and infrastructure (CROW)’ is the back bone of Netherlands success regarding to bicycling. The assessments going to be made here are based on the recently published document of this organization entitled ‘Traffic Engineering Design Manual for Bicycle Traffic.’

There are five main requirements for bicycle friendly infrastructure provision in the Netherlands according to CROW, these are;

- Cohesion: connection of origins/destinations and other modes of transport, completeness of routes and networks.
- Directness: provision of the shortest, quickest, and most convenient routes.
- Attractiveness: perception and social safety.
- Safety: speed and volume of vehicles, and the risk and severity of collisions, appropriate separation of vehicle types, minimizing conflicts with other vehicles, obstacles.
- Comfort: mental and physical exertion, ease of way finding, nuisance, and minimizing shortcomings in the cycling network.

The Netherland’s facility selection guidance is based on the cycle vehicle conflicts or encounters analysis, and hence variables such as volume of vehicles, volume of cycles and operating speeds are necessary in the decision process. Facility selection tools in Figure 2-6 and Figure 2-7 are with these variables or parameters, and in addition to be guided by this tools it suggests;

- Need of flexibility in acquiring the above five requirements.
- For urban roadways that serve both a mobility role and an access role some form of cycle facility separation is advisable.

- On roadways where on street parking is provided with more than 20% of a road's length it is advisable to provide a marked parking lane or parking bays to maintain a straight riding path for cyclists. Under these conditions, the travel width available for motorized traffic should be limited.

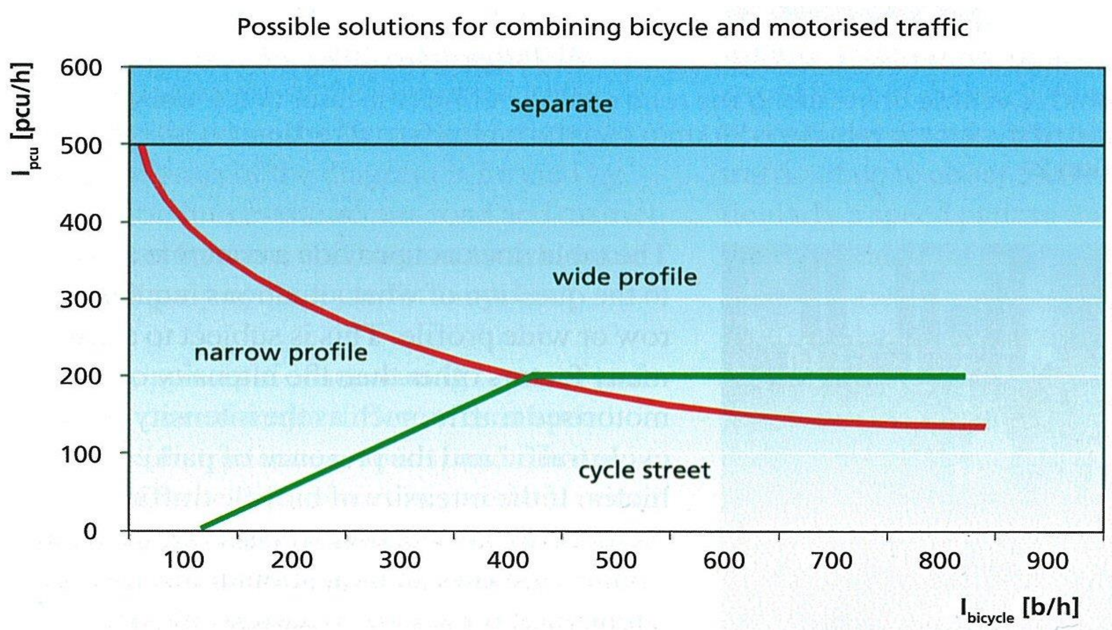

Figure 2-6 Facility selection tool of Netherlands (Traffic Engineering Design Manual for Bicycle Traffic, Netherlands 2007)

Road category	Max. speed of motorised traffic (km/h)		Motorised traffic intensity (pcu/day)	Cycle network category: basic network ($I_{bicycle}$ > work 750/day)	cycle route ($I_{bicycle}$ 500-2500/day)	main cycle route ($I_{bicycle}$ > 2000/day)
	n/a		0	solitary track		
Estate acces roead	walking pace or 30 km/h		1 - 2.500	combined traffic		cycle street or cycle lane (with right of way)
			2.000 - 5.000			
			> 4.000	cycle lane or cycle track		
District acces road	50 km/h	2x1 lanes	irrelevant			
		2x2 lanes		cycle track or parallel road		
	70 km/h			cycle track,moped/cycle track or parallel road		

Figure 2-7 Facility selection tool of Netherlands (Traffic Engineering Design Manual for Bicycle Traffic, Netherlands 2007)

AASHTO Guide on Selecting Bicycle Facility Type

AASHTO suggests the following points to be considered while selecting facility types: these are;

- The bicyclists' skill level, the specific corridor conditions, and facility cost.
- Continuity and consistency of bicycle facilities.
- Children bicyclists using a separated path to get to school should not have to cross a major arterial without some intersection controls.
- Shoulders and bike lanes should not end abruptly at difficult intersections or busy segments of highway.
- Bicycle facility selection is a policy decision to be made by State and local agencies.
- Aesthetics
- Conflicts with other traffic modes.

The facility selection guidance is largely centered on the skill levels of bicyclists and what types of facilities they prefer. The AASHTO (1999) guide suggests identification of three bicycle user types before going to selection of particular facility type; advanced or experienced riders, basic or less confident adult riders and children, riding on their own or with their parents. But it doesn't have selection charts or monographs as those of CROW and Michael kings guide.

Michael king's way on selecting bicycle facility type

Michael King (2002) provides a more detailed and comparative facility selection guide based on comparison of many countries bikeway design guides. He compared North American states and oversea countries (UK, Germany, Australia, Netherlands, and Denmark) materials from 36 sources. But he didn't include some guidelines from this figure, especially guidelines which did not discuss bicycle facilities with respect to vehicle speed or volume. He used the following terminology to describe similar bicycle facilities types used by different guidelines:

- N=narrow lane: 9-12 feet (2.75-3.65m) wide. For the purposes of this exercise 11 feet (3.35m). Cyclists would either operate in the margins or take the lane. No special provisions are provided for the cyclist, i.e. mixed traffic or share the road.
- W=wide lane: 13-15 feet (3.96-4.57m) wide. For the purposes of this exercise 14 feet (4.26m). Cyclists generally can operate alongside vehicles but may take over the lane. Some refer to this as a shared lane or a wide curb lane.

- B=bike lane: 4-6 feet (1.22-1.83m) wide and striped (marked). For the purposes of this exercise 5 feet adjacent to an 11-feet (3.35m) travel lane. In some locations the bike lane doubles as a narrow shoulder.
- S=separated lane: Anything wider than a 6-feet (1.83m) on-street bike lane. This includes 7 and 8-feet(2.13 & 2.44m) wide bike lanes, bike lanes with separation striping or markings, bike lanes separated by bollards or a curb, raised bike lanes (cycle tracks), bike lanes on the sidewalk or completely separated paths (shared use path).

For comparison, he developed volume speed matrix for each country; and to translate the guidelines, he used assumptions for those guidelines that didn't use parking turnover, volume and 85th percentile speed to describe conditions. Then he forwarded the following comparative points. These are;

- North American guidelines are more planning oriented about how to increase cycling and provide more bike specific facilities.
- Overseas guidelines are much more inclusive in terms of seeing the bicycle as an integral part of the transportation system making each street safe for cyclists.
- North Americans rely much more on wide lanes for bicycle accommodation than their counterpart overseas.
- North Americans generally do not include separated facilities in their guidelines except where it is appropriate, to connect specific location, and if space permits. Elsewhere vehicle bicycle separation is more common and encouraged.

Generally, he created one matrix for each level of service A up to F and compared the matrixes with level of service in the BCI. He divided the matrixes in to North Americans and overseas, and plotted the facility selection chart under volume (vertical) and 85th percentile speed (horizontal) profiles for both North Americans and overseas. He finally aggregated the charts as worldwide speed volume chart or as universal design tool/standard. Here is the universal developed guide taken from (Michael king 2004).

BICYCLE FACILITY SELECTION

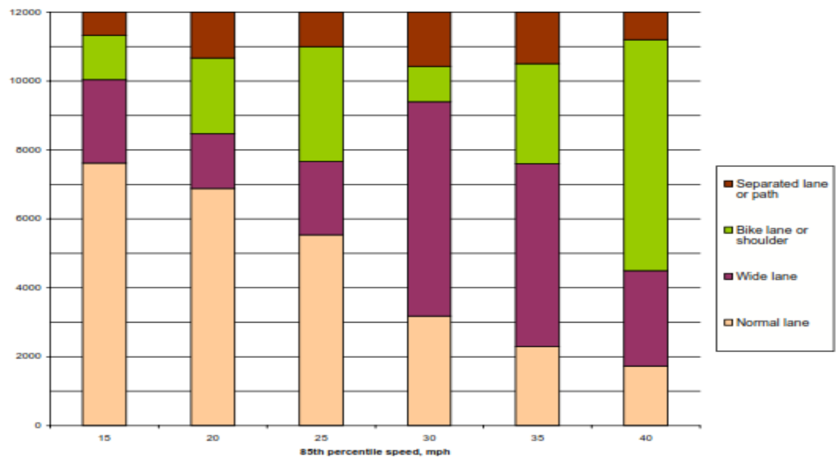

Figure 7: Worldwide Speed-Volume Chart

Michael King
for the UNC-HSRC Pedestrian and Bicycle Information Center 23

Figure 2-8 Michael kings facility selection tool (Michael king 2004)

Hence, generalizing these guidelines based on the above review of three bicycle facility selection tools, the following summaries are made:

- The CROW facility selection tool is somehow complex and sophisticated, so that it can't be applied without any modification. It should be summarized and shortened to apply it directly along with theoretical suggestions to be considered during facility selection.
- The AASHTO facility selection method doesn't have charts or monographs for direct application which makes it not easy for application. But the requirements they made to be considered during facility selection should be valued and contextualized.
- Michael king's way of facility selection tool is done based on 16 countries guidelines assessment and it is well summarized and easy for application.

2.9 Junctions

At junctions the most severe problem areas in bicycle facility provision are; intersections, roundabouts and driveways. At bridges, interchanges and grade separated junctions it is simpler than those severe problem areas (Robinson et al. 2000).

2.9.1 Roundabouts

Roundabouts are circular intersections with specific design and traffic control features. These features include yield control of all entering traffic, channelized approaches, and appropriate geometric curvature to ensure that travel speeds on the circulatory roadway are typically less than 50 km/hr (Robinson et al. 2000).

Provision and selection of type of bikeways to be provided with roundabouts depends on the functional, operating and structural characteristics of roundabouts (Joe bared 2000; Wim van der Wijk 2012). According to him these characteristics will include the following elements:

- capacity
- speed limit
- diameter of the island
- circular lane width
- Lane number
- Approach type of roadways
- Design Features
- Cross slopes
- Exit and entry types
- Islands curb height
- Signage and markings
- Accident types associated with them

Different countries roundabouts classification with respect to cycle facility types

United States of America as detailed by Robinson et al. (2000) have the following recommendations for cycle facilities with different roundabout types:-

Mini-roundabouts: small roundabouts used in low-speed urban environments in which mixed use of cycles are recommended.

- Recommended Maximum entry speed 25km/hr
- Inscribed central island diameter 13-25m
- Entry lane 1
- Marked flat and raised if possible
- Traffic volume of 10,000ADT
- Recommended when there is insufficient right-of-way for an urban compact roundabout.
- the central island is mountable, and larger vehicles may cross over the central island

Urban compact roundabouts: intended to be pedestrian and bicyclist-friendly because their perpendicular approach legs require very low vehicle speeds to make a distinct right turn into and out of the circulatory roadway.

- Recommended Maximum entry speed 25km/hr
- Inscribed central island diameter25- 30m
- Entry lane 1
- Raised splitter island
- Traffic volume of 15,000ADT
- Non-mountable central island
- apron surrounding the non-mountable part of the compact central island to accommodate large vehicles

Urban single-lane roundabouts: characterized as having a single lane entry at all legs and one circulatory lane. Cycle facility is not recommended since the entries and exists are tangential but fully segregated outside built up areas cycle facility are recommended.

- Recommended Maximum entry speed 35km/hr
- Inscribed central island diameter 30-40m
- Entry lane 1
- Raised splitter island
- Traffic volume of 20,000ADT
- tangential entries and exit
- larger inscribed circle diameters

- non-mountable central island
- Preferably, no apron.

Urban double-lane roundabouts: includes roundabouts that have at least one entry with two lanes and roundabouts with entries on one or more approaches that flare from one to two lanes. Alternative route alignment, bypass or slip lanes are recommended for bicyclists.

- Recommended Maximum entry speed 40km/hr
- Inscribed central island diameter 45-55m
- Entry lane 2
- Raised splitter island
- Traffic volume of 20,000ADT
- wider circulatory roadways to accommodate more than one vehicle traveling side by side
- no truck apron
- non-mountable central island
- Appropriate horizontal deflection.

Germany according to Brilon (2011) has the following cycle facility recommendation for each roundabout classification:-

Mini-roundabouts: with a traversable island and diameters between 13 and 25 m. cycle facility is not recommended outside built-up areas due to safety concerns.

- maximum allowable speed 50km/h
- inscribed circle diameter 13-14m
- circular roadway width 4-6m
- cross slope 2.5% inclined to the outside
- maximum capacity of 20000 veh/day
- no flaring of the entries
- Only single-lane entries and exits.
- central island with a maximum height of 12 cm in the center and 4-5 cm curb outside

Compact single-lane roundabouts: with diameters between 26 and 45m. Cycle lanes at the peripheral margin of the circle are not allowed. Up to a traffic volume of about 15,000 veh/day, cyclists can be safely accommodated on the circular lane due to similar speeds of cyclists and cars between 15 and 25 km/h). Above the volume of 15,000veh/day, separate cycle paths are regarded to be useful at a distance of 4-5m at entry and exit crossings.

- inscribed circle diameter 26- 45m
- Circular roadway width 8m for 26m diameter and apron on the approach.
- single-lane entries and exits
- single circulatory lane
- cross slope 2.5% inclined to the outside
- Intersection arms rectangular to the circle.
- No tangential entries are allowed.
- The curb transition between the entry lane curbs and the circle, 12-16 m for entries and 14-18m for exits.

Compact two lane roundabouts: No bicyclists are allowed on the circle lane.

- Outer diameter: 40 to 60 m
- circle lane width: 8 to 10 m; without lane marking (to prevent drivers from overtaking)
- single- or two-lane entries according to traffic volumes
- Single-lane exits only.

Larger roundabouts: no cyclists are allowed.

- Larger/ multilane Roundabouts are allowed with signalization which are possible at sites with volumes up to 50,000 veh/day.

Washington US according to WSDOT Design Manual (2013) has the following recommendations of cycle facilities for different roundabout types:-

Mini roundabout: mixed use or solid line separated cycling facilities are recommended.

  - Used in 25 mph or less urban/suburban environments
  - Used in less than 6,000 AADT
  - Used to replace a stop-controlled or uncontrolled intersection to reduce delay and increase capacity.
  - 2-inch mountable curb for the splitter islands and the central island is desirable

- Single-lane roundabout: segregated cycle facilities are recommended.
  - single-lane entries at all legs and one circulating lane

    - mountable raised splitter islands,
    - A mountable truck apron, and
    - A central island, which is typically landscaped.
- Multilane roundabout: fully segregated cycle facilities are recommended.
    - At least one entry or exit with two or more lanes
    - more than one circulating lane
    - trucks encroach adjacent lanes
- Teardrop roundabout: alternative or bypass cycle facilities are recommended.
    - Associated with ramp terminals at diamond interchanges
    - allow the “wide node, narrow link” concept
    - Unlike circular roundabouts, teardrops do not allow for continuous 360° travel

Netherlands according to National Transport Authority (2011) has the following roundabout types with cycle facilities:-

Mini roundabouts: characterized by a painted central island. And mixed and striped cycle facilities are recommended.

- Painted Central Island of 0.5m to 2.0m in radius.
- Domed to a maximum height of 75mm (25mm on bus routes).
- Very visible painted arrows indicating the gyratory direction.
- Narrow single traffic lane approaches
- Shared circulating area with a ‘tight’ geometry to ensure minimal traffic speed.
- Used in mixed street environments at junctions with design capacities of up to 2,000 vehicles per day.
- Vehicular speed on the approach roads, less than 30km/h.
- Larger vehicles can negotiate the tight geometry by over-running the central island.

Shared roundabouts: characterized by a built central island clearly defined by a solid curb. Mixed or striped cycle facilities are recommended.

- Raised Central Island, minimum 150mm high.
- Central island radius of 2m or larger.
- Single traffic lane approaches
- Shared single circulating lane no wider than 4m.

- used in mixed street environments at junctions with design capacities of up to 6,000 veh/day
- Vehicular speed on the approach roads is less than 50km/h.

Segregated cycle tracks on roundabouts: characterized by a dedicated circulating cycle track that is highly visible and segregated from the main vehicular circulating lane by curbs.

- Built Central Island clearly defined by a solid curb.
- Central island radius between 4m and 12m.
- Used with traffic volume of 6,000 – 10,000 vehicles per day.
- Dedicated space for cyclists both on the roundabout and at the entry and exit points.

Fully segregated cycle tracks on roundabouts: required for higher traffic volumes.

- Approaches have segregated cycle tracks.
- Single traffic circulating lane.
- Segregated circulating cycle track.
- Built Central Island clearly defined by a solid curb
- Central island radius between 4m and 12m.
- Required for traffic volume greater than 10,000veh/day.

Multilane roundabouts: one or more circulating lanes and/or multiple approach and exit lanes.

- Not suitable for cyclists.
- Fully segregated grade separated or alternative/bypass cycle alignment solutions are required for cyclists.

Turbo roundabouts: it is the modern roundabout currently being adopted by many countries. from the major entries a second lane is added on the inner side of the ring, whereas at exits with a significant exiting flow the vehicles on the outside lane are forced to continue their way into the exit. Outside built up area cycle facilities are recommended.

- Recommended at locations where the through traffic has larger volumes(Germany)

Delflandplein roundabout: it is a recently rebuilt roundabout in delft, Netherlands, transformed from signalized intersection of 4 legs with three entry lane at each leg, paired tram truck turning 90^0 in the median reservation.

- All approaches reduced to a single entry lane from three entry lanes and single exit lane.

- Bus and trams through the middle of the roundabout island receiving priority from other traffics
- Less delay from original signalized intersection with 50 percent lane reduction
- Alerting signals for motorists, cyclists and pedestrians about approaching transit vehicles
- With fully segregated two way cycle track at 90^0 approaches to roadways to be safe since it increases visibility and psychological awareness.

Figure 2-9 Rebuilt, Netherlands, Delflandplein modern roundabout, National Transport Authority (2011)

From the above detail discussions of different countries roundabout design practice from cycle facilities perspective, the Netherlands have been found to have better practice and experience on bicycle facility treatment provisions at roundabout junctions. And hence, adopting the Netherlands way of facility provision guidance with other good practices from other countries is found to be preferable. Accordingly, the following classifications and specifications of bikeway treatments are summarized using mainly Netherlands style including other countries good practice from discussions made above.

Bikeway treatments summary at roundabouts:-

I. Mixed without cycle lane

- Bicyclists are mixed with motorized traffics.
- It is cost effective and space efficient with traffic volumes of less than 6,000 vehicles per day.
- No signals and all traffics have to yield to traffic already in the roundabout.
- Possible in mini and shared roundabouts
- safer than roundabouts with bicycle lanes in avoiding a chance of right hook collision

- Cycle facilities should be bent to the road about 20-30m before the roundabout.

Figure 2-10 Mini roundabouts with mixed/shared traffic, National Transport Authority (2011)

II. Striped cycle lanes

- Striped bike lanes circulate the circulatory roadway's outer margin.
- Striped bicycle lanes are considered the least safe in the Netherlands.
- Striped bike lanes are not recommended based on research showing their higher crash rate.
- Can be used on single lane roundabouts
- Better if colored & slightly elevated in addition to being marked.
- It is part of the circulatory carriageway.

Figure 2-11 striped & colored roundabout cycle lane (Daniels 2008)

III. Cycle tracks Segregated from traffic

- Better safety than striped bike lanes according to CROW.
- Recommended on single roundabouts in the Netherlands.
- Are of two types

  a. Segregated cycle tracks

- Bicycle lanes are segregated from other traffics by physical means of heightened curb or as they call it Hogback C curb.

- Hogback C curb gives psychological awareness for motorists about cyclists use and gives a barrier for motorists not to jump over cycle tracks at exits.
- Highly visible and segregated cycle track separated by curbs from circular lane to prevent the cyclist from being squeezed for roundabouts with deign capacities of 6,000 – 10,000 vehicles per day.
- Priority for bicycles over entering and exiting vehicles reinforced by ‘shark’s teeth’, instructs where to yield.

Figure 2-12 roundabout cycle track separated by C curb, National Transport Authority (2011)

b. Fully segregated cycle tracks

- For traffic volume greater than 10,000 vehicles per day.
- It can be priority for bicycles type smooth flow and ongoing colored surface, and/or priority for cars type zig zag and no colored surface.
- Greater separation gives greater safety.
- Up to 6 meters raised median dividing motor vehicles and bicycles.
- Priority for bicycles over entering and exiting vehicles reinforced by ‘shark’s teeth’, instructs where to yield.
- Hogback C curb where space is extremely limited.

Figure 2-13 fully segregated cycle track, National Transport Authority (2011)

IV. Grade separated cycle lanes

- Used in Multi-lane roundabouts with one or more circulating lanes and/or multiple approach and exit lanes, since the risk of collision is too great.
- Cycle lanes are provided on the sky.

Figure 2-14 roundabouts on the sky cycle lanes (Daniels 2008)

V. Underpass cycle lanes

- Used in Multi-lane roundabouts with one or more circulating lanes and/or multiple approach and exit lanes, since the risk of collision is too great.
- Underpass connecting two ends of minor routes where cycle use are vigilant

Figure 2-15 Roundabout underpass cycle lanes, National Transport Authority (2011)

VI. Bypass cycle lanes or alternative cycle alignment

- Used in Multi-lane roundabouts with one or more circulating lanes and/or multiple approach and exit lanes, since the risk of collision is too great.
- Used as an alternative solution in case grade separated cycle lanes may be expensive or not possible to ensure continuity.
- Accomplished by using a different route parallel to the roundabout.

2.9.2 Intersections

There are three types of intersections with different controlling mechanisms or rules of operation. These are: signalized intersections, stop/yield sign intersections and priority intersections. The signalized intersections work by signal light and stop/yield sign intersections work by yielding (slowing down the approaching traffic) or stopping the approaching traffic in order that everything can be seen, managed, and transited safely; and priority/basic rule intersections work on the basis of priority for through traffics over turning traffics and appropriate provision of sight distance (Bikila 2011).

In the intersection designs, NACTO suggests a two stage turn queuing boxes (NACTO bikeway design guide 2013). Bicyclists will mix up with motorists to transit the intersection by two stage queuing boxes without having continuous cycle lanes that ends before the intersection and starts after the intersection. The queuing boxes lead cyclists to delay and make them exist in a very unsafe position in the middle of the junction, which will discourage cycle users where cyclists have to wait while motorized traffic passes on all sides. But this is not the case in the Netherlands design guide, CROW. The Netherlands use space gap/corner Island between intersection roadways and cycle tracks in which cyclists don't enter to the intersection and revolve the intersection as in the roundabout (National Transport Authority, Netherlands 2011). Cycle tracks are continuous and right hook accidents between right turn motor traffics and through cyclists are minimized by corner islands.

In the Netherlands bicycle stop line for bicycles are very close to the intersection while stop line for motors are far away from the intersection, the distance between two stop lines may be as far as 14m (National Transport Authority, Netherlands 2011). Since the motorists speed are faster than the bicyclists, the distance between the stop lines may help cyclists to clear from the intersection before automobiles reach there. This stop line distance between these two traffics may also help to avoid right hook conflict. But in the US stop lines are the same for both traffics, which will not be safe for bicyclists & decreases the intersection comfort level.

In the US there are many indexes or models developed regarding to intersections that are used to check bikeway compatibility for intersections as well as bicycle safety for intersections. Bikeway compatibility model is used to check whether the intersection can accommodate bikeway or not, but bicycle safety model is used to check whether the provided bikeways at intersections are safe for bicyclists or not. An intersection may have a space to accommodate bicycling lanes, but it may not be safe. As it has been discussed in section 2.3, almost all models have developed intersection compatibility indexes while they were developing link compatibility indexes. But most of the models are not confidential in the intersection indexes they have developed and they themselves said the models are not well developed and invite other scholars to modify or develop the intersection indexes.

In stop/yield intersections the big questions that are being arisen are; who (bicyclists or motorists) should yield or stop? (Schmitt 2014). There are many different divergent ideas regarding this in different concerned bodies. In some of cities of the Netherlands like city of Assen, bicyclists have a priority over motorists i.e. motorists have to wait till cyclists are being cleared from the intersection. But in the US in most cases motorists have a priority over bicyclists except in Idaho State where cyclists are allowed to treat stop signs as yield signs (Schmitt 2014).

In priority intersections giving priority/yielding for major route traffic (including cycle traffic) over minor route traffic and yielding for right of way traffic are mechanisms of operation (IsolateCyclist 2012). But, the US Utah state uses signal detection for bicycles at priority intersections in order that they can gather themselves safely and motorists can better notice them. But there is a difficulty that bicycles are often too light to cause the light to change and therefore have trouble traveling through the intersection (Allred 2013).

Summary of bikeway treatments at Intersections

If space allows motor and pedestrian only signalized intersections can be changed to all traffic intersections, by providing corner islands and pedestrian platforms with fully segregated cycle lanes as in the Netherlands. Bicycles should also be provided with traffic signals for safe use of the intersections. Right turn motorist should also be prohibited on red phasing in order to keep cyclists from right hook conflicts or optionally distancing away stop lines for motorists while providing stop lines for bicyclists close to the intersections entrance can also be used to keep cyclists from right hook conflict. Slight distancing of motorists stop line from the intersection should always be provided to make safe slowest cyclists from right hook conflicts. Left turn for bicyclists should be made on a two stage turn as in the Netherlands whether there is bike only signal phasing or not, to keep the safety of slowest bicyclists. The availability of bike only signal phasing should also be appreciated if there is no need of making the motorists being hurried or if the fastest movement of motorists is not required.

Provision of corner islands should be appreciated in all cases of bicycle lanes meaning whether the cycle lane is fully segregated or partially segregated type on the approach. If fully segregated, the refugee islands or pedestrian platforms can be made on the median that found between the cycle lane and roadway. If partially segregated bicycle lane approach is there, pedestrians should wait on the sidewalk till the pedestrian signal turns green.

If there is no space to provide for corner islands, right turn motorists must be provided with sole traffic signal phasing or they must be obliged not to turn right on red phasing for through motorists i.e. they should wait for their green time.

In order to avoid conflicts between bicyclists and pedestrians, pedestrian refugee islands should be made wide to accommodate for all bicyclist if space allows.

2.9.3 Grade separated junctions

Grade separation is a process used to improve traffic flow at intersections and junctions (Azuza n.d.). But here, the concern of this part is about those junctions which are combinations of under passes or over passes with roundabouts and intersections. The other types will be covered in grade separated interchanges later.

In the Netherlands and other cycle friendly countries and cities, it is suggested that bike lanes at grade separated junctions should continue as it comes on the approach i.e. if it approaches in the median it should continue in the median; but if the median has a continuity on the under pass or on the over pass, the median should be well widened and guarded with guardrails to protect cyclists from weaves, and if it comes on the right of way it should continue that way to reduce the conflicting points (Azuza n.d.). Then, treating this way, grade separated junctions will be reduced to single junctions. Thus, bikeway treatments recommended for single junctions can be applied then.

2.9.4 Interchanges

VTA Bicycle Technical Guidelines (Caltrans 2012) describes interchanges as of two types: grade separated interchanges and non-grade separated interchanges.

2.9.4.1 Grade separated interchanges

In the US, at grade separated interchanges, there is a possibility of providing bikeways to interchange overpasses unlike the Netherlands, who rarely provide suggests bike lanes to interchange overpasses. Bypass bike paths may also be used so that bicyclists can avoid the weave on the far side of merging points (Adam Fry & Jeffrey Eisenhaur 2011). Circulation difficulties at grade separated interchanges for bicyclists may happen due to grade of overpass/flyover, high design speed and travel speed, lack of shoulders or bike lanes on overpass, unsafe weaves and merges in order to traverse through the interchange, and design that results in bicyclists having to be in uncomfortable and/or illogical lanes forcing a merge across a full lane of high speed traffic. The solutions for these difficulties according to (VTA Bicycle Technical Guidelines, Caltrans 2012) are provision of maximum design speed of 35 mph, maximum grade of 5%, 8ft shoulders or bike lanes throughout and by pass bike paths.

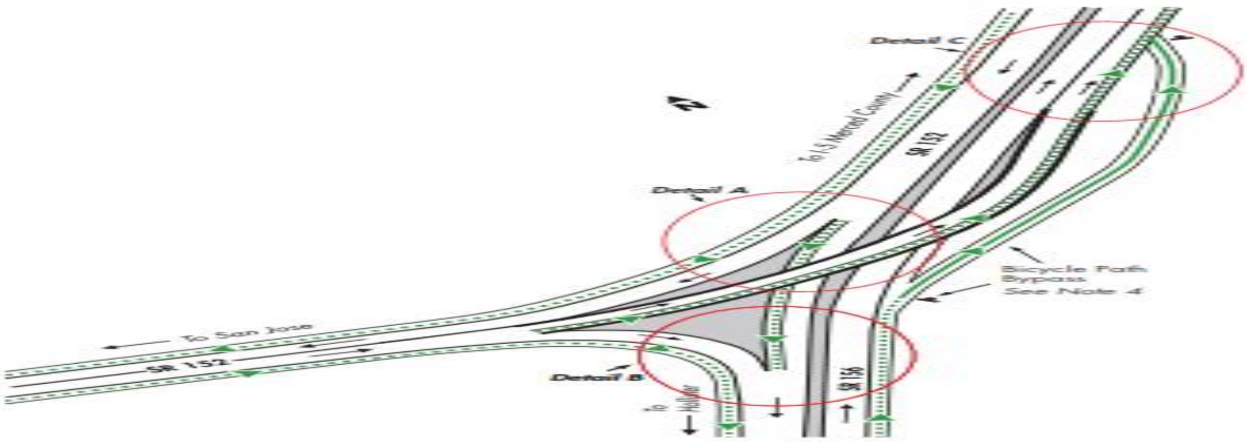

Figure 2-16 broken lines indicate bike lanes and solid lines indicate bypasses bike path at grade separated interchanges (VTA Bicycle Technical Guidelines, Caltrans 2012).

Figure 2-17 Wide shoulders at grade separated interchanges with bicycle railing to accommodate the bicyclists on overpass (VTA Bicycle Technical Guidelines, Caltrans 2012).

As indicated earlier the case is different in the Netherlands, they rarely provide cycle tracks to interchange overpasses, rather they used a separate bypass route from the interchanges.

Figure 2-18 Bypass routes of bicyclists in the Netherlands (Adam Fry & Jeffrey Eisenhaur 2011)

2.9.4.2 Non grade separated interchanges

There are different types of non-grade separated interchanges, these are interchanges with diverging ramps and merging ramps (Amy Ibrahim 2012). At both types of non-grade separated interchanges, ways of bikeway provision in the US and in the Netherlands are too much different. In the US, in both cases of diverging and merging ramps, through bikeways made continuous as it comes on the approach with provision of road markings according to traffic volume and traffic speed of the road in need. For lower speed diverging ramps, bike lanes made continues by using dashed lines for through cyclists. But for diverging cyclists there is no lane provision as the diverging ramp operates with lower speed, they used mixed traffic in this case. In the case of merging ramps with lower speeds, through cyclists lanes made continuous by dashed lines and merging cyclists also merge without cycle lane as in the case of lower speed diverging ramps, but motorists are provided with acceleration lane and yield sign. For high speed merging and diverging ramps, through cyclist lanes are provided with boulevards and there will also be queuing island in which cyclists wait and traverse the interchange. Merging and diverging bicycle traffics will also be provided with dedicated cycle lane, as motorists ramps are high speed ramps (Amy Ibrahim 2012). They may also use auxiliary lanes and bike lanes together at arterials in order to reduce conflicts between merging and weaving traffics (VTA Bicycle Technical Guidelines, Caltrans 2012).

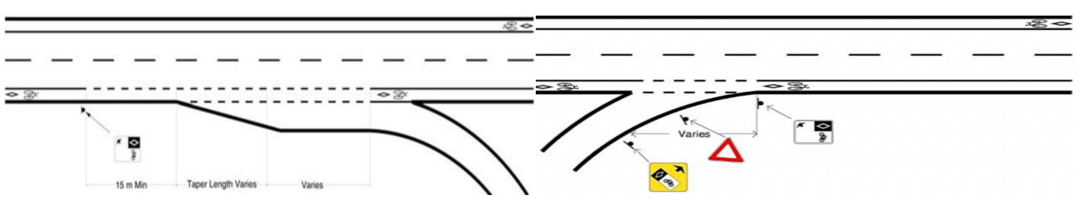

Figure 2-19 Low speeds diverging and merging ramps with dashed line through cycle lane and mixed traffic ramps (Amy Ibrahim 2012)

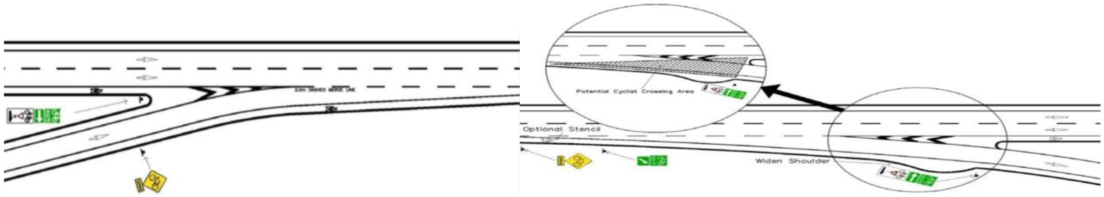

Figure 2-20 High speed merging and diverging ramps with boulevard for through cycle lane and with dedicated cycle lane ramps (Amy Ibrahim 2012)

Figure 2-21 Auxiliary lane and bike lane (VTA Bicycle Technical Guidelines, Caltrans 2012).

But in the Netherlands, for safety matters, bicyclists at interchanges are provided with separate cycle tracks making a U shape movement as they separate from roadway and return back to roadway. This applies in both cases whether it is merging or diverging ramp. They may also be provided with signal lights for both motorists and cyclists as in the signalized intersections when there is no enough space to make U shape turn and when there is a sharp right turn. In case of rural interchanges; if possible, the Netherlands will use two way cycle tracks to traverse the interchanges. Cyclists diverging ramps can also safely diverge from the existing cycle track without conflicting with motorists (Adam Fry & Jeffrey Eisenhaur 2011).

Figure 2-22 Interchange ramps with U turn, two way cycle track and signal lights respectively from left to right (Adam Fry & Jeffrey Eisenhaur 2011)

Summary of bikeway treatments at interchanges

According to the above discussions, the Netherlands way of providing bikeways to interchanges of both types is safer than that of US. In the US there is a problem of discontinuity and safety at interchanges as compared to the Netherlands, but the Netherlands way may also require wide space to provide their U shape turn at non grade separated interchanges and bypass cycle track at grade separated interchanges. Therefore, the Netherlands ways of treatments are better in safety than the USs ways but requires relatively more space and higher investment than the USs.

2.9.5 Bridges

At bridge sites the possible bikeway treatments are mixing the traffic if there is no space to make the bikeway continuous, making the bikeway continuous on the existing infrastructure if there is a space to do so and providing another bike only bridge on the right of way (Daniels 2008; BicycleDutch 2011).

CHAPTER 3 Research methodology

3.1 Study area

The study area is Addis Ababa (also called Finfinne in Afaan Oromo), the capital of Ethiopia and Oromia regional state. The city is the country's political and economic center; administrative center/headquarter of African union and United Nations economic commission for Africa; and many other international and national organizations. It is found at the center of Ethiopia in Oromia regional state at geographical coordinates of $9^0$2'0" North (latitude) and $38^0$42'0" East (longitude) at an altitude of 2,300m. Addis Ababa has a subtropical highland climate with daily maximum temperature of 23^0c and minimum temperature that can drop to freezing.

The city's major means of transportations are mainly walking, which accounts to 70% and motor transportation, which accounts to 30%. The infrastructures being used for transportation purposes in the city are roads, junctions and bridges, which includes motorways and walkways, and excludes cycle ways. The study will include selected road segments, junctions and bridges in Addis Ababa. The particular area of study will be selected later.

3.2 Sampling and data collection

The study subjects or participants are roads, junctions, and bridges that will be encountered on the selected routes. The samples are selected based on the results of site visit and desk study. The site visit has been made using the site visit worksheet developed depending on the site selection criteria listed as follows (For details refer to appendix F). The criteria used for site selections are:

- width of the carriageways, shoulders, and medians
- trip attraction abilities of route ends
- trip producing ability of route origins
- currently available transportation facilities on the route
- availability of transport stations on route end and origin
- gradient of the route
- length of the route
- frequency of junctions
- right of way land use development
- population density in the area(desk study)
- accident record of the route(desk study)

- master plan(desk study)

According to site visit and desk studies made based on these criteria, the following eleven routes are selected among the many proposed routes:

- Ayat Roundabout - Chafe/Ayat Condominium
- Imperial Roundabout - 17 Health Center
- Ayat Roundabout – Summit Factory
- CMC Roundbout – Summit Factory
- Ayat Roundabout – Yeka Abado
- Ayertena- Alem bank
- General Winget School - Pasteur
- Michael Roundabout – Jomo 3 Condominium
- Akaki Bridge – AASTU/Addis Ababa Science And Technology University/
- Kera- Kirkos
- German Roundabout – Gofa Camp

These eleven routes are among which the three streets will be reselected for implementation of bikeway based on detail analyses later. After reselection of the three routes, junction types and bridges that will be included on the study will be identified from junctions and bridges found on the reselected routes.

Secondary data is the primary source of this research. It has been accessed from AACRA (Addis Ababa City Road Authority) and AACRTB (Addis Ababa City Road and Transport Bureau). The voluntarily or conveniently found data's has been used at first. For data's that are not found voluntarily from secondary data, assumptions have been made based on the estimators used methods of assumptions. For data's that has been impossible to attain from secondary sources and assumptions, original survey has been conducted to get the primary data. The inquired data's are topographic, geometric, traffic, right of way and environmental characteristics. It will be detailed in section 3.3 along with plan of data analysis.

3.3 Plan of data analysis and data requirements

Data analysis is different for different road elements and for different assessment methods used.

3.3.1 Topographic plan of data analysis

The three selected methods for topographic analysis:

i. Developed method of topographic analysis

The maximum bikeable slope for athletes is 15% grade, for healthy humans' 4%-6% grade and for average humans 3%. Therefore, provision of isolated bikeway facilities as well as roadway bikeway facilities with gradient of up to 3% grade is possible for any length, up to 4% grade is not frequently possible and up to 6% grade should be only for connectivity matters. More than 6% there should not be bikeway.

ii. AASHTO method of topographic analysis

AASHTO suggests grades less than 5% are bikeable for any length. However, AASHTO offers the following suggested lengths for certain grades greater than 5%:

- 5-6% is acceptable for up to 800 feet=243.84m
- 7% is acceptable for up to 400 feet=121.92m
- 8% is acceptable for up to 300 feet=91.44m
- 9% is acceptable for up to 200 feet=60.96m
- 10% is acceptable for up to 100 feet=30.48m

iii. Cyclingnews.com

Cyclingnws.com points out the following lists of how various gradients might feel.

- 0%: A flat road
- 1-3%: Slightly uphill but not particularly challenging. A bit like riding into the wind.
- 4-6%: A manageable gradient that can cause fatigue over long periods.
- 7-9%: Starting to become uncomfortable for seasoned riders, and very challenging for new climbers.
- 10%-15%: A painful gradient, especially if maintained for any length of time
- 16%+: Very challenging for riders of all abilities. Maintaining this sort of incline for any length of time is very painful.

3.3.2 Method of data analysis for road segments

3.3.2.1 Bicycle compatibility index (BCI)

BCI method has its own worksheet that helps in the data analysis. The worksheets are data entry, intermediate calculation, and level of service worksheets. Here are the data requirements and method of data analysis for the model. For the formula and for level of service rank see section 2.3.

Data requirements:

- BL- presence of bicycle lane or paved shoulder > or = 0.9m; yes=1, or no=0
- BLW- bicycle lane or paved shoulder width (in m to the nearest tenth)
- CLW- Curb lane width (in m to the nearest tenth)
- CLV- Curb lane volume in one direction (VPH in one direction)
- LV- other same direction lane(s) volume (VPH in one direction
- SPD- 85th percentile speed of traffic (in km/hr)
- PKG- presence of parking lane with more than 30% occupancy (yes=1, no=0)
- AREA- type of road side development (residential=1, other type=0)
- AF- adjustment factors for trucks or buses, right turn volumes and parking turnovers
- AF= $f_t+f_r+f_p$; f_t- adjustment factor for truck volumes, f_r - adjustment factor for parking turnover, f_p- adjustment factor for right turn volumes
  - ✓ Hourly curb lane large truck volume (HCLLTV), used to obtain f_t value.
  - ✓ Parking time limit in minute (PTLIM), used to obtain f_p value.
  - ✓ Hourly right turns volume (HRTV), used to obtain f_r value.

Method of data analysis:

Table 3-1 BCI data entry worksheet

Location	Geometric and road side data					Traffic operations data					Parking data		
Mid-block identified	No. of Lanes (one direction)	Curb Lane Width (m)	Bicycle Lane Width (m)	Paved Shoulder Width (m)	Residential Development (y/n)	Speed Limit (km/h)	85^{th} %tile Speed (km/h)	AADT	Large Truck % (HV)	Right Turn % (R)	Parking Lane (y/)	Occupancy (%)	Time Limit (minutes)

Table 3-2 BCI Intermediate calculations worksheet

Location	Peak hour computations							Adjustment factors				
Middle block identified	Peak Hour Factor (K-factor)	Directional Split (D-factor)	Curb Lane %	Curb Lane Truck % (T-factor)	Peak Hour Volume (PHV)	Peak Hr Curb Lane Volume (CLV)	Peak Hr Other Lane(s) Vol (OLV)	Peak Hr Curb Lane Truck Vol (CLTV)	Large Truck Adjustment Factor (Ft)	Peak Hr Right Turn Volume	Right Turn Adjustment Factor (Frt)	Parking Adjustment Factor (Fp)

Table 3-3 Bicycle Compatibility Index and Level of Service Computations worksheet

Location	BCI model variables									Results		
Midblock identifier	BL	BLW	CLW	CLV	OLV	SPD	PKG	AREA	AF	BCI	Level of Service	Bicycle Compatibility level

$$\mathbf{BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF}$$

3.3.2.2 Bicycle level of service (BLOS)

BLOS also has its own worksheets: BLOS data entry & calculations worksheet, and BLOS score and level of service calculations worksheet. They are presented as follows:

Data requirements:

- Vol_{15} = Volume of directional motorized vehicles in the peak 15 minute time period
- L = Total number of directional through lanes
- SP_t = Effective speed factor = 1.1199 In (SPp - 20) + 0.8103
- SPp = Posted speed limit (a surrogate for average running speed)
- HV = percentage of heavy vehicles
- PR_5 = FHWA's five point pavement surface condition rating
- W_e= Average effective width of outside through lane (which incorporates the existence of a paved shoulder or bicycle lane if present)
- W_t= total width of outside lane (and shoulder) pavement

- %OSP = percentage of segment with occupied on-street parking
- W_l= width of paving between the outside lane stripe and the edge of pavement
- Wps = width of pavement striped for on-street parking
- W_v= Effective width as a function of traffic volume

Method of data analysis:

Table 3-4 BLOS data entry & calculations worksheet

Route name	Vol_{15}	L	SP_p	SP_t	HV	PR_5	W_e	W_t	%OSP	W_l	Wps	W_v	AADT

Table 3-5 BLOS score and level of service calculations worksheet

Route name	Vol_{15}	L	SP_t	HV	PR_5	W_e	BLOS score	letter grade	Level of service

$$\boldsymbol{BLOS} = \mathbf{0.507\,ln}\left(\frac{\mathbf{Vol_{15}}}{\mathbf{L}}\right) + \mathbf{0.199SP_t}\,(\mathbf{1} + \mathbf{10.38HV})^{\mathbf{2}} + \mathbf{7.066}\left(\frac{\mathbf{1}}{\mathbf{PR_5}}\right)^{\mathbf{2}} - \mathbf{0.005}(\mathbf{W_e})^{\mathbf{2}} + \mathbf{0.760}$$

3.3.2.3 Brent Hugh's Excel analysis method

In addition, there is an excel file developed by Brent Hugh (2003) which can calculate BCI, BLOS, CBF (Chicago land Bicycle Federation Bicycle Map Criteria) and IDOT(Illinois Department of Transportation memo) level of service scores. It makes the calculations so easy; however, it doesn't consider right turn factors.

BLOS and BCI analyses can be done by both methods, which are by Brent Hugh's Excel analysis method that doesn't consider right turn factors, and model analysis methods that consider right turn factors as in the section *3.5.2.1* and *3.5.2.2.* But CBF analysis will be done by only excel analysis method of Brent Hugh since in both analysis methods it doesn't consider right turn factors. Since IDOT (Illinois Department of Transportation memo) was developed for rural roads and it doesn't apply well to urban roads i.e. since it assumes fast rural speed limits, it is impossible to apply it here confidentially.

Table 3-6 Brent Hugh's BCI, BLOS, and CBF excel calculator

Road Name/ID #1:	*Road Name/ID #2:*	*Road Name/ID #3:*	*Road Name/ID #4:*
Lanes per direction	*Lanes per direction*	*Lanes per direction*	*Lanes per direction*
curb lane width	*curb lane width*	*curb lane width*	*curb lane width*
shoulder/bike lane width	*shoulder/bike lane width*	*shoulder/bike lane width*	*shoulder/bike lane width*
Bi-directional ADT	*Bi-directional ADT*	*Bi-directional ADT*	*Bi-directional ADT*
Speed limit	*Speed limit*	*Speed limit*	*Speed limit*
% heavy trucks	*% heavy trucks*	*% heavy trucks*	*% heavy trucks*
Pavement condition (5 best)	*Pavement condition (5 best)*	*Pavement condition (5 best)*	*Pavement condition (5 best)*
% on-street parking	*% on-street parking*	*% on-street parking*	*% on-street parking*
Parking time limit	*Parking time limit*	*Parking time limit*	*Parking time limit*
1=residential, 0=not resident'l	*1=residential, 0=not resident'l*	*1=residential, 0=not resident'l*	*1=residential, 0=not resident'l*
BCI	BCI	BCI	BCI
BLOS	BLOS	BLOS	BLOS
CBF	CBF	CBF	CBF

Instructions: *Enter appropriate data. BCI, BLOS, and CBF will calculate automatically.*

3.3.3 Junctions method of data analysis and data requirements

3.3.3.1 Roundabout plan of data analysis

No roundabout bicycle compatibility model is found to be existent. So, roundabout method of data analysis should be summarized according to the obtained literature review findings. The critical roundabout parameters that will greatly affect the compatibility of roundabouts to bikeway facilities as discussed & identified on the literature review are type of the roundabout, existence of bike lane, inscribed circle diameter, roundabout traffic volume, approach traffic speed, roundabout traffic speed, available right of way space of the roundabout, entry types and number of entry lanes, and exit types and number of exit lanes.

Some of the parameters have high degree of influence and some have less degree of influence in deciding roundabouts compatibility to bikeway. Hence factors that have high degree of influence are roundabout type, roundabout traffic speed, roundabout traffic volume and available right of way space; and the factors that have less degree of influence are inscribed circle diameter, entry types and number of entry lanes, and exit types and number of exit lanes. Hence according to this, the data requirements & the summarized method of data analysis are described as follows.

Data requirements:

- RT=Roundabout type
- RSPD= roundabout traffic speed

- TV= roundabout traffic volume
- ASPD= approach traffic speed
- RWS= available right of way space of the roundabout
- ICD=Inscribed circle diameter
- ENTL= entry types and number of entry lanes
- EXTL= exit types and number of exit lanes

Method of data analysis:

Table 3-7 Roundabout method of data analysis

<table>
<tr><th>Roundabout Type</th><th>Traffic volume (kveh/day)</th><th>Right of way space available(m)</th><th>Possible Treatments</th></tr>
<tr><td rowspan="7">Multi-lane roundabout</td><td>10-20</td><td>Any</td><td>Segregated cycle track with single lane roundabout if approach types are flared & right angled</td></tr>
<tr><td>20-35</td><td>>=2.5m</td><td>Fully segregated cycle track in side built up area priority for bicycles</td></tr>
<tr><td>45-55</td><td>>3m</td><td>Fully segregated cycle track in side built up area priority for bicycles</td></tr>
<tr><td></td><td><2m</td><td>Bypass, alternative cycle route or under pass cycle lane if topography allows.</td></tr>
<tr><td rowspan="2">>> 50</td><td>>4m</td><td>Fully segregated cycle track outside built up area priority for motorized vehicles</td></tr>
<tr><td><4m</td><td>Separate cycle lane on the sky or under pass cycle lane if topography allows: if and only if bypass or alternative cycle route is impossible</td></tr>
<tr><td><6</td><td>Any</td><td>Mixed Roundabout</td></tr>
<tr><td rowspan="3">Single lane Roundabout</td><td rowspan="2">6-10</td><td><2.5m</td><td>Segregated cycle track with heightened curb</td></tr>
<tr><td>>2.5m</td><td>Fully segregated cycle track if more safety is required</td></tr>
<tr><td>>10</td><td>>2.5m</td><td>Fully segregated cycle track</td></tr>
<tr><td rowspan="5">Mini Roundabout</td><td rowspan="3"><6</td><td>Any</td><td>Mixed Roundabout</td></tr>
<tr><td>Wide Carriageway</td><td>Roundabout with cycle lane delineated by solid line</td></tr>
<tr><td>Wide Carriageway</td><td>Segregated cycle track with heightened C curb if safety is required and if bicyclists traffic is expected to be high</td></tr>
<tr><td>>6(slightly greater)</td><td>Any</td><td>Mixed roundabout if there is a smooth traffic flow record</td></tr>
<tr><td>>6(highly greater)</td><td>Wide Carriageway</td><td>Single lane roundabout with segregated cycle track</td></tr>
</table>

3.3.3.2 Intersection plan of data analysis

There are intersection compatibility models developed by BCI and BLOS models but they are not suitable to use as discussed in the literature review. Because 1) the model developers themselves are not confidential in the model they developed and they invite others to modify it, and 2) since the models are developed by Americans; the model they developed are the suitability to check for their two stage queuing box intersection transit system, which has been discussed that it is less safe than Netherlands type of intersection transit. Hence it is better to use the critical parameters or factors that can affect provision of bikeway to intersections in the way of the Netherlands.

The critical parameters/factors that can affect provision of bikeway to the intersection as discussed in the literature review are; right of way space (sidewalk + the rest), elevation difference between the roadway and the right of way space, visibility of the intersection from all sides and approach traffic volume of the intersection legs.

Data requirements:

- Available right of way space in meter
- Elevation difference between the roadway and the right of way
- Visibility of the intersection from all sides
- Approach traffic volume of the intersection legs

Method of data analysis:

Right of way available space (sidewalk + the rest) in m

- Sidewalks should be their widths known and checked according to the pedestrian concentration on the area
- The rest of empty spaces available on the right of way should be known

Elevation difference between the roadway and the right of way space or the sidewalks

- Visual comment should be made

Visibility of the intersection from all sides

- Whether the intersection is easily visible from each side of its leg to the other

Approach traffic volume of the intersection legs

- Whether it is low, moderate or high

Then, the Netherlands way of protected intersection bikeway treatment can be adopted & used.

3.3.3.3 Method of data analysis for bridges

The most probable treatments that can be applied for bridges are:-

- Making bike lanes continuous as it comes on the approach,
- Mixing motorized and bicycle traffics at bridge sites
- Providing another bike only isolated bridge on both side of the bridge.
- Making bike lanes continuous if already shared and isolated bike lanes exist on the approach.

Making bike lanes continuous as it comes on the approach

- This will be possible if the roadway at bridge sites are not narrowed (the same width with the approach roadway) and if curb heights are short.

Mixing motorized and bicycle traffics at bridge sites

- This treatment is possible for low volume traffic and if the first treatment is not possible due to narrow and curbed bridge sites.
- It will be conflicting for pedestrians and bicyclists if road combination is motor traffic lane-pedestrian walkway-bike lane. And these conflicts can be avoided by providing yield signs for both bicyclists and motorists, and turn lanes for bicyclists as they enter to roadways and as they exit from roadway. No problem will happen if road combination is motor traffic lane-bike lane- pedestrian walkway in this case.

Providing another bike only isolated bridge on both side of the bridge

- This should be used in case the above three treatments are not possible.
- In this case there may be conflicts between pedestrians and bicyclists if bikeway provision on the approach and exit is 'right side adjoining bike lane' next to motorized traffic lane. And these conflicts can be avoided by providing yield signs and turn lanes for bicyclists as they are being out of bike lanes and as they enter back to bike lanes. No problem will happen for this treatment if road combination is motorized traffic lane-pedestrian walkway-bike lane' from inside out.
- And also there may be conflicts between motorized traffics and bicyclists if bikeway provision is adjoining left side type of 'median left side adjoining bike lane' and buffered

median lane left side adjoining bike lane'. This conflict can be avoided by making bike lanes continuous in the median and this must be a must, otherwise it will be unwise design and the conflicts will continue with pedestrians.

Already shared and isolated bike lanes on the approach shall continue as on the approach

- Shared road types are already shared and isolated bike lane types are also already isolated, and hence shall continue as such
- Isolated bike lanes may intersect at bridges sites if there is no possibility of making isolated the isolated bike lanes.

Bicycle bridges can also be underpass (inverted bridge) or overpass. Overpasses will be for safe traversing of rivers, valleys and crowded motorways. Underpasses will help to avoid major car traffic by having their bike paths go underneath rather than over highways if the topographic feature allows. Shared pedestrian and bike bridges may also be possible in case the roadway bridges don't allow more traffic due to constrained narrow width and heightened curbs. It can also be bike only bridge.

The plan of data analysis for bridges is related to either of how bicycles traverse the motorists' bridge or how bicycle bridges themselves have to be provided to traverse the motorists' bridge. Here also for bridges, there are no developed bicycle compatibility check model has found. So, as it has been done on the other parts, it is better to summarize plan of data analysis for it, depending on the critical factors which has a great ability to affect bikeway provision at bridge sites.

Therefore, the critical parameters or the data requirements are:

- TVOB= traffic volume on bridge,
- TSOB= traffic speed on bridge,
- BLWOA= Bike lane whereabouts on the approach,
- SWB= Shoulder width of the bridge,
- AHC= Availability of heightened curb,
- ASORWB= Available space on right of way of the bridge,

- ASTF= Available spaces topographic feature,
- MWB=Median width at bridges,
- AOG=availability of guardrails, and
- TMMMOAB=type of material median is made of at bridges.

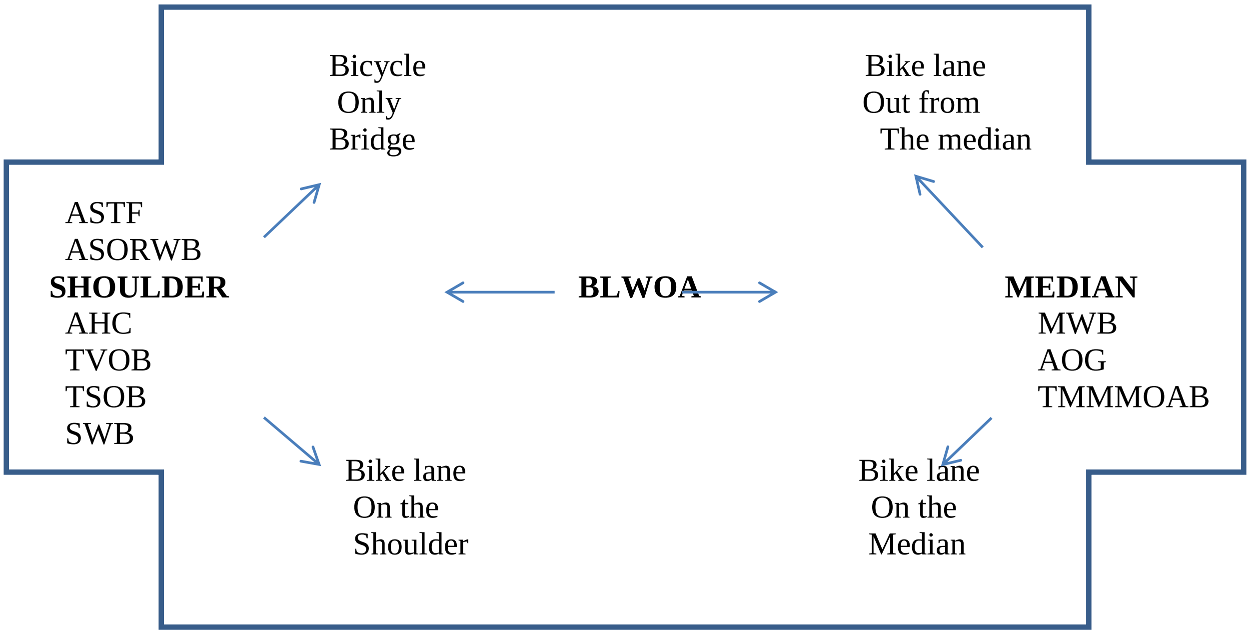

Figure 3-1 bridge data entry and analysis

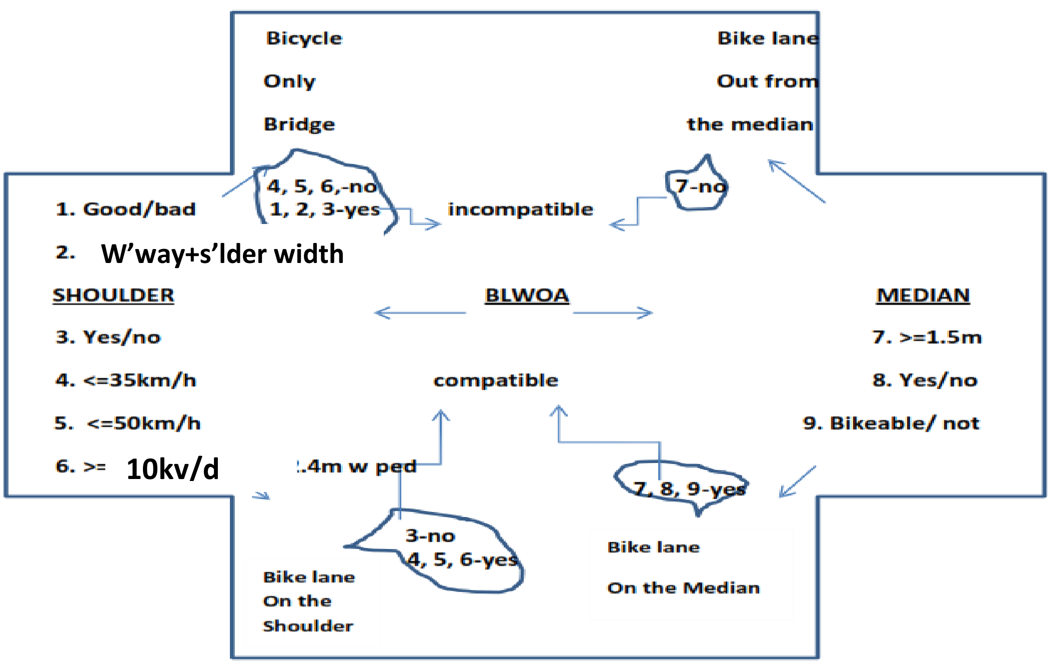

Figure 3-2 bridge plan of data analysis

CHAPTER 4 Analysis and Results

4.1 Topographic analysis

Before executing bikeway compatibility test it is necessary to conduct detail topographic study of the selected routes. This is because the bikeway compatibility test models don't consider the effect of gradient of the road on bicyclists. Hence, the topographic analysis will be made based on three methods of analysis that has been identified in the literature review: Developed method of topographic analysis, AASHTO, and cyclingnews.com (refer to section 2.5.1).

To show the way the analysis is made; two routes, which are Ayat round about to Ayat condominium (chafe) and Akaki Bridge to AASTU, have been selected among the eleven selected routes and the analysis of other road segments can be referred from Appendix A.

4.1.1 Ayat round about to Ayat condominium /chafe/

Table 4-1 Ayat round about to Ayat condominium /chafe/ topographic analysis

Chainages in m.(from)	Chainages in m.(to)	Gradient (%)	Developed method	AASHTO	Cyclingnews.com
0+000	0+281.4	-1.2	Bikeable	Bikeable	Bikeable
0+281.4	0+409.7	-2.8	Bikeable	Bikeable	Bikeable
0+409.7	0+572.2	-5.4	For connectivity	Bikeable 162.5m<243.834m	Manageable
0+572.2	0+747.8	5.3	For connectivity	Bikeable 175.6m<243.834m	Manageable
0+747.8	0+967.3	2.9	Bikeable	Bikeable	Bikeable
0+967.3	1+217.9	0.1	Bikeable	Bikeable	Bikeable
1+217.9	1+367.7	-1.8	Bikeable	Bikeable	Bikeable
1+367.7	1+566.0	-1.2	Bikeable	Bikeable	Bikeable
1+566.0	1+701.0	-3.8	Possible to apply	Bikeable	Not challenging

All other chainages gradients are less than 3%, which is considered as a bikeable gradient by all methods used to check the gradients, except at these chainages:-

- 0+409.7 – 0+572.2 = 162.5m ⟶ -5.4 %
- 0+572.2 – 0+747.8 = 175.6m ⟶ 5.3%

Developed method: - 5.4% & 5.3% [5-6] % (only possible for connectivity matters)

AASHTO: - - 5.4% & 5.3% [5-6] % and [162.5m & 175.6m] < 243.84m (bikeable)

Cycling news com: - 5.4% and 5.3% [4-6] % (manageable gradient)

- 1+66.0 – 1+701 ⟶ -3.8%

Developed method: 3.8% < 4% (possible)

AASHTO: 3.8% < 5% (bikeable)

Cyclingnews.com: 3.8% <4% (manageable gradient)

Therefore, generally the route 'Ayat roundabout to Ayat condominium /chafe/' is bikeable with respect to gradient.

4.1.2 Akaki Bridge to AASTU (Addis Ababa science and Technology University)

Table 4-2 Akaki Bridge to AASTU topographic analysis

Chainages in m.(from)	Chainages in m.(to)	Gradient (%)	Developed method	AASHTO	Cyclingnews.com
0+000	0+175.8	3.7	Possible to apply	Bikeable	Not challenging
0+175.8	0+306.5	2.2	Bikeable	Bikeable	Bikeable
0+306.5	0+491.6	4.8	For connectivity	Bikeable	Manageable
0+491.6	0+651.4	2.8	Bikeable	Bikeable	Bikeable
0+651.4	0+886.5	5.8	For connectivity	Bikeable 235.1m<243.934m	Manageable
0+886.5	1+081.8	4.7	For connectivity	Bikeable	Manageable
1+081.8	1+506.1	2.4	Bikeable	Bikeable	Bikeable
1+506.1	2+009.6	2.5	Bikeable	Bikeable	Bikeable
2+009.6	2+708.4	2.4	Bikeable	Bikeable	Bikeable
2+708.4	3+356.9	3.6	Possible to apply	Bikeable	Not challenging

All other chainages gradients are between (2-3) % and all are uphill, which are bikeable since the gradients are less than 3%, except at these challenges, which are more than 3% but all uphill:

- 0+000.0 - 0+175.8 ⟶ 3.7%
- 2+708.4 – 3+356.g ⟶ 3.6%

Developed method 3.7% and 3.6% < 4% (possible)

AASHTO: 3.7%&3.6% <5% (bikeable)

Cyclingnews.com: 3.7% & 3.6% (manageable gradient)

- 0+306.5 - 0+491.6 ⟶ 4.8%
- 0+886.5 – 1+081.8 ⟶ 4.7%

Developed method: 4.8 % and 4.7% < 6% (only possible for connectivity matters)

AASHTO: - 4.8% & 4.7 %< 5% [bikeable]

Cycling news.com: 4.8% & 4.7 % (manageable gradient)

- 0+651.4-0+886.5 =235.1m ⟶ 5.8%

Developed method: 5.8% < 6% (only possible for connectivity matters)

AASHTO: 5.8% (5-6%) & 235.1m<243.843m (bikeable)

Cycling news com: 5.8% (4-6%) (Manageable gradient)

Therefore, the route is bikeable according to the above analysis with respect to gradient, but it can cause difficulty/fatigue over long period of time for frequent users since all the gradients are uphill and since there are no gradients less than 2% grade that can give high relief for riders when they turn from one high gradient riding to the other.

4.2 Compatibility analysis

4.2.1 Analysis by BCI (Bicycle Compatibility Index) for Akaki Bridge to AASTU and Ayat roundabout to Ayat condominium /chafe/

Table 4-3 Data entry for Ayat - chafe and Akaki - AASTU

Location	Geometric and road side data					Traffic operations data					Parking data		
Midblock identifier	No. of Lanes (one direction)	Curb Lane Width (m)	Bicycle Lane Width (m)	Paved Shoulder Width (m)	Residential Development (y/N)	Speed Limit (km/h)	85th %tile Speed (km/h)	AADT	Large Truck % (HV)	Right Turn % (R)	Parking Lane (y/N)	Occupancy (%)	Time Limit (minutes)
Ayat – Chafe	3	3.5	0	0	Y	35	50	9237	0.01	0.02	N	0	<15
Akaki-AASTU	2	3.5	0	0	Y	35	50	8054	0.01	0.025	N	0	<15

Description of the entered data's:
Curb lane width for both is 3.5m = 11.67 ft.

Totally there is no bicycle lane provision in Addis Ababa. Therefore, bicycle lane width is '0'.

Since there are no paved shoulders that can be rideable or bikeable by cyclists on these routes, it is possible to take paved shoulder width as 0 [for both routes].

Since there is a residential development on the route corridors of especially, Ayat-chafe as well as on its origins & destinations, it is possible to say the residential development of the area as 'yes'. For Akaki-AASTU route, since the condominium's being built are at their finishing stage, it is likely that the inhabitants will take/ receive it soon. So, it is better to say 'yes' for this route too.

As the information obtained from the concerned bodies, 35km/h posted speed limit is generally being used in all urban streets of Addis Ababa except on ring road.

85^{th} percentile speed can be obtained by adding 15km/hr on the metric posted speed limit and 10mi/h on mileage posted speed limit as the model recommends.

- 85^{th} % ile speed (metric) = 35km/hr+15km/hr = 50km/hr
- 85^{th} % ile speed (mileage) = 22.5mi/hr+10mi/hr = 32.5mi/hr

Existing/base line traffic volume calculation:

For Ayat-chafe route, since the road has been built long time ago, the traffic volume obtained from the existing design document (converted to date by economic growth rate of the area) is used by comparing with one directional traffic count that has been made at peak hour and on peak direction, and for Akaki-AASTU route, since the road has been built recently, the traffic volume obtained from traffic study and pavement design part of the report of consultants during construction of the existing road has been used by converting it to date by economic growth rate of the area.

- $AADT_{base}$ (Ayat – chafe) = 1890

  Large truck (HV %) = [15 heavy + 15 articulated] = $\frac{30}{1890}$ = 0.016%-from previous study

- $AADT_{base}$ (Akaki - AASTU) = 2450

  Large truck (HV %) = [13 heavy + 13 articulated] = $\frac{26}{2450}$ = 0.01%-from previous study

Using the AADT and large truck percentage values from inventories may not give more safety because the data's were collected before years. Hence, to be convenient or to be safe the base line AADT can be converted to current AADT for at least considering 3 years from the time these data are collected to date by AACRA's economic growth rate of the area. And also, it is important to note that the model recommends only usage of the current/existing traffic volume but not that of the design AADT.

So, $AADT_{converted} = AADT_{base} * \frac{(1+i)^n-1}{i}$, where i -growth rate and n – growth year

Table 4-4 AACRA economic zone summary (AACRA manual, 2004)

2004 AACRA manual(road package) economic zone summary		
Route name	Economic zone	Recommended growth rate(i)
Ayat-Chafe(A-C)	3	7
Akaki-AASTU(A-A)	6	9.3

- $i_{\text{A-C}}$ = 7% - [Economic zone- 3]
- AADT $_{\text{converted}}$ (Ayat-chafe) = 1890*($\frac{(1+0.07)^3-1}{0.07} = 6076$ (from inventories)
- $(Vol_d)_{15min}$[Ayat-chafe]=127veh/15min (from traffic count)
- PHV=127veh/15min*60min=508veh/hr
- PHV (Peak hour volume) = AADT *K*D => AADT=PHV/K*D=508/0.1*0.55= 9237
- So, $AADT_{count}$>$AADT_{converted}$, using $AADT_{count}$ =9237 will be more reliable
- $i_{\text{A-A}}$ = 9.3% - [economic zone- 6]
- AADT $_{\text{converted}}$ (Akaki-AASTU) = 2450 * $\frac{(1+0.093)^3-1}{0.093} = 8054$

To consider heavy vehicle percentages AACRA manual presents the percentage of different vehicles on different road classifications, so it is better to use the AACRA provided values as presented in table 4.5.

Table 4-5 Typical values of Addis Ababa traffic (AACRA manual, 2004)

Road classification	AADT(Two ways)	Vehicle groups typical percentage				
		Car	Light	Medium	Heavy	Articulated
Arterial	10000	80	17	2	0	1
Sub arterial	9000	89	9	1	0	1
Collector	4000	91	8	1	0	0
Local	1500	97	3	0	0	0

So, percentage of large trucks for both Arterial and sub-arterials is 1 % (heavy + articulated).

Since there are no data’s found about the right turn volume, judgment should be made as the model recommends user judgments to be made if the data is not available. So, there are no frequent driveways observed on the route corridors of both sites. Therefore, considering right turn volume of < 270 may be possible, say 200, then by dividing this value to the corresponding AADT’s, right turn percentage(R %) can be obtained.

- (R %) $_{A-C}$ = $\frac{200}{9237}$ = 2%, (R %) $_{A-A}$ = $\frac{200}{8054}$ = 2.5%

Since there are no on street parking allowed in Addis Ababa (the current allowance being seen is only temporary until enough off-street parking buildings will be built) as the information obtained from the concerned bodies and since there are no parking lane built for this purpose, it is possible to consider/say parking lane as ‘No’ = ‘N’ and since, on street parking will possibly be (must be) prohibited or provided with door zone if bikeway is provided to the roads by rearranging & realigning the existing carriage way, it is possible to consider parking occupancy as ‘0’.

Because of the frequent here and there stoppage of taxis on the outer curb lane to load and unload passengers, and also because the way and where the bikeway will be built is unknown,

it is important to take parking time limit as ‘less than 15 min’ to consider especially the taxis and less importantly buses.

Table 4-6 Intermediate calculations for Ayat - chafe and Akaki – AASTU

Location	Peak hour computations							Adjustment factors				
Middle block identifier	Peak Hour Factor (K-factor)	Directional Split (D-factor)	Curb Lane %	Curb Lane Truck % (T-factor)	Peak Hour Volume (PHV)	Peak Hr Curb Lane Volume (CLV)	Peak Hr Other Lane(s) Vol (OLV)	Peak Hr Curb Lane Truck Vol (CLTV)	Large Truck Adjustment Factor (Ft)	Peak Hr Right Turn Volume	Right Turn Adjustment Factor (Frt)	Parking Adjustment Factor (Fp)
Ayat–chafe	0.1	0.55	0.33	0.8	508	170	338	4	0	10	0	0.6
Akaki – AASTU	0.1	0.55	0.5	1	443	222	221	5	0	11	0	0.6

Description of the entered data:

Peak hour factors (k) for both routes are not found on the previous studies made during the design of the existing road. So, it should be taken from the models default value that ranges from 0.07 to 0.15 since both routes are found at around the city margins, let’s consider/assume a moderate increase of traffic volume at peak hours for both routes and take an average value of 0.1.

Directional split factor (D) of 0.55 can be used from the model's default value for both routes, since there are no value of directional split factor found on the previous studies.

Percentage of vehicles travelling in the curb lane can be found by the method the model itself recommends as this value also not found on the previous studies.

So, curb lane%= $\frac{1}{No.\ of\ lane}$; (Curb lane %) $_{A\text{-}C}$ = $1/3$ = 0.33 and (Curb lane %) $_{A\text{-}A}$ = $1/2 = 0.5$

Curb lane truck % (T-factor) can be taken from the recommended model default values, i.e. '1' on two lane streets and 0.8 on multi-lane streets. These values are larger than the Percentage of vehicles travelling in the curb lane calculated above, so it can give better safety; $T_{A\text{-}C}$ = 0.8 and $T_{A\text{-}A}$ = 1.

- PHV (Peak hour volume) = AADT *K*D

  (PHV) $_{A\text{-}C}$ = 9237 *0.1*0.55 = 508, & (PHV) $_{A\text{-}A}$ = 8054*0.1*0.55 = 443
- Curb lane volume (CLV) = $\frac{PHV}{N}$, where N is No. of lane

  (CLV) $_{A\text{-}C}$ = $\frac{508}{3}$ = 170

  (CLV) $_{A\text{-}A}$ = $\frac{443}{2}$ = 222
- Other lane volume (OLV) = PHV-CLV

  (OLV) $_{A\text{-}C}$ = 508 -170 = 338

  (OLV) $_{A\text{-}A}$ = 443 -222 = 221
- Peak hour curb lane truck volume (CLTV) = PHV * HV*T

  (CLTV) $_{A\text{-}C}$ = 508 *0.01*0.8=4

  (CLTV) $_{A\text{-}A}$ = 443*0.01*1=5

Large truck adjustment factors, since peak hour curb lane truck volumes are 4 and 5 which are less than 10 (4&5<10), the corresponding f_t (adjustment factor for truck volume) is 0.0 for both routes from adjustment factors table developed by the model.

- Peak hour right turn volume (PHRTV) = PHV *R%, where R% is right turn percentage

  (PHRTV) $_{A\text{-}C}$ = 508 *0.02 = 10

  (PHRTV) $_{A\text{-}A}$ = 443*0.025 = 11

Adjustment factor for right turn volume has been already assumed that it is less than 270, therefore, f_{rt} = 0.0 can be taken from adjustment factors table developed by the model.

- Adjustment factor (f_p) for parking turnover can be taken as 0.6 for parking time limit of < 15min as it has been discussed earlier.
- AF (adjustment factor) = $f_t + f_{rt} + f_p$

  = 0+0+0.6

  = 0.6 (the same for both routes)

Table 4-7 Bicycle Compatibility Index and Level of Service Computations for Ayat - chafe and Akaki – AASTU

Location	BCI model variables									Results		
Midblock identifier	BL	BLW	CLW	CLV	OLV	SPD	PKG	AREA	AF	BCI	Level of Service	Bicycle Compatibility level
Ayat–chafe	0	0	3.5	170	338	50	0	1	0.6	3.838	D	Moderately low
Akaki - AASTU	0	0	3.5	222	221	50	0	1	0.6	3.89	D	Moderately low

BCI = 3.67 – 0.966BL – 0.410BLW – 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG – 0.264AREA + AF

$(BCI)_{A\text{-}C}$=3.67-0.966(0)-0.410(0)-0.498(3.5)+0.002(170)+0.0004(338)+0.022(50)+0.506(0)-0.264 (1)+0.6

= 3.67-1.743+0.34+0.135+1.1+0-0.264+0.6

= 3.838- moderately low

(BCI)A-A=3.67-0.966(0)-0.410(0)-0.498(3.5)+0.002(222)+0.0004(221)+0.022(50)+0.506(0) 0.264(1)+0.6

= 3.67-1.743+0.444+0.0888+1.1-0.264+0.6

= 3.89- moderately low

For Bicycle Compatibility Index (BCI) level of service categories refer to table 2.2.

4.2.2 Analysis by BLOS (Bicycle level of service) for Akaki Bridge to AASTU and Ayat round about to Ayat condominium /chafe

Table 4-8 BLOS data entry & calculations for Ayat - chafe and Akaki – AASTU

Route name	Vol_{15}	L	SP_p	SP_t	HV	PR_5	W_e	W_t	%OSP	W_l	Wps	W_v	AADT
Ayat–chafe	127	3	22.5	1.83	0.016	5	11.67	11.67	0	0	0	11.67	9237
Akaki-AASTU	111	2	22.5	1.83	0.01	5	11.67	11.67	0	0	0	11.67	8054

Descriptions of the entered data:

Volume of directional traffic in 15 minute time period (VOL $_{15}$): (VOL $_{15}$) $=\frac{ADT*D*Kd}{4*PHF}$, where ADT-average daily traffic, D-directional split, K_d-peak to daily factor and PHF- peak hour factor. $(VOL_{15})_{A\text{-}C}$ = 9237*0.55*0.1/4*1 = 127, by taking directional factor from previously assumed during the analyses by BCI method as 0.55, K_d= peak to daily factor as 0.1 from the model recommended default values if the value is unknown and PHF= peak hour factor as '1' from the model recommended value if the value is unknown from previous studies. Doing the same to Akaki-AASTU route, $(VOL_{15})_{A\text{-}A}$ = 8054*0.55*0.1/4*1 = 111.

Total number of directional through lane, $L_{A\text{-}C}$ = 3 & $L_{A\text{-}A}$=2.

Posted speed limit (Sp_p) for both routes is 35km/hr = 22.5mi/hr.

Effective speed limit (Sp_t) =1.1199ln (Sp_p-20) +0.8103. So, $(Sp_t)_{A\text{-}C\&A\text{-}A}$=1.1199ln (22.5-20) +0.8103=1.83.

Percentage of heavy vehicles can be taken from BCI analysis made on section 4.2.1 $(HV)_{A\text{-}C}$ = 0.016% & $(HV)_{A\text{-}A}$ = 0.01%

PR_5= five point surface condition rating can be considered as '5' since both routes are newly built asphalts even if Akaki –AASTU route has deteriorations at its early stage; however, taking the highest value of surface condition '5' may be good as to consideration of the countries as well as the cities living standard.

W_t= total width of outside lane (& shoulder) pavement is equals to 3.5m (as previously taken on BCI analysis on section 4.2.1) since the shoulders (walk ways) are not bikeable as previously stated on BCI analysis $(W_t)_{A\text{-}C\ \&\ A\text{-}A}$ = 3.5m = 11.67 feet.

Effective width as a function of traffic volume = $w_v = w_t$ since both AADT's, 9237 & 8054, are greater than (>) 4000veh/day & since both streets are not striped as the model recommends. The value for both routes is, i.e. $(W_V)_{A\text{-}C\ \&\ A\text{-}A} = W_t$ = 3.5m = 11.67ft.

W_l = width of paving between the outside lane stripe and the edge of pavement =0 for both routes.
W_{ps}= width of pavement striped for on-street parking equals '0' for all routes as there are no on-street parking allowed as previously stated on BCI analysis
Average effective width of outside through lane:

$W_e = w_r$- (10ft*%OSPA) for the above w_l & w_{ps} values i.e

$(W_e)_{A\text{-}C\ \&\ A\text{-}A} = W_v$ – (10ft*%OSPA)

= 11.67 – (10*0), % OSPA=0

$(W_l)_{A\text{-}C\ \&\ A\text{-}A}$ = 11.67ft

Table 4-9 BLOS score and level of service calculations for Ayat - chafe and Akaki – AASTU

Route name	Vol_{15}	L	SP_t	HV	PR_5	W_e	BLOS score	letter grade	Level of service
Ayat - chafe	127	3	1.83	0.016	5	11.67	2.756	C^+	Moderately high
Akaki –AASTU	111	2	1.83	0.01	5	11.67	2.64	C^+	Moderately high

$$BLOS = 0.507\ln\left(\frac{\mathrm{Vol}_{15}}{\mathrm{L}}\right) + 0.199\mathrm{SP_t}\,(1 + 10.38\mathrm{HV})^2 + 7.066\left(\frac{1}{\mathrm{PR_5}}\right)^2 - 0.005(\mathrm{W_e})^2 + 0.760$$

$(BLOS)_{A\text{-}C} = 0.507\ln\left(\frac{127}{3}\right) + 0.199\ (1.83)\ (1+10.38*0.016)^2 + 7.066\ (1/5)^2 - 0.005\ (11.67)^2 + 0.760$

= 1.899 + 0.495+0.283 – 0.681 + 0.76

= 2.756- moderately high

$(BLOS)_{A\text{-}A} = 0.507\ln\left(\frac{111}{2}\right) + 0.199\,(1+10.38*0.01)2 + 7.066\left(1/5\right)^2 - 0.005\,(11.67)2 + 0.760$

$= 2.036+0.242+0.283-0.680+0.760$

$= 2.64$ – moderately high

For Bicycle Level Of Service (BLOS) categories refer to table 2.3.

4.2.3 Brent Hugh's excel method of analysis for Akaki Bridge to AASTU and Ayat round about to Ayat condominium/chafe

Table 4-10 Brent Hugh's excel method results for Ayat - chafe and Akaki – AASTU

Akaki- AASTU			Hayat- Chafe		
2	*Lanes per direction*		3	*Lanes per direction*	
11.67	*curb lane width*		11.67	*curb lane width*	
0	*shoulder/bike lane width*		0	*shoulder/bike lane width*	
8054	*Bi-directional ADT*		9237	*Bi-directional ADT*	
28.5	*Speed limit*		28.5	*Speed limit*	
1	*% heavy trucks*		1	*% heavy trucks*	
5	*Pavement condition (5 best)*		5	*Pavement condition (5 best)*	
0	*% on-street parking*		0	*% on-street parking*	
15	*Parking time limit*		15	*Parking time limit*	
1	*1=residential, 0=not resident'l*		1	*1=residential, 0=not resident'l*	
BCI			BCI		
2.986	C	Moderately High	2.911	C	Moderately High
BLOS			BLOS		
3.034	C	Moderately High	2.898	C	Moderately High
CBF			CBF		
Red	Cautionary Recommendation		Red	Cautionary Recommendation	

For compatibility analyses of all routes refer to Appendix B.

4.3 Topographic and Compatibility Analysis results

4.3.1 Topographic analysis results

Ayat-chafe: the route is bikeable with respect to gradient. There is only one place close to the route origin that can pose difficulty but it is still bikeable.

Akaki-AASTU: the route is bikeable according to the above analysis with respect to gradient, but can cause difficulty/fatigue over long period of time (for frequent users) since all the gradients are uphill and since there are no gradients less than 2% grade that can give high relief for riders when they turn from one high gradient riding to the other.

CMC-summit: this route don't have a difficult or unbikeable gradient until 7008.44ft=2102.53m length by all tools used to analyze topography, after this length or chainages the route has difficult gradient of up to 9%, which is unbikeable gradient by all tools.

Ayat-Yeka: this route is bikeable until 11000ft=3300m, after this route length or chainages, there is high gradient of more than 6%.

Ayat-summit: this route has unbikeable gradient of up to 8.6% and other difficult gradients at some other chainages. It is unbikeable with respect to gradient.

Imperial-17 health center: the route is bikeable with respect to gradient; the 6.38% gradient may be a mistake since there is no such an uphill observed there. Even if it is, it is only for 36m, which is short and bikeable.

Kera-Kirkos: this route is bikeable by all analysis methods used here. But, since all gradients are –ve i.e. all downhill and all uphill in opposite direction, the opposite direction may cause little difficulty for beginners.

Michael RA-Jomo3: this route is bikeable throughout its length.

German-Gofa: the route is generally bikeable with respect to gradient. There is 8 and 6.6% grade at two points but they are for very short distances.

Ayertena-Alembank: this route has difficult or unbikeable gradients of up to 8% and all are uphill to alembank direction. The route is bikeable at most of its chainages but unbikeable at some chainages which makes the route unbikeable.

Winget - medhanialem pester: have difficult sight distance problems & unbikeable gradients.

Table 4-11 topographic bikeway suitability ranking

Route name	Ranking
Michael RA-Jomo3	1^{st}
CMC-Semit	2^{nd}
Imperial-17 health center	3^{rd}
Ayat-yeka	4^{th}
Ayat-chafe	5^{th}
Kera-Kirkos	6^{th}
German-Gofa	7^{th}
Akaki-AASTU	8^{th}
Ayertena- alembank	9^{th}
Ayat-semit	10^{th}

4.3.2 BCI and BLOS analysis results for all routes with right turn factor consideration

Comparing all routes by their compatibility level based on the above and Appendix B analysis, the following results are presented with and without right turn factor consideration.

4.3.2.1 BCI results

Table 4-12 BCI analysis results for all routes with right turn factor consideration

Location	BCI model variables									Results			Ranking
Midblock identifier	BL	BLW	CLW	CLV	OLV	SPD	PKG	AREA	AF	BCI	LOS	Bicycle Compatibility level	
Ayat RA – semit condominium	0	0	3.5	144	144	50	0	1	0.6	3.7086	D	Moderately LOW	2nd
Ayat RA – yeka Condominium	0	0	3.5	156	156	50	0	1	0.6	3.7374	D	Moderately LOW	3rd
Ayat RA – Hayat condominium/Chaffee	0	0	3.5	170	338	50	0	1	0.6	3.838	D	Moderately LOW	4th
CMC - Semit Condon'm	0	5	3.5	186	186	50	0	1	0.6	1.7594	B^{+}	Very high	1st
17 Health center - Gergi/imperial	0	0	3.5	240	480	50	0	1	0.6	4.035	D	Moderately low	8th
Ayertena- Alembank	0	0	3.5	199	397	50	0	1	0.6	3.9198	D	Moderately low	6th
Winget-medhanialem/Pasteur	0	0	3.5	400	800	50	0	1	0.7	4.583	E	Very low	9th
Michael adebabay – Jomo 3 condominium	0	0	3.5	574	574	50	0	1	0.7	4.8406	E	Very low	10th
Akaki Bridge – AASTU	0	0	3.5	222	222	50	0	1	0.6	3.8958	D	Moderately low	5th
Kera- kirkos	0	0	3.5	272	272	50	0	1	0.6	4.0158	D	Moderately low	7th
German-Gofa	0	0	3.5	622	622	50	0	1	0.7	4.9558	E	Very low	11th

4.3.2.2 BLOS results

Table 4-13 BLOS analysis results for all routes with right turn factor consideration

Route name	Vol_{15}	L	SP_t	HV	PR_5	W_e	BLOS score	letter grade	Level of service	Ranking
Ayat RA – semit condominium	72	2	1.83	1%	5	11.67	2.623	C^+	Moderately high	2nd
Ayat RA – yeka Condominium	78	2	1.83	1%	5	11.67	2.663	C^+	Moderately high	3rd
Ayat RA – Hayat condominium/Chaffee	127	3	1.83	1%	5	11.67	2.705	C^+	Moderately high	4th
CMC - Semit Condon'm	93	3	1.83	1%	5	28.34	-0.582	A^+	Extremely high	1st
17 Health center - Gergi/imperial	180	3	1.83	1%	5	11.67	2.882	C+	Moderately high	7th
Ayertena- Alembank	149	3	1.83	1%	5	11.67	2.786	C+	Moderately high	5th
Winget-medhanialem/Pasteur	300	3	1.83	1%	5	11.67	3.141	C-	Moderately high	9th
Michael adebabay – Jomo 3 condominium	287	2	1.83	1%	5	11.67	3.324	C-	Moderately high	10th
Akaki Bridge – AASTU	111	2	1.83	1%	5	11.67	2.842	C+	Moderately high	6th
Kera- kirkos	136	2	1.83	1%	5	11.67	2.945	C+	Moderately high	8th
German-Gofa	311	2	1.83	1%	5	11.67	3.365	C-	Moderately high	11th

4.3.3 BCI and BLOS analysis results for all routes without right turn factor consideration

Table 4-14 BCI and BLOS analysis results for Ayat-semit, Ayat-Chafe, Ayat- yeka, & CMC- semit routes

	Ayat-semit	*Ayat-Chafe*	*Ayat- yeka*	*CMC- semit*
Lanes per direction	2	3	2	2
curb lane width	11.67	11.67	11.67	28.34
shoulder/bike lane width	0	0	0	0
Bi-directional ADT	5237	9237	5673	6764
Speed limit	28.5	28.5	28.5	28.5
% heavy trucks	1	1	1	1
Pavement condition (5 best)	5	5	5	5
% on-street parking	0	0	0	0
Parking time limit	15	15	15	15
1=residential, 0=not resident'l	1	1	1	1
BCI	2.867 C Moderately High	2.911 C Moderately High	2.885 C Moderately High	0.401 A+ Extremely High
BLOS	2.815 C+ Moderately High	2.898 C Moderately High	2.856 C Moderately High	-0.390 A+ Extremely High

Table 4-15 BCI and BLOS analysis results for 17HC-imperial RA, Ayertena-Alembank, winget-pasteur& Michael RA-Jomo3

	17HC-imperial RA	*Ayertena*-Alembank	*winget*-pasteur	*Michael RA*-Jomo3
Lanes per direction	3	3	3	2
curb lane width	11.67	11.67	11.67	11.67
shoulder/bike lane width	0	0	0	0
Bi-directional ADT	13091	10834	21819	20873
Speed limit	28.5	28.5	28.5	28.5
% heavy trucks	1	1	1	1
Pavement condition (5 best)	5	5	5	5
% on-street parking	0	0	0	0
Parking time limit	15	15	15	15
1=residential, 0=not resident'l	1	1	1	1
BCI	3.022 C Moderately High	2.957 C High	3.274 C- Moderately High	3.531 D+ Moderately Low
BLOS	3.074 C Moderately High	2.978 C High	3.333 C- Moderately High	3.516 D+ Moderately Low

Table 4-16 BCI and BLOS analysis results for Akaki-AASTU, Kera-Kirkos and Germen-Gofa

Akaki-AASTU			*Kera*-Kirkos			*Germen*-Gofa		
2	*Lanes per direction*		2	*Lanes per direction*		2	*Lanes per direction*	
11.67	*curb lane width*		11.67	*curb lane width*		11.67	*curb lane width*	
0	*shoulder/bike lane width*		0	*shoulder/bike lane width*		0	*shoulder/bike lane width*	
8073	*Bi-directional ADT*		9891	*Bi-directional ADT*		22619	*Bi-directional ADT*	
28.5	*Speed limit*		28.5	*Speed limit*		28.5	*Speed limit*	
1	*% heavy trucks*		1	*% heavy trucks*		1	*% heavy trucks*	
5	*Pavement condition (5 best)*		5	*Pavement condition (5 best)*		5	*Pavement condition (5 best)*	
0	*% on-street parking*		0	*% on-street parking*		0	*% on-street parking*	
15	*Parking time limit*		15	*Parking time limit*		15	*Parking time limit*	
1	*1=residential, 0=not resident'l*		1	*1=residential, 0=not resident'l*		1	*1=residential, 0=not resident'l*	
	BCI			BCI			BCI	
2.987	C	Moderately High	3.064	C-	Moderately High	3.605	D+	Moderately Low
	BLOS			BLOS			BLOS	
3.035	C	Moderately High	3.138	C	Moderately High	3.557	D+	Moderately Low

Table 4-17 Summary of BCI and BLOS ranking

Route name	BCI ranking	BLOS ranking
CMC-semit	1st	1st
Ayat-semit	2nd	2nd
Ayat-yeka	3rd	3rd
Ayat-chafe	4th	4th
Imperial-17HC	7th	7th
Michael RA-Jomo3	10th	10th
Akaki-AASTU	6th	6th
Winget-Pasteur	9th	9th
Kera-kirkos	8th	8th
German-Gofa	11th	11th
Ayertena-Alembank	5th	5th

Notice: BCI and BLOS rankings are the same but their results are different in both analysis of with & without right turn factor consideration.

Note that: depending on the above topographic and compatibility analysis results the following routes are re-selected for further investigation of population perception analysis.

i. CMC roundabout – summit factory
ii. Ayat roundabout – Ayat condominium/Chafe
iii. Kera - kirkos
iv. Imperial roundabout – 17 health center
v. Ayertena taxi station – alembank roundabout

Having these routes at hand, the populations' perception towards cycling has been studied on these five routes and their results are presented in table 4-18.

4.4 Population perception analysis

Table 4-18 population perception analysis result

Route name	Riding interest		Population size	Sample size	Buying interest		Riding ability				Family allowance	
	Wants to ride	Don't wants to ride			Wants to buy	Don't wants to buy	Qualified riders	good riders	trial riders	can't rides	Allow	don't allow
Kera-kirkos	96 ±10%	4% ±10%	19759	100	58% ±10%	1% ±10%	36% ±10%	21% ±10%	19% ±10%	12% ±10%	58% ±10%	1% ±10%
Ayertena-alembank	96% ±10%	4% ±10%	32866	100	58% ±10%	1% ±10%	40% ±10%	13% ±10%	25% ±10%	18% ±10%	58% ±10%	1% ±10%
Ayat-chafe	96 ±10%	4 ±10%	32262	100	76 ±10%	3 ±10%	39 ±10%	34 ±10%	13 ±10%	11 ±10%	73 ±10%	7 ±10%
CMC-summit	97% ±10%	3% ±10%	20228	100	45 ±10%	0 ±10%	51 ±10%	21 ±10%	17 ±10%	8 ±10%	45 ±10%	0 ±10%
Imperial-17HC	96 ±10%	4 ±10%	31757	100	50 ±10%	2 ±10%	37 ±10%	16 ±10%	20 ±10%	23 ±10%	51 ±10%	0 ±10%

Notice: despite the sameness of the above population perception analysis results CMC-summit, Ayat-chafe and Imperial-17HC have already frequent mixed bicycle users due to the bicycle taxi renters found there.

For detail of this part refer to Appendix C.

Therefore, depending on the above population perception analysis, topography and availability of existing bicycle taxi, the final three routes selected for bikeway design and bikeway provision are:-

i. CMC-summit,
ii. Ayat-chafe and
iii. Imperial-17HC.

4.5 Junctions' analysis

The following junctions that exist on the selected three routes are selected for detail study.

Roundabouts:

- CMC roundabout on CMC roundabouts – summit factory street
- Ayat roundabout on Ayat roundabout - chafe/Ayat condominium street
- Imperial roundabout on Imperial roundabout – 17 health center street

Intersections:

- 17 health center intersection on Imperial roundabout - 17 health center street
- The T- intersection between the main gate of the stadium and 17 health center intersection on Imperial roundabout - 17 health center street
- The intersection at the main gate of the stadium on Imperial roundabout - 17 health center street

Bridges:

- Bridge on Ayat roundabout – chafe/Ayat condominium street
- Bridge on imperial roundabout - 17 health center intersection street

4.5.1 Roundabout analysis

Imperial roundabout is classified under multilane roundabout of less than 4m right of way space and greater than 50,000veh/day, hence separate cycle lane on the sky or transiting the roundabout by pushing the cycle are the possible treatments that can be applied considering economic limitations since topography don't allow for under pass cycle lane, since there are many utility lines on the right of way of the roundabout and since there is no possible bypass or alternative cycle route.

Both CMC and Ayat roundabout are classified under multilane roundabout type with roundabout traffic volume of 10,000-20,000Veh/day and greater than 3m right of way space (7m>3m). They have large inscribed circle diameter with approach 85th percentile traffic speed of 50km/hr, unknown/un-posted roundabout traffic speed, and two un-flared entry and exit lanes. Therefore, the type of treatment designated for these types of roundabouts according to developed method of data analysis in section 3.3.3 is fully segregated cycle track in side built up area priority for bicycles.

4.5.2 Intersection analysis

17 health center intersection have right of way space of 4-6m wide walkway in three of its legs except on western leg of west bound's right, which have only 2m wide walkway. It has good elevation difference between the carriageway and the right of way that can help in safety and visibility of the intersection from all sides. Approach traffic volume (AADT) of the imperial-17 HC-shalla Park route is 13,091veh/day; and that of Ednamall-17HC-hayahulet is 15,000veh/day. Therefore, since the existing situations are good, Netherlands type of adopted signalized protected intersection with either provision of bike only green time for bicyclists or bicyclists operating with other traffics can be applied.

A T- priority intersection in between 17HC intersection and the gate of stadium has also good visibility and elvetion separation between the carriageway and the walkway with AADT of 2,500veh/day on the leg of the T-intersection. For this type of intersection a semi-protected stop/yield priority for bicycles intersection shall be used.

The other is a mixed type of intersection with stop/yield intersection at the far side of the gateway to the stadium and a priority intersection on the side of the gate of the stadium, which has a clear visibility and elvetion separation between the carriageway and the walkway, with AADT of 4,000veh/day on the leg of stop/yield intersection at the far side of the gateway to the stadium. The treatment for this type of intersection can be semi-protected stop and yield intersection priority for bicyclists on the far side, and priority intersection on the side of the gate of stadium.

4.6 Bridge analysis

Bridge on Ayat-chafe route has no constriction and it has 5m wide walkway on both of its sides but the upstream side of the bridge has very short span length and the downstream side of the bridge has very long span. The AADT on the bridge is 9,237veh/day and the 85th percentile on the bridge is 50km/hr. On the approach of the bridge the bikeway is designed on the shoulder (behind walkway) and the available space on the right of way is >3m.

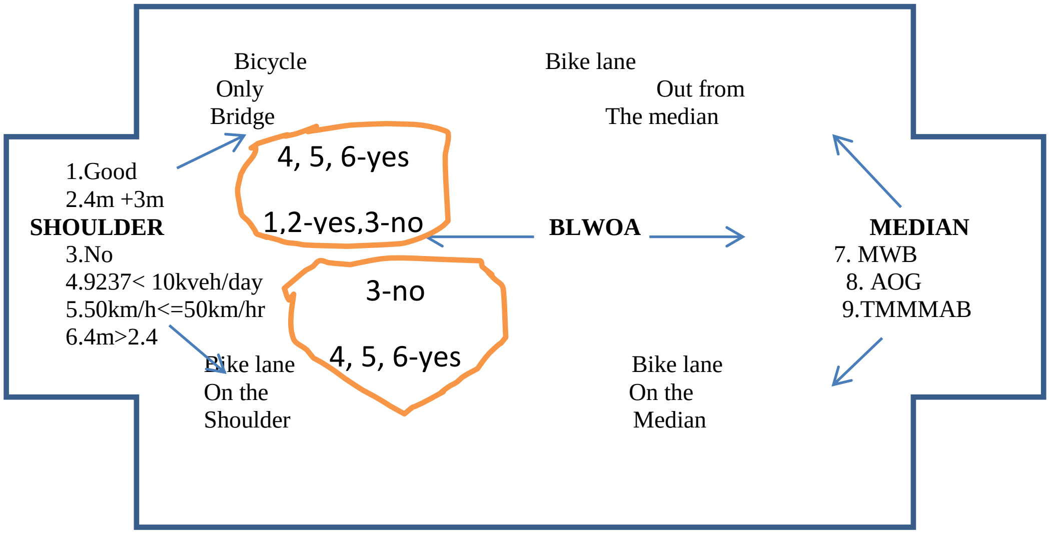

Figure 4-1 bridge analysis

Therefore, according to this analysis since 3-no &; 4, 5 & 6-yes, the treatment bike lane on the shoulder is possible.

CHAPTER 5 Implementation study

5.1 Facility selection

Table 5-1 suitable bikeway facility types for CMC - Summit, Ayat - Chafe & Imperial – 17HC based on different facility selection tools

Route name	AADT	85^{th} percentile speed(mph)	Curb lane width(m)	Facility type(Michael king)	Facility type(UK)	Facility type(Denmark)	Facility type(Australia)	Facility type(new Zealand)
CMC-Summit	6764	32.5	3.5m	Wide curb lane	Segregated cycle facility	Cycle track with dividing verge	Bicycle lanes or shoulders	Cycle lanes or sealed shoulders
Ayat – chafe	9237	32.5	3.5m	Bike lane or shoulder	Segregated cycle facility	Cycle track with dividing verge or cycle track	Bicycle paths	Cycle paths
Imperial – 17HC	13091	32.5	3.5m	Separated lane or Path	Segregated cycle facility	Cycle track	Bicycle paths	Cycle paths

For detail of this facility selection refer to Appendix D

Except Michael king's facility selection tool, which recommends wide curb lane for CMC-Summit, all other tools recommend different ways of segregation/separation of cycle facility from other motor traffics. Therefore, use of different kind of separation should be considered for design.

5.2 Retrofitting

5.2.1 Road segments retrofitting

Regarding the existing situations, for full length of CMC-summit and for 1.7km length of Ayat-chafe routes, there are wide open spaces behind the walkway and the existing carriageways are divided into two lanes of each 3.5m width. For 1.5km length of Ayat-chafe and for full length of Imperial-17 health center, property lines are close to the walkway margins and the existing carriageways are divided into three lanes of each 3.5m width.

Hence, to provide the suggested segregated/separated bikeways according to the facility selection tools and according to the available existing situations, the following are selected safest bikeway types.

- CMC-summit: provision of bikeway behind the walkway for its full length
- Ayat-Chafe: provision of bikeway behind the walkway for 1.7km of two lane stretches and provision of bikeway by retrofitting the existing carriageway for 1.5km length of three lane stretches.
- Imperial-17 health center: provision of bikeway by retrofitting the existing carriageway for its full length.

Accordingly, the existing situations and designs are presented as follows;

Treatments for CMC-summit and Ayat-chafe two lane stretches

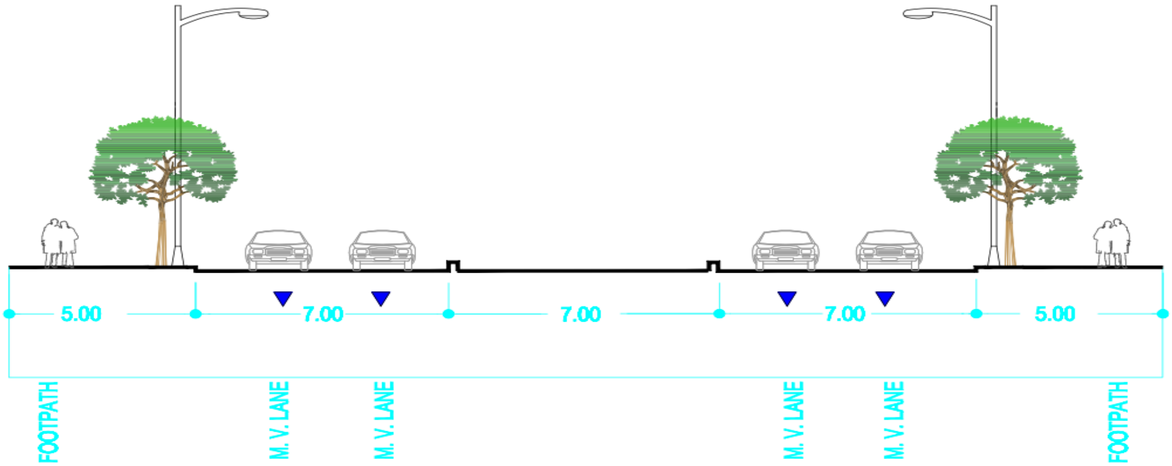

Figure 5-1 CMC-summit and Ayat-chafe two lane stretch existing

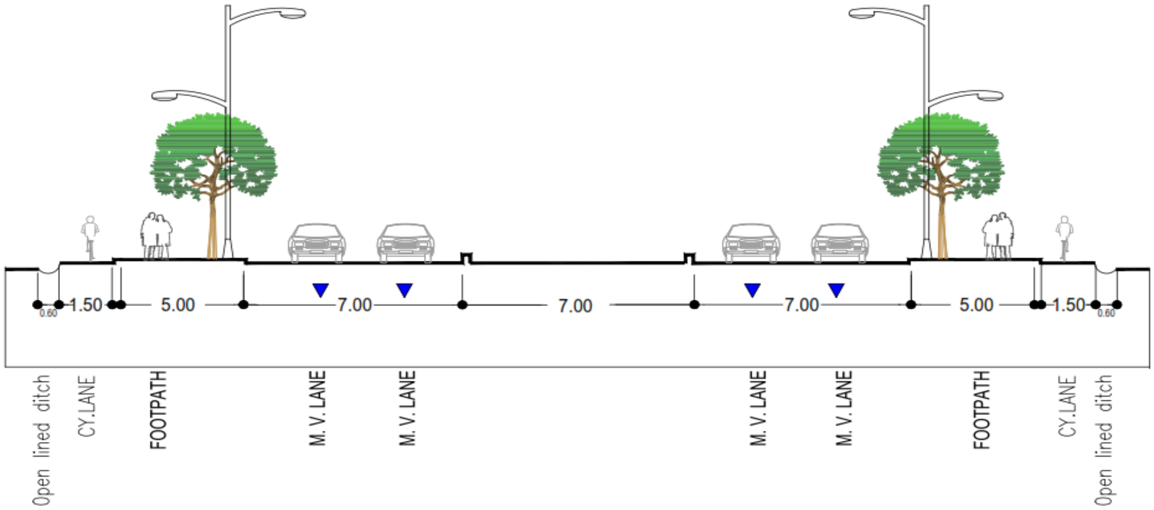

Figure 5-2 CMC-summit and Ayat-chafe two lane stretch bikeway section view

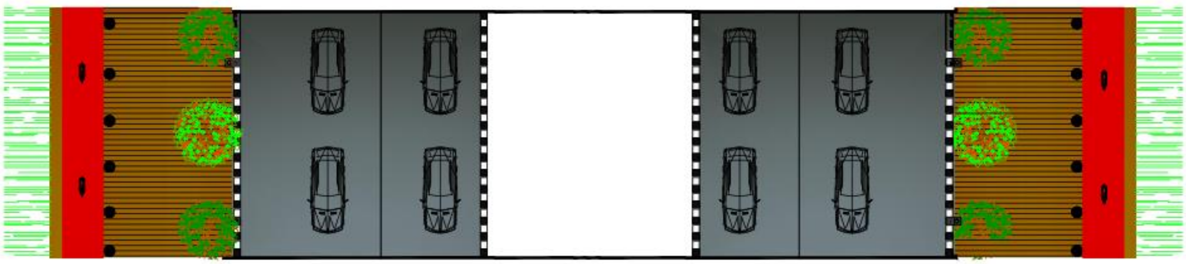

Figure 5-3 CMC-summit and Ayat-chafe two lane stretch bikeway top view

Treatments for Imperial-17 health center and Ayat-chafe three lane stretches

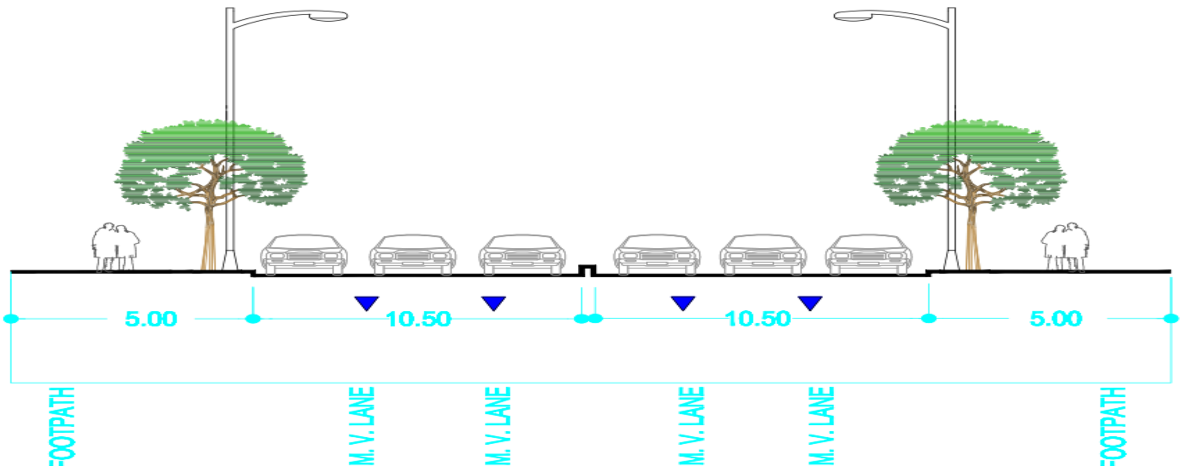

Figure 5-4 Imperial-17 health center and Ayat-chafe three lane stretches existing

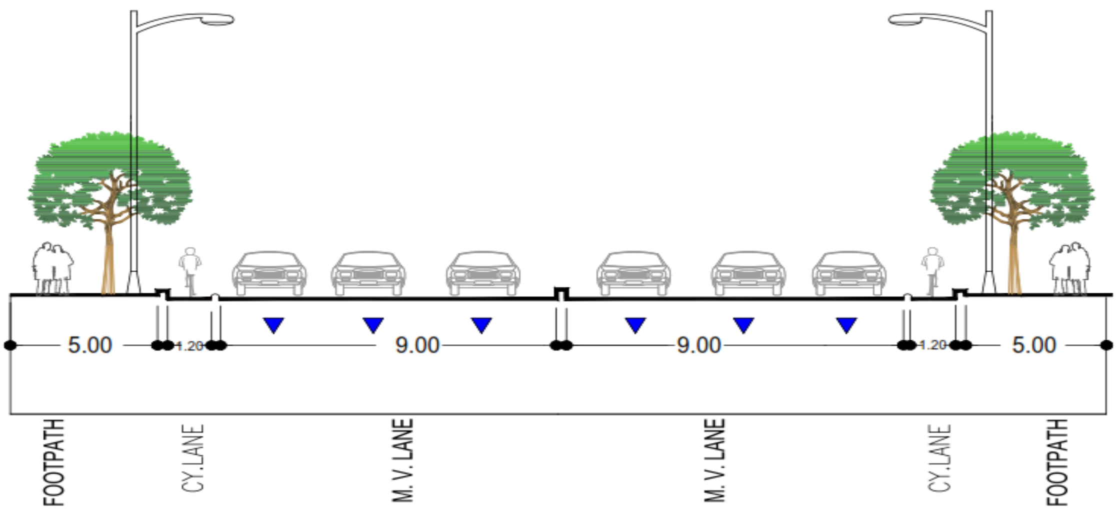

Figure 5-5 Imperial-17 health center and Ayat-chafe three lane stretches bikeway section view

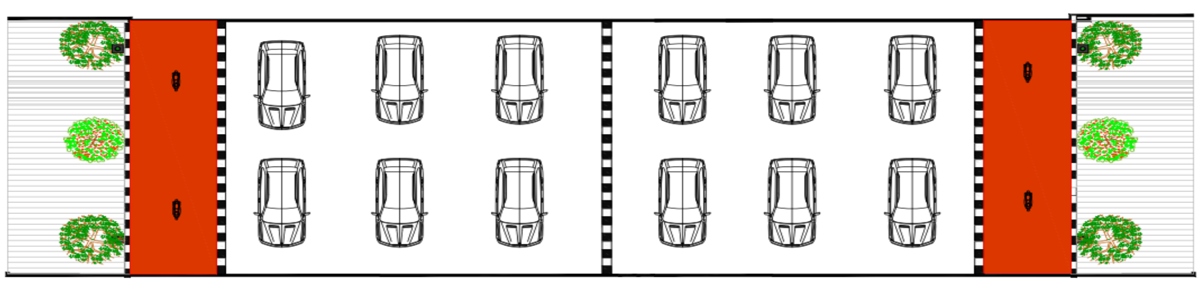

Figure 5-6 Imperial-17 health center and Ayat-chafe three lane stretches bikeway top view

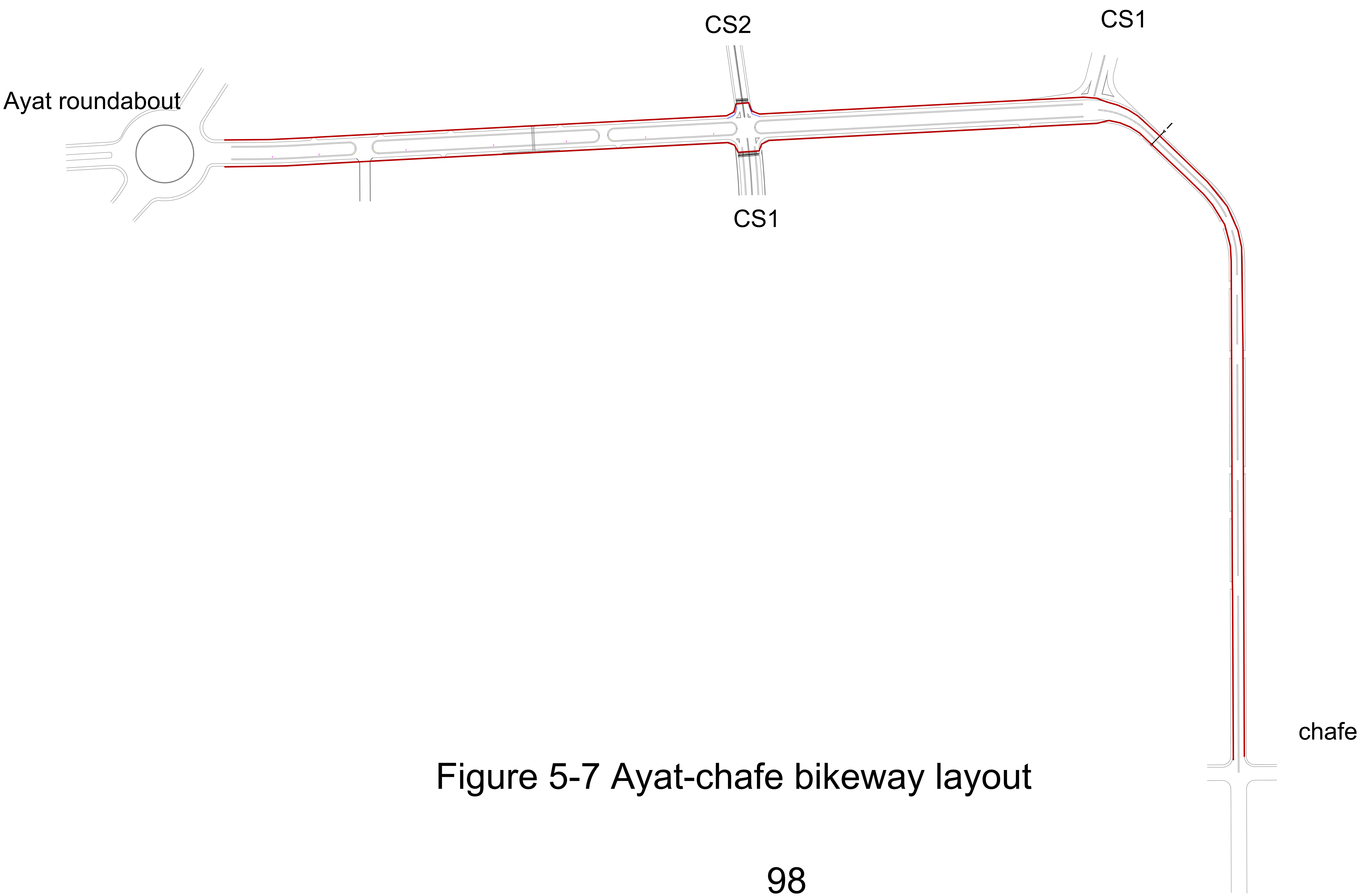

Figure 5-7 Ayat-chafe bikeway layout

Figure 5-8 Imperial-17 health center bikeway layout

R_R

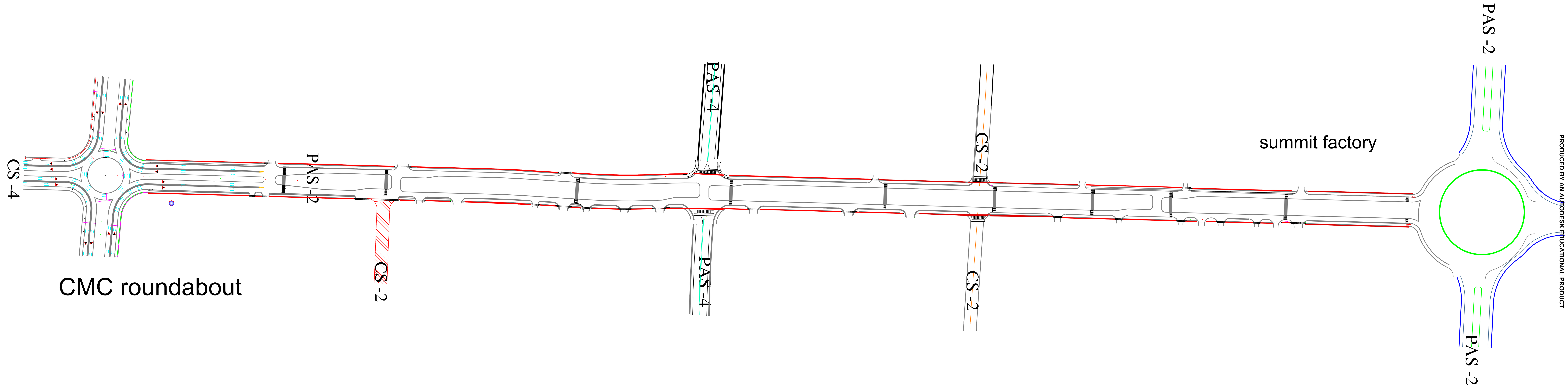

Figure 5-9 CMC-Summit bikeway layout

5.2.2 Junctions retrofitting

5.2.2.1 Roundabouts retrofitting

The designated treatment for Ayat and CMC roundabout is fully segregated cycle track in side built up area priority for bicycles as shown on Figure 5-10. If the bikeway width is 1.5m and the remaining walkway area will be 5.5m.

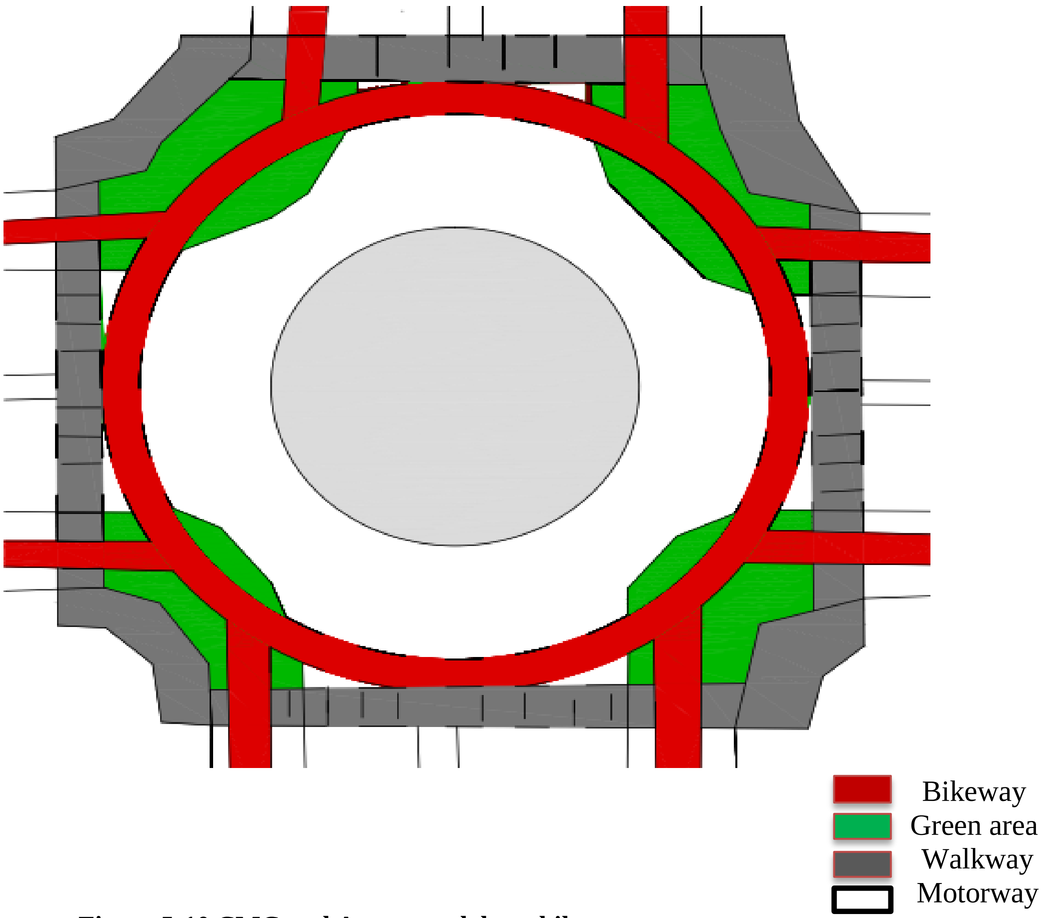

Figure 5-10 CMC and Ayat roundabout bikeway treatment

5.2.2.2 Intersections retrofitting

According to the recommended adopted protected intersection type of the Netherlands style, the following is the picture of signalized protected intersection with either all green time for cyclists or cyclists operating with other traffics.

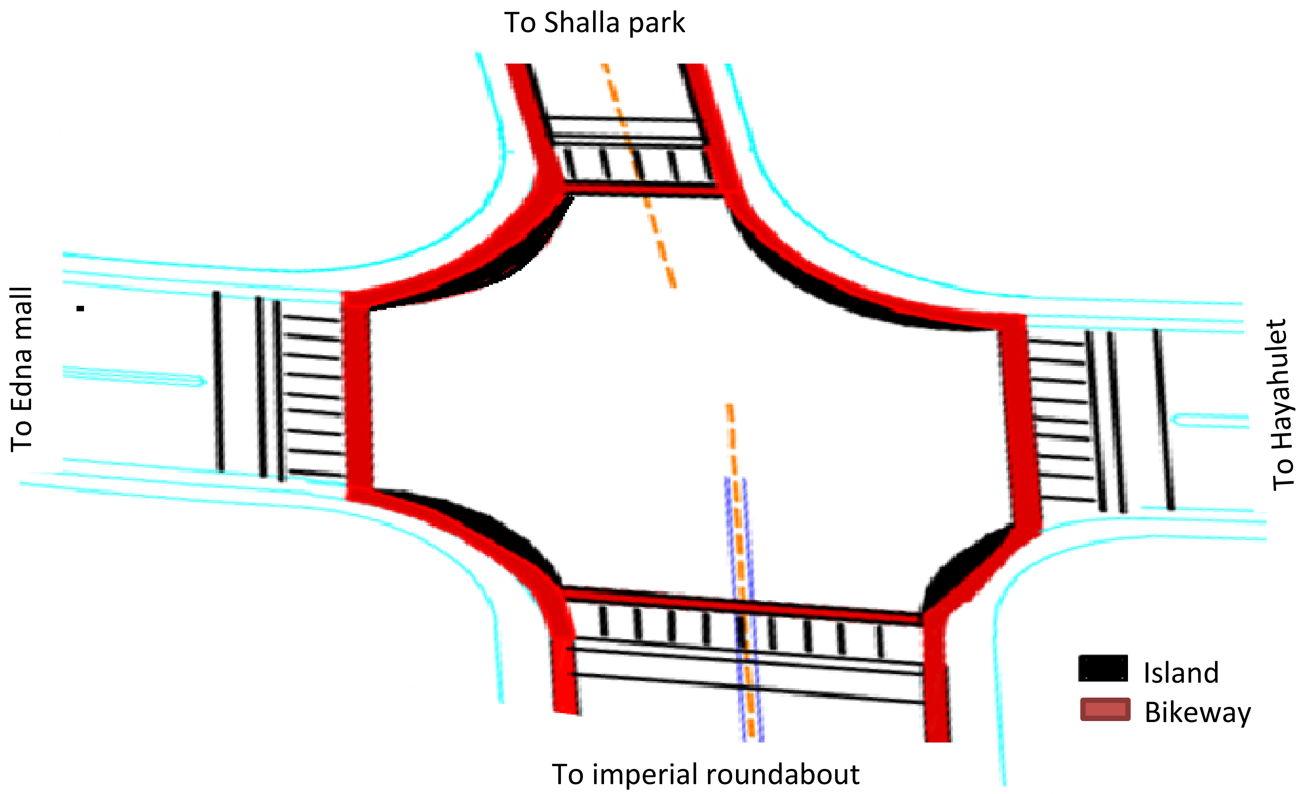

Figure 5-11 17HC protected signalized intersection with all green time for bicyclist

A treatment recommended for the T- priority intersection in between 17HC intersection and the gate of the stadium is a semi-protected stop/yield priority for bicycles intersection in which semi-protection can be guaranteed by using only curb provision.

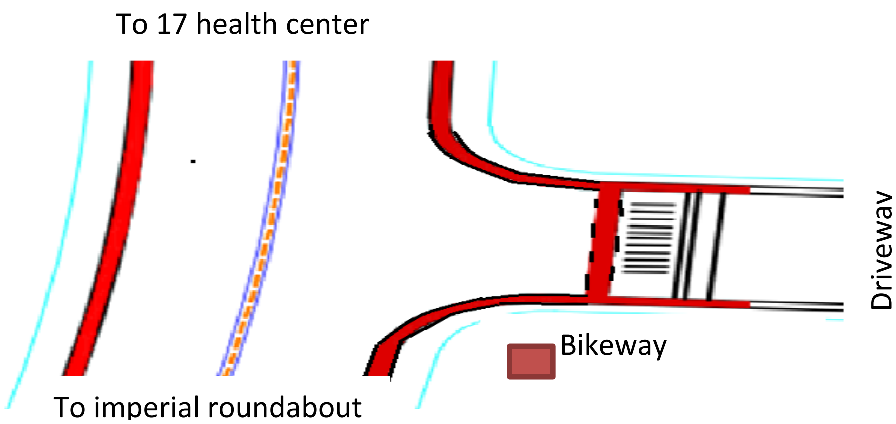

Figure 5-12 protected stop and yield intersection priority for bicyclists

The treatment recommended for this intersection is semi-protected stop and yield intersection priority for bicyclists on the right, and priority intersection on the left. Therefore, these can be implemented by curb protection with stop and yiled sign on the right; and broken line on the left.

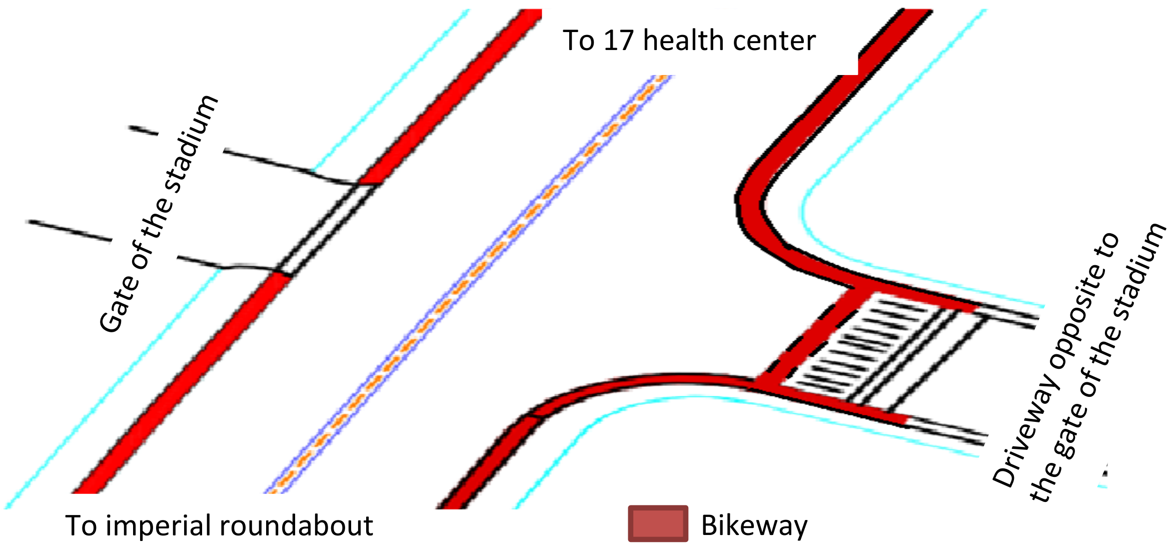

Figure 5-13 protected stop and yield intersection priority for bicyclists on the right, and priority intersection on the left at the gate of the stadium

5.2.2.3 Bridges retrofitting

The treatment recommended for both bridges that found on Ayat-chafe and Imperial-17HC is provision of bike lane on the shoulder. This can be implemented by removing the tiles on the outer verge of the walkway and replacing it with either asphalt concrete or cement concrete for bridge on Ayat-Chafe, and by maintaining the outer verge of the carriageway for bridge on Imperial-17HC. Then, after transiting the bridge bicyclists can return to their original lane.

5.3 Construction materials

For CMC-summit and Ayat-chafe two lane stretches, in which provision of bikeway behind the walkway is suggested, asphalt concrete finish shall be used. Each layers thickness according to South Australia bikeway manual (2013) as presented under appendix E is

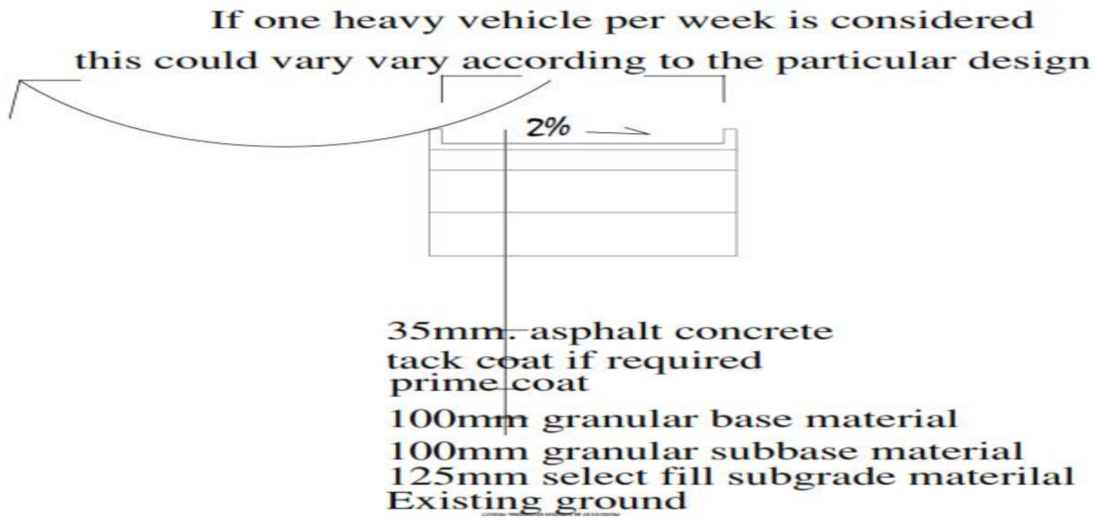

Figure 5-14 bikeway pavement thickness and material of construction

For Imperial-17 health center and Ayat-chafe three lane stretches, in which provision of bikeway by retrofitting the existing carriageway is suggested, delineator, which can delineate motor and bicycle traffic, made by either asphalt concrete or cement concrete shall be used at 1.5m clearances apart. The binding material for asphalt concrete can be tack coat, and for cement concrete it can be mortar. In both cases a little scratching of the existing ground before the application of the binding material can help the binding or the attachment. And in between the delineator and the outer curb i.e. the bikeway should be painted with red accent 2 darker 25% resistant to UV rays and weathering.

For detail of this part refer to Appendix E.

5.4 Traffic calming improvements

The following are the signages and markings selected to be installed on the bikeways.

Figure 5-15 road sign posts (NACTO 2013; Federal Negarit Gazeta 2011)

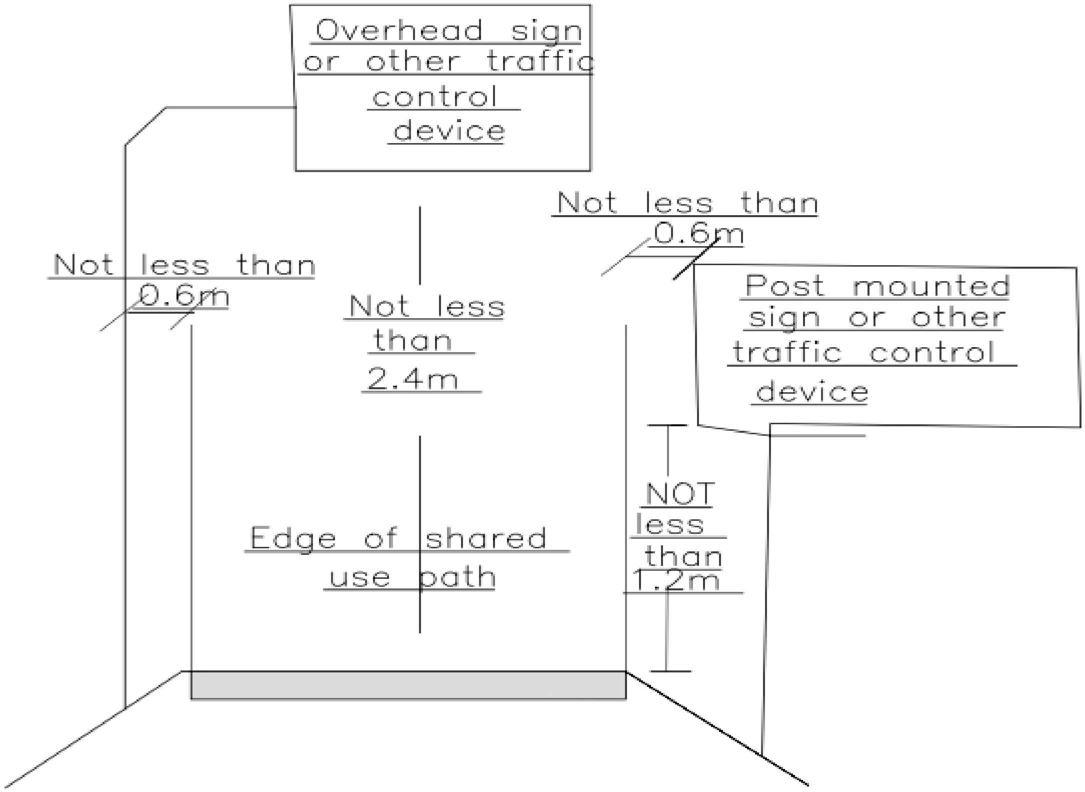

Figure 5-16 road sign posts placement (AASHTO 2011)

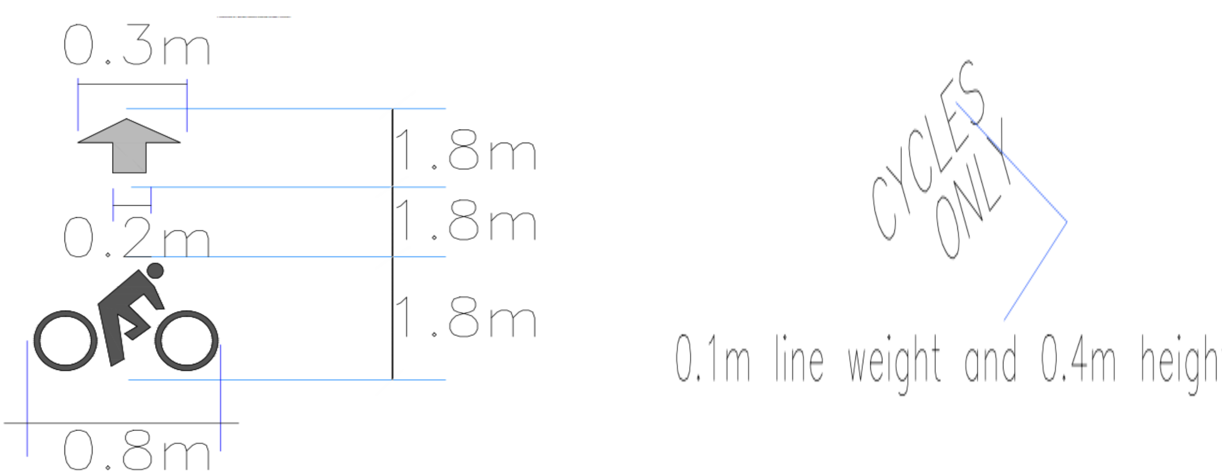

Figure 5-17 road markings (AASHTO 2011)

Signage and road marking on imperial-17HC, Hayat-chafe & CMC-summit respectively

Figure 5-18 sign posts and road markings for Imperial-17HC

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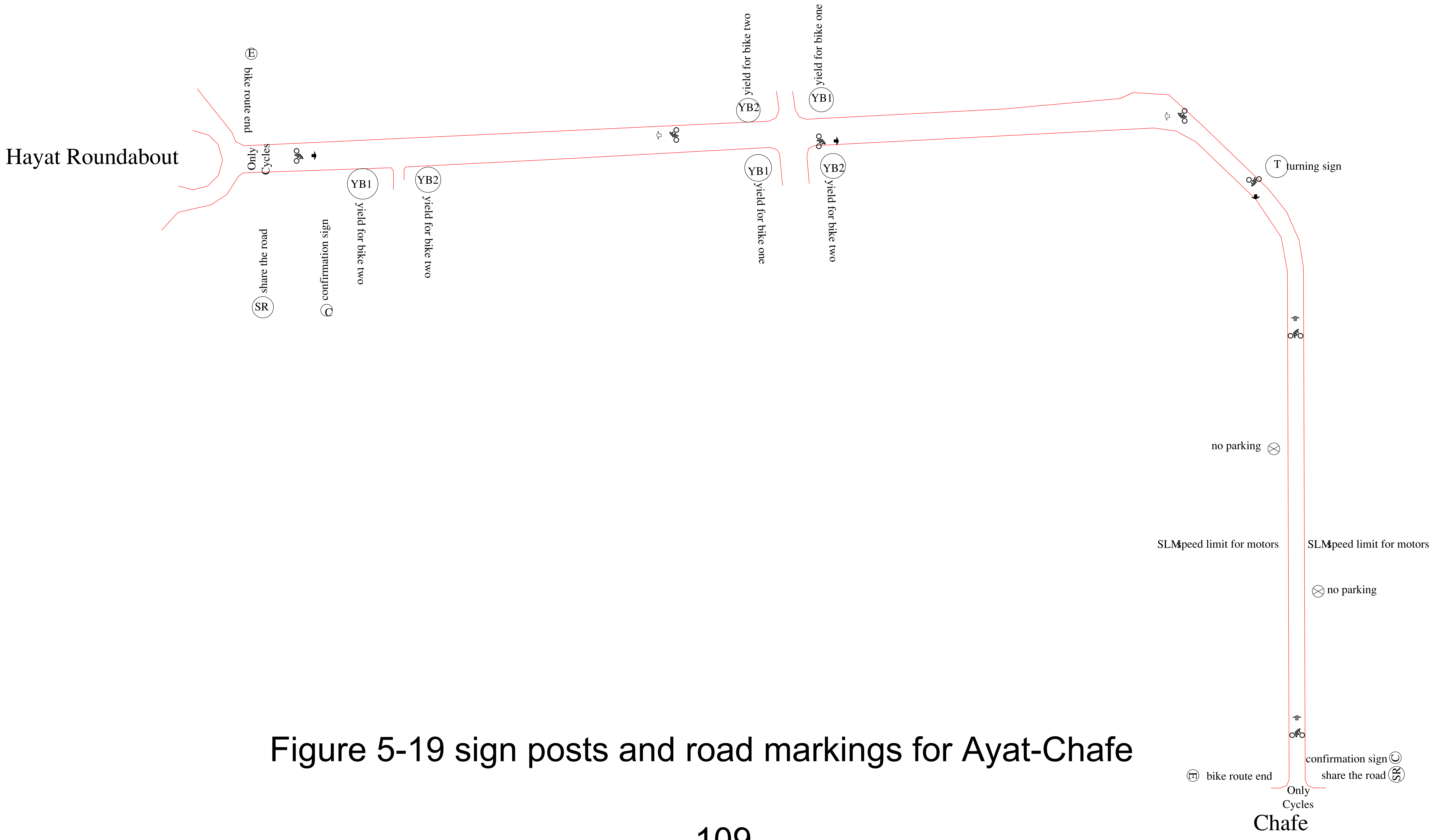

Figure 5-19 sign posts and road markings for Ayat-Chafe

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Figure 5-20 sign posts and road markings for CMC-Summit

CHAPTER 6 Conclusions and recommendations

6.1 Conclusions

The results from compatibility analysis show that almost all studied routes are moderately compatible. But roads with asphalt concrete paved shoulder or walkway, and roads with three directional motor traffic lanes are highly compatible.

It has been found from topographic analysis results that all the studied routes are bikeable, but one will be more bikeable than the other. Relatively, routes studied from East-West are more flat and bikeable than routes from North-South of Addis Ababa.

The results of population perception analysis show that peoples around the studied routes are highly interested in using bicycles if the bikeways are built safe.

The study shows that roads in the newly developed areas, which are found at the outskirts of Addis Ababa, are more bikeable than roads in the city centers, mainly because roads on the newly developed areas have wider right of way reservations better than roads at the city centers.

The study shows that the Netherlands way of junctions' bikeway treatments and road segment bikeway treatments are safer than any other countries.

6.2 Recommendations

The city should try to adopt the Netherlands way of junctions' bikeway treatment since they are safer and the Americans way of road segment bikeway treatment since they are more suitable to Addis Ababa city's constricted road nature.

The Americans way of bikeway compatibility checking methods like BCI (bicycle compatibility index) and BLOS (bicycle level of service) should be developed based on the city's and the country's status quo to help in the analysis of roads for bikeway planning and design purposes.

The city should develop its own bikeway design guide.

The city administrations should think of providing bikeways to city roads, especially to currently being built roads as they are too difficult to provide them bikeway once they are built free of bikeway.

Residential area local streets can be a potentially suitable area to provide bikeways, either isolated or shared with motor traffics and pedestrians, for residents transport to public transport stations of like taxis, buses, and light rail transits.

River sides can be provided with bikeways for recreation purposes if the river water is proved free of waste disposals or at least free of bad sniffs.

Old rail trails are the main open potential areas that can be provided with bikeways, either isolated or shared with pedestrians, in order to minimize construction costs since its substructures are already constructed.

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Appendices

Appendix A: Topographic analysis

The data used for topographic analysis for the following six routes is taken from goggle earth with 500ft=150m chainages gap since it was impossible to obtain the data's from secondary materials (previous studies during the design of the existing route). Hence, the topographic analysis of these routes may not be accurate.

CMC –Summit

Length (ft)	Level ft)	Gradient (%)	Developed	AASHTO	Cyclingnews,com
0	7844	0	Bikeable	Bikeable	Bikeable
499.73	7827	-3.4	Possible to apply	Bikeable	Manageable
1007.8	7816	-2.16	Bikeable	Bikeable	Bikeable
1495.55	7809	-1.43	Bikeable	Bikeable	Bikeable
2003.83	7804	-0.787	Bikeable	Bikeable	Bikeable
2504.26	7799	-0.999	Bikeable	Bikeable	Bikeable
3007.15	7787	-2.386	Bikeable	Bikeable	Bikeable
3501.75	7778	-1.819	Bikeable	Bikeable	Bikeable
4001.59	7767	-2.2	Bikeable	Bikeable	Bikeable
450678	7756	-2.18	Bikeable	Bikeable	Bikeable
5004.17	7759	0.6	Bikeable	Bikeable	Bikeable
5504.95	7767	1.5975	Bikeable	Bikeable	Bikeable
6007.78	7771	0.795	Bikeable	Bikeable	Bikeable
6500.97	7768	0.6	Bikeable	Bikeable	Bikeable
7008.44=2102.53m	7759	-1	Bikeable	Bikeable	Bikeable
7505.84	7713	-9.2	Unbikeable	Unbikeable	Unbikeable
8006.37	7668	-9.0	Unbikeable	Unbikeable	Unbikeable

This route don't have a difficult or unbikeable gradient until 7008.44=2102.53m length by all tools used to analyze topography, after this length or chainages the route has difficult gradient of up to 9%, which is unbikeable gradient by all tools.

Kera-Kirkos

Length (ft)	Level ft)	Gradient (%)	Developed	AASHTO	Cyclingnews.com
0	7726				
502.05	7716	-1.9918	Bikeable	Bikeable	Bikeable
1000.74	7701	-3	Bikeable	Bikeable	Not challenging
1500.84	7688	-2.6	Bikeable	Bikeable	Bikeable
2000.55	7677	-2.2	Bikeable	Bikeable	Bikeable
2501.28	7670	-1.4	Bikeable	Bikeable	Bikeable

3002.42	7660	-2	Bikeable	Bikeable	Bikeable
3502.61	7654	-1.2	Bikeable	Bikeable	Bikeable
4001.79	7641	-2.6	Bikeable	Bikeable	Bikeable
4502.94	7629	-2.4	Bikeable	Bikeable	Bikeable
5000.5	7606	-4.6	For connectivity	Bikeable	Manageable
5503.38	7594	-2.4	Bikeable	Bikeable	Bikeable
6000.06	7571	-4.6	For connectivity	Bikeable	Manageable
6500.28	7552	-3.8	Possible to apply	Bikeable	Manageable
7005.42	7540	-2.4	Bikeable	Bikeable	Bikeable
7503.04	7533	-1.4	Bikeable	Bikeable	Bikeable
8001.48	7526	-1. 4	Bikeable	Bikeable	Bikeable
8238.7	7524	-0.4	Bikeable	Bikeable	Bikeable

This route is bikeable by all analysis methods used here. But, since all gradients are –ve i.e. all downhill and all uphill in opposite direction, the opposite direction may cause little difficulty for beginners.

Ayat - Summit

Length (ft)	Level ft)	Gradient (%)	Developed	AASHTO	Cyclingnews.com
0	7889				
503.86	7879	-2	Bikeable	Bikeable	Bikeable
1005.35	7876	-0.6	Bikeable	Bikeable	Bikeable
1504.63	7878	0.4	Bikeable	Bikeable	Bikeable
2002.05	7873	-1	Bikeable	Bikeable	Bikeable
2501.54	7864	-1.8	Bikeable	Bikeable	Bikeable
3004.7	7852	-2.4	Bikeable	Bikeable	Bikeable
3502.75	7832	-4	Possible to apply	Bikeable	Manageable gradient
4001.05	7797	-7	Impossible	Unbikeable 150m>121.921m	Very challenging
4503.35	7760	-7.4	Impossible	Unbikeable 150m>121.921m	Very challenging
5005.2	7748	-2.4	Bikeable	Bikeable	Bikeable
5505.66	7763	+3	Possible	Bikeable	Not challenging
6000	7768	1	Bikeable	Bikeable	Bikeable
6504	7766	-0.4	Bikeable	Bikeable	Bikeable
7005.04	7746	-4	Possible	Bikeable	Not challenging
7500	7712	-6.8	Impossible	Unbikeable 150m>121.921m	Very challenging
8006	7671	-8.2	Impossible	Unbikeable 150m>91.441m	Very challenging
8500	7114	+8.6	Impossible	Unbikeable	Very challenging

				150m>121.921m	
9005	7739	+5	For connectivity	Bikeable 150m<243.843m	Manageable
9500	7750	2.2	Bikeable	Bikeable	Bikeable
10005	7762	2.4	Bikeable	Bikeable	Bikeable
10502	7757	-1	Bikeable	Bikeable	Bikeable
11962	7762	1	Bikeable	Bikeable	Bikeable

This route has unbikeable gradient of up to 8.6% and other difficult gradients at some other chainages. It is unbikeable with respect to gradient.

Ayat RA – Yeka Abado

Length (ft)	Level ft)	Gradient (%)	Developed	AASHTO	Cyclingnews.com
0	7903				
502.94	7921	3.6	Bikeable	Bikeable	Not challenging
1011	7934	2.6	Bikeable	Bikeable	Bikeable
1502	7946	2.4	Bikeable	Bikeable	Bikeable
2000	7963	3.4	Bikeable	Bikeable	Bikeable
2502	7976	2.6	Bikeable	Bikeable	Bikeable
3008	7983	1.4	Bikeable	Bikeable	Bikeable
3506	7992	1.8	Bikeable	Bikeable	Bikeable
4008	7991	-0.2	Bikeable	Bikeable	Bikeable
4500	7995	0.8	Bikeable	Bikeable	Bikeable
5000	8000	1	Bikeable	Bikeable	Bikeable
5505	7998	-0.4	Bikeable	Bikeable	Bikeable
6010	7998	0	Bikeable	Bikeable	Bikeable
6502	8002	0.4	Bikeable	Bikeable	Bikeable
7004	8012	2	Bikeable	Bikeable	Bikeable
7503	8022	2	Bikeable	Bikeable	Bikeable
8012	8042	4	Possible to apply	Bikeable	Manageable
8505	8062	4	Possible to apply	Bikeable	Manageable
9007	8064	0.4	Bikeable	Bikeable	Bikeable
9509	8068	0.8	Bikeable	Bikeable	Bikeable
10013	8072	0.8	Bikeable	Bikeable	Bikeable
10505	8071	-0.2	Bikeable	Bikeable	Bikeable
11000=3300m	8060	-2.2	Bikeable	Bikeable	Bikeable
11505	8030	-6	For connectivity	Bikeable 150m<243.843	Manageable
12012	8017	-2.6	Bikeable	Bikeable	Bikeable

This route is bikeable until 11,000=3,300m, after this route length or chainages, there is high gradient of more than 6%.

Ayertena- Alembank

Length (ft)	Level ft)	Gradient (%)	Developed	AASHTO	Cyclingnews.com
0	7628				
500.99	7646	3.6	Possible to apply	Bikeable	Not challenging
1000	7656	2	Bikeable	Bikeable	Bikeable
1500	7670	2.8	Bikeable	Bikeable	Bikeable
2001	7699	5.8	For connectivity	Bikeable 150<243.843	Bikeable
2500	7728	5.8	For connectivity	Bikeable 150<243.843	Manageable
3002	7752	4.8	For connectivity	Bikeable 150<243.843	Manageable
3501	7767	3	Bikeable	Bikeable	Bikeable
4001	7792	8	Impossible	Unbikeable 150m>91.441m	Very challenging
4502	7822	6	For connectivity	Bikeable 150m<243.843	Manageable
5001	7833	2.2	Bikeable	Bikeable	Bikeable
5501	7850	3.4	Possible to apply	Bikeable	Not challenging
6002	7873	4.6	For connectivity	Bikeable	Manageable
6502	7906	6.6	Impossible	Bikeable 150m<243.843m	Manageable
7000	7931	5	For connectivity	Bikeable	Manageable
7501	7955	4.8	For connectivity	Bikeable	Manageable
8003	7972	3.4	Possible to apply	Bikeable	Not challenging
8501	7981	1.8	Bikeable	Bikeable	Bikeable
9001	7993	2.4	Bikeable	Bikeable	Bikeable
9502	8000	1.4	Bikeable	Bikeable	Bikeable
10000	8021	4.2	For connectivity	Bikeable	Manageable

This route has difficult or unbikeable gradients of up to 8% and all are uphill to Alembank direction. The route is bikeable at most of its chainages but unbikeable at some chainages which makes the route unbikeable.

Michael - Jomo 3

Length (ft)	Level ft)	Gradient (%)	Developed	AASHTO	Cyclingnews.com
0	7371				
500.19	7363	-1.6	Bikeable	Bikeable	Bikeable
1001.34	7359	-0.8	Bikeable	Bikeable	Bikeable
1501.37	7350	-1.8	Bikeable	Bikeable	Bikeable
2000.86	7344	-1.2	Bikeable	Bikeable	Bikeable
2500.33	7343	-0.2	Bikeable	Bikeable	Bikeable
3000.31	7347	-0.8	Bikeable	Bikeable	Bikeable
3500.7	7346	-0.2	Bikeable	Bikeable	Bikeable
4000.26	7354	1.6	Bikeable	Bikeable	Bikeable
4500.59	7352	-0.4	Bikeable	Bikeable	Bikeable
5000.61	7361	1.8	Bikeable	Bikeable	Bikeable
5500.39	7359	-0.4	Bikeable	Bikeable	Bikeable
6001.24	7360	0.2	Bikeable	Bikeable	Bikeable
6500.01	7354	-1.2	Bikeable	Bikeable	Bikeable
7005.3	7359	1	Bikeable	Bikeable	Bikeable
7501.35	7363	0.8	Bikeable	Bikeable	Bikeable
8009.88	7363	0	Bikeable	Bikeable	Bikeable
8500.36	7367	0.8	Bikeable	Bikeable	Bikeable
9003.13	7346	-4.2	For connectivity	Bikeable	Manageable
9500.74	7364	3.6	Possible to apply	Bikeable	Not challenging
10211.00	7370	1.2	Bikeable	Bikeable	Bikeable

This route is bikeable throughout its length.

The data used for topographic analysis of the following four routes is taken from previous studies during the design of the existing route. Hence, the topographic analysis of these routes is confidential.

Ayat - chafe

Chainages in m.(from)	Chainages in m.(to)	Gradient (%)	Developed	AASHTO	Cyclingnews.com
0+000	0+281.4	-1.2	Bikeable	Bikeable	Bikeable
0+281.4	0+409.7	-2.8	Bikeable	Bikeable	Bikeable
0+409.7	0+572.2	-5.4	For connectivity	Bikeable 162.5m<243.834m	Manageable
0+572.2	0+747.8	5.3	For connectivity	Bikeable 175.6m<243.834m	Manageable
0+747.8	0+967.3	2.9	Bikeable	Bikeable	Bikeable
0+967.3	1+217.9	0.1	Bikeable	Bikeable	Bikeable
1+217.9	1+367.7	-1.8	Bikeable	Bikeable	Bikeable
1+367.7	1+566.0	-1.2	Bikeable	Bikeable	Bikeable
1+566.0	1+701.0	-3.8	Possible to apply	Bikeable	Not challenging

Imperial - 17 health center

Chainages in m.(from)	Chainages in m.(to)	Gradient (%)	Developed	AASHTO	Cyclingnews.com
0+000	0+110	-3.439	Possible to apply	Bikeable	Not challenging
0+110	0+336	2.788	Bikeable	Bikeable	Bikeable
0+336	0+458	1.95	Bikeable	Bikeable	Bikeable
0+458	0+560	2.784	Bikeable	Bikeable	Bikeable
0+560	0+800	-1.075	Bikeable	Bikeable	Bikeable
0+800	1+060	4.048	Possible to apply	Bikeable	Manageable
1+060	1+164	0.106	Bikeable	Bikeable	Bikeable
1+164	1+200	6.38	Not possible	Bikeable 36m<243.843m	Manageable

The route is bikeable with respect to gradient; the 6.38% gradient may be a mistake since there is no such an uphill observed there. Even if it is, it is only for 36m, which is short and bikeable.

Akaki bridge-AASTU

Chainages in m.(from)	Chainages in m.(to)	Gradient (%)	Developed	AASHTO	Cyclingnews.com
0+000	0+175.8	3.7	Possible to apply	Bikeable	Not challenging
0+175.8	0+306.5	2.2	Bikeable	Bikeable	Bikeable
0+306.5	0+491.6	4.8	For connectivity	Bikeable	Manageable
0+491.6	0+651.4	2.8	Bikeable	Bikeable	Bikeable
0+651.4	0+886.5	5.8	For connectivity	Bikeable 235.1m<243.934m	Manageable
0+886.5	1+081.8	4.7	For connectivity	Bikeable	Manageable
1+081.8	1+506.1	2.4	Bikeable	Bikeable	Bikeable
1+506.1	2+009.6	2.5	Bikeable	Bikeable	Bikeable
2+009.6	2+708.4	2.4	Bikeable	Bikeable	Bikeable
2+708.4	3+356.9	3.6	Possible to apply	Bikeable	Not challenging

Gofa-german

Chainages in m.(from)	Chainages in m.(to)	Gradient (%)	Developed	AASHTO	Cyclingnews.com
0+000	0+105.36	-4.67	For connectivity	Bikeable	Manageable
0+105.36	0+251.82	0.00	Bikeable	Bikeable	Bikeable
0+251.82	0+383.91	3	Bikeable	Bikeable	Bikeable
0+383.91	0+548.71	6.6	Impossible	Bikeable 165m<243.843m	Manageable
0+548.71	0+632.4	0.8	Bikeable	Bikeable	Bikeable
0+632.4	0+740.9	8	Impossible	Unbikeable 108m>91.411m	Very challenging
0+740.9	1+032.04	3.22	Possible to apply	Bikeable	Not challenging
1+032.04	1+376.03	1.93	Bikeable	Bikeable	Bikeable
1+376.03	2+204.33	0.5	Bikeable	Bikeable	Bikeable
2+204.33	2+237.9	0.592	Bikeable	Bikeable	Bikeable

The route is generally bikeable with respect to gradient. There is 8 and 6.6% grade at two points but they are for very short distances.

Appendix B: Compatibility study

BCI (Bicycle Compatibility Index) analysis

Data Entry worksheet

Location	Geometric and road side data					Traffic operations data					Parking data		
Midblock identifier	No. of Lanes (one direction)	Curb Lane Width (ft)	Bicycle Lane Width (ft)	Paved Shoulder Width (ft)	Residential Development (y/n)	Speed Limit (mi/h)	85th %tile Speed (mi/h)	AADT	Large Truck % (HV)	Right Turn % (R)	Parking Lane (y/)	Occupancy (%)	Time Limit (minutes)
Ayat-semit	2	3.5	0	0	Y	35km/h	50km/h	5237	0.01	0.02	N	0	<15
Ayat-yeka	2	3.5	0	0	Y	35km/h	50km/h	5673	0.01	0.02	N	0	<15
Ayat-chafe	2/3	3.5	0	0	Y	35km/h	50km/h	9237	0.01	0.02	N	0	<15
CMC-Summit	2	3.5	0	5	Y	35km/h	50km/h	6764	0.01	0.03	N	0	<15

<u>AADT</u>

Ayat-summit: Vol_{15min}=72, PHV=72*4=288, AADT= PHV/K*D= 288/0.1*0.55=5237

Ayat-yeka: Vol_{15min}=78, PHV=78*4=312, AADT= PHV/K*D= 312/0.1*0.55=5673

Ayat-chafe: Vol_{15min}=127, PHV=127*4=508, AADT= PHV/K*D= 508/0.1*0.55=9237

CMC-summit: Vol_{15min}=93, PHV=93*4=372, AADT= PHV/K*D= 372/0.1*0.55=6764

<u>Large truck factor</u>

From AACRA manual-1% (heavy 0% + articulated 1%) for principal arterials

Intermediate calculations worksheet

Location	Peak hour computations							Adjustment factors				
Middle block identifier	Peak Hour Factor (K-factor)	Directional Split (D-factor)	Curb Lane %	Curb Lane Truck % (T-factor)	Peak Hour Volume (PHV)	Peak Hr Curb Lane Volume (CLV)	Peak Hr Other Lane(s) Vol (OLV)	Peak Hr Curb Lane Truck Vol (CLTV)	Large Truck Adjustment Factor (Ft)	Peak Hr Right Turn Volume	Right Turn Adjustment Factor (Frt)	Parking Adjustment Factor (Fp)
Ayat-summit	0.1	0.55	0.5	1	288	144	144	3	0	6	0	0.6
Ayat–yeka	0.1	0.55	0.5	1	312	156	156	4	0	7	0	0.6
Ayat-Chafe	0.1	0.55	0.33	0.8	508	170	338	5	0	11	0	0.6
CMC–Summit	0.1	0.55	0.33	0.8	372	124	248	4	0	12	0	0.6

CLV=PHV/no. of lane, OLV=PHV-CLV, CLTV=PHV*HV*T

$(CLV)_{A-S}$=288/2=144, OLV=288-144=144, CLTV=288*0.01*1=3

$(CLV)_{A-Y}$=312/2=156, OLV=312-156=156, CLTV=312*0.01*1=4

$(CLV)_{A-C}$=508/3=170, OLV=508-170=338, CLTV=508*0.01*1=5

$(CLV)_{C-S}$=372/2=186, OLV=372-186=186, CLTV= 372*0.01*1=4

Peak hour right turn volume = PHV *R%

$(PHRTV)_{A-S}$ = 288 *0.02 = 6, $(PHRTV)_{A-Y}$ =312*0.02 = 7, $(PHRTV)_{A-C}$ = 508 *0.02 = 11 and $(PHRTV)_{C-S}$ =372*0.03 = 12

Level of Service Computations worksheet

Location	BCI model variables									Results		
Midblock identifier	BL	BLW	CLW	CLV	OLV	SPD	PKG	AREA	AF	BCI	Level of Service	Bicycle Compatibility level
Ayat – summit	0	0	3.5	144	144	50	0	1	0.6	3.7086	D	Moderately LOW
Ayat – yeka	0	0	3.5	156	156	50	0	1	0.6	3.7374	D	Moderately LOW
Ayat-chafe	0	0	3.5	170	338	50	0	1	0.6	3.838	D	Moderately LOW
CMC – Summit	0	5	3.5	186	186	50	0	1	0.6	1.7594	B^+	Moderately LOW

BCI = 3.67 – 0.966BL – 0.410BLW – 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG – 0.264AREA + AF

$(BCI)_{A-S}$=3.67-0.966*0-0.410*0-0.498*3.5+0.002*144+0.0004*144+0.022*50+0.506*0-0.264*1+0.6

=3.67-1.743+0.288+0.0576+1.1-0.264+0.6

=3.7086

$(BCI)_{A-Y}$=3.67-0.966*0-0.410*0-0.498*3.5+0.002*156+0.0004*156+0.022*50+0.506*0-0.246*1+0.6

=3.67-1.743+0.312+0.0624+1.1-0.264+0.6

=3.7374

$(BCI)_{A-C}$=3.67-0.966(0)-0.410(0)-0.498(3.5)+0.002(170)+0.0004(338)+0.022(50)+0.506(0)-0.264 (1)+0.6

= 3.67-1.743+0.34+0.135+1.1+0-0.264+0.6

= 3.838- moderately low

$(BCI)_{C-S}$=3.67-0.996*0-0.410*5-0.498*3.5+0.002*186+0.0004*186+0.022*50+0.506*0-0.264*1+0.6

=3.67-2.05-1.743+0.372+0.0744+1.1-0.264+0.6

=1.7594

Data Entry worksheet

Location	Geometric and road side data					Traffic operations data					Parking data		
Midblock identifier	No. of Lanes (one direction)	Curb Lane Width (ft)	Bicycle Lane Width (ft)	Paved Shoulder Width (ft)	Residential Development (y/n)	Speed Limit (mi/h)	85th %tile Speed (mi/h)	AADT	Large Truck % (HV)	Right Turn % (R)	Parking Lane (y/n)	Occupancy (%)	Time Limit (minutes)
Imperial-17 HC	3	3.5	0	0	Y	35	50	13091	0.01	0.02	N	0	<15
Ayertena-Alembank	3	3.5	0	0	Y	35	50	10834	0.01	0.02	N	0	<15
Winget-Pasteur	3	3.5	0	0	Y	35	50	21819	0.01	0.03	N	0	<15
Michael – Jomo 3	2	3.5	0	0	Y	35	50	20873	0.01	0.01	N	0	<15

AADT

Imperial-17HC: Vol_{15min}=180, PHV=180*4=720, AADT= PHV/K*D= 720/0.1*0.55=13091

Ayertena-Alembank: Vol_{15min}=149, PHV=149*4=596, AADT= PHV/K*D= 596/0.1*0.55=10834

Winget-pastuer: Vol_{15min}=300, PHV=300*4=1200, AADT= PHV/K*D= 1200/0.1*0.55=21819

Michael-Jomo3: Vol_{15min}=287, PHV=287*4=1148, AADT= PHV/K*D= 1148/0.1*0.55=2087

Large truck factor

From AACRA manual-1%(heavy 0% + articulated 1%) for principal arterials

Intermediate calculations worksheet

Location	Peak hour computations						Adjustment factors				
Middle block identifier	Peak Hour Factor (K-factor)	Directional Split (D-factor)	Curb Lane %	Curb Lane Truck % (T-factor)	Peak Hour Volume (PHV)	Peak Hr Curb Lane Volume (CLV)	Peak Hr Other Lane(s) Vol (OLV)	Peak Hr Curb Lane Truck Vol (CLTV)	Large Truck Adjustment Factor (Ft)	Peak Hr Right Turn Volume	Right Turn Adjustment Factor (Frt)	Parking Adjustment Factor (Fp)
Imperial-17HC	0.1	0.55	0.33	1	720	240	480	8	0	15	0	0.6
Ayertena-Alembank	0.1	0.55	0.33	1	596	199	397	6	0	12	0	0.6
Winget-Pasteur	0.1	0.55	0.33	1	1200	400	800	12	0.1	36	0	0.6
Michael–Jomo3	0.1	0.55	0.5	0.8	1148	574	574	10	0.1	12	0	0.6

CLV=PHV/no. of lane

$(CLV)_{I-17}$=720/3=240, OLV=720-240=480, CLTV= PHV * HV*T=720*0.01*1=8

$(CLV)_{A-A}$=596/3=199, OLV=596-199=397, CLTV= PHV * HV*T=596*0.01*1=6

$(CLV)_{W-P}$=1200/3=400, OLV=1200-400=800, CLTV= PHV * HV*T=1200*0.01*1=12

$(CLV)_{M-J}$=1148/2=574, OLV=1148-574=574, CLTV= PHV * HV*T=1148*0.01*0.8=10

Peak hour right turn volume = PHV *R%

$(PHRTV)_{I-17}$ = 720*0.02 = 15, $(PHRTV)_{A-A}$ =596*0.02 = 12, $(PHRTV)_{W-P}$ = 1200*0.03 = 36 and $(PHRTV)_{M-J}$ =1148*0.01 = 12

Level of Service Computations worksheet

Location	BCI model variables									Results		
Midblock identifier	BL	BLW	CLW	CLV	OLV	SPD	PKG	AREA	AF	BCI	LOS	Bicycle Compatibility level
Imperial-17HC	0	0	3.5	240	480	50	0	1	0.6	4.035	D	Moderately low
Ayertena-Alembank	0	0	3.5	199	397	50	0	1	0.6	3.9198	D	Moderately low
Winget-Pasteur	0	0	3.5	400	800	50	0	1	0.7	4.583	E	Very low
Michael-Jomo 3	0	0	3.5	574	574	50	0	1	0.7	4.8406	E	Very low

BCI = 3.67 – 0.966BL – 0.410BLW – 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG – 0.264AREA + AF

$(BCI)_{17-I}$= 3.67 – 0.966*0 – 0.410*0 – 0.498*3.5 + 0.002*240 + 0.0004*480 + 0.022*50 + 0.506*0 – 0.264*1 + 0.6

=3.67-1.743+0.48+0.192+1.1-0.264+0.6

=4.035

$(BCI)_{A-AL}$ = 3.67 – 0.966*0 – 0.410*0 – 0.498*3.5 + 0.002*199 + 0.0004*397 + 0.022*50 + 0.506*0 – 0.264*1 + 0.6

=3.67-1.743+0.398+0.1588+1.1-0.264+0.6

=3.9198

$(BCI)_{W-P}$ = 3.67 – 0.966*0 – 0.410*0 – 0.498*3.5 + 0.002*400 + 0.0004*800 + 0.022*50 + 0.506*0 – 0.264*1 + 0.7

=3.67-1.743+0.8+0.32+1.1-0.264+0.7

=4.583

$(BCI)_{W-P}$ = 3.67 – 0.966*0 – 0.410*0 – 0.498*3.5 + 0.002*574 + 0.0004*574 + 0.022*50 + 0.506*0 – 0.264*1 + 0.7

=3.67-1.743+1.148+0.2296+1.1-0.264+0.7

=4.8406

Data Entry worksheet

Location	Geometric and road side data					Traffic operations data					Parking data		
Midblock identifier	No. of Lanes (one direction)	Curb Lane Width (ft)	Bicycle Lane Width (ft)	Paved Shoulder Width (ft)	Residential Development (y/n)	Speed Limit (mi/h)	85th %tile Speed (mi/h)	AADT	Large Truck % (HV)	Right Turn % (R)	Parking Lane (y/)	Occupancy (%)	Time Limit (minutes)
Akaki–AASTU	2	3.5	0	0	Y	35	50	8073	0.01	0.02	N	0	<15
Kera-kirkos	2	3.5	0	0	Y	35	50	9891	0.01	0.02	N	0	<15
German-Gofa	2	3.5	0	0	Y	35	50	22619	0.01	0.03	N	0	<15

<u>AADT</u>

Akaki-AASTU: Vol_{15min}=111, PHV=111*4=444, AADT= PHV/K*D= 444/0.1*0.55=8073

Kera-kirkos: Vol_{15min}=136, PHV=136*4=544, AADT= PHV/K*D= 544/0.1*0.55=9891

German- gofa: Vol_{15min}=311, PHV=311*4=1244, AADT= PHV/K*D= 1244/0.1*0.55=22619

<u>Large truck factor</u>

From AACRA manual-1%(heavy 0% + articulated 1%) for principal & sub arterials

Intermediate calculations worksheet

Location	Peak hour computations							Adjustment factors				
Middle block identifier	Peak Hour Factor (K-factor)	Directional Split (D-factor)	Curb Lane %	Curb Lane Truck % (T-factor)	Peak Hour Volume (PHV)	Peak Hr Curb Lane Volume (CLV)	Peak Hr Other Lane(s) Vol (OLV)	Peak Hr Curb Lane Truck Vol (CLTV)	Large Truck Adjustment Factor (Ft)	Peak Hr Right Turn Volume	Right Turn Adjustment Factor (Frt)	Parking Adjustment Factor (Fp)
Akaki–AASTU	0.1	0.55	0.5	1	444	222	222	5	0	9	0	0.6
Kera-kirkos	0.1	0.55	0.5	1	544	272	272	6	0	11	0	0.6
German-Gofa	0.1	0.55	0.5	1	1244	622	622	13	0.1	38	0	0.6

CLV=PHV/no. of lane, OLV=PHV-CLV, and CLTV= PHV * HV*T

$(CLV)_{A-A}$=444/2=222, OLV=444-222=222, CLTV=444*0.01*1=5

$(CLV)_{K-K}$=544/2=272, OLV=544-272=272, CLTV=544*0.01*1=6

$(CLV)_{G-G}$=1244/2=622, OLV=1244-622=622, CLTV=1244*0.01*1=13

Peak hour right turn volume = PHV *R%

$(PHRTV)_{A-A}$ = 444*0.02 = 9, $(PHRTV)_{K-K}$ =544*0.02 = 11 and $(PHRTV)_{G-G}$ = 1244*0.03 = 38

Level of Service Computations worksheet

Location	BCI model variables									Results		
Midblock identifier	BL	BLW	CLW	CLV	OLV	SPD	PKG	AREA	AF	BCI	LOS	Bicycle Compatibility level
Akaki – AASTU	0	0	3.5	222	222	50	0	1	0.6	3.8958	D	Moderately low
Kera- kirkos	0	0	3.5	272	272	50	0	1	0.6	4.0158	D	Moderately low
German-Gofa	0	0	3.5	622	622	50	0	1	0.7	4.9558	E	Very low

BCI = 3.67 – 0.966BL – 0.410BLW – 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG – 0.264AREA + AF

$(BCI)_{A-A}$=3.67-0.966*0-0.410*0-0.498*3.5+0.002*222+0.0004*222+0.022*50+0.506*0 0.264*1+0.6

=3.67-1.743+0.444+0.0888+1.1-0.264+0.6

=3.8958

$(BCI)_{K-K}$=3.67-0.966*0-0.410*0-0.498*3.5+0.002*272+0.0004*272+0.022*50+0.506*0-0.264*1+0.6

=3.67-1.743+0.544+0.1088+1.1-0.264+0.6

=4.0158

$(BCI)_{G-G}$=3.67-0.966*0-0.410*0-0.498*3.5+0.002*622+0.0004*622+0.022*50+0.506*0-0.264*1+0.6

=3.67-1.743+1.244+0.2488+1.1-0.264+0.7

=4.9558

BLOS (bicycle level of service) analysis

BLOS data entry & calculations worksheet

Route name	Vol_{15}	L	SP_p	SP_t	HV	PR_5	W_e	W_t	%OSP	W_l	Wps	W_v	AADT
Ayat– summit	72	2	22.5	1.83	1%	5	11.67	11.67	0	0	0	11.67	5237
Ayat – yeka	78	2	22.5	1.83	1%	5	11.67	11.67	0	0	0	11.67	5673
Ayat– Chafe	127	3	22.5	1.83	1%	5	11.67	11.67	0	0	0	11.67	9237
CMC– Summit	93	2	22.5	1.83	1%	5	28.34	28.34	0	0	0	28.34	6764

C-S -> W_v=Wt, W_t=3.5+5=8.5m=28.34ft, W_v=8.5=28.34ft, W_{ps}=0 and W_l=0, and

Hence W_e=W_v=8.5m=28.34ft

BLOS score and level of service calculations worksheet

Route name	Vol_{15}	L	SP_t	HV	PR_5	W_e	BLOS score	letter grade	Level of service
Ayat-summit	72	2	1.83	1%	5	11.67	2.623	C^+	Moderately high
Ayat-yeka	78	2	1.83	1%	5	11.67	2.663	C^+	Moderately high
Ayat–Chafe	127	3	1.83	1%	5	11.67	2.705	C^+	Moderately high
CMC-Summit	93	3	1.83	1%	5	28.34	-0.5824	A^+	Extremely high

$$BLOS = 0.507\ln\left(\frac{\mathrm{Vol}_{15}}{\mathrm{L}}\right) + 0.199\mathrm{SP_t}\,(1+10.38\mathrm{HV})^2 + 7.066\left(\frac{1}{\mathrm{PR}_5}\right)^2 - 0.005(\mathrm{W_e})^2 + 0.760$$

$(BLOS)_{H\text{-}S}$=0.507ln(72/2)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(11.67)^2+0.76

=1.817+0.444+0.283-0.681+0.76

=2.623

$(BLOS)_{H\text{-}Y}$=0.507ln(78/2)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(11.67)^2+0.76

=1.857+0.444+0.283-0.681+0.76

=2.663

$(BLOS)_{H\text{-}C}$=0.507ln(127/3)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(11.67)^2+0.76

=1.899+0.444+0.283-0.681+0.76

=2.705

$(BLOS)_{C\text{-}S}$=0.507ln(93/2)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(28.34)^2+0.76

=1.9466+0.444+0.283-4.016+0.76

= -0.5824

BLOS data entry & calculations worksheet

Route name	Vol_{15}	L	SP_p	SP_t	HV	PR_5	W_e	W_t	%OSP	W_l	Wps	W_v	AADT
Imperial- 17Hc	180	3	22.5	1.83	1%	5	11.67	11.67	0	0	0	11.67	13091
Ayertena-Alembank	149	3	22.5	1.83	1%	5	11.67	11.67	0	0	0	11.67	10834
Winget- Pasteur	300	3	22.5	1.83	1%	5	11.67	11.67	0	0	0	11.67	21819
Michael-Jomo3	287	2	22.5	1.83	1%	5	11.67	11.67	0	0	0	11.67	20873

BLOS score and level of service calculations worksheet

Route name	Vol_{15}	L	SP_t	HV	PR_5	W_e	BLOS score	letter grade	Level of service
Imperial-17HC	180	3	1.83	1%	5	11.67	2.882	C^+	Moderately high
Ayertena- Alembank	149	3	1.83	1%	5	11.67	2.786	C^+	Moderately high
Winget-pastuer	300	3	1.83	1%	5	11.67	3.141	C^-	Moderately high
Michael-Jomo3	287	2	1.83	1%	5	11.67	3.324	C^-	Moderately high

$$BLOS = 0.507\ln\left(\frac{\mathrm{Vol}_{15}}{\mathrm{L}}\right) + 0.199\mathrm{SP_t}\,(1+10.38\mathrm{HV})^2 + 7.066\left(\frac{1}{\mathrm{PR}_5}\right)^2 - 0.005(\mathrm{W_e})^2 + 0.760$$

$BLOS)_{I-17}$=0.507ln(180/3)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(11.67)^2+0.76

=2.076+0.444+0.283-0.681+0.76

=2.882

$BLOS)_{A-AL}$=0.507ln(149/3)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(11.67)^2+0.76

=1.98+0.444+0.283-0.681+0.76

=2.786

$BLOS)_{W-P}$=0.507ln(300/3)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(11.67)^2+0.76

=2.335+0.444+0.283-0.681+0.76

=3.141

$BLOS)_{M-J}$=0.507ln(287/2)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(11.67)^2+0.76

=2.518+0.444+0.283-0.681+0.76

=3.324

BLOS data entry & calculations worksheet

Route name	Vol_{15}	L	SP_p	SP_t	HV	PR_5	W_e	W_t	%OSP	W_l	Wps	W_v	AADT
Akaki – AASTU	111	2	22.5	1.83	1%	5	11.67	11.67	0	0	0	11.67	8073
Kera- kirkos	136	2	22.5	1.83	1%	5	11.67	11.67	0	0	0	11.67	9891
German-Gofa	311	2	22.5	1.83	1%	5	11.67	11.67	0	0	0	11.67	22619

BLOS score and level of service calculations worksheet

Route name	Vol_{15}	L	SP_t	HV	PR_5	W_e	BLOS score	letter grade	Level of service
Akaki – AASTU	111	2	1.83	1%	5	11.67	2.842	C^+	Moderately high
Kera- kirkos	136	2	1.83	1%	5	11.67	2.945	C^+	Moderately high
German-Gofa	311	2	1.83	1%	5	11.67	3.365	C^-	Moderately high

$$BLOS = 0.507\ln\left(\frac{\mathrm{Vol}_{15}}{\mathrm{L}}\right) + 0.199\mathrm{SP_t}\,(1+10.38\mathrm{HV})^2 + 7.066\left(\frac{1}{\mathrm{PR_5}}\right)^2 - 0.005(\mathrm{W_e})^2 + 0.760$$

$BLOS)_{A-A}$=0.507ln(111/2)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(11.67)^2+0.76

=2.036+0.444+0.283-0.681+0.76

=2.842

$BLOS)_{K-K}$=0.507ln(136/2)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(11.67)^2+0.76

=2.139+0.444+0.283-0.681+0.76

=2.945

$$BLOS)_{G\text{-}G}=0.507\ln(311/2)+0.199*1.83(1+10.38*0.01)^2+7.066(1/5)^2-0.005(11.67)^2+0.76$$

$$=2.559+0.444+0.283-0.681+0.76=3.365$$

Brent Hugh's excel method of analysis

	Ayat-semit		*Ayat-Chafe*		*Ayat- yeka*		*CMC- semit*
2	*Lanes per direction*	3	*Lanes per direction*	2	*Lanes per direction*	2	*Lanes per direction*
11.67	*curb lane width*	11.67	*curb lane width*	11.67	*curb lane width*	28.34	*curb lane width*
0	*shoulder/bike lane width*	0	*shoulder/bike lane width*	0	*shoulder/bike lane width*	0	*shoulder/bike lane width*
5237	*Bi-directional ADT*	9237	*Bi-directional ADT*	5673	*Bi-directional ADT*	6764	*Bi-directional ADT*
28.5	*Speed limit*	28.5	*Speed limit*	28.5	*Speed limit*	28.5	*Speed limit*
1	*% heavy trucks*	1	*% heavy trucks*	1	*% heavy trucks*	1	*% heavy trucks*
5	*Pavement condition (5 best)*	5	*Pavement condition (5 best)*	5	*Pavement condition (5 best)*	5	*Pavement condition (5 best)*
0	*% on-street parking*	0	*% on-street parking*	0	*% on-street parking*	0	*% on-street parking*
15	*Parking time limit*	15	*Parking time limit*	15	*Parking time limit*	15	*Parking time limit*
1	*1=residential, 0=not resident'l*	1	*1=residential, 0=not resident'l*	1	*1=residential, 0=not resident'l*	1	*1=residential, 0=not resident'l*
	BCI		BCI		BCI		BCI
2.867	C Moderately High	2.911	C Moderately High	2.885	C Moderately High	0.401	A+ Extremely High
	BLOS		BLOS		BLOS		BLOS
2.815	C+ Moderately High	2.898	C Moderately High	2.856	C Moderately High	-0.390	A+ Extremely High

	17HC-imperial RA		*Ayertena*-Alembank		*winget*-pasteur		*Michael RA*-Jomo3
3	*Lanes per direction*	3	*Lanes per direction*	3	*Lanes per direction*	2	*Lanes per direction*
11.67	*curb lane width*	11.67	*curb lane width*	11.67	*curb lane width*	11.67	*curb lane width*
0	*shoulder/bike lane width*	0	*shoulder/bike lane width*	0	*shoulder/bike lane width*	0	*shoulder/bike lane width*
13091	*Bi-directional ADT*	10834	*Bi-directional ADT*	21819	*Bi-directional ADT*	20873	*Bi-directional ADT*
28.5	*Speed limit*	28.5	*Speed limit*	28.5	*Speed limit*	28.5	*Speed limit*
1	*% heavy trucks*	1	*% heavy trucks*	1	*% heavy trucks*	1	*% heavy trucks*
5	*Pavement condition (5 best)*	5	*Pavement condition (5 best)*	5	*Pavement condition (5 best)*	5	*Pavement condition (5 best)*
0	*% on-street parking*	0	*% on-street parking*	0	*% on-street parking*	0	*% on-street parking*
15	*Parking time limit*	15	*Parking time limit*	15	*Parking time limit*	15	*Parking time limit*
1	*1=residential, 0=not resident'l*	1	*1=residential, 0=not resident'l*	1	*1=residential, 0=not resident'l*	1	*1=residential, 0=not resident'l*
	BCI		BCI		BCI		BCI
3.022	C Moderately High	2.957	C Moderately High	3.274	C- Moderately High	3.531	D+ Moderately Low
	BLOS		BLOS		BLOS		BLOS
3.074	C Moderately High	2.978	C Moderately High	3.333	C- Moderately High	3.516	D+ Moderately Low

Akaki-AASTU			*Kera*-Kirkos			*Germen*-Gofa		
2	*Lanes per direction*		2	*Lanes per direction*		2	*Lanes per direction*	
11.67	*curb lane width*		11.67	*curb lane width*		11.67	*curb lane width*	
0	*shoulder/bike lane width*		0	*shoulder/bike lane width*		0	*shoulder/bike lane width*	
8073	*Bi-directional ADT*		9891	*Bi-directional ADT*		22619	*Bi-directional ADT*	
28.5	*Speed limit*		28.5	*Speed limit*		28.5	*Speed limit*	
1	*% heavy trucks*		1	*% heavy trucks*		1	*% heavy trucks*	
5	*Pavement condition (5 best)*		5	*Pavement condition (5 best)*		5	*Pavement condition (5 best)*	
0	*% on-street parking*		0	*% on-street parking*		0	*% on-street parking*	
15	*Parking time limit*		15	*Parking time limit*		15	*Parking time limit*	
1	*1=residential, 0=not resident'l*		1	*1=residential, 0=not resident'l*		1	*1=residential, 0=not resident'l*	
	BCI			BCI			BCI	
2.987	C	Moderately High	3.064	C-	Moderately High	3.605	D+	Moderately Low
	BLOS			BLOS			BLOS	
3.035	C	Moderately High	3.138	C	Moderately High	3.557	D+	Moderately Low

Appendix C: Population perception analysis

መጠይቅ/questionaire

በተዘጋጁት ሳጥኖች ውስጥ ምርጫዎን ራይት(✓) በማድረግ ይተባበሩን፡፡ (አንዱ ላይ ብቻ ራይት ያድርጉ)

1) ጾታ ወ ☐ ሴ ☐

2) ዕድሜ ሀ) ከ14 እስከ 18 ዓመት ☐ ለ) ከ19 እስከ 50 ዓመት ☐ ሐ) ከ51 ዓመት በላይ ☐

3) ደህንነቱ የተጠበቀ የባይስክል መንገድ ቢዘጋጅልዎ ባይስክልን ለመጠቀም ፍላጎት አልዎት?

ሀ) አዎ ከፍተኛ ፍላጎት አለኝ ☐ ለ) አዎ እፈልጋለው ☐ ሐ) ምናልባት ☐

መ) የመንገዱን ሁኔታ አይቼ ልጠቀም እችላለሁ ☐ ሠ) በፍጹም ፍላጎት የለኝም ☐

መልስዎ ፍላጎት የለኝም ከሆነ ምክንያት

____

4) ደህንነቱ የተጠበቀ የባይስክል መንገድ ቢዘጋጅ ባይስክልን ገዝተው ለመጠቀም ፍላጎት አለዎት?

ሀ) አዎ ከፍተኛ ፍላጎት አለኝ ☐ ለ) አዎ ፍላጎት አለኝ ☐ ሐ) ምናልባት ☐

መ) የሚገነባውን መንገድ አይቼ እጠቀማለው ☐ ሠ) ፍላጎት የለኝም ☐

መልስዎ ፍላጎት የለኝም ከሆነ ምክንያት__________________________________

5) ደህንነቱ የተጠበቀ የባይስክል መንገድ ቢዘጋጅ ልጅዎን ወይም ቤተሰብዎን ባይስክል እንዲጠቀም ይፈቅዳሉ?

ሀ) አዎ በጣም እፈቅዳለሁ ☐ ለ) አዎ እፈቅዳለሁ ☐ ሐ) ምናልባት ☐

መ) የሚገነባውን መንገድ ደህንነት ካየው በኃላ ልፈቅድ እችላለሁ ☐ ሠ) አልፈቅድም ☐

ረ) በፍጹም አልፈቅድም ☐

6) ብስክሌት መንዳት ይችላሉ

ሀ) በደምብ እችላለሁ ☐ ለ) አዎ እችላለሁ ☐ ሐ) እሞክራለሁ ☐ መ) አልችልም ☐

☞ መጠይቁን በመሙላት ላደረጉልን መልካም ትብብር ከልብ እናመሰግናለን፡፡

Population size and sample size determination

Route name	Population size	Sample size
Kera-kirkos	19759	100
Ayertena-alembank	32866	100
Ayat-chafe	32262	100
CMC-summit	20228	100
Imperial-17HC	31757	100

Note that: The population size is taken from national central statistics agency of Ethiopia (2013/14).

The sample size for all population is determined based on the use of ±10% margin of error from the following table.

Sample size determination (Yamane 1967)

Size of Population	Sample Size (n) for Precision (e) of:			
	±3%	±5%	±7%	±10%
500	A	222	145	83
600	A	240	152	86
700	A	255	158	88
800	A	267	163	89
900	A	277	166	90
1,000	A	286	169	91
2,000	714	333	185	95
3,000	811	353	191	97
4,000	870	364	194	98
5,000	909	370	196	98
6,000	938	375	197	98
7,000	959	378	198	99
8,000	976	381	199	99
9,000	989	383	200	99
10,000	1,000	385	200	99
15,000	1,034	390	201	99
20,000	1,053	392	204	100
25,000	1,064	394	204	100
50,000	1,087	397	204	100
100,000	1,099	398	204	100
>100,000	1,111	400	204	100

Kera – kirkos

Riding interest (Q1, 2&3)

Riding interest											
Wants to ride						Don’t wants to ride					
89						11					
Male			Female			Male			Female		
61			28			6			5		
Age			Age			Age			Age		
13-18	19-50	>50	13-18	19-50	›50	13-18	19-50	›50	13-18	19-50	>50
23	38	0	12	16	0	1	5	0	0	5	0

Percentage of people who wants to ride is 89% and this means between 79% and 99% of the people wants to cycle.61% i.e. 51%-71% of the population who wants to ride is males and 28% i.e. 18%-38% of the population who wants to ride is females.

Percentage of people who don’t want to ride is 11% and this means between 1% and 21% of the people don’t want to ride. 6% i.e.0%-16% of the population who don’t wants to cycle are males and 5% i.e. 0%-15% of the population who don’t wants to cycle are females. The reason why they don’t wants to cycle, for most of the riders, is safety and for some is having no ability to ride.

Buying interest (Q4)

Buying interest							
Wants to buy				Don’t wants to buy			
Male		Female		Male		Female	
Age		Age		Age		Age	
19-50	>50	19-50	›50	19-50	›50	19-50	>50
36	0	15	0	2	0	1	0

Percentage of people who wants to buy is 61%$\pm$10%, 36% $\pm$10% are males and 15% $\pm$10% are females. Percentage of people who don’t wants to buy are 3%$\pm$10%, 1%$\pm$10% are females and 2%$\pm$10% is males.

Allowing (Q5)

Allowing							
I will allow				I will not allow			
Male		Female		Male		Female	
Age		Age		Age		Age	
19-50	>50	19-50	›50	19-50	›50	19-50	>50
37	0	16	0	1	0	0	0

Percentages of people who will allow are 53%±10% and out of this 37%±10% are males and 16%±10% are females. 1% ±10% of the population will not allow their families to ride and out of this 1% ±10% are males and 0±10% are females.

Ability to ride (Q6)

Male

Male/wants to ride											
61											
Age											
13-18				19-50				>50			
23				38				0			
Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride
12	6	4	0	23	5	7	3				

Percentage of people with qualified riding ability are 12%±10%, with medium riding ability are 6%±10%, with trial ability are 4%±10% and cant rides are 0%±10% for 13-18 age range. Percentage of people with qualified riding ability are 23%±10%, with medium riding ability are 1%±10%, with trial ability are 3%±10% and cant rides are 2%±10% for 19-50 age range. Percentage of people with qualified riding ability are 23%±10%, with medium riding ability are 5%±10%, with trial ability are 7%±10% and cant rides are 3%±10% for >50 age range.

Female

Female/wants to ride											
28											
Age											
13-18				19-50				›50			
12				16				0			
Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride
0	3	5	4	1	7	3	5	0	0	0	0

Percentage of people with qualified riding ability are 0%±10%, with medium riding ability are 3%±10%, with trial ability are 5%±10% and cant rides are 4%±10% for 13-18 age range. Percentage of people with qualified riding ability are 1%±10%, with medium riding ability are 7%±10%, with trial ability are 3%±10% and cant rides are 5%±10% for 19-50 age range. Percentage of people with qualified riding ability are 0%±10%, with medium riding ability are 0%±10%, with trial ability are 0%±10% and cant rides are 0%±10% for >50 age range.

Ayertena- alembank

Riding interest (Q1, 2&3)

Riding interest											
Wants to ride						Don't wants to ride					
96						4					
Male			Female			Male			Female		
73			23			1			3		
Age			Age			Age			Age		
13-18	19-50	>50	13-18	19-50	›50	13-18	19-50	›50	13-18	19-50	>50
21	49	3	16	7	0	0	1	0	0	3	0

Percentage of people who wants to ride is 96%$\pm$10% and this means between 86% and 100% of the people wants to cycle. 73$\pm$10% i.e. 63%-83% of the population who wants to ride is males and 23$\pm$10% i.e. 13%-33% of the population who wants to ride is females.

Percentage of people who don't want to ride is 4%$\pm$10% and this means between 0% and 14% of the people don't want to ride. 1$\pm$10% i.e. 0%-11% of the population who don't wants to cycle are males and 3$\pm$10% i.e. 0%-13% of the population who don't wants to cycle are females. The reason why they don't wants to cycle, for most of the riders, is safety and for some is having no ability to ride.

Buying interest (Q4)

Buying interest							
Wants to buy				Don't wants to buy			
Male		Female		Male		Female	
Age		Age		Age		Age	
19-50	>50	19-50	›50	19-50	›50	19-50	>50
48	3	7	0	1	0	0	0

Percentage of people who wants to buy is 58%$\pm$10%, 51% $\pm$10% are males and 7% $\pm$10% are females. Percentage of people who don't wants to buy are 1%$\pm$10%, 1%$\pm$10% are females and 0%$\pm$10% is females.

Allowing (Q5)

Allowing							
I will allow				I will not allow			
Male		Female		Male		Female	
Age		Age		Age		Age	
19-50	>50	19-50	›50	19-50	›50	19-50	>50
49	2	7	0	0	1	0	0

Percentages of people who will allow are 58%±10% and out of this 49%±10% are males and 7%±10% are females. 1% ±10% of the population will not allow their families to ride and out of this 1% ±10% are males and 0±10% are females.

Ability to ride (Q6)

Male

Male/wants to ride											
73											
Age											
13-18				19-50				>50			
23				38				0			
Qualified rider	Medium rider	Trial rider	Can’t ride	Qualified rider	Medium rider	Trial rider	Can’t ride	Qualified rider	Medium rider	Trial rider	Can’t ride
11	4	3	2	26	6	11	7	2	0	0	1

Percentage of people with qualified riding ability are 11%±10%, with medium riding ability are 4%±10%, with trial ability are 3%±10% and cant rides are 2%±10% for 13-18 age range. Percentage of people with qualified riding ability are 26%±10%, with medium riding ability are 6%±10%, with trial ability are 11%±10% and cant rides are 7%±10% for 19-50 age range. Percentage of people with qualified riding ability are 2%±10%, with medium riding ability are 0%±10%, with trial ability are 0%±10% and cant rides are 1%±10% for >50 age range.

Female

Female/wants to ride											
23											
Age											
13-18				19-50				›50			
Qualified rider	Medium rider	Trial rider	Can’t ride	Qualified rider	Medium rider	Trial rider	Can’t ride	Qualified rider	Medium rider	Trial rider	Can’t ride
0	2	8	6	1	1	3	2	0	0	0	0

Percentage of people with qualified riding ability are 0%±10%, with medium riding ability are 2%±10%, with trial ability are 8%±10% and cant rides are 6%±10% for 13-18 age range. Percentage of people with qualified riding ability are 1%±10%, with medium riding ability are 1%±10%, with trial ability are 3%±10% and cant rides are 2%±10% for 19-50 age range. Percentage of people with qualified riding ability are 0%±10%, with medium riding ability are 0%±10%, with trial ability are 0%±10% and cant rides are 0%±10% for >50 age range.

CMC-summit

Riding interest (Q1, 2&3)

Riding interest											
Wants to ride						Don't wants to ride					
97						3					
Male			Female			Male			Female		
79			18			1			2		
Age			Age			Age			Age		
13-18	19-50	>50	13-18	19-50	›50	13-18	19-50	›50	13-18	19-50	>50
39	40	0	13	5	0	0	1	0	0	2	0

Percentage of people who wants to ride is 97%±10%. 79±10% of the population who wants to ride is males and 18±10% of the population who wants to ride is females.

Percentage of people who don't want to ride is 3%±10%. 1±10% of the population who don't want to cycle are males and 2±10% of the population who don't wants to cycle are females. The reason why they don't wants to cycle, for most of the riders, is safety and for some is having no ability to ride.

Buying interest (Q4)

Buying interest							
Wants to buy				Don't wants to buy			
Male		Female		Male		Female	
Age		Age		Age		Age	
19-50	>50	19-50	›50	19-50	›50	19-50	>50
40	0	5	0	0	0	0	0

Percentage of people who wants to buy is 45%±10%, 40% ±10% are males and 5% ±10% are females. Percentage of people who don't wants to buy are 0% ±10%, 0%±10% is males and 0%±10 is females.

Allowing (Q5)

Allowing							
I will allow				I will not allow			
Male		Female		Male		Female	
Age		Age		Age		Age	
19-50	>50	19-50	›50	19-50	›50	19-50	>50
40	0	5	0	0	0	0	0

Percentages of people who will allow are 45%±10% and out of this 40%±10% are males and 5%±10% are females. 0% ±10% of the population will not allow their families to ride and out of this 0% ±10% are males and 0±10% are females.

Ability to ride (Q6)

Male

Male/wants to ride											
79											
Age											
13-18				19-50				>50			
39				40				0			
Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride
26	10	3	0	23	9	7	1	0	0	0	0

Percentage of people with qualified riding ability are 26%±10%, with medium riding ability are 10%±10%, with trial ability are 3%±10% and cant rides are 0%±10% for 13-18 age range. Percentage of people with qualified riding ability are 23%±10%, with medium riding ability are 9%±10%, with trial ability are 7%±10% and cant rides are 1%±10% for 19-50 age range. Percentage of people with qualified riding ability are 0%±10%, with medium riding ability are 0%±10%, with trial ability are 0%±10% and cant rides are 0%±10% for >50 age range.

Female

Female/wants to ride											
18											
Age											
13-18				19-50				›50			
Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride
1	1	6	5	1	1	1	2	0	0	0	0

Percentage of people with qualified riding ability are 1%±10%, with medium riding ability are 1%±10%, with trial ability are 6%±10% and cant rides are 5%±10% for 13-18 age range. Percentage of people with qualified riding ability are 1%±10%, with medium riding ability are 1%±10%, with trial ability are 1%±10% and cant rides are 2%±10% for 19-50 age range. Percentage of people with qualified riding ability are 0%±10%, with medium riding ability are 0%±10%, with trial ability are 0%±10% and cant rides are 0%±10% for >50 age range.

Imperial -17HC

Riding interest (Q1, 2&3)

Riding interest											
Wants to ride						Don’t wants to ride					
96						4					
Male			Female			Male			Female		
58			38			0			4		
Age			Age			Age			Age		
13-18	19-50	>50	13-18	19-50	›50	13-18	19-50	›50	13-18	19-50	>50
21	36	1	23	15	0	0	0	0	2	1	1

Percentage of people who wants to ride is 96%±10%, 58±10% of the population who wants to ride is males and 38±10% of the population who wants to ride is females.

Percentage of people who don’t want to ride is 4%±10%. 0±10% of the population who don’t want to cycle are males and 4±10% of the population who don’t want to cycle are females. The reason why they don’t wants to cycle, for most of the riders, is safety and for some is having no ability to ride.

Buying interest (Q4)

Buying interest							
Wants to buy				Don’t wants to buy			
Male		Female		Male		Female	
Age		Age		Age		Age	
19-50	>50	19-50	›50	19-50	›50	19-50	>50
35	1	14	0	1	0	1	0

Percentage of people who wants to buy is 50%±10%, 35% ±10% are males and 14% ±10% are females. Percentage of people who don’t wants to buy are 2%±10, 1%±10% are females and 1%±10% are females.

Allowing (Q5)

Allowing							
I will allow				I will not allow			
Male		Female		Male		Female	
Age		Age		Age		Age	
19-50	>50	19-50	›50	19-50	›50	19-50	>50
35	1	15	0	0	0	0	0

Percentages of people who will allow are 51%±10% and out of this 36%±10% are males and 15%±10% are females. 0% ±10% of the population will not allow their families to ride and out of this 0% ±10% are males and 0±10% are females.

Ability to ride (Q6)

Male

Male/wants to ride											
58											
Age											
13-18				19-50				>50			
21				36				1			
Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride
14	4	1	2	20	8	6	2	1	0	0	0

Percentage of male with qualified riding ability are 14%±10%, with medium riding ability are 4%±10%, with trial ability are 1%±10% and cant rides are 2%±10% for 13-18 age range. Percentage of people with qualified riding ability are 20%±10%, with medium riding ability are 8%±10%, with trial ability are 6%±10% and cant rides are 2%±10% for 19-50 age range. Percentage of people with qualified riding ability are 1%±10%, with medium riding ability are 0%±10%, with trial ability are 0%±10% and cant rides are 0%±10% for >50 age range.

Female

Female/wants to ride											
38											
Age											
13-18				19-50				›50			
Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride
1	2	6	14	1	2	7	5	0	0	0	0

Percentage of female with qualified riding ability are 1%±10%, with medium riding ability are 2%±10%, with trial ability are 6%±10% and cant rides are 14%±10% for 13-18 age range. Percentage of people with qualified riding ability are 1%±10%, with medium riding ability are 2%±10%, with trial ability are 7%±10% and cant rides are 5%±10% for 19-50 age range. Percentage of people with qualified riding ability are 0%±10%, with medium riding ability are 0%±10%, with trial ability are 0%±10% and cant rides are 0%±10% for >50 age range.

Ayat RA-Chafe

Riding interest (Q1,2&3)

Riding interest											
Wants to ride						Don’t wants to ride					
96						4					
Male			Female			Male			Female		
82			15			2			2		
Age			Age			Age			Age		
13-18	19-50	>50	13-18	19-50	›50	13-18	19-50	›50	13-18	19-50	>50
16	66	0	2	13	0	1	1	0	0	2	0

Percentage of people who wants to ride is 96%±10%. 82±10% of the population who wants to ride is males and 15±10% of the population who wants to ride is females.

Percentage of people who don’t want to ride is 4%±10% . 2±10% of the population who don’t want to cycle are males and 2±10% of the population who don’t want to cycle are females. The reason why they don’t wants to cycle, for most of the riders, is safety and for some is having no ability to ride.

Buying interest (Q4)

Buying interest							
Wants to buy				Don’t wants to buy			
Male		Female		Male		Female	
Age		Age		Age		Age	
19-50	>50	19-50	›50	19-50	›50	19-50	>50
64	0	12	0	0	2	1	0

Percentage of people who wants to buy is 76%±10%, 64% ±10% are males and 12% ±10% are females. Percentage of people who don’t wants to buy are 3%±10%, 1%±10% is females and 2%±10% is females.

Allowing (Q5)

Allowing							
I will allow				I will not allow			
Male		Female		Male		Female	
Age		Age		Age		Age	
19-50	>50	19-50	›50	19-50	›50	19-50	>50
60	0	13	0	6	1	0	0

Percentages of people who will allow are 73%±10% and out of this 60%±10% are males and 13%±10% are females. 7% ±10% of the population will not allow their families to ride and out of this 7% ±10% are males and 0±10% are females.

Ability to ride (Q6)

Male

Male/wants to ride											
82											
Age											
13-18				19-50				>50			
23				38				0			
Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride
9	5	1	1	29	28	5	4	0	0	0	0

Percentage of people with qualified riding ability are 9%±10%, with medium riding ability are 5%±10%, with trial ability are 1%±10% and cant rides are 1%±10% for 13-18 age range. Percentage of people with qualified riding ability are 29%±10%, with medium riding ability are 28%±10%, with trial ability are 5%±10% and cant rides are 4%±10% for 19-50 age range. Percentage of people with qualified riding ability are 0%±10%, with medium riding ability are 0%±10%, with trial ability are 0%±10% and cant rides are 0%±10% for >50 age range.

Female

Female/wants to ride											
15											
Age											
13-18				19-50				›50			
Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride	Qualified rider	Medium rider	Trial rider	Can't ride
1	0	0	1	0	1	7	5	0	0	0	0

Percentage of people with qualified riding ability are 1%±10%, with medium riding ability are 0%±10%, with trial ability are 0%±10% and cant rides are 1%±10% for 13-18 age range. Percentage of people with qualified riding ability are 0%±10%, with medium riding ability are 1%±10%, with trial ability are 7%±10% and cant rides are 5%±10% for 19-50 age range. Percentage of people with qualified riding ability are 0%±10%, with medium riding ability are 0%±10%, with trial ability are 0%±10% and cant rides are 0%±10% for >50 age range.

Appendix D: bikeway facility type selection

Bikeway facility type selection results according to the underlying monographs

Route name	AADT	85th percentile speed(mph)	Curb lane width(m)	Facility type(Michael king)	Facility type(UK)	Facility type(Denmark)	Facility type(Australia)	Facility type(new Zealand)
CMC-Summit	6764	32.5	3.5m	Wide curb lane	Segregated cycle facility	Cycle track with dividing verge	Bicycle lanes or shoulders	Cycle lanes or sealed shoulders
Ayat - chafe	9237	32.5	3.5m	Bike lane or shoulder	Segregated cycle facility	Cycle track with dividing verge or cycle track	Bicycle paths	Cycle paths
Imperial-17HC	13091	32.5	3.5m	Separated lane or Path	Segregated cycle facility	Cycle track	Bicycle paths	Cycle paths

Michael kings facility selection monograph

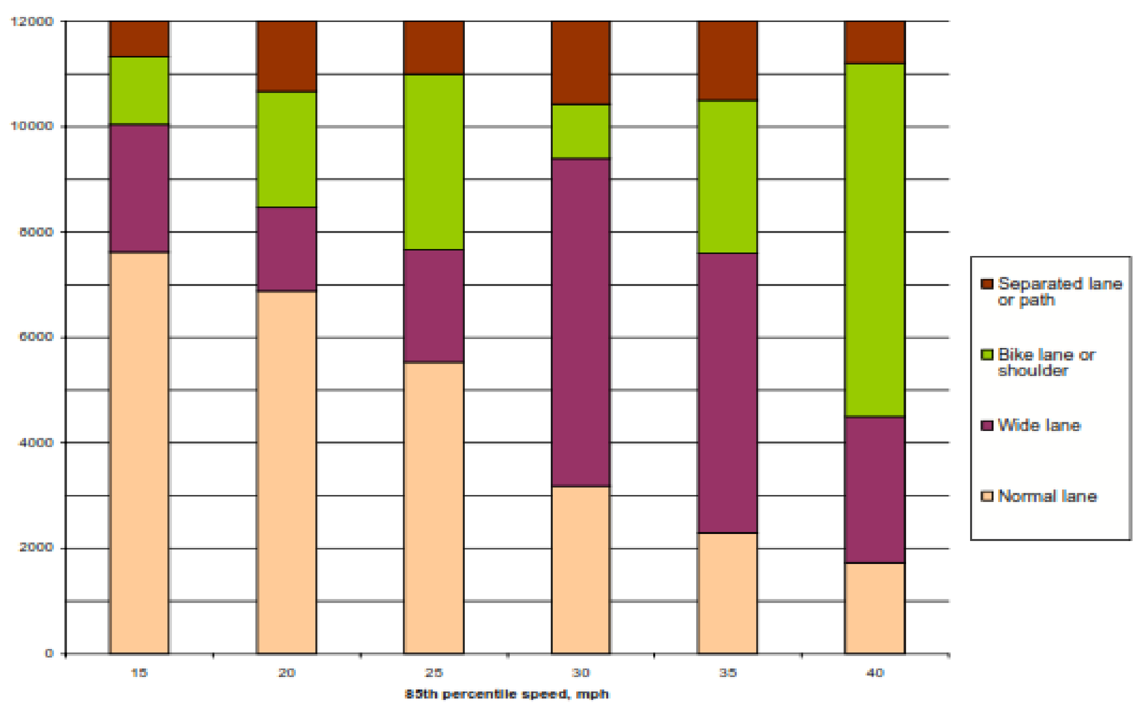
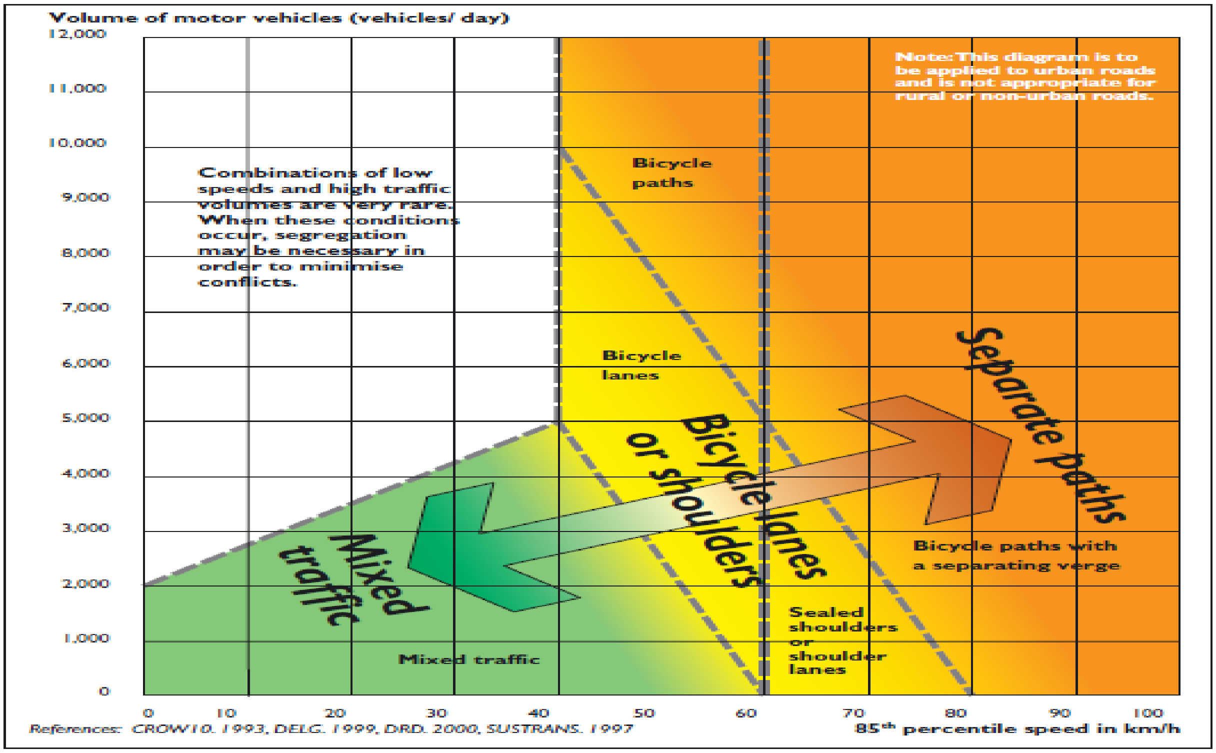


Figure 7: Worldwide Speed-Volume Chart

Australian's facility selection monograph



New Zealand's facility selection monograph

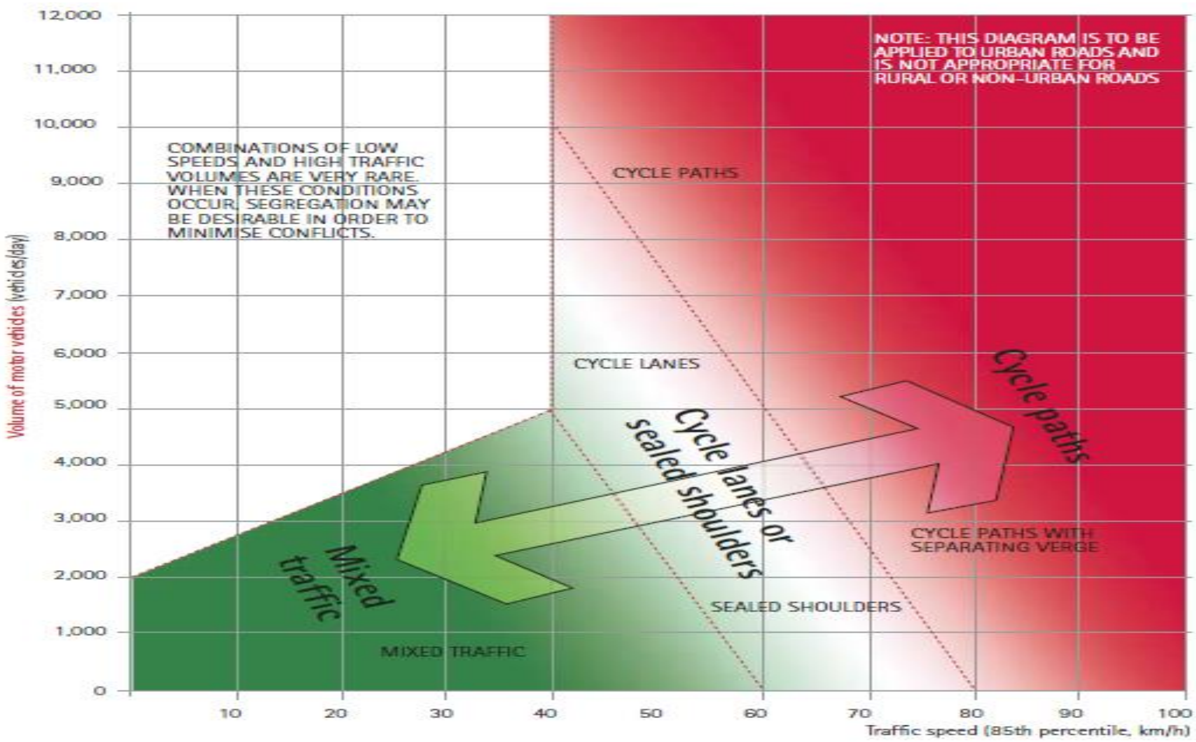
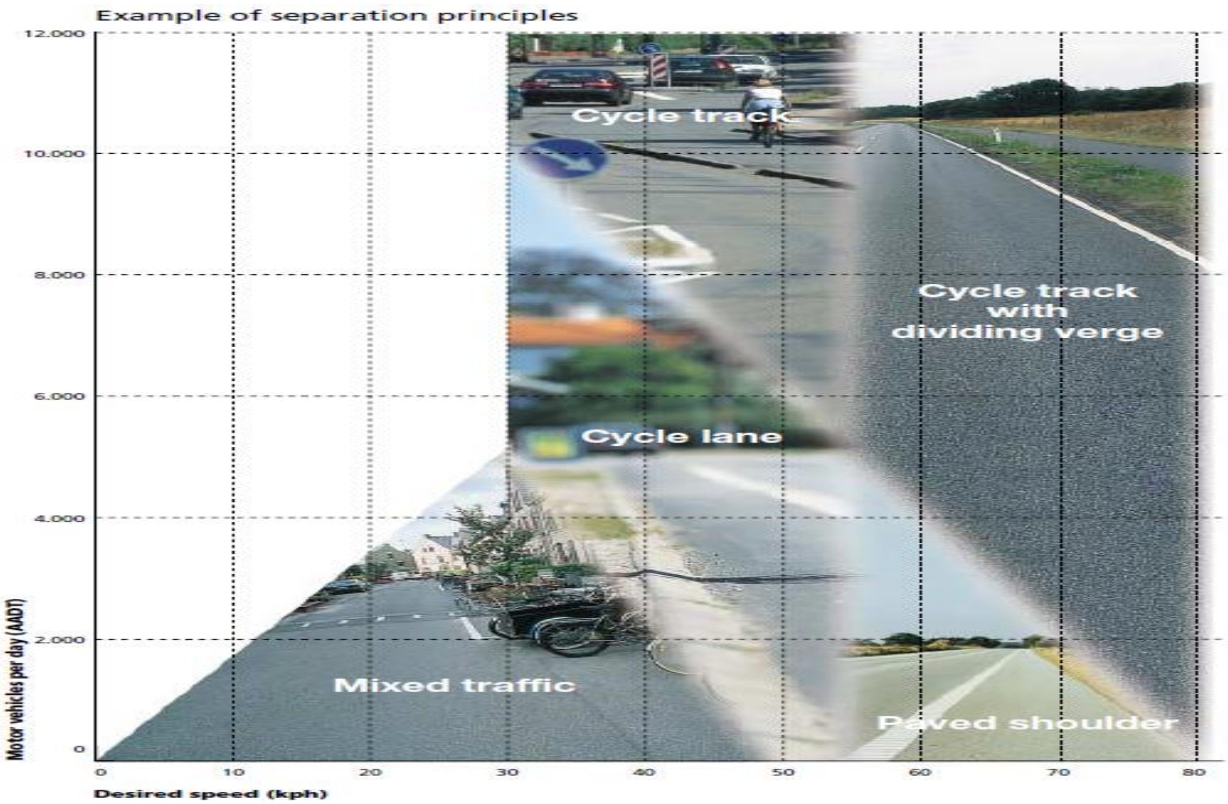
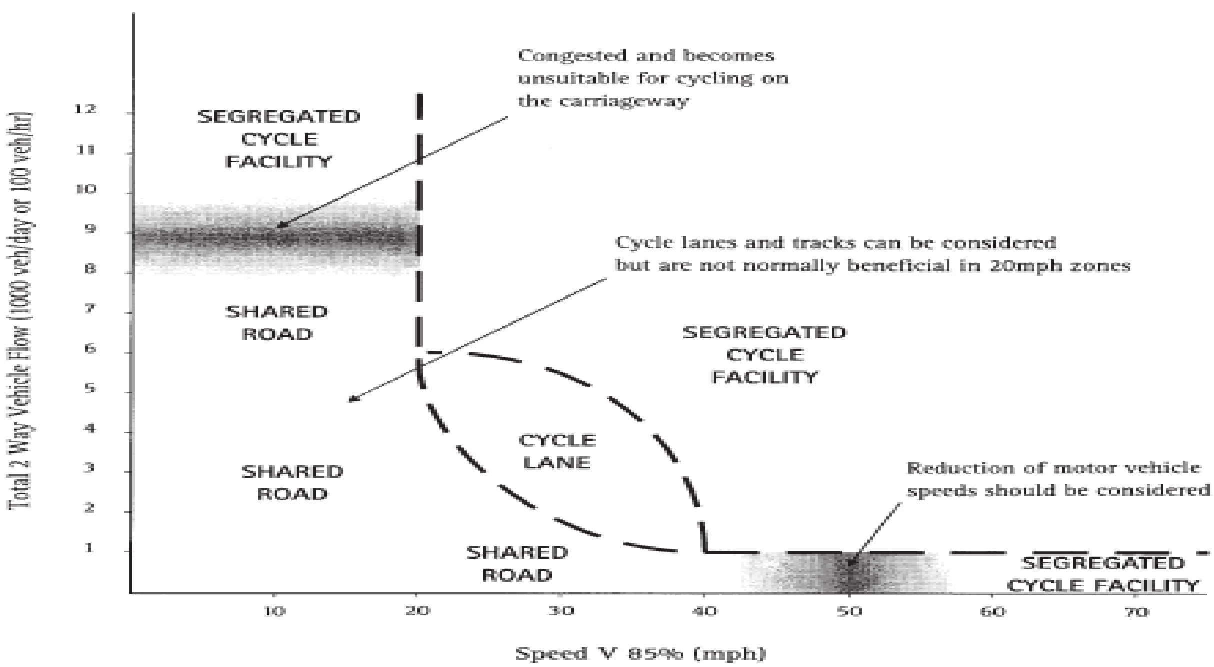


Figure 6.1: Preferred separation of bicycles and motor vehicles according to traffic speed and volume.
This diagram is based on RTA NSW (2003) and Jensen et al (2000), also DELG (1999), Ove Arup and Partners (1997) and CROW 10 (1993).

Denmark's facility selection monograph



UK facility selection monograph

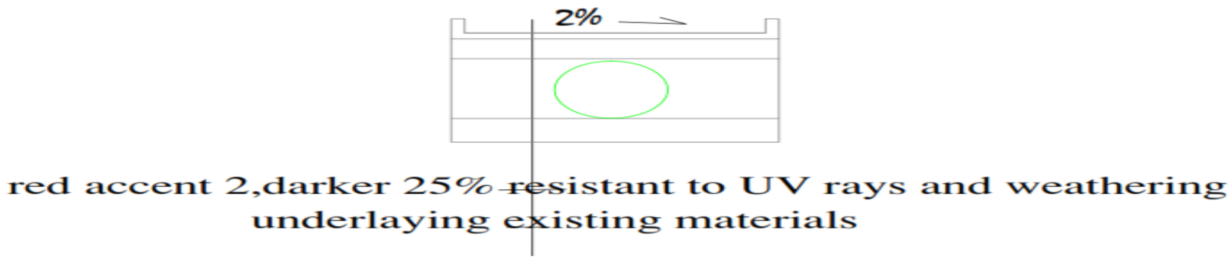


Appendix E: Bikeway pavement design

Two main types of bikeways are suggested: shared use paths on the existing motorways with delineators and paths for the exclusive use of cyclists. Both of them require their own design that can fit to the traffic loads and soil types. Accordingly soil type assessment and traffic load analysis are required to design.

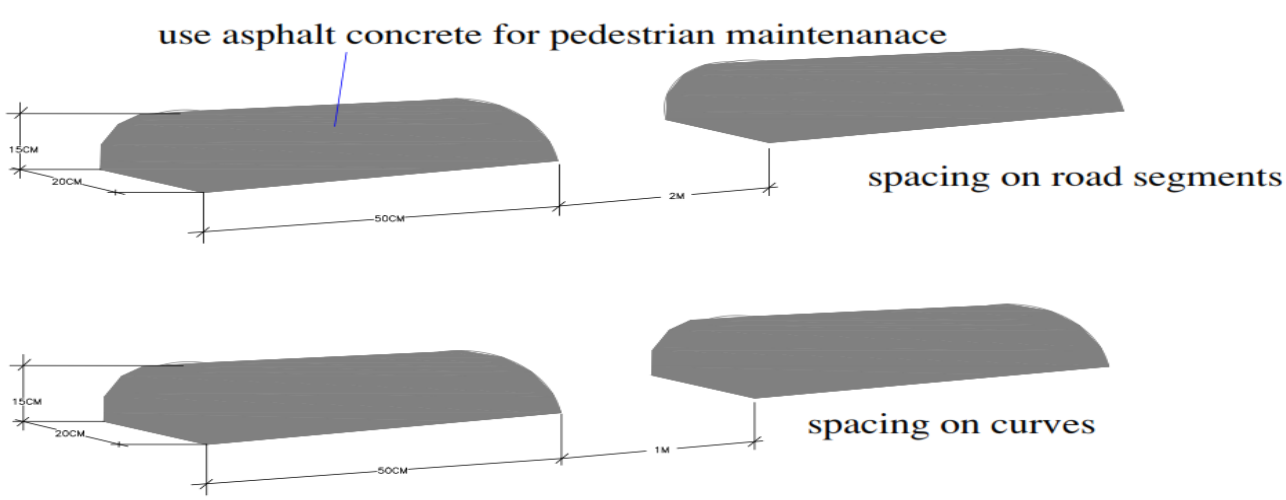
Shared use paths bikeway pavement design

This type of treatment which has been proposed to be implemented on Imperial roundabout-Atlas Hotel and on the three lane stretch of Ayat-Chafe will not require pavement design since it has already been designed for larger traffic loads. The required are painting and delineator design. The delineator material shall be asphalt concrete or cement concrete to be placed at 1.5m distances apart on road segments and at 1m distance at junction curves as shown on figure ii. Hence, the design and the installation of the painting and delineator should be as follows.



Painting material of the bikeway

Design and placement of the delineator



Installation of the delineator

Scratch the existing pavement with in the limit of the contact area of the delineator and the existing pavement, apply tack coat with 0.3L/m^2 rate, place the asphalt concrete with designated length, height and width and paint the delineated route with red accent 2,darker 25% resistant to UV rays and weathering.

Bikeway pavement design for paths used for the exclusive use of cyclists

This type of treatment is suggested for Ayat-chafe's two way stretch and on CMC-summit. It requires detail assessment of soil characteristics to design the bikeway pavement. Hence, using soil tests result that have been made during the design of the existing motorway road will save time and money that will be spent to conduct the primary soil investigation. Below is soil test result of Hayat-Chafe and CMC-Summit:

Summary of test results for CMC-summit (AACRA)

Sr No	Station	Proctor Density		CBR at MDD & OMC		Swell	Wet Sieve Analysis			Atterberg Limit			AASHTO
		MDD g/cc	OMC %	2.54(mm)	5.08(mm)		2mm	0.425mm	0.075mm	LL	PL	PI	Class n
1	0+300	1.66	22.5	11	10	0.8	100	88.05	71.83	45	29	16	A-7-5(12)
2	0+600	1.4	29.5	2	2	5.77	100	96.88	95.01	93	49	44	A-7-5(55)
3	0+900	1.41	29	2	2	4.77	100	98.3	95.13	83	40	43	A-7-5(51)
4	1+200	1.37	31	2	1	7.8	100	98.33	96.6	95	47	48	A-7-5(60)
5	1+500	1.45	28.5	2	2	7.35	100	95.17	90.65	78	42	36	A-7-5(41)
6	1+800	1.38	30	2	1	6.79	100	96.52	93.85	89	46	43	A-7-5(52)
7	2+100	1.39	30.5	2	2	9.92	100	97.24	94.77	97	48	49	A-7-5(60)

Summary of test results for Ayat-chafe (AACRA)

BEST CONSULTING ENGINEERS PRIVATE LIMITED COMPANY

Geotechnical Laboratory Tel 011-633-0065 Fax 011-663-0064 P.O.Box 101472 A.A. Ethiopia

Project : Addis Ababa 2004 EC Access Road Package Ayat Roundabout-Ayat Condominium Road
Client : Addis Ababa 2004 EC Access Road
Sampled by : BEST Consulting Engineers Plc.
Test Specied by : BEST Consulting Engineers Plc.
Date Reported : Jan. 10, 2012
Material Type : Subgrade

SUMMARY OF TEST RESULT / SUBGRADE

Sr No	Station	Proctor Density		CBR at MDD & OMC		Swell	Wet Sieve Analysis			Atterberg Limit			AASHTO
		MDD g/cc	OMC %	2.54(mm)	5.08(mm)		2mm	0.425mm	0.075mm	LL	PL	PI	Class n
1	0+000	1.27	36.0	1.8	1.7	2.99	97.6	95.7	95.1	103	53	50	A-7-5(20)
2	0+300	1.33	33.7	1.6	1.6	2.45	98.7	97.7	96.6	85	50	35	A-7-5(20)
3	0+690	1.51	24.0	3.5	2.8	2.59	68.6	58.6	53.1	56	32	24	A-7-5(11)
4	1+000	1.37	28.4	1.1	1.0	4.31	98.6	95.8	93.1	87	48	39	A-7-5(20)
5	1+300	1.31	33.2	3	2	2.60	90.4	79.2	73.3	66	41	25	A-7-5(17)
6	2+150	1.25	34.9	4	4	1.35	98.2	83.1	74.2	58	36	22	A-7-5(16)
7	2+400	1.24	29.2	43	41	0.08	56.0	43.3	33.8	50	35	15	A-2-7(1)
8	2+700	1.41	21.0	40	39	0.07	40.6	30.7	22.8	48	34	14	A-2-7(0)
9	3+050	1.34	34.8	2	2	3.58	92.1	73.9	67.3	50	30	20	A-7-5(11)
10	3+370	1.30	37.0	2	2	2.10	93.4	85.0	81.0	75	44	31	A-7-5(20)

Reported by: __________
Approved by : __________

Page 1

In evaluating these soil test results south Australia bikeway manual (2013) will be used. This Guide characterizes the subgrade into three broad categories based on subgrade strength with respect to CBR: Low Strength- (Design CBR >=2%)

Moderate Strength- (Design CBR>= 5%)

High Strength- (Design CBR>= 10%)

So, according to this category the CMC-summit and Hayat-Chafe roads can be evaluated as such:-

Ayat-chafe from the 0+000 to 1+700 subgrade soil evaluation

	Station	CBR at MDD & OMC		Strength
		2.54mm	5.08mm	
1.	0+000	1.8	1.7	Very Low
2.	0+300	1.6	1.6	Very Low
3.	0+690	3.5	2.8	Low
4.	1+000	1.1	1.0	Very Low
5.	1+300	3	2	Low
6.	2+100	4	4	Low

CMC-Summit from the 0+000 to 1+700 subgrade soil evaluation

	Station	CBR at MDD & OMC		Strength
		2.54mm	5.08mm	
1.	0+300	11	10	High
2.	0+600	2	2	Low
3.	0+900	2	2	Low
4.	1+200	2	1	Very Low
5.	1+500	2	2	Low
6.	1+800	2	1	Very Low
7.	2+100	2	2	Low

According to this guide suggested pre-treatments for low strength subgrade soils are:

- removal and replacement with a stronger fill material to provide a better construction platform
- insitu stabilization using lime, if soil conditions are compatible; or
- Use of a geosynthetic as a support and separation layer

If the soil is expansive soil, the guide characterizes its reactivity as such:

Guide to classification of expansive soils, Austroads cited in South Australia bikeway manual (2013)

Expansive Nature	Liquid Limit (%)	Plasticity Index	PI x % < 0.425 mm	Potential Swell % [1.]
Very high	>70	>45	>3200	>5.0
High	>70	>45	2200-3200	2.5-5.0
Moderate	50-70	25-45	1200-2200	0.5-2.5
Low	<50	<25	<1200	<0.5

Note: 1. Swell at OMC and 98% MDD using Standard compactive effort; 4-day soak, 4.5kg surcharge.

Hence, according to this category, the Ayat-Chafe road i.e. from the 0+000 to 1+700 can be evaluated as in the following:

Expansiveness of Ayat-Chafe route from 0+000 to 1+700

	Station	Liquid limit	Plasticity index	Swell %	Expansive nature
1.	0+000	103	50	2.99	Very high
2.	0+300	85	35	2.45	High
3.	0+690	56	24	2.59	Moderate
4.	1+000	87	39	4.31	Very high
5.	1+300	66	25	2.60	Moderate
6.	2+100	58	22	1.35	Moderate

Expansiveness of CMC-summit route

	Station	Liquid limit	Plasticity index	Swell %	Expansive nature
1.	0+300	45	16	0.8	Very high
2.	0+600	93	44	5.77	High
3.	0+900	83	43	4.77	High
4.	1+200	95	48	7.8	Very high
5.	1+500	78	36	7.35	Moderate
6.	1+800	89	43	6.79	High
7.	2+100	97	49	9.92	Very high

Pavement design according to the above test results and subgrade evaluations

Deign traffic loading

The type of the traffic that will use the road is cycle traffic. The other traffics that may use the road are human traffics and vehicular traffics only at bikeway driveway sections. There will also be a need for access by emergency vehicles of police, ambulance, fire control etc., as well as for normal maintenance of the path or environs. Hence, considering heavy vehicles may be safe and good for the pavement to serve well in its design period.

Indicative loadings for bikeway traffic categories (Australia manual, 2013)

Design Traffic Category	User or Vehicle Type					
		motor car (2WD)	light utility (2WD)	Light truck <3tonne	Trucks with gross mass less than 12 tonnes	Trucks with gross mass greater than 12 tonnes
Foot and bicycle	✓	?	?	✗	✗	✗
Heavy vehicles	✓	✓	✓	✓	✓	✗

? indicates a few repetitions per year of this load type may be acceptable.

Recommended design traffic loadings for bikeway structural designs (Australia manual, 2013)

Loading	Characterised by	Flexible and concrete block pavements 20 year design period	Rigid pavement 40 year design period
Foot and bicycle	Foot and bicycle loading only	NA	NA
Heavy vehicles	1 pass of two-axle rigid truck per week, 12t gross mass per veh	4,000 ESA	12,000 HVAG or 6000 truck repetitions

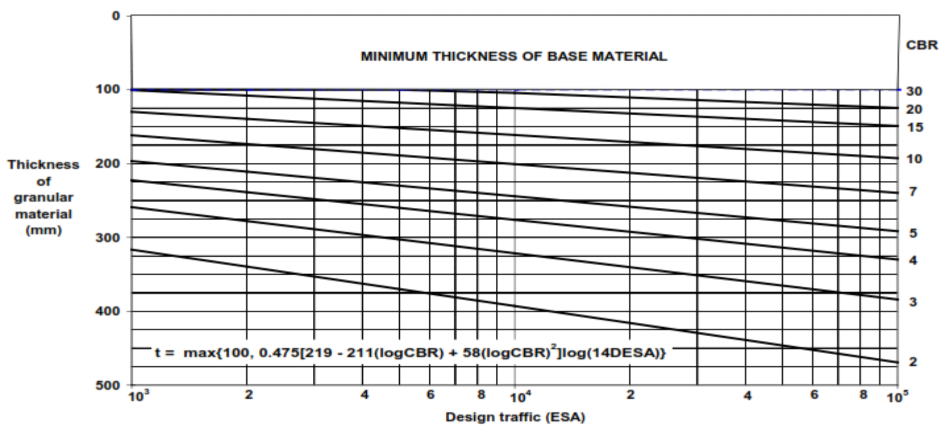
Minimum designs for asphalt-surfaced granular bikeway (Australia manual, 2013)

Soil Strength	Foot/bike traffic (no vehicle access)	Heavy Vehicles (eg maintenance) N_{DT} = 4000 ESA
Low Strength *(CBR ≥ 2%)*	25 mm FineAC7L 100 mm PM3/20 100 mm Type A Material ***225 mm Total Thickness***	35 mm FineAC10L 100 mm PM2/20 100 mm PM2/20 or PM3/20 125 mm Type A material ***360 mm Total Thickness***
Moderate Strength *(CBR ≥ 5%)*	25 mm FineAC7L 125 mm PM3/20 ***150 mm Total Thickness***	35 mm FineAC10L 100 mm PM2/20 100 mm PM2/20 or PM3/20 ***235 mm Total Thickness***
High Strength *(CBR ≥ 10%)*	25 mm FineAC7L 100 mm PM3/20 ***125 mm Total Thickness***	35 mm FineAC10L 120 mm PM2/20 ***155 mm Total Thickness***

Notes: Soaked CBR of Type A Material to exceed 15%.
Nominal application rate for primes – 1.0*l/m²* and tack coats – 0.3 *l/m²* (residual).
L; Light grade asphalt with C170 asphalt binder.

Thickness designs for base/sub base granular material with 35mm asphalt concrete on top:

Design chart for granular materials of bituminous surfacing (Australia bikeway manual, 2013)



Note:
1. Appropriate local conditions, environmental and drainage issues must be considered in using these design curves.
2. Thin asphalt surfacings may be included in total granular thickness. However, the minimum thickness of the granular base is 100 mm.

Base/subbase granular material thickness design for Ayat-Chafe road by using design traffic load of 4*10³ ESA and CBR values

	Station	CBR at MDD & OMC		Strength	Thickness of Granular material
		2.54mm	5.08mm		
1.	0+000	1.8	1.7	Very Low	360mm+AC
2.	0+300	1.6	1.6	Very Low	360mm+AC
3.	0+690	3.5	2.8	Low	300mm+AC
4.	1+000	1.1	1.0	Very Low	400mm+AC
5.	1+300	3	2	Low	320mm+AC
6.	2+100	4	4	Low	250mm+AC

Base/subbase granular material thickness design for CMC-Summit road by using design traffic load of 4*103 ESA and CBR values

	Station	CBR at MDD & OMC		Strength	Thickness of granular material
		2.54mm	5.08mm		
1.	0+300	11	10	High	125mm+AC
2.	0+600	2	2	Low	360mm+AC
3.	0+900	2	2	Low	360mm+AC
4.	1+200	2	1	Very Low	360mm+AC
5.	1+500	2	2	Low	360mm+AC
6.	1+800	2	1	Very Low	360mm+AC
7.	2+100	2	2	Low	360mm+AC

Material specifications according to South Australia bikeway manual (2013)

Sub base and base

20 mm (diameter of the largest size aggregate) Class 2/3 dense graded crushed rock quarry sourced or recycled material shall be used as pavement sub base on foot & cycle traffic loads, & on medium traffic roads.

Select fill

Material properties required for select fill comprise:

- A weighted PI (% passing the 0.425 sieve x the PI) of less than 1000, to eliminate expansive material
- A maximum particle size of less than 40% of the constructed layer thickness, to provide some mechanical interlock, minimize segregation, and reduce permeability; and
- Mica, shale and similar laminated materials, adherent coatings or other foreign material shall not be present in form or sufficient quantity to produce adverse effect upon the usage and performance of the material.

Detail specification for select fill type A material

Property	*Limit*
% passing 75 mm	100
% passing 37.5 mm	80 – 100
% Passing 0.075 mm	0 - 25
Plasticity Index	Maximum 12
Linear Shrinkage	Maximum 6
Weighted Plasticity Index	Maximum 1000

Asphalt concrete specifications

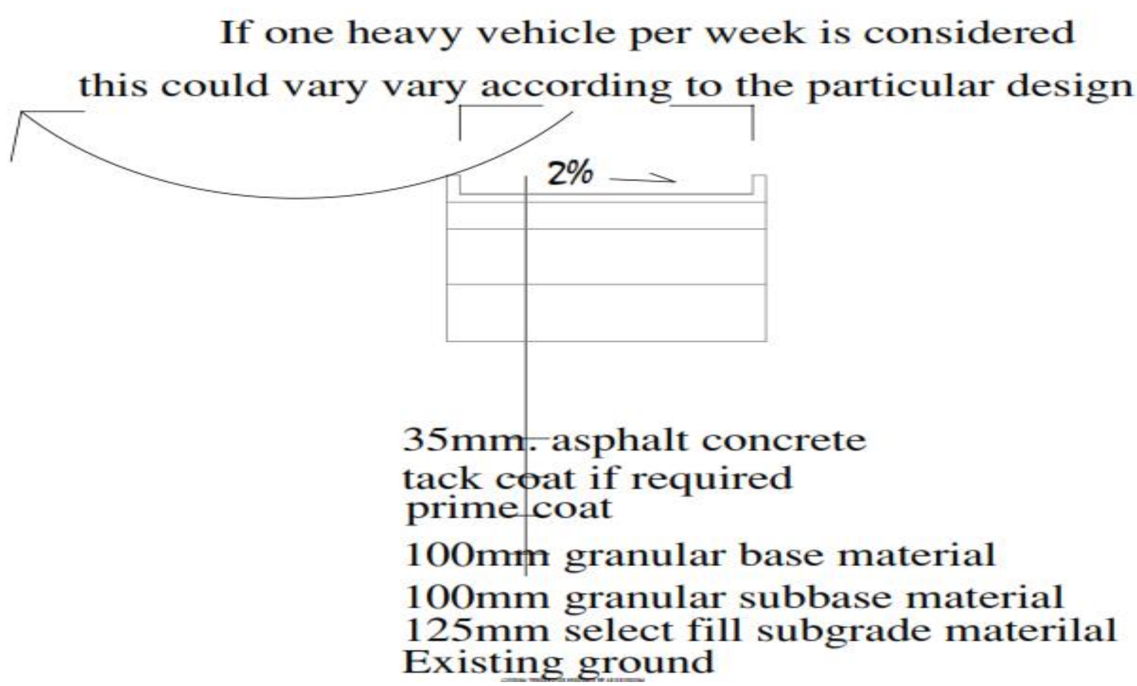
Asphalt types for light traffic (Australia manual, 2013)

Source	Name	Properties	Reference
DPTI	FineAC7L, FineAC10L (7 mm and 10 mm)	Dense graded mix with additional 0.5% binder	DPTI Master Specification Division 2: Roadworks
ARRB Group	ARRB Gap-graded mix	10 mm size with 6.8% Class 170 bitumen by total mass	Oliver (1986) & Mulholland (1989)
Austroads	Dense and Fine Gap Graded and Stone Mastic Asphalt	Sizes 7 mm and 10 mm; (Part 4B)	Austroads (2014b)
Australian Standard	Dense and Fine Gap Graded and Stone Mastic Asphalt	Sizes 7 mm and 10 mm; 5% to 7% bitumen by mass	AS 2150 – 2005 Hot mix asphalt

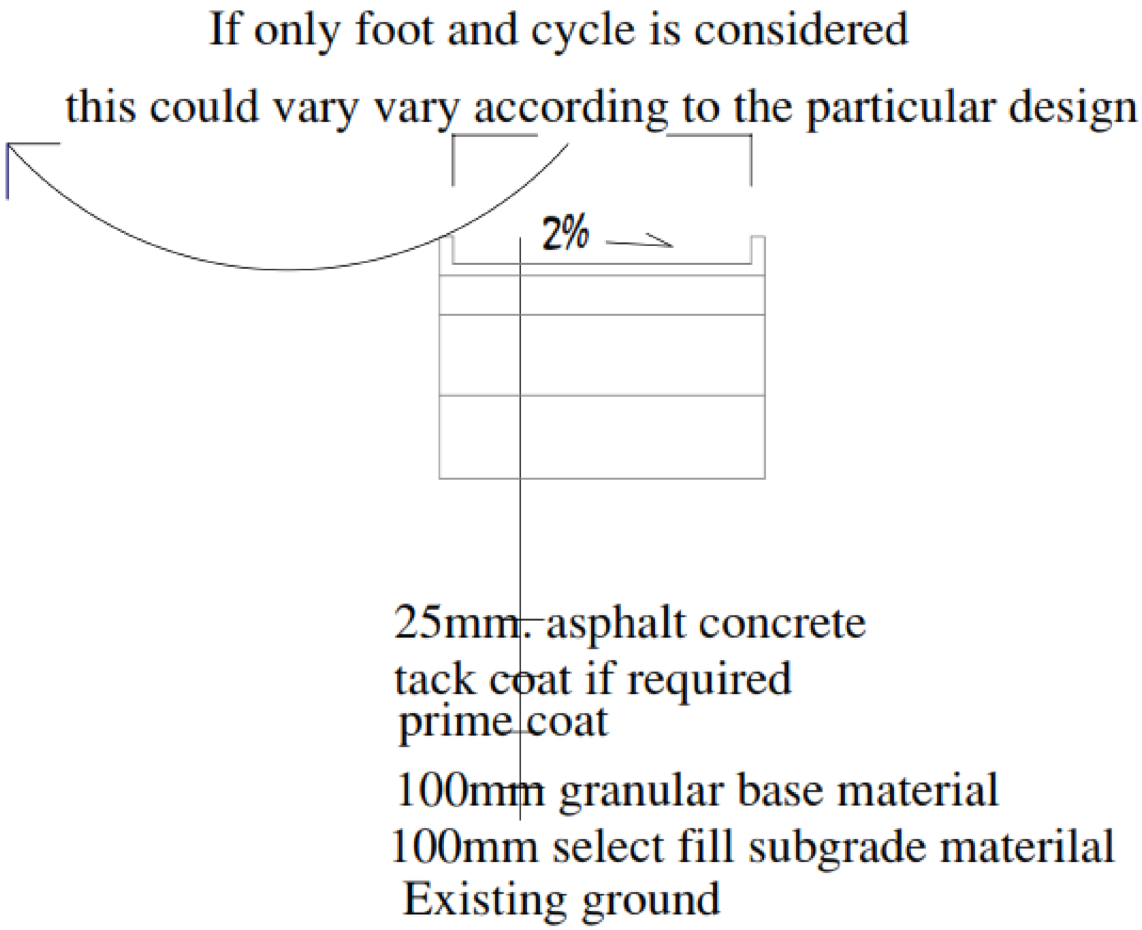
Note: Asphalt containing a mixture of aggregate of maximum 7 mm size produces size 7 asphalt, usually referred to as AC7.

The diameter of the largest size aggregate (mm) is typically used to name the granular material; e.g. a nominal 20 mm material may be called a fine crushed or a 20 mm dense-graded aggregate i.e. PM1/20 to denote a 20 mm Class 1 material or PM2/30 to denote a 30 mm Class 2 material

Therefore, this is the pavement design for Hayat-chafe's 1.7km and CMC-summits full length



Pavement design for Ayat-chafe's 1.7km and CMC-summit's full length considering one heavy vehicle per week



Pavement design for Ayat-chafe's 1.7km and CMC-summit's full length considering only foot and cycle

Appendix F: Site visit worksheet

Site visit worksheet

Route name						
	I. Origin Condition					
Sex	Male			Female		
Population density/no.						
Age	<25	25-50	>50	<25	25-50	>50

✓ Vehicle ownership	Bicycle		Car		
✓ Transport mode currently being used and their composition	Car	Taxi	Bus		Bicycle
			Mid	Max	
✓ Ability to ride bicycle	Athlete	Good rider	Trial rider		Can't ride
✓ Bicycle training centers	Yes		No		
✓ Rental conditions	Yes		No		

	II. Destination Condition				
✓ Public transport stations- bus, taxi, train, plane	Bus	Taxi	Train	Plane	
✓ Working places	Yes		No		
✓ Commercial centers	Yes		No		
✓ Shopping centers	Super markets		Mini shops		
✓ Schools	Elementary	High school	TVETs	Colleges	
✓ Recreation centers	Cinemas	Cafeterias	Restaurants	Bars	
✓ Air refreshments	Yes		No		
✓ Religious institutions	Churches	Mosques	Others		
✓ Sporting centers	Football	Basket ball	Bicycle training	Athletics	Gymnasium

III. Right of way land use development	Left		Right	
✓ Working places	Yes	No	Yes	No
✓ Commerce/markets	Yes	No	Yes	No
✓ Shopping	Yes	No	Yes	No
✓ Schools	Yes	No	Yes	No
✓ Recreation centers	Yes	No	Yes	No
✓ Residents	Yes	No	Yes	No
✓ Sporting centers	Yes	No	Yes	No
✓ Religious institutions	Yes	No	Yes	No

IV. Type of road	Paved				Unpaved(may be if there for some length of the road)		
✓ The roads pavement types	Flexible	Rigid	cobble stone	gravel	Earth		
✓ Sidewalks	Paved		Cobble stone		Brick	Sealed	Earth

V. Dimension identification					
✓ Of the existing road	Lane number	Total width	Curb lane width	Side walk width	Empty space width
✓ Of the existing drainage structures and utilities	Length	Height	Width		
- Gutter					
- Manhole					
- drain grates					
- seamless curbs					
- utility covers					
- utility cuts					

VI. Existing infrastructure	On the road	on the right of way
✓ Roundabouts		
✓ Intersections		
✓ Interchanges		
✓ drainage structures		
✓ bridges		
✓ guard rails		
✓ pedestrian overpasses		
✓ underpasses		

VII. Topographic features				
✓ grades of the road	Length of grades <5%		Length of grades >5%	
✓ landscape conditions of the right of way	Escarpment	Mountainous		Flat
VIII. Environmental x-stics of the area				
✓ Hot weather(extreme hotness) and	Yes		No	
✓ Cold weather (ice accumulation, cloud racks	Yes		No	

Note: Make ☑ and ☒ marks, or fill the information in the spaces provided.