The Memorial Link

Cycle Track Investigation and Preliminary Street Redesign

A Student Project Developed By:

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Abstract

The city of Thunder Bay, Ontario is located on the northwest shore of Lake Superior with a population of approximately 108 359 (Census 2011). A request has been made by The Memorial Link Group to analyze the feasibility of incorporating a cycling facility along a 5 km stretch of Memorial Avenue called the May-Memorial corridor. The corridor runs from Miles Street to John Street but in order for a proper analyses to be conducted in a timely manner, a section from Central Avenue to 13th Avenue has been selected to represent the corridor has a whole.

The amalgamation of vehicular, pedestrian and cyclist traffic is an ever increasing dilemma traffic engineer's encounter. Currently the May-Memorial corridor has an emphasis on vehicular traffic and with the utilization of case studies, simulation software and specifications, the issue of involving all forms of transportation within the corridor will be addressed. With an emphasis on cycling facilities, various parameters such as safety, mobility and access can be assessed to produce an optimal complete street.

Based on the following a detailed complete street design will be conducted:

- Preliminary Observations
    - field observations
    - as-constructed drawings
- Safety Analysis
    - Trend Development
    - Economic Analysis of countermeasures
- Operational Analysis
    - Simulation comparisons
    - Cycle Facility Selection
- Geometric Analysis
    - Stopping Sight Distance
    - Super-elevation
- Specifications

The complete street cross section in Figure 0-1 below has been recommended to be implemented on Memorial Avenue:

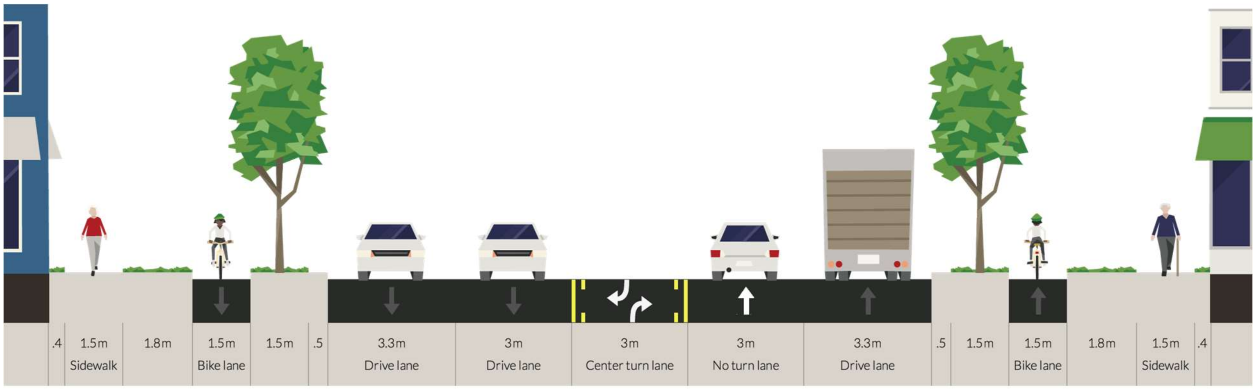

Figure -1 - Proposed Typical Cross Section

Additional resultants such as adjustments to signal timing and the implementation of protected intersection will also be exercised.

These conclusion suggests that the resulting analyses for the complete street with an emphasis on a cycling facility will exemplify not only cyclist but all parties involved within the complete street.

Acknowledgements

The project team recognizes that the completion of the Cycle Track Investigation and Preliminary Street Redesign degree project would not have been accomplished without the many individuals who contributed along the way. John, Lukas and Stefano would like to thank the City of Thunder Bay Police Services and the Engineering and Operations Department for the information on traffic counts, signal timing, collision reports, drawing file templates and design information given to the project team. The following individuals provided this much needed data in order to complete this research:

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- Ryan Love, Certified Technologist of the Infrastructure and Operations Division with the City of Thunder Bay
- Adam Krupper, Mobility Coordinator of the Engineering Division with the City of Thunder Bay

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Table of Contents

Disclaimer ii

Abstract iii

Acknowledgements v

1 Introduction and Background 2

1.1 Project Background 2
1.2 Project Statement 2
1.3 Project Objective 3
1.4 Project Organization 4

2 Literature Review 6

2.1 Cycle Track Studies 6
2.1.1 City of Calgary 6
2.1.2 City of Ottawa 7
2.1.3 City of Thunder Bay 8
2.1.4 City of Vancouver 9
2.2 Intersection Studies 10
2.2.1 Current Intersection Approaches 10
2.2.2 Protected Intersections 12
2.2.2.1 Signal Phases for a Protected Intersection 16
2.3 Safety Considerations 17
2.3.1 Collision Reports 17
2.3.2 Crash Reduction Factor 18
2.3.3 Crash Costs 18
2.3.4 Economic Analysis 19
2.3.5 Buffer Zones 20
2.4 Simulation Programs and Operational Tools 21
2.4.1 Synchro 9.0 21
2.4.2 SimTraffic 34
2.4.3 3D Viewer 35
2.4.4 Cycling Facility Selection Decision Support Tool 35
2.4.5 Traffic Counts 38
2.4.6 Types of Cycling Facilities 39
2.5 Accessibility Considerations 40
2.5.1 Depressed Curb and Tactile Plates 40
2.5.2 Pedestrian Signal Indicators 41
2.6 Complete Street Design Considerations 42
2.6.1 Roadway 42
2.6.2 Boulevard 56
2.6.2.1 Greenspace 57
2.6.2.2 Additional Considerations 59
2.6.3 Civil 3D Software 62

3 Methodology....64
3.1 Site Selection....64
3.2 Field Observations....65
3.3 As-Constructed and Survey Observations....65
3.4 Data Collection....66
3.4.1 Collision Data....66
3.4.2 Traffic Data....67
3.4.2.1 Traffic Counting....67
3.4.2.2 Signal Phase Timing....67
3.5 Design Options....67
3.6 Safety Analysis....70
3.6.1 Collision Trends....70
3.6.2 Crash Reduction Factors....71
3.6.3 Crash Cost and Economic Analysis....71
3.7 Operational Analysis....72
3.7.1 Lane Reduction....72
3.7.1.1 Bus Route Consideration....73
3.7.2 Sensitivity Analysis....73
3.7.3 Right-Turn Requirement....73
3.7.4 Optimization....74
3.7.5 Cycling Facility....74
3.7.5.1 Access and Cost Considerations....75
3.7.6 Intersection Selection....75
3.8 Geometric Analysis....75
3.9 Additional Considerations....76
4 Data Analysis and Results....78
4.1 Safety Analysis....78
4.1.1 Collision Data Analysis....78
4.1.2 Countermeasure Justification....85
4.1.2.1 Central Avenue....85
4.1.2.2 10th Avenue....87
4.1.2.3 11th Avenue....89
4.1.2.4 12th Avenue....91
4.1.2.5 13th Avenue....92
4.1.3 Summary of Safety Analysis....94
4.2 Operational Analysis....95
4.2.1 Field Counts....95
4.2.2 Simulation Comparison....97
4.2.2.1 Lane Reductions....98
4.2.2.2 Heavy Vehicle Sensitivity Analysis....99
4.2.2.3 Right-Turn Lane....101
4.2.2.4 Traffic Signals....101
4.2.2.5 Growth Factor....102
4.2.2.6 Safety Recommended Simulations....103
4.2.3 Cycling Facility Investigations....104

4.2.4 Buffer Zone Selection 107
4.2.5 Intersection Type Comparison 108
4.3 Geometric Analysis 111
4.3.1 Friction Coefficients 111
4.3.2 Stopping Sight Distance 112
4.3.2.1 Straight 112
4.3.2.2 In Radius 112
4.3.3 Minimum Radius and Super-Elevation 113
4.4 Additional Considerations 114
4.4.1 Accessibility for Ontarians with Disabilities Act 114
4.4.2 Greenspace 114
4.4.3 Specifications 114
4.5 Results 114
4.6 Field Specific Considerations 118
4.6.1 Pre & Post Construction Survey 118
4.6.2 Drainage and Profile 118
4.6.3 Retaining Wall 119
4.6.4 Relocation of Services, Appurtenances and Utilities 119
5 Summary, Conclusions and Recommendations 121
5.1 Summary 121
5.2 Conclusions 122
5.3 Recommendations 123
6 References 125
Appendix A – Cycling Facility Selection 128
Appendix B – Tactile Plate Standards 132
Appendix C – Safety 142
Appendix D – Simulations and Additional Files 145
Appendix E – Super Elevation Calculation 147
Appendix F – Reduced Preliminary Drawings 149

List of Figures

FIGURE -1 - PROPOSED TYPICAL CROSS SECTION iv
FIGURE 2-1 - INTERSECTION TREATMENT FOR SEPARATED ON GRADE CYCLE TRACK (MINISTRY OF TRANSPORTATION, 2013) 11
FIGURE 2-2 - INTERSECTION TREATMENT FOR CURB SEPARATED CYCLE TRACK (MINISTRY OF TRANSPORTATION, 2013) 12
FIGURE 2-3 – PROTECTED INTERSECTION TYPICAL DESIGN (ALTA, 2015) 13
FIGURE 2-4 - TYPICAL SETBACK FOR CYCLIST AND PEDESTRIAN CROSSING (ALTA, 2015) 14
FIGURE 2-5 - BICYCLE QUEUE AREA (ALTA, 2015) 15
FIGURE 2-6 - MOUNTABLE TURNING APRON AND CHANNELIZED TURN LANE WITH RAISED CROSSWALK (ALTA, 2015) 15
FIGURE 2-7 - BOLLARD BUFFER ZONE (MINISTRY OF TRANSPORTATION, 2013) 20
FIGURE 2-8 - HATCHED BUFFER ZONE (MINISTRY OF TRANSPORTATION, 2013) 20
FIGURE 2-9 - MEDIAN BUFFER -DEPICTED WITH PLANTER BOX (MINISTRY OF TRANSPORTATION, 2013) 21
FIGURE 2-10 - CURB AND GREENSPACE SEPARATED (MINISTRY OF TRANSPORTATION, 2013) 21
FIGURE 2-11 - BREAKDOWN OF FRICTIONAL FORCES WITHIN A CURVE (TRANSPORTATION ASSOCIATION OF CANADA, 1999) 44
FIGURE 2-12 - TRAFFIC ARROW DIMENSIONS AND VISUAL AID (MINISTRY OF TRANSPORTATION, 2000) 50
FIGURE 2-13 - LAYOUT OF PAINT MARKINGS ON A 5-LANE ROAD WITH SHARED LEFT TURN (MINISTRY OF TRANSPORTATION, 2000) 51
FIGURE 2-14 - PAVEMENT MARKING FOR CYCLING FACILITIES (MINISTRY OF TRANSPORTATION, 2000) 52
FIGURE 2-15 - PAVEMENT MARKINGS FOR A SHARED CROSSWALK (MINISTRY OF TRANSPORTATION, 2000) 53
FIGURE 2-16 - PEDESTRIAN PUSH BUTTON SIGN (MINISTRY OF TRANSPORTATION, 2000) 54
FIGURE 2-17 - PEDESTRIAN AND CYCLIST COMMUNICATION SIGNAGE (MINISTRY OF TRANSPORTATION, 2013) 54
FIGURE 2-18 - CYCLE LANE SIGN (MINISTRY OF TRANSPORTATION, 2000) 55
FIGURE 2-19 - BICYCLE SIGNAL HEAD (MINISTRY OF TRANSPORTATION, 2013) 55
FIGURE 2-20 - PEDESTRIAN CROSSING SIGNAL (MINISTRY OF TRANSPORTATION, 2010) 56
FIGURE 2-21 - ARTERIAL ROAD SAMPLE CROSS SECTION (CITY OF THUNDER BAY, 2012) 56
FIGURE 2-22 - PLANTER BOX DETAIL (CITY OF LONDON, 2016) 58
FIGURE 2-23 – CROSS-SECTION VIEW OF DRAINAGE TO CURB (TRANSPORTATION ASSOCIATION OF CANADA, 1999) 60
FIGURE 2-24 - RIDER OPERATING REQUIREMENTS (TRANSPORTATION ASSOCIATION OF CANADA, 1999) 60
FIGURE 3-1 - MEMORIAL AVENUE FROM 13TH AVENUE TO CENTRAL AVENUE 64
FIGURE 3-2 - EXAMPLE OF THE EXISTING PRIVATE DRAINAGE 65
FIGURE 3-3 - TRAFFIC DATA COLLECTOR 67
FIGURE 3-4 - CROSS SECTION 1 WITH OFF GRADE ONE-WAY CYCLE TRACK 68
FIGURE 3-5 - CROSS SECTION 2 WITH MEDIA SEPARATED ONE-WAY CYCLE TRACK 68
FIGURE 3-6 - CROSS SECTION 3 WITH BOLLARD AND REMOVABLE CURB SEPARATED ONE-WAY CYCLE TRACK 69
FIGURE 3-7 - CROSS SECTION 4 CYCLE LANE WITH NO SEPARATION 69
FIGURE 4-1 - COLLISION DIAGRAM (MEMORIAL AVE. AND CENTRAL AVE.) 80
FIGURE 4-2 - COLLISION DIAGRAM (MEMORIAL AVE. AND 10TH AVE.) 81
FIGURE 4-3 - COLLISION DIAGRAM (MEMORIAL AVE. AND 11TH AVE.) 82
FIGURE 4-4 - COLLISION DIAGRAM (MEMORIAL AVE. AND 12TH AVE.) 83
FIGURE 4-5 - COLLISION DIAGRAM (MEMORIAL AVE. AND 13TH AVE.) 84
FIGURE 4-6 - MEMORIAL AVE. AND WALMART RAW TRAFFIC DATA 95
FIGURE 4-7 - MEMORIAL AVE. AND 10TH AVE. RAW TRAFFIC DATA 96
FIGURE 4-8 – PRE-SELECTION NOMOGRAPH FOR CYCLING FACILITY 104
FIGURE 4-9 - INTERSECTION TREATMENTS (ALTA, 2015 AND MINISTRY OF TRANSPORTATION, 2013) 108

FIGURE 5-1 - ALTERNATIVE CYCLING FACILITIES (MINISTRY OF TRANSPORTATION, 2013)....................................122
FIGURE 5-2 - PROPOSED TYPICAL CROSS SECTION 122

List of Tables

TABLE 2-1 - LANE UTILIZATION FACTORS (TRAFFICWARE, 2015) 29
TABLE 2-2 - LEVEL OF SERVICE GRADES (HIGHWAY CAPACITY MANUAL, 2010) 32
TABLE 2-3 - LANE WIDTHS FOR THROUGH LANES ON URBAN ROADS (TRANSPORTATION ASSOCIATION OF CANADA, 1999) 45
TABLE 2-4 - TYPICAL PAVEMENT MARKING DIMENSIONS (MINISTRY OF TRANSPORTATION, 2000) 49
TABLE 3-1 - COLLISION SUMMARY (INFORMATION OBTAINED FROM THUNDER BAY POLICE SERVICES) 70
TABLE 3-2 - COSTS ASSOCIATED WITH COLLISIONS (VALUES PROVIDED BY THE CITY OF THUNDER BAY) 72
TABLE 3-3 - EXISTING SIGNAL TIMINGS 74
TABLE 4-1 - COLLISION SUMMARY FOR MEMORIAL AND CENTRAL AVE. 85
TABLE 4-2 - COLLISION SUMMARY FOR MEMORIAL AND 10TH AVE 87
TABLE 4-3 - COLLISION SUMMARY FOR MEMORIAL AND 11TH AVE 89
TABLE 4-4 - COLLISION SUMMARY FOR MEMORIAL AND 13TH AVE. 92
TABLE 4-5 - EXISTING TURNING MOVEMENT PHASES 98
TABLE 4-6 - EFFECTS OF LANE WIDTH REDUCTIONS 99
TABLE 4-7 - EXISTING HEAVY VEHICLE PERCENTAGES 100
TABLE 4-8 - HEAVY VEHICLE SENSITIVITY COMPARISON 100
TABLE 4-9 - NORTHBOUND RIGHT-TURN AT CENTRAL AVENUE INVESTIGATIONS 101
TABLE 4-10 - SIGNAL TIMING OPTIMIZATION COMPARISON 102
TABLE 4-11 - GROWTH FACTOR COMPARISON (2016 TO 2026) 102
TABLE 4-12 - SAFETY RECOMMENDED CHANGES COMPARISON TO OPTIMIZED SIGNAL TIMINGS 103
TABLE 4-13 - SITE SPECIFIC QUESTIONS RELATING TO CYCLING FACILITY SELECTION 105
TABLE 4-14 - INTERSECTION TREATMENT COMPARISON (ALTA, 2015 AND MINISTRY OF TRANSPORTATION, 2013) 109
TABLE 4-15 - SIGNAL TIMING CHANGES FROM EXISTING TO PROPOSED 116

CHAPTER 1

Introduction and Background

1 Introduction and Background

1.1 Project Background

The city of Thunder Bay, Ontario is located on the northwest shore of Lake Superior with a population of approximately 108 359 (Census 2011). Before the city was known as Thunder Bay it was two smaller cities called Fort William and Port Arthur. On January 1, 1970 the two cities amalgamated to the city now known as Thunder Bay.

Since the merge, many connecting roads have been developed, one of the most widely used facilities today is the May-Memorial corridor, connecting the city's downtowns. The corridor connection currently has an emphasis on vehicular traffic. The May-Memorial corridor is considered to be a minor arterial roadway based on the Average Annual Daily Traffic (AADT) of approximately 22000 vehicles in 2012. Commercial and residential accesses are prevalent throughout the entire stretch of the corridor making access and mobility dually important in the design consideration.

The Memorial Link Group has proposed the idea of a complete street redesign connecting the two historic cores with an emphasis on combining cyclist, pedestrian and vehicular traffic. The limits of the proposed project are John Street (north limit) and Miles Street (south limit), a total of roughly 5 kms. The purpose of the project is to provide a complete street facility that will encourage cyclists of all capabilities to utilize bicycles as a primary mode of transportation.

The redesign of the street, is projected to give a new level of confidence to concerned cyclist. With an increased volume in cyclist traffic this will create an inviting, safe, interconnected community environment between the former two cities.

1.2 Project Statement

In order to accommodate all forms of transportation within the complete street an analysis of the Memorial-May corridor is required. Due to the size and allotted time period of the project a 690m section along Memorial Avenue spanning from Central Avenue to 13th Avenue was selected to be analyzed. This section was selected because it is one of the oldest pieces of infrastructure within the corridor according to the as constructed drawings. It is expected that the city of Thunder Bay will consider this section a priority for moving forward with standard infrastructure renewal. This section also includes a number of potential challenges that will adequately represent the feasibility of the project, such as, right-of-way constraints due to the number of lanes present, horizontal curve considerations, channelized right turn lanes and commercial accesses.

1.3 Project Objective

The main objective of this project is to determine the feasibility of incorporating a cycle track and to administer a preliminary complete street redesign, to produce a safer path of travel for both pedestrians and cyclists, without interrupting the current flow of vehicular traffic at Memorial Street to achieve the main objective of this project.

The design requirements are referenced from the document "The Memorial Link Project":

1. "Grade- or curb-separated cycle track in the existing boulevard space
2. Protected intersections where traffic is heavy and painted intersections otherwise. The opportunity may exist to restrict left-hand turns at some intersections
3. Safe driveways:
    a. Driveways may not interrupt the sidewalk or cycle track
    b. Driveways may not influence the elevation of the sidewalk or cycle track
    c. Driveways may not have priority over pedestrians or cyclists
4. Enhanced silviculture along the route for traffic-calming and storm water and shade management and to improve the comfort of the built environment
5. Reduction in lane widths per NACTO guidelines and recent research
6. Rationalization of existing lane counts and motor-vehicle cross sections and possible reallocation of space/road diet
7. Enhanced sidewalk and pedestrian spaces
8. Space included for snow containment and drainage, possibly in-situ"

By following these requirements and completing an extensive literature review, a safe and feasible solution will be proposed, ensuring cyclists, pedestrians and vehicular traffic are optimally amalgamated within the complete street redesign.

1.4 Project Organization

The report is composed into 5 key chapters, beneficial to the ease of the reader and the overall fluidity of the report. The following chapters are laid out in detail:

Chapter 1 - Introduction and Background

It provides a brief overview of the projects background, statement and objective. The section promotes the problem, area of consideration, and the overall objective to accomplish.

Chapter 2 - Literature Review

This chapter includes details past study findings that are utilized to establish baseline trends from current projects. Specifications, guidelines, safety and operational parameters are defined to be implemented in the evaluation and design of the complete street, with an emphasis on the cycle track. An introduction to software programs incorporated in the analysis of the design are thoroughly explained.

Chapter 3 – Methodology

This section establishes the systematic path taken to evaluate the proposed complete street designs of the project.

Chapter 4 - Data Analysis and Results

This chapter presents a detailed structure of the data collection process for this project. Also consists of computations and analyses with regard to safety, operations, geometrics and additional considerations for the Memorial Street segment.

Chapter 5 – Summary, Conclusion and Recommendations

It includes the summary of the methodology, research results, project conclusions and recommendation.

CHAPTER 2

Literature Review

2 Literature Review

A review of the existing literature has been conducted in order to develop a working knowledge of current complete street practices within Canada and Internationally as they apply to cycling facilities in particular. The following subsections will direct the evaluation of safety, operation, accessibility and geometric considerations for implementation.

2.1 Cycle Track Studies

Cycle tracks are gaining popularity in cities across North America. The following case studies show some initiatives developed in Canadian cities, some projects are pilots while others have been at the forefront of Canadian cycle track initiatives.

2.1.1 City of Calgary

The City of Calgary located in Alberta, Canada has a population of approximately 1.2 million people (Statistics Canada, 2015), and has an average of 126 cm of snowfall each year (based on 30 years of snowfall data). With an ever increasing demand to mobilize people within the dense corridors of the city, alternative measures to automobile transportation have been considered (CBC, 2015).

The City of Calgary is currently underway with the implementation of a cycle track pilot project, the cycle track pilot project includes cycling routes located on:

- 5 Street (on the east side from 3 Ave. S.W. to 17 Ave. S.W.)
- 12 Avenue (on the north side from 11 St. S.W. to 4 St. S.E.)
- 8 Avenue / 9 Avenue (on the north and south sides from 11 St. S.W. to 3 St. S.W. and Macleod Trail to 4 St. S.E.)

This endeavour began in June of 2015 and will conclude in December of 2016. The resulting data from the pilot project will enhance the city's confidence to include the utilization of cycle tracks within the city's traffic plan.

During the month of September, 2015, a telephone survey was conducted regarding the cycle track pilot project. Based on the 515 Calgarians interviewed 64% were in favour of the cycle track pilot. The interview also revealed an increase in cycle, pedestrian and bus usage, with a decrease in vehicle usage (based on a 2014 data baseline) among the downtown city core.

2.1.2 City of Ottawa

The city of Ottawa is located in Ontario, Canada. The Ottawa-Gatineau area has a population of approximately 1.32 million (Statistics Canada, 2015) and receives about 175.4 cm of snow per year. Studies have shown that cycling is increasing throughout the city, however, it is most frequently used in the dense urban core of Ottawa where travel distance is less than 4 kms.

The city has successfully implemented an official Cycling Plan, which was revised in 2013. The initiative is a long term commitment to providing a safe and functional network for the cyclists. The objective is to "make cycling an attractive everyday mobility option for a range of residents" (City of Ottawa, 2013). In the course of the year's 2005 to 2011, cyclist counts during the morning peak grew by 41%. This can be credited to the impressive network that has been established. In 2013 the cycling network consisted of:

- 161 kms of bike lanes
- 167 kms of paved shoulders
- 258 kms of multi-use pathways.

Furthermore, the city of Ottawa hired a consultant to complete a detailed study in 2011 that would assist engineers in determining an appropriate facility for cyclists. This was triggered by a dangerous multi-cyclist collision involving a vehicle within the designated cycling lane. The study referenced many case studies of international leaders in cycling network implementation. The result was the “Cycling Facility Selection Decision Support Tool” which has since been incorporated into the Ontario Traffic Manual (OTM) Book 18 as the provincial standard when considering cycling facilities (MMM Group, 2011).

2.1.3 City of Thunder Bay

Thunder Bay is a city in Northern Ontario, Canada with a population of approximately 108 000 (Census, 2011). Up until the summer of 2015 the city had no protected bicycle lanes. The Arundel and Hudson active living corridor is the first protected multi-use trail implemented in the city. For this corridor, the city investigated cycling networks in Montreal, Ottawa and Guelph to establish previous design considerations. City Engineers also looked at design specifications from the Quebec Transportation Design Standards accompanied with the Ontario Traffic Manual, Book 18 (Cycling Facilities). The cycling facility is 3 kms long and consists of a buffer zone with bollards. The location of the Arundel and Hudson corridor was selected due to the proximity of existing parks and recreational facilities, as well as the few number of driveways and intersections along the road which made separation feasible.

The buffer zone has a 0.5m width, which is the minimum design specification from the Ontario Traffic Manual Book 18. Spacing for each bollard is 20m (Quebec Standards for Bollards) in order to protect the 3.0m width two-way shared trail as recommended by the recreational department. The city would have preferred a permanent buffer zone, such as concrete, however as a result of budget constraint this was not feasible. In addition to this, bollards were used because they produce visual noise, where vehicles passing the bollards creates a sound. This measure is taken to reduce vehicle speeds along the corridor. The bollards have been removed during the winter season, due to city planners avoiding the potential of damage done to them.

The city of Thunder Bay plans to add more bollards to streets in the 2017 construction year. Engineers and planners want to see the effects of the protected lane for one full year before any more roads are equipped with cycling track facilities.

In addition to seeing the effects of the protection, public opinion is of interest in new projects. According to a city staff member, currently public surveys have not been conducted regarding feedback on the multi-use trail. However, current residents who have experienced the facility find the cycle network to be a wonderful addition. It has also been found that some vehicle operators find the bollards to be a distraction and tend to hug the centerline due to fear of contacting a bollard.

2.1.4 City of Vancouver

The city of Vancouver is located on the west coast of British Columbia, and is the eighth largest city in Canada, with a population of 2.50 Million (Statistics Canada, 2015). Despite the dense nature of the city, Vancouver has become one of the most cycle friendly cities in North America. The current cycle network within the city is one of the largest constructed in North America. In 2011 cycling accounted for 4.4% of all work trips in the city of Vancouver. The city has challenged itself to become the greenest city in world by 2020. As a result, by 2020 the city wants half the population to walk, bike or take transit to work.

In 2012 the city of Vancouver conducted a cycling safety study to address potential issues with cyclists. The study showed certain areas within the city that had high rates of bicycle collisions and also showed the most common type of collisions for cyclists. Listed below are 12 key issues that cyclists encountered:

- Doorings
- Conflict Zones
- Right Hooks
- Left Crosses
- Sidewalk Cycling
- Two way stops
- Non-Motor vehicle collisions
- High Collision Corridors
- High Collision Locations

- Designated Bike Lanes
- PM Peak
- Adverse weather and Low light

The 2012 safety study also identified certain corridors in the downtown core that possess repeat issues and gave priority to streets needed to be corrected first. The highest priority was given to Main Street and Burrad Street, with low priority given to Clark Drive, Pacific Street and Cypress Street.

In 2015 the city developed an updated version of the current bicycle network. To better protect cyclists an action plan is currently underway to educate people on bicycle safety, enforce the laws of both motor vehicle and bicycle transportation and to develop better engineering practices. The city is currently working on having an annual review with the Insurance Corporation of British Columbia (ICBC) and Vancouver police department, for future education programs and engineering actions.

2.2 Intersection Studies

Intersection approaches that incorporate cycling facilities are considered to be a crucial part of the cycling network. This section looks at the typical approach for Ontario as well as the protected intersection approach that originated in Europe.

2.2.1 Current Intersection Approaches

The Ontario Traffic Manual is a set of traffic standards the province of Ontario has developed. For cycling facilities, the Book 18 contains the implementation and design of cycle tracks and bike lanes. These standards are based on research from various sources such as, MUTCD, NACTO and Literature Reviews completed by cities. Figure 2-1 illustrates the current intersection treatment for a separated bike lane as follows:

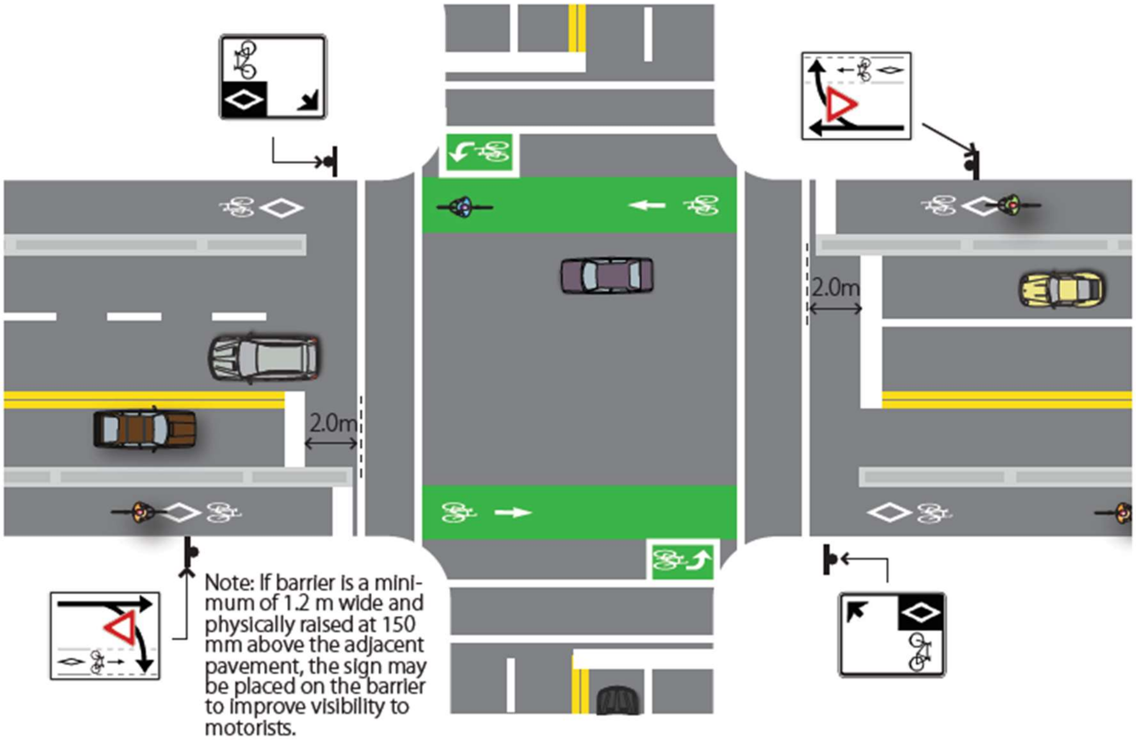


Figure 2-1 - Intersection Treatment for Separated on Grade Cycle Track (Ministry of Transportation, 2013)

From the current intersection treatment, it is clear that operational characteristics are optimal for straight through and right turn cyclist movements, however suboptimal for cyclists turning left. Cyclists have a queue box and are expected to stop within and complete the turn as the signals permit. Stop bars are provided closer to the intersection than that of the motor vehicle traffic, such to increase driver awareness. Safety concerns arise in particular due to the expected lack of compliance with the queue box approach.

For elevated/curb separated bike path intersection treatments for a straight through path are as shown in Figure 2-2:

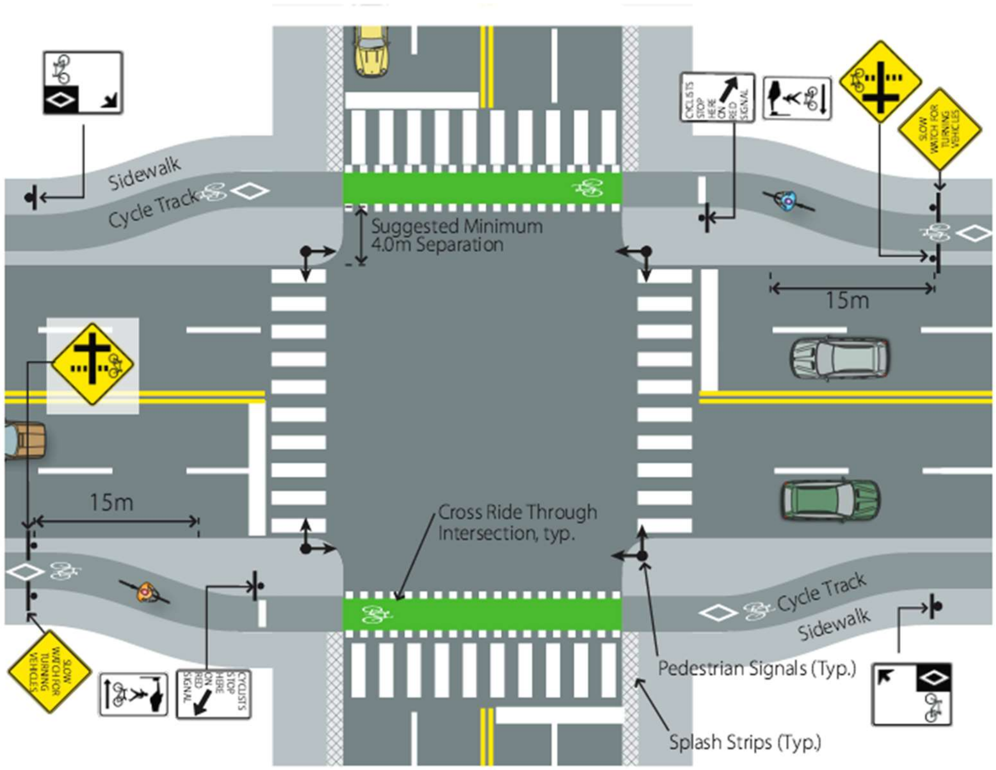


Figure 2-2 - Intersection Treatment for Curb Separated Cycle Track (Ministry of Transportation, 2013)

As seen in the figure, a slight jog in the bike path and sidewalk as they approach the intersection reduces the operational characteristics of the bike path to some degree since a cyclist typically will reduce speed to follow the jog. On the other hand, increased separation from right turning vehicles provides a larger buffer zone for increased safety. Queue boxes would be introduced to provide left turn access, this figure is limited as a straight through path. When developing intersection treatments, the measures taken must demand compliance.

2.2.2 Protected Intersections

There are several health benefits associated with cycling, however studies have shown that what deters people the most is safety. Many cyclists feel too close to vehicles and other pedestrians while traveling. One way to increase safety for all three modes of transportation is to integrate protected intersections into the engineering planning and design. The University of British Columbia conducted a study that compared the effects of infrastructure on cycling injuries at intersections and non-intersections. The study found that, the types of routes meeting and the intersection design influenced safety (BICE, 2008)

Protected intersections or "Dutch Junctions" are a form of cycling and pedestrian infrastructure that separate pedestrians, cyclists and vehicles at intersections and are extremely common in major European cities. The primary physical feature providing protection to users are the corner safety islands. They are used to define the traffic movement (ALTA, 2015). The corner islands serve many additional purposes, some of which are as follows:

- Helps to control the speed of a vehicle turning right
- Improves the visibility of cyclists
- Increases comfort for a cyclist waiting at the intersection

However, it does have a drawback. The dimension of the corner island may impact the turning of a larger vehicle. Figure 2.3 shows the typical layout of a protected intersection.

Figure 2-3 – Protected Intersection typical design (ALTA, 2015)

As mentioned previously, the corner island has many functions. It also creates a setback for cyclists and pedestrians to cross the roadway. The setback illustrated in Figure 2-4 will improve sightlines by moving the stop bar back and establish priority (ALTA, 2015). Vehicles become more aware of cyclists on the road before making a turn. In order to achieve the desired setback and corner island radius, more space is required than the traditional intersection.

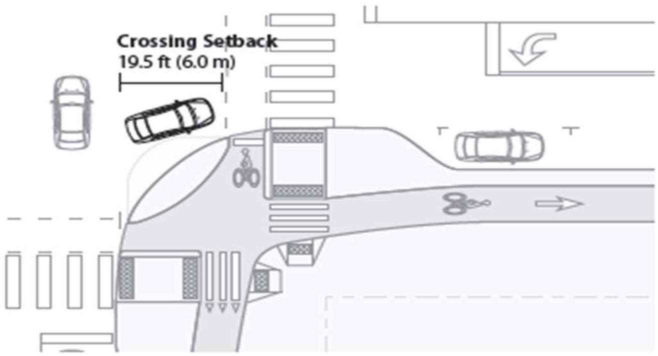


Figure 2-4 - Typical Setback for Cyclist and Pedestrian Crossing (ALTA, 2015)

According to U.S. guidelines for yielding to crosswalks a setback is one car length (6 m) (ALTA, 2015, NCHRP, 2010). In order to improve upon the setback distance, bike lane guidelines support a distance of 25 ft (7.5 m) as a setback in more advanced intersections. Setback distances are selected based upon the corner radii to encourage slow turning speeds and vehicle alignment. Lane blockages could occur if setback distances are inadequate.

The extended setback allows, for cyclists waiting in the queue to cross the street at a location clearly labeled with pavement markings. If possible the dimensions of a two-stage turn box should be 3.0m by 2.0m deep (FHWA, ALTA, 2015). The inside radius should be maximized for the corner safety island to allow for more maneuverability and capacity for cyclists in the queue box, as shown in Figure 2-5, the minimum distance of 3.0m should be provided from behind the safety island to the sidewalk for new construction (ALTA, 2015).

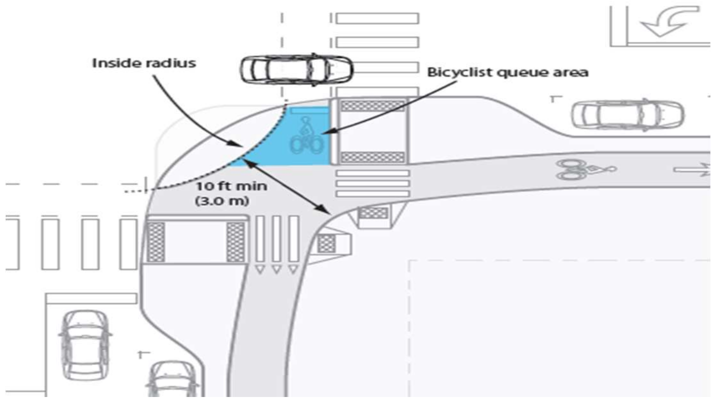


Figure 2-5 - Bicycle Queue Area (ALTA, 2015)

As stated previously, larger vehicles require a greater corner radius. If this is the case a mountable corner apron should be installed. This is intended to make passenger vehicles avoid the apron at a lower turning speed of 5 to 10 mph while allowing larger vehicles to use the apron as required. To deter passenger vehicle from driving on the apron, it should be visually distinct from both the roadway and corner safety island (ALTA, 2015). As shown in Figure 2-6, this may require painting be used or some sort of surface texture to be installed so passenger vehicles will be discouraged from making use of it.

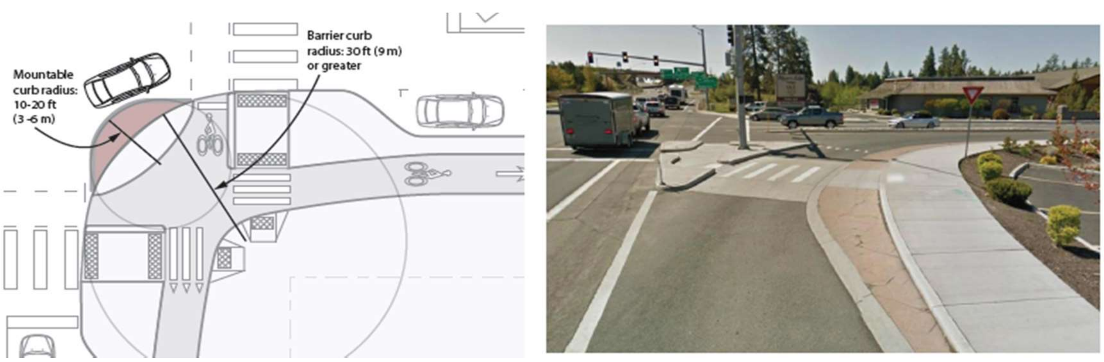


Figure 2-6 - Mountable Turning Apron and Channelized Turn Lane with Raised Crosswalk (ALTA, 2015)

As the diagrams developed by ALTA become more accepted, protected intersection are becoming more popular in the design and planning stages of road construction. It provides separation of motorist, cyclist and pedestrian traffic, which reduces the risk of potential conflicts. Vehicles become more aware of cyclists and slow their speed while traveling through or turning onto an intersection. Protected intersections, and route infrastructure can be designed for primary prevention of injuries to cyclist (Route Infrastructure, 2012). The efficiency of a protected intersection is heavily dependent on the signalization.

2.2.2.1 Signal Phases for a Protected Intersection

For a protected intersection there may be different types of signalization depending on traffic volumes and pedestrian volumes. Each intersection is unique and approaches need to be designed for local conditions. For protected intersections there are four signal phases that can be compatible. Also note that these four types should be reviewed by an engineer to identify sight lines, capacity, safety, impact on traffic progression and timing with adjacent signals. These four types of phases are:

Protected but Concurrent Phasing

Left and right turns have their own separate through movements. Pedestrian and cyclist crossing runs at a different time from the conflicting turn phase but concurrent with vehicular traffic through phase. The corner island safety acts to provide comfort for the waiting cyclists under this phasing scheme.

Protected Left Turn Phasing

Allows a protected left turn phase for vehicles, however also allows for right turns to happen concurrently with conflicting pedestrian and cyclist through movements. This phasing scheme is common practice today, as it is assumed that vehicles will yield to pedestrian and cyclist.

Permissive-only Signal Phasing

This type of signal phasing requires both left and right turning drivers yielding to cyclists and pedestrians before making the turn. Left and right turn movements travel with the concurrent through movement traffic. For this type of signal scheme, the corner safety island should be designed to slow the driver turning speed.

Exclusive All-Way Bicycle/Pedestrian Phasing

This phase offers a movement of just pedestrians and cyclists in all directions at once. This type of signal scheme may work better on a low volume street with two-phase permissive.

For a look at the traffic control devices used for these processes, see section 2.5.2.

2.3 Safety Considerations

The following section addresses the safety data and elements that are recommended for consideration in order to improve the overall function of a roadway.

2.3.1 Collision Reports

A collision report is simply a documented form that explains the who, what, when, where, and why of a collision. There are two forms of collision reports, the self-reporting collision report and the officer-on-scene report also known as the motor vehicle accident report. The collision data needs to be reduced (typically by police services) in order to provide the valid records for a location and timeframe of typically 3 years. From here collision trends can be established and analyzed to produce countermeasures that could reduce the collision rate. Important factors when assessing trends include, but not limited to:

- Type of collision
- Random Nature of Collision
- Date
- Weather
- Road Condition
- Driver Action.

2.3.2 Crash Reduction Factor

Crash Reduction Factor (CRF) is the percent of crashes that have occurred after a countermeasure has be implemented. For a CRF to be considered the Engineer must first decide whether the countermeasure should be installed for a particular condition. "*A CRF should be regarded as a generic estimate of the effectiveness of a countermeasure. The estimate is a useful guide, but it remains necessary to apply engineering judgment and to consider site-specific environmental, traffic volume, traffic mix, geometric, and operational conditions which will affect the safety impact of a countermeasure."* (US Department of Transportation, 2008). The US Federal Highway Administration has established several tables for a variety of countermeasures and the corresponding CRF that may be implemented. As noted previously, the CRF is an approximation and as such a standard of error is calculated. The standard error is the standard deviation of the error in the estimate of the CRF. If a standard is high the CRF is not well known, while a smaller error indicates that the reduction factor is precisely known.

2.3.3 Crash Costs

After a collision has occurred on a city street, there are costs that the municipality must incur. Crash cost can range from specific direct costs such as property damage or emergency response costs to more complex indirect costs such as pain, suffering and grief. Generally, a collision cost model can be developed using 3 types of cost categories which include, Direct Costs, Human Capital Costs and Willingness-to-Pay (de Leur Consulting Ltd., 2010).

Direct Costs

These types of costs can usually be readily available. Direct cost includes property damage, emergency services, medical expenses, legal costs, travel delay costs and costs that can be associated with time away from work. Direct cost data is in some cases available through the city or municipality.

Human Capital Costs

Is the production value that has been lost to a society as a result of a collision (de Leur Consulting Ltd., 2010). This cost represents the measure of value of an individual to society. This value can be calculated by subtracting a victim's future net consumption from their future net production.

Willingness-to-Pay

This is the cost a society is willing to pay to reduce the risk of collisions that may result in an injury or death. This cost type involves a sample survey of the population in order to understand the trade-offs between collision risk and economic resources that are available to the city.

When crash costs are in the Human Capital stages, it can become very complex of how to put a value on pain, suffering and grief. Collision costs can have a wide range of values from $1 million to $20 million if a fatality occurs (de Leur Consulting Ltd., 2010).

2.3.4 Economic Analysis

For economic analysis, the benefit to cost analysis is a typical justification process. This is the process of collecting all previously discussed parameters and assessing them. It is based on crash reduction factor coupled with the historical severity of the collision and is compared to the cost of implementing the countermeasure, if the benefit to cost ratio is greater than 1 then implementation is justified. The first step is to calculate the total benefit using Equation 2-1, and once a cost of implementation has been developed, the benefit to cost ratio (Equation 2-2) can be assessed.

$$Total\ Benefit = CRF\ \times\ Collision\ Cost\ \times\ Current\ Number\ of\ Collision\ Type$$

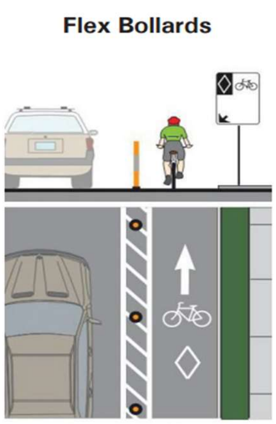
(Equation 2-1)

$$Benefit\ to\ Cost\ ratio = \frac{Total\ Benefit}{Cost}$$

(Equation 2-2)

2.3.5 Buffer Zones

For a cycle track, a buffer zone is intended to create an added layer of separation between motor vehicles and cyclists. Buffers can consist of hatch pavement markings, physical barrier such as bollards, concrete median, or curb and greenspace between the two modes of transportations. Physical separation restricts the encroachment of motor vehicle traffic into the separated bicycle lane, and is perceived to create a more secure and comfortable environment for cyclists. (Ministry of Transportation, 2013). According to the Ontario Traffic Manual, Book 18 for Cycling Facilities whether the buffer zone is a permanent physical barrier or pavement markings the width should range from 0.5m to 1.5m. Figure 2-7 to 2-10 illustrate the different types of buffer zones.



Bollards can come in both removable and retractable form. Removal bollards are economical and simple to install. They can be easily removed in case of an emergency situation. However, the metal sleeve that is placed below grade can become jammed from gravel and debris on the bike route which could make it more difficult to remove if an emergency did arise. Retractable bollards are costlier however are less likely prone to damage.

Figure 2-7 - Bollard Buffer Zone (Ministry of Transportation, 2013)

Diagonally hatched lines are typically applied for a bicycle lane separated by a marked buffer. The spacing between the diagonal hatches is generally a function of vehicular speed. On roadways with faster moving motor vehicles, the hatched lines should be spaced farther apart. On roadways with slower moving motor vehicles, the hatched lines should occur more frequently (Ministry of Transportation, 2013).

Figure 2-8 - Hatched Buffer Zone (Ministry of Transportation, 2013)

Figure 2-9 - Median Buffer -Depicted with Planter Box (Ministry of Transportation, 2013)

The planter or median buffer provides a physical barrier that prohibits vehicles from encroaching on the bike route making cyclists feel safer. However, with a permanent structure additional maintenance costs may occur. Designers should check the requirements for their municipality and factor in higher maintenance costs should their chosen facility widths require the use of specialized equipment (Ministry of Transportation, 2013). If maintenance is not an option, placement of a removable curb within an extended asphalt buffer can be considered as well.

The elevated cycle track is separated by curb as well as greenspace (width differs by regional specification). It is an ideal solution when the cycle track has few intersections to cross (Ministry of Transportation, 2013). The greenspace provides the opportunity for trees to be planted, which is an appealing option for urban planners. It is ideal when the road has many private entrances, as a bollard and median buffer will have an unpractical amount of breaks in continuity for access.

Figure 2-10 - Curb and Greenspace Separated (Ministry of Transportation, 2013)

2.4 Simulation Programs and Operational Tools

The following section describes the simulation programs, tools and additional parameters to be considered to assess the operational feasibility of a roadway.

2.4.1 Synchro 9.0

Synchro 9.0 is a simulation software developed by Trafficware. It is used to simulate road networks by use of macroscopic parameters. Modeling based on design peak hours is a current approach to any development or road related construction in which changes to current traffic volumes are anticipated or changes to the existing road condition are proposed. Cities and Municipalities often require simulation modeling in order to assess the operational effects of proposed construction on the existing condition.

Simulations can be developed by use of the Bing maps feature, in which a to scale map can be set as the background. Tools such as link drawing tool are used in order to produce the network. Once all links (roads) have been drawn into the model, input parameters are required to establish the physical condition for simulation.

Input Parameters

The following parameters are used to define the roadway characteristics for most realistic simulations. They can be broken down into four main categories: lane settings, volume settings, timing settings and phasing settings. For more information on the following parameters, see the Synchro Studio 9.0 User Guide (2015).

Lane Settings

The following lane setting parameters are important in the development of a model.

Lanes and Sharing

Lanes and sharing are where the amount of lanes and the direction of traffic flows are specified. It is a drop down system with arrows specifying amount of straight through lanes and whether or not the turning movement is a separate lane or not.

Traffic Volumes

The amount of vehicles passing a node in a given direction per hour (vph). Typically taken from traffic counts.

Link Speed

It is the specified speed anticipated for the area under consideration. For an arterial road, the link speed should be set to the anticipated safe operating speed (km/h).

Lane Widths

The lane width is the dedicated zone for a vehicle to be in for its respective movement. Default lane widths are 3.7m. Each lane width also has a lane width factor that is developed based on the Highway Capacity Manual 2010.

Storage Length

The distance from the end of taper to the actual turning movement is the storage length of a turning lane. It is allotted space for vehicles to wait in queue without impeding straight through movements.

Allow Right Turn on Red (RTOR)

This field is a check box which, as it sounds allows vehicles to make right turn movements when space is available. This will effect simulation and flow rate calculations.

Curb Radius

It is for right turns with turn-islands implemented, the curb radius is specified to make the turning movement as realistic as possible.

Volume Settings

The following volume settings have important implications on output and overall performance.

Peak Hour Factor

The ratio of volume for the peak hour to the flow rate for the 15 minute peak within the same interval. The program default is 0.92 which is the default for congested conditions.

Growth Factor

Growth factors are used to adjust volumes to future values. They range from 0.5 to 3.0 and a formula is used for their calculation when a growth factor hasn't been specified by the municipality or city.

Heavy Vehicle Percentage

The percentage of traffic for a given movement that will impact the operational performance by slower start times and extend stopping times. The default is 2% and should be calculated based on the ratio of heavy duty (truck) vehicle to total traffic for a given movement. This is an important characteristic as changes to roads and timing have greater consequence for heavy vehicles.

Conflicting Pedestrians

It is the number of pedestrians impeding or crossing a vehicular movement. The program default is zero and should be adjusted to either a conservative design value or to raw data that has been collected.

Conflicting Bicycles

It is the number of cyclists impeding or crossing a vehicular movement. The program default is zero and should be adjusted to either a conservative design value or to raw data that has been collected.

Pedestrian Walking Speed

It is the speed pedestrians travel while crossing at an intersection (node). this speed is also used for the simulation model.

Timing Settings

The following timing settings have important implications on output and overall performance.

Turn Types

The turn type sets the level of protection for a vehicle making either a left or right handed turn. The Turn Type will also set a default phase as well as detector numbers to the dedicated turn lane.

For a left movement turn type there are 8 categories of turns:

1. *Permitted* (*Perm*): There is no protection for left turn movements. Vehicles who are making a left turn movement must yield to oncoming traffic and pedestrians crossing the road.
2. *Protected* (*Prot*): Left turns will only be allowed during an arrow signal indication.
3. *Permitted and Protected* (*pm+pt)*: The left turn movements will be protected when a green arrow signal is indicated. After which will be permitted during the standard green phase.
4. *Split*: Left turn and through movement traffic share a lane. A shared lane will also create a shared protected phase.
5. *Dallas Permitted* (*D.Pm*): A special type of turn movement used in Dallas, Texas. The left turn lane has its own signal head that is louvered to make it invisible to adjacent lanes.
6. *Dallas Permitted plus Protected* (*D.P+P*): A special type of turn movement used in Dallas, Texas. The left turn lane has its own signal head that is louvered to make it invisible to adjacent lanes. After which will become permitted during the green indication.
7. *NA*: Left turns are not allowed.
8. *Custom*: A combination of the standard left turn movements is developed.

For a right movement turn type there are 8 categories of turns:

1. *Permitted* (*Perm*): Right turn movements are not protected and vehicles must yield to pedestrians crossing.
2. *Protected* (*Prot*): Right turn movements are protected with an indication of a green right arrow. The right turn does not interfere with pedestrians on the crosswalk.
3. *Overlap* (*over*): This turn movement allows for a right turn arrow with while also having a protected left turn movement at the intersecting street.
4. *Permitted + Overlap* (*pm+ov*): This turn movement type allows for a right-turn arrow indication while also having a left turn with a permitted green indication through phase.

5. *Protected + Overlap (pt+ov)*: This turn movement type allows for a right-turn arrow indication while also having a left turn and a through movement associated with a right-turn.
6. *Free*: A free turn type does not have a signal phase and a vehicle turning right must still yield to pedestrians. This type of turn should only be used to if there is an accelerated lane downstream.
7. *N.A.*: This turn type is 'Not Applicable' which means no right turn is allowed.
8. *Custom:* A right turn movement is created from the non-standard right turn types.

Protected Phases

Phases in which, vehicles can move without conflict throughout. Therefore, vehicles do not have to yield to oncoming traffic.

Permitted Phases

For permitted phases there is no protection for vehicles. Therefore, vehicles turning left will have to yield to oncoming through traffic and vehicles turning right will have to yield to pedestrians.

Minimum Initial (Minimum Green)

Minimum initial is the shortest time that will guarantee a phase to be serviced. In other words, the minimum green is the lowest amount of time it will take vehicles that have been detected to cross the intersection.

Minimum Split

The split is the shortest amount of time that a phase is allowed. The minimum split incorporates the minimum initial as well as the yellow and all red times. For Synchro a minimum split has to fall between 3 seconds and 840 seconds.

Total Split

Total split is the summation of the green, yellow and all red times for a particular phase. It is possible for total split times to overlap multiple phases.

Yellow Time

The amount of time allocated to the yellow interval phase. Synchro allows a range of between 2.0 to 10.0 seconds. For most provincial and municipal standards yellow times are between 3.0 and 5.0 seconds.

All Red Time

The amount of time for the all red interval phase. For the all red phase the time needs to be sufficient enough so all vehicles and pedestrians clear the intersection before traffic is released.

Phasing Settings

Most phasing settings overlap with timing settings with the exception of the following.

Walking Time

It is the amount of time it takes a pedestrian to walk across the intersection during a pedestrian phase. A pedestrian phase will only occur when there is a pedestrian call or a recall. The walk time can be ignored if the pedestrian phase is in maximum recall and the split will be sufficient enough for pedestrians to cross safety.

Highway Capacity Manual 2010

The Highway Capacity Manual has been incorporated into Synchro. It is a separate window from the Synchro characteristics, however it makes use of the Synchro inputs to generate results and effects that pedestrians and cyclists have on traffic and vice versa. It does not physically add sidewalks or bike lanes, to the model, the assessment is strictly based on user inputs.

Bicycle Mode

Bicycle mode is an option that produces a bicycle saturation flow rate with the unit of bicycles/hour (b/h). The bicycle saturation flow rate is the maximum bicycle rate of flow measured at the stop line during the green indication. Within this mode it assesses the performance and compliance of a typical bike lane (no separation).

Output Parameters

The following parameters are calculated based on input values. They can also be broken down into four main categories: lane settings, volume settings, timing settings and phasing settings. For more information on the following parameters, see the Synchro Studio 9.0 User Guide (year).

Lane Settings

The following lane settings are useful resulting values used in the justification of operation.

Saturated Flow Rate

Saturated flow rate is determined by assuming an intersection's approach signal are to stay green for an entire hour, with traffic density being relative to the lane group in question. The number of vehicles passing through the intersection during the one hour increment is the saturation flow rate for this lane group. The saturation flow rate is based on many variables as, listed below:

$$S = So * Fw * Fn * Fhv * Fg * Fp * Fbb * Fa * Flu * Flt * Frt * FLpb * FRpb$$

(Equation 2-3)

Where,

$S =$ Saturation flow rate for the subject lane group, expressed as a total for all lanes in the lane group, veh/h

$So =$ Base saturation flow rate per lane, pc/h/ln, (Default 1900 pc/h/ln)

$N =$ Number of lanes in the lane group

$Fw =$ Adjustment factor for the lane width

$Fhv =$ Adjustment factor for heavy vehicles in the traffic stream

$Fg =$ Adjustment factor for approach grade

$Fp =$ Adjustment factor for the existence of a parking lane and parking activity adjacent to the lane group

$Fbb =$ Adjustment factor for the blocking effect of local buses that stop within the intersection area

$Fa =$ Adjustment factor for area type

$Flu =$ Adjustment factor for lane utilization

$Flt =$ Adjustment factor for left turns in the lane group

Fr Adjustment factor for right turns in the lane group

$FLpb$ Pedestrian adjustment factor for left-turn movements

$FRpb =$ Pedestrian/Bicycle adjustment factor for right-turn movements

Lane Utilization Factor

The lane utilization factor is the determination of how traffic volumes assigned to a lane group are distributed across each lane. If a value of 1 is computed the there is a single lane operating the movement(s). A value less than 1 decreases the saturation flow rate due to all lanes not performing to full capacity. Lane utilization factors are selected based on Table 2-1, although factors can be overwritten due to special cases.

Table 2-1 - Lane Utilization Factors (Trafficware, 2015)

Lane Group Movements	# of Lanes	Lane Utilization Factor
Thru or shared	1	1.00
Thru or shared	2	0.95
Thru or shared	3	0.91
Thru or shared	4+	0.86
Left	1	1.00
Left	2	0.97
Left	3+	0.94
Right	1	1.00
Right	2	0.88
Right	3	0.76

Turn Factors

The following turn factors are useful resulting values used in the justification of operation.

Right Turn Factors

The right turn factor is utilized to decrease the saturated flow rate. The basis of the factor is the proportion of right-turns in the lane group and the type of lane that is servicing the right-turn. If an exclusive right-turn lane is incorporated, then the protected right-turn factor is used.

Left Turn Factors

The left turn factor is utilized to decrease the saturated flow rate, with the same principals, with respect to the left-turn, as the right turn factor.

Pedestrian Factors

The following pedestrian factors are useful resulting values used in the justification of safety and operation.

Right Ped Bike Factor

The right ped bike factor is the pedestrian/bicycle adjustment factor for right-turn movements, which is used within the saturated flow rate. The factor is based on the number of pedestrians and bicycles crossing the right turn movement.

Left Ped Factor

The left ped factor is the pedestrian adjustment factor for left-turn movements, which is utilized in calculation of the saturated flow rate. The factor is based on the number of pedestrians and bicycles crossing the permitted left turn movements.

Volume Settings

The following volume settings are useful resulting values used in the justification of operation.

Adjusted Flow

The adjusted flow is measured in vehicles per hour (vph) and is the future volume that is modified by the peak hour factor and the growth factor.

Lane Group Flow

The lane group flow assigns net volumes to each lane group by combining the adjusted flow and the traffic in shared lane (%) values. If there is no turning lanes present, the turning volume is assigned to the through lane group.

Timing Settings

The following timing settings are useful resulting values used in the justification of intersection operation.

Actuated Effective Green

The actuated effective green time is an average of the five percentile green times, dependent on yellow plus all-red time with the subtraction of the total lost time. The resulting value represents the average green time while the signal is set in actuated mode.

Actuated G/C Ratio (Green to Cycle)

The actuated green to cycle ratio is the average actuated green time divided by the actuated cycle length.

Actuated V/C Ratio (Volume to Capacity)

The actuated volume to capacity ratio is the amount of congestion for each lane group. For any volume to capacity ratio greater than or equal to 1, the approach is operating above capacity.

Control Delay

The control delay in Synchro is used to analyze the effects of coordination, actuation and congestion. Control delay is caused by the downstream control device and does not include Queue Delay (Trafficware 9).

Queue Delay

Queue delay is the value which represents an analysis of the effects on queues and blocking for short links and short turning bays. It includes spillback, starvation, and storage blocking. Queue Delay is also used for optimizations. Which will help with timing plans.

Total Delay

Total Delay is the sum of queue delay and control delay for a lane group.

LOS (Level of Service)

Level of service (LOS) is a quality measure that describes operational conditions in a traffic flow where it generally measures the speed and travel time, interruptions of traffic, freedom of mobility, comfort and convenience. There can be several methods to define the level of service but the most common methods to determine the level of service are based on delay and probability of clearing the arrivals. Synchro uses the total intersection delay which then produces a level of service from A to F. Delay is a measure of driver discomfort and frustration, fuel consumption, and lost travel time (Ministry of Transportation, 2013).

For the current edition of Synchro 9.0, the Control Delay Per Vehicle is used for each of the five levels of service shown in Table 2-2. These have been indicated under the Highway Capacity Manual 2010.

Table 2-2 - Level of Service Grades (Highway Capacity Manual, 2010)

Control Delay Per Vehicle	Level of Service	LOS Characteristics
≤10	A	The highest quality of traffic flow. Drivers have freedom of operation. Free flow.
>10-20	B	Stable flow. Drivers somewhat constricted. Vehicles may have to wait to complete minor movements
>20-35	C	Vehicle Operation is stable. Queues short start to develop for short periods.
>35-55	D	Traffic is becoming unstable. Vehicles are more restricted, with increasing delays. Enough gap clearance to prevent excessive backups.

Table 2-2 - Level of Service Grades (Highway Capacity Manual, 2010)

>55-80	E	Capacity has occurred. Vehicles are waiting in long queues and delays are extended.
>80	F	Unstable flow. Capacity at intersection has been exceed and intersection has failed.

Approach Delay

This delay represents the entire approach. It is a volume weighted average for the total delays in each lane group (Trafficware 9, 2015).

Fuel Used

The quantity of fuel that was consumed for a specific interval. Fuel and emissions can be calculated using the following formula from Trafficware 9.

$$F = Total\ Trave\ \ x\ K1 + Total\ Delay\ x\ K2 + Stops\ x\ K3 \qquad \textit{(Equation 2-4)}$$

Where,

K1= 0.075283 - 0.0015892*Speed + 0.000015066 *Speed^2

K2 = 0.7329

K3 = 0.0000061411*Speed^2

Fuel consumed in gallons

Speed = Cruise Speed in mph.

Total Travel = Vehicle Miles Traveled

Total Delay = Total Signal Delay in hours

Stops = Total Stops in vehicles per hour.

Queue Length 50th Percentile

The 50th Percentile represents the average back of queue and experience for a typical cycle.

Queue Length 95th Percentile

The 95th percentile queue refers to the maximum back of queue with the 95th percentile of traffic volumes. The 95th percentile queue may not even be experienced due to upstream metering (Trafficware 9). The 95th percentile can be calculated from the following formula:

$$v95 = v * PHFx * \left[1 + 1.64 * \frac{\sqrt{vc}}{vc}\right] = 95th\ Percentile\ Arrival\ Rate\ (vph)$$

(Equation 2-5)

Where,

vc = Vehicles Per Cycle = v *C/3600

PHFx = Minimum of PHF or 0.9

Phase Settings

Vehicular traffic flow varies throughout the day. Synchro models the actuated green times and traffic flows for five different scenarios. The scenarios include the 90th, 70th, 50th 30th and 10th percentile cycles for the hour where volume data are available. If a sample of 100 cycles is used, the 50th percentile would represent average traffic flow conditions, while the 90th percentile would represent 90 cycles that have less volume then the remaining 10 cycles. This is can be used to assess the stability of the flow.

2.4.2 SimTraffic

After all information is gathered and implemented in Synchro, SimTraffic produces animated real world scenarios for pedestrians and vehicular traffic. SimTraffic is used to design models of signalized and un-signalized traffic flows. This allows engineers and planners to deal with complex traffic situations. This is very useful as it allows the operator to see visual blockages at certain stages of the intersection. Although SimTraffic can be very useful in generating reports or for animation purposes, it does however have some drawbacks. Currently SimTraffic is unable to model bus routes and stops, light rail, on-street parking, driveway ramps and separated bike lanes. Simulation models traffic at 0.1 second increments but records the data for every 0.5 seconds. The data are record and can be played back at a later date. Timing speed of the simulation can be adjusted as well as the length of recording time. SimTraffic also allows the user to make volume changes or signal timing changes without stopping the network, however this feature only works if the SimTraffic simulation was created directing from Synchro.

2.4.3 3D Viewer

Synchro Studio 9.0 also includes 3D viewer, a program used to convert two dimensional modes from SimTraffic, to a 3D Viewer application. The application has the capability to create detailed visualizations by adding buildings and scenery. Once the additions are made, a digital video is produced to present the 3D application. The primary modes for playback of SimTraffic data within the 3D environment include scene, ride and track mode. Scene mode enables the user to navigate the entire simulation, ride mode enables the user to navigate from the driver's point-of-view and track mode gives the user the ability to follow a vehicles movement as an observer above the vehicle.

2.4.4 Cycling Facility Selection Decision Support Tool

The nature of cycling safety and operation is very difficult to model in a program since there are so many considerations and factors to be accounted for, some of those defined by AASHTO and others are as follows:

- Volume of cyclists
- Volume of vehicular traffic
- Location of cycling facility
- Frequency of stops
- Potential safety issues
- Connectivity of major trip generators
- Conflicts with other modes of transportation
- Level of comfort
- Level of skill
- Cycling trip purpose

As a result of these factors, it is inherently difficult to generalize a cyclist pattern for simulation purposes. In an initiative to increase safety and awareness of cyclists within the network, the City of Ottawa hired Delphi-MRC (A member of MMM Group) in 2011. Dephi-MRC completed an extensive background study on many countries around the world including:

- Netherlands
- Denmark
- Germany
- Australia
- New Zealand
- United States
- United Kingdom

The findings from the study were not directly applicable to Canada as the functionality and form of networks are far more established in most of the countries of study. To emphasis some of the differences that were faced as challenges, The Ontario Traffic Manual, Book 18, states that in urban areas cyclists can be separated into the following categories:

- Strong and Fearless (1%)
- Enthused and Confident (7%)
- Interested but Concerned (60%)
- No way, No How (32%)

This is a clear difference in ridership breakdowns from that of countries with well-established cycling networks. Netherlands for example, has developed five main requirements for “bicycle-friendly” infrastructure; Cohesion, Directness, Attractiveness, Safety and Comfort which have all contributed to more enthused and confident type riders.

Most countries research showed similar requirements to Netherlands and have implemented a “technically based” facility selection method that are primarily developed on potential conflicts and operating speeds of vehicles. Modifications were made in order to reflect the developing cycle networks in Ottawa, and as a result the Cycling Facility Selection Decision Support Tool was developed and implemented into the Ontario Traffic Manual, Book 18 (see Appendix A: Cycling Facility Selection). It consists of the following steps:

- Step 1: A *pre-selection nomograph* – used to guide the designer for an initial/expected facility type, considers traffic volumes coupled with vehicular speed
- Step 2: A *decision tree* – used to answer questions in more detail, to confirm the compatibility of the pre-selected facility, areas of particular concern are:
    - Speed
    - Volume
    - Roadway function
    - Vehicle mix
    - On-street parking
    - Intersection and access density
    - Collision history
    - Available space
    - User skill level
    - Cycling demand
    - Function of cycle route
    - Type of improvement project
    - Project cost/funding
- Step 3: A *summarization process* – to justify your thinking

After the three step process has been completed, proper justification should have established an appealing, safe and functional cycling facility solution, from here, geometric designs must be developed in accordance with standards to be addressed later on. In addition to using the tool, it is also a good idea to conduct public surveys throughout the process to make sure you are meeting public needs as well.

2.4.5 Traffic Counts

Traffic counts are used for operation analysis of a project. If existing counts aren't available, a group must physically collect raw data from the site under consideration. Today counts can be completed on site using a traffic counter such as that developed by Jamar Technologies Incorporated, by automatic means such as pneumatic tube placement, or by pad and paper. Regardless of the method, data collected should be presented in a suitable form for later analysis (Institute of Transportation Engineers, n.d.). Typically traffic counts include the following details:

- Duration of count (Count Period)
- Form of intersection control (i.e. signalized)
- Location under consideration
- Weather
- Counting team
- Specified period
- Volume in each direction of travel
    - In some cases, form of transportation (i.e. cyclist, trucks and cars)
- Pedestrian crossings

Counts to be used for development are typically conducted in order to establish one-hour peak volumes for morning, afternoon and evening. They should also consider whether the area of concern would have a larger weekend peak hour volume compared to weekday. Although, one-hour peak is typically of concern, count intervals can vary in duration, some other time intervals are as follows:

- 15 minute (sub-hourly within peak hour)
- 2-hour peak period
- 4-hour (morning and afternoon)
- 6-hour (morning, midday and afternoon)
- 8-hour (workday)

- 12-hour (daytime) (Institute of Transportation Engineers, n.d.)

It is important to check design standards to ensure that the correct design time interval is being used. For example, a heavy retail location will most likely require a design hour of the afternoon peak hour for weekday and weekend.

2.4.6 Types of Cycling Facilities

Within the right-of-way cycling facilities exist in different forms. They can be distinguished by separation, as well as the measures taken place to command both cyclist and vehicle attention. Cycling facilities exist in the following forms:

- *Two-way separated cycle track* – an offset path off the back of curb leaving cyclists with less vehicular conflicts through segments of road. Issues exist at intersections. The path includes line paint to provide flow in both directions. This method is used for the Arundel Street multi-use trail in Thunder Bay.

- *One-way separated cycle track* – an offset path off the back of curb or by way of separation on the roadway leaving cyclists with less vehicular conflicts through segments of road. Issues exist at intersections. Typically exist on both sides of the road to provide travel in the direction of adjacent vehicular traffic. This is used in Calgary and throughout many communities.

- *Cycle lane* – a dedicated lane for bicycles on the asphalt edge of the road which may or may not include a buffer zone (0.5 m minimum). This is used along Beverly St. in Thunder Bay.

- *Combined traffic* – a roadway where vehicular and cycling traffic share all lanes of the road. These can exist as 'wider' lane widths such that vehicles can pass cyclists, or as 'narrow' lane widths where passing is not permitted. It is recommended that lane widths not fall below 4 m for a shared road. (MMM Group, 2011)

2.5 Accessibility Considerations

The Ontario Regulation 191/11, the Integrated Accessibility Standards, also known as Accessibility for Ontarians with Disabilities Act, 2005, was created to assist citizens of Ontario living with disabilities. There are five main parts to the act which includes Design of Public Spaces Standards (Accessibility Standards for the Build Environment-Part 4). In particular, this Act addresses a need for tactile metal plates.

2.5.1 Depressed Curb and Tactile Plates

The act states that where a depressed curb (seamless transition from standard curb to a dropped form for connection of the sidewalk at the intersection), is used on an 'exterior path of travel' the following conditions must be met:

"1. The depressed curb must have a maximum running slope of 1:20.
2. The depressed curb must be aligned with the direction of travel.
3. Where the depressed curb is provided at a pedestrian crossing, it must have tactile walking surface indicators that,
    i. Have raised tactile profiles,
    ii. Have high tonal contrast with the adjacent surface,
    iii. Are located at the bottom portion of the depressed curb that is flush with the roadway,
    iv. Are set back between 150 mm and 200 mm from the curb edge, and
    v. Are a minimum of 610 mm in depth. O. Reg. 413/12, s. 6." (AODA, 2005)

The tactile plates used where depressed curb meets an intersection are 610 mm by 610 mm metal material and can be bolted together. They are to be placed in the freshly poured sidewalk and have circular ribs which are used to communicate with the visually impaired, whom are using a "white cane". Thus, communicating that they are entering a crosswalk. See Appendix B, for details of tactile plates for London, Ontario, a city which is in the process of a significant accessibility initiative.

2.5.2 Pedestrian Signal Indicators

On top of the requirement of tactile plates, the act proceeds to also state the following regarding pedestrian signals being installed or replaced:

“1. They must have a locator tone that is distinct from a walk indicator tone.

2. They must be installed within 1500 mm of the edge of the curb.

3. They must be mounted at a maximum of 1100 mm above ground level.

4. They must have tactile arrows that align with the direction of crossing.

5. They must include both manual and automatic activation features.

6. They must include both audible and vibro-tactile walk indicators. O. Reg. 413/12, s. 6.

Where two accessible pedestrian signal assemblies are installed on the same corner, they must be a minimum of 3000 mm apart. O. Reg. 413/12, s. 6.

Where the requirements in subsection [above] cannot be met because of site constraints or existing infrastructure, two accessible pedestrian signal assemblies can be installed on a single post, and when this occurs, a verbal announcement must clearly state which crossing is active. O. Reg. 413/12, s. 6.” (AODA, 2005)

The locator tone is an important accessibility feature to accompany the previously mentioned tactile plates. This is designed to let the visually impaired know when the pedestrian walking phase is active, and the direction of travel. By following these sections of the act an intersection can be made accessible to all Ontarians.

2.6 Complete Street Design Considerations

This section describes all design standards to be followed as well as the software used for geometric design. All findings in this section are derived from the following standards, guidelines and initiatives:

- The City of Thunder Bay Engineering and Development Standards (2015)
- The City of Thunder Bay Urban Design and Landscape Guidelines (2012)
- The City of Thunder Bay Urban Forest Management Plan (2011)
- The Transportation Association of Canada (TAC) Geometric Guide for Canadian Roads (1999)
- The Ontario Traffic Manuals (years vary)

2.6.1 Roadway

The roadway subsection consists of all surface and subgrade considerations from curb to curb.

Design Speed

This is the speed used for geometric design purposes. The Geometric Guide for Canadian Roads (1999) specifies that the design speed should be chosen based on logic with regard to terrain and anticipated driving speed, however it shall not exceed 20 km/h over posted speed. Some cities across Ontario have been known to add additional 10 km/h to posted speed on general principle. For additional information reference the Transportation Association of Canada, 1999.

Minimum Turn Radii at intersections

Where arterial roads intersect collectors, design vehicle turning templates should be used to confirm a feasible radius. The minimum turning radius for an arterial road is specified as 12m at intersections (City of Thunder Bay, 2015). In addition to this, AASHTO has online templates for vehicle turning movements. A template that represents a 53 ft trucks turning movement is typically used where heavy vehicle traffic is present, in order to satisfy requirements beyond minimum specifications.

Stopping Sight Distance

It is the amount of distance to react and come to a stop. The reaction distance accounts for the time required for a driver to detect, identify, decide and respond to an object that requires stopping. The physical reduction of speed down to a stop is termed braking distance. Stopping sight distance for a straight stretch of road can be expressed mathematically as follows:

$$d_s = 0.278Vt + \frac{{s_i}^2 - {s_f}^2}{254(f \mp g)} \qquad \textit{(Equation 2-6)}$$

Where,

V = Traveling initial velocity (km/h)

t = Perception reaction time (TAC uses 2.5 seconds)

s_i = Initial vehicle speed (km/h)

s_f = Final vehicle speed (km/h)

f = Longitudinal friction coefficient

g = Longitudinal profile grade (decimal)

Circular Horizontal Curves

Horizontal curves are often based on a constant radial point. The TAC, 1999 specifies an equation for the relationship between cross fall, friction, speed and radius such to hold vehicles in the curve by way of centripetal and centrifugal force. Manipulation of the formula provides an equation relative to minimum radius for design.

$$e + f = \frac{V^2}{127R} \quad OR \quad R_{min} = \frac{V^2}{127(e_{max} + f_{max})}$$ *(Equation 2-7)*

Where,

e = Pavement cross fall in decimal form (rise/run)

f = Friction force factor between tires and pavement (lateral friction)

V = Speed (km/h)

R = Radius (m)

Braking Distance on Curves

Through a curve, frictional properties of a roadway work as force components. Due to this phenomenon, the braking distance is longer within a curve. This must also be considered for site distance. The breakdown of frictional components are as shown in Figure 2-11:

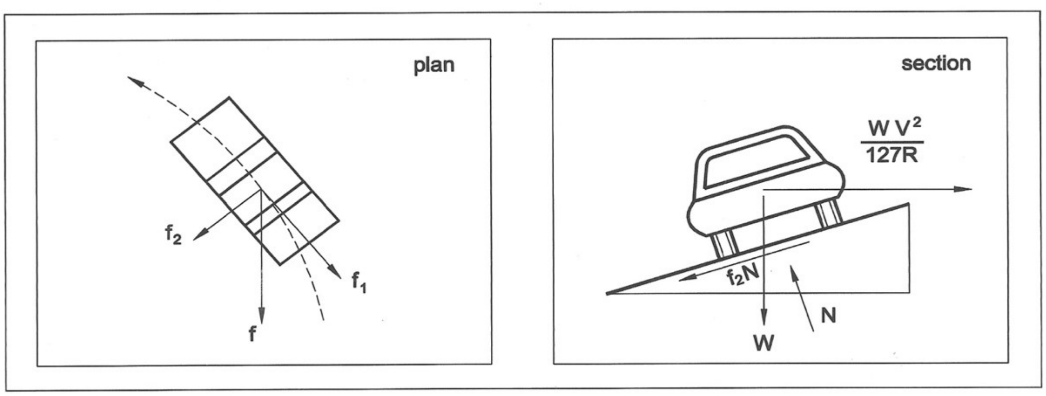


Figure 2-11 - Breakdown of Frictional Forces Within a Curve (Transportation Association of Canada, 1999)

From the figure frictional component formula can be developed as follows:

$$f_2 = \sqrt{f^2 - f_1{}^2}$$ *(Equation 2-8)*

Where,

f = Longitudinal coefficient of friction available (used in SSD calculations)

f_1 = Reduced coefficient of friction for braking distance purposes

f_2 = Lateral friction coefficient

From here, the braking distance can be calculated within a curve:

$$d\ (in\ metres) = \frac{V^2}{254 f_1} \qquad \text{(Equation 2-9)}$$

This can be implemented into Equation 2-6 and the following is developed:

$$d_s = 0.278Vt + \frac{V^2}{254 f_1} \qquad \text{(Equation 2-10)}$$

Lane Widths

The current standard for lane widths is found in the Geometric Design Guide for Canadian Roads (1999) based on road classification. Table 2-3 shows lane widths specified by the Transportation Association of Canada (1999).

Table 2-3 - Lane Widths for Through Lanes on Urban Roads (Transportation Association of Canada, 1999)

Through Lane		Lane Width (m)
i) Freeway and expressway		3.7
ii) Major arterial		3.7
iii) Minor arterial (60 km/h design speed)		3.5 -3.7
iv) Collector	- residential	3.5 - 3.7
	- industrial/ commercial	3.7
v) Local	- residential	3.0 - 3.7
	- industrial/ commercial	3.5 - 3.7

Further research has been completed to explore the effect of shrinking lane widths below the standard values for arterial roadways:

A report found on NACTO's webpage titled "The Influence of Lane Widths on Safety and Capacity: A Summary of the Latest Findings" (Sprinkle, n.d.). Indicates that as complete streets become more popular across North America, communities find themselves in need of additional space for sidewalks, bike lanes and potentially green space. This paper focuses on the ever present issue of finding the space to successfully design a complete street.

Municipalities and cities are all to familiar with these issues. They typically have two basic options for implementation, purchase land or reduce the lane widths such to allow additional space. Sprinkle's research found that on arterial roads, in most cases (with exception of some), two results were common:

- Narrowing lanes had no indication that collision rates had increased, and
- In some cases, narrower lanes reduced collision rates (Sprinkle, n.d.).

The Highway Capacity Manual states that "the capacity of a 10 ft (3.0 m) lane is only 93% of the capacity of a 12 ft lane" (Sprinkle, n.d.). Further research found that saturated flow rates would significantly reduce only if lane width is less than 10-feet (3.0 m).

Sprinkle's report summarizes that lane reductions to 10 ft (3.0 m) have generally have no adverse effects on the safety and capacity of the roadway. NACTO states that "10 ft lanes are appropriate for urban areas".

Crossfall

The desired crossfall for an arterial road is 2%. To allow adequate drainage towards the curb and gutter. For additional information see the Thunder Bay Engineering and Development Standards, 2015.

Profile grade

The city of Thunder Bay specifies a minimum longitudinal grade of 0.30%, where possible 0.50% is to be used as the minimum, while the maximum longitudinal grade is 6.0%. Typically, roads with minimal longitudinal grade changes do not require vertical curves. However, when used, vertical curves shall consider, K values and vertical sight distance in accordance with Geometric Design Guide for Canadian Roads (1999). Furthermore, sag curves are not to be used at intersections due to drainage issues.

Subgrade and Base

The road structure is the supporting material from the asphalt down to the subgrade (limits of excavation). It typically consists of coarse and fine grain granular material. The city of Thunder Bay specifies that the road structure shall be at minimum:

- Asphalt – HL4 Mix – 2 lifts at 40 mm thick
- Granular A – 140 mm thick
- Granular B – 500 mm thick

These values are subject to a thorough geotechnical investigation and bore holes which may result in additional thickness in order to remove material subject to frost heave. In Thunder Bay historically along arterial roads the increased by 100 mm based on specific site situations.

All material should meet the Ontario Provincial Standard for material requirements.

Curb Type

The curb type is of particular importance for plan view drawings in order to establish a width of concrete within the right-of-way. Typical curb types used for roads are as specified by the following specifications:

- City of Thunder Bay Engineering Standards, 2015, DWG. No. R-109-1, or
- Ontario Provincial Standard Drawing (OPSD 600.04)

Where driveways and sidewalk ramps occur, curb is to be dropped. When curb is used in a median or turning island, super elevation may be required based on the cross fall of the road.

Pavement Markings

An important aspect to successful safety and operation of any road, is the communication between the design engineer and the road users. Tools for communication are traffic control devices and pavement markings. The Ontario Traffic Manual specifies the typical pavement markings for roadways. Table 2-4 shows a clear use and dimensions for each form of lane marking:

Table 2-4 - Typical Pavement Marking Dimensions (Ministry of Transportation, 2000)

	NAME OF LINE	DIMENSIONS (m)	USE
LONGITUDINAL	SOLID	0.10	EDGE LINES (WHITE OR YELLOW), DIRECTIONAL DIVIDING LINES (YELLOW), LANE LINES PROHIBITING LANE CHANGES (WHITE)
LONGITUDINAL	DOUBLE SOLID	0.10 0.10 0.10	DIRECTIONAL DIVIDING LINES (YELLOW)
LONGITUDINAL	SIMULTANEOUS SOLID AND BROKEN	3.0 6.0 3.0; 0.10 0.10 0.10	DIRECTIONAL DIVIDING LINES TWO-WAY LEFT-TURN LANES (YELLOW)
LONGITUDINAL	CONDENSED BROKEN	1.0 1.0 1.0 1.0 1.0; 0.20	GUIDING LINES (E.G. INTERSECTION MOVEMENTS) (WHITE)
LONGITUDINAL	WIDE BROKEN	3.0 3.0 3.0 3.0 3.0; 0.20 TO 0.30	CONTINUITY LINES (WHITE)
LONGITUDINAL	BROKEN	3.0 6.0 3.0; 0.10	DIRECTIONAL DIVIDING LINES (YELLOW) URBAN LANE LINES, LOW SPEED (WHITE)
LONGITUDINAL	BROKEN	3.0 9.0 3.0; 0.10	LANE LINES (WHITE) HIGH SPEED ROADWAY
TRANSVERSE	STOP	0.30 TO 0.60	INTERSECTION STOP LINES (WHITE)
TRANSVERSE	CROSSWALK	0.10 TO 0.20	CROSSWALKS (WHITE)

Additionally, Figure 2-12 denotes the dimensions of arrows used to guide traffic:

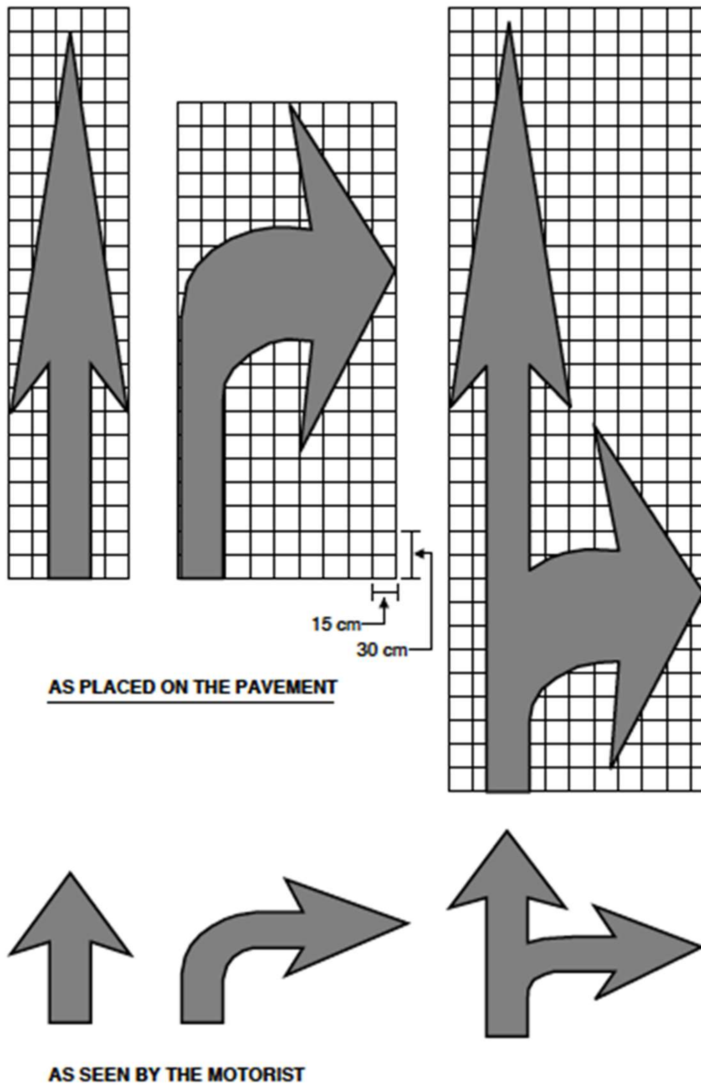


Figure 2-12 - Traffic Arrow Dimensions and Visual Aid (Ministry of Transportation, 2000)

Figure 2-13 incorporates the uses of arrows and line paint for a 5-lane road with shared left turn lanes. It clearly shows the spacing required between arrows. For more details on the background development of these lane markings see the Ontario Traffic Manual (Book 11).

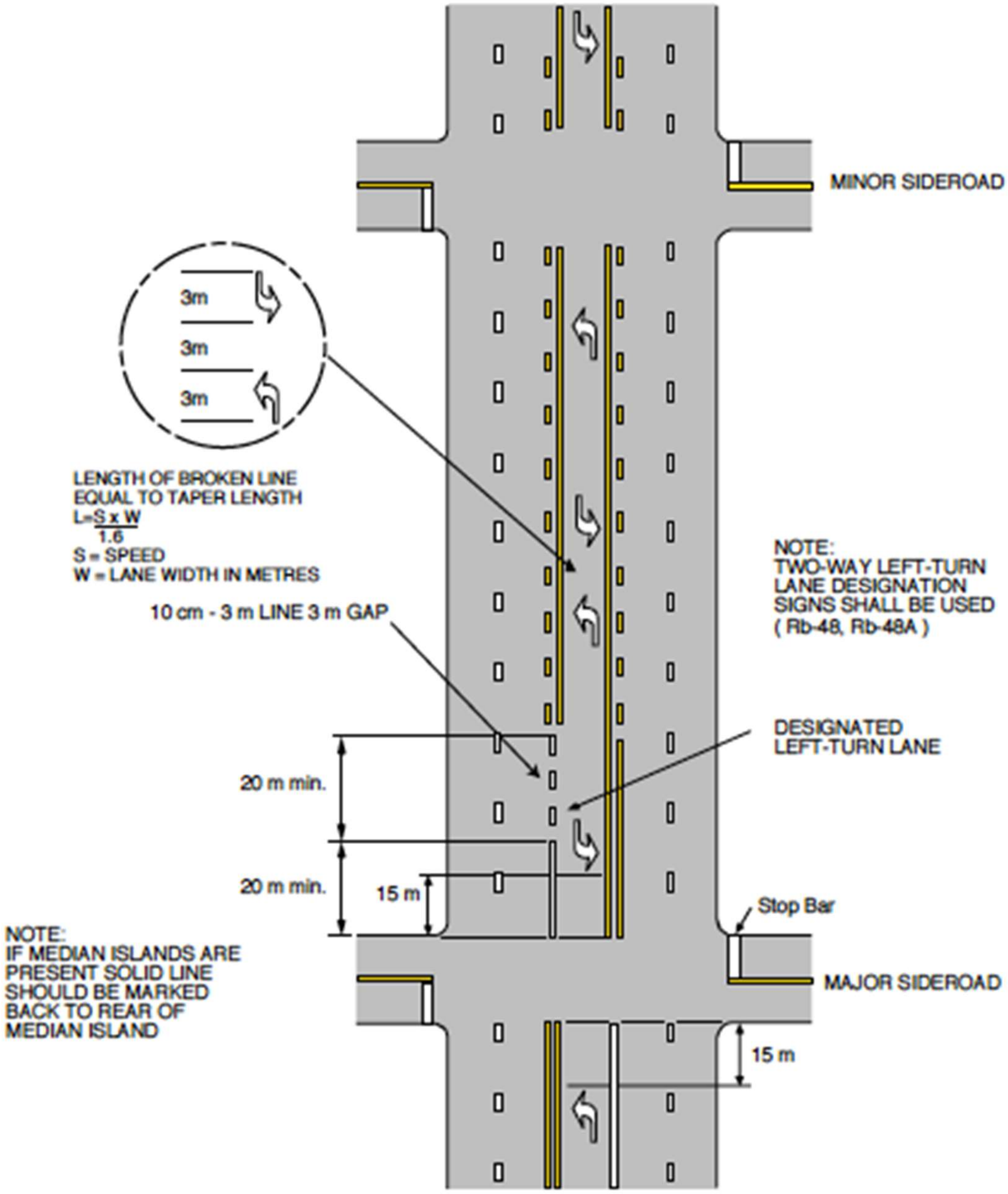


Figure 2-13 - Layout of Paint Markings on a 5-Lane Road with Shared Left Turn (Ministry of Transportation, 2000)

For cycling facilities there are differing spacing and slight modifications to the symbols depending on the facility selected. Figure 2-14 shows the typical symbol used when there is a shared (cyclists and vehicles) facility within a roadway on the left, and delineated cycling facility on the right:

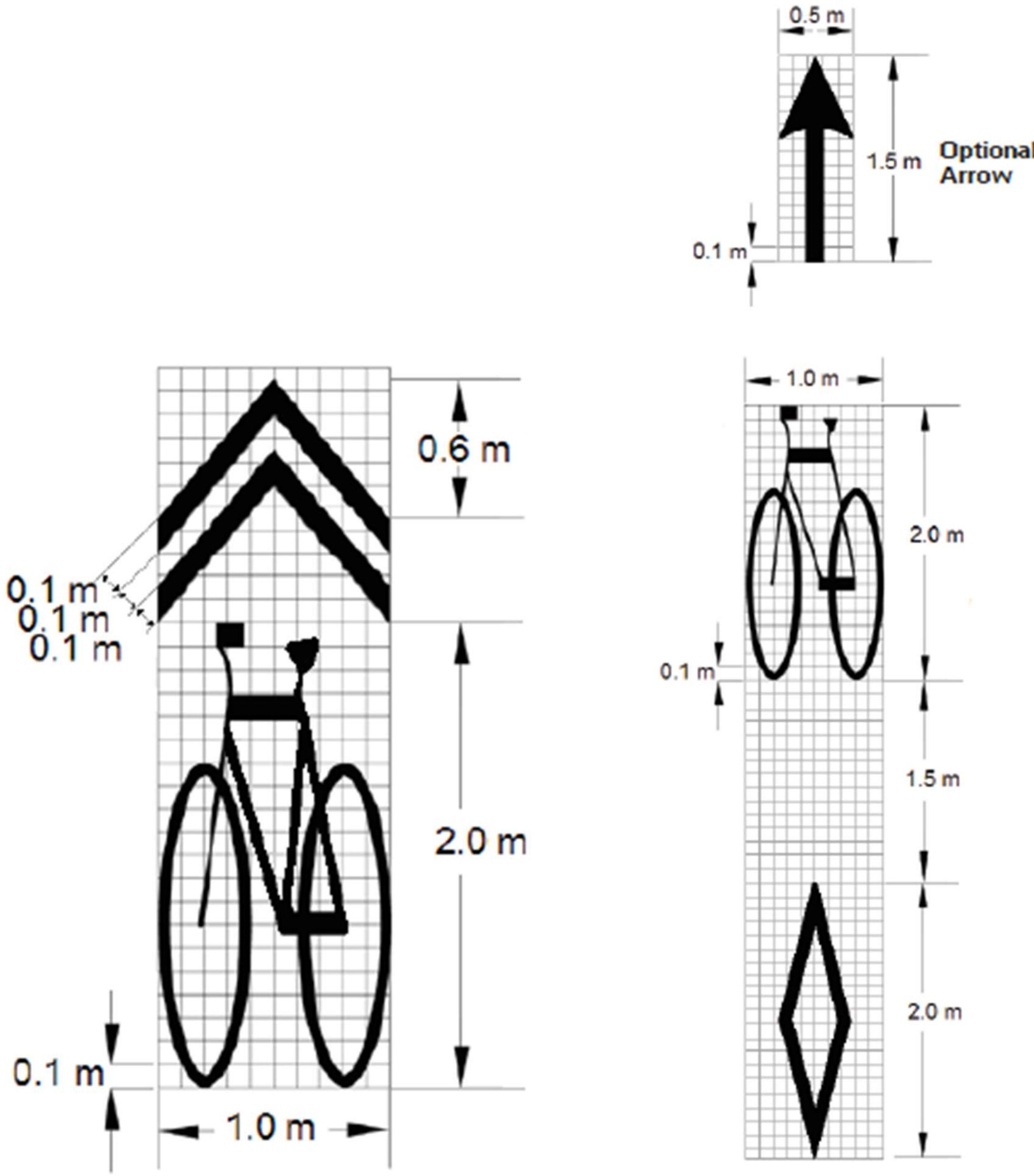


Figure 2-14 - Pavement Marking for Cycling Facilities (Ministry of Transportation, 2000)

Furthermore, for cycling facilities green surface treatments are recommended at points of conflict. Video studies have shown that use of surface treatments (varying colour by jurisdiction) have resulted in positive impacts with regard to motor vehicle awareness and response to cyclist traffic. Where pedestrians and cyclists are allowed to share a cross walk, it shall be delineated as shown in Figure 2-15:

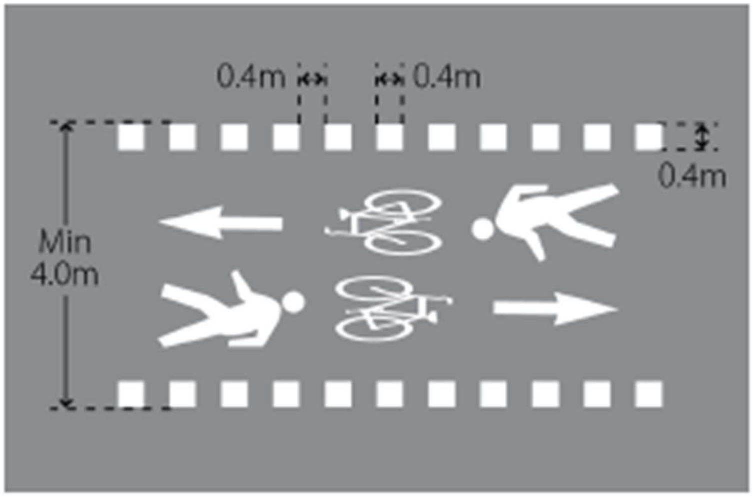


Figure 2-15 - Pavement Markings for a Shared Crosswalk (Ministry of Transportation, 2000)

Signage/Traffic Control

The use of traffic control devices is to convey a clear message to the road user whether it be driver, cyclist or pedestrian (Schroeder, 2010). They must fulfill a need, command attention, convey clear/simple message, command the respect of road users and give adequate time for response. The following traffic control devices are of particular concern to cyclists and pedestrians. They can be found in The Ontario Traffic Manual (Book 5):

Pedestrian Push Button Sign

Ra-13	45 cm x 60 cm
Font	N/A
Colour	Legend – Black Background – White Reflective

Figure 2-16 - Pedestrian Push Button Sign (Ministry of Transportation, 2000)

Figure 2-16 illustrates the ‘Pedestrian Push Button Sign’. This sign is used to communicate the proper action for a pedestrian at an intersection.

Communication Signs

Figure 2-17 - Pedestrian and Cyclist Communication Signage (Ministry of Transportation, 2013)

Figure 2-17 shows two signs used for communication:

The upper sign is used for communication with cyclists so that they are aware of proper stopping location should it differ from the stop bar for motor vehicles.

The lower sign is used when cyclists and pedestrians have parallel running intersection crossings and can therefore be guided by the same signal.

Bike Lane Sign

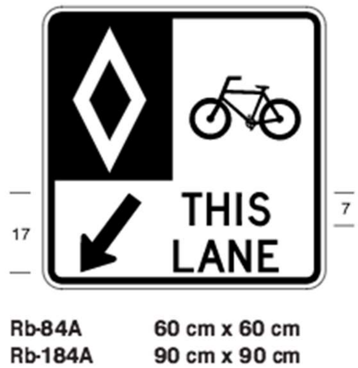


Figure 2-18 - Cycle Lane Sign (Ministry of Transportation, 2000)

Figure 2-18 illustrates a 'Bike lane Sign'. It is used to denote a specified bike lane. This can be used for a buffer separated facility or a bike path painted in line with lanes.

Standard Bicycle Signal Head

Figure 2-19 - Bicycle Signal Head (Ministry of Transportation, 2013)

Figure 2-19 shows a bicycle signal head, these signals are currently pending approval, however, upon approval, could be used to direct flow of cyclists, such as advanced greens. Dutch junction style intersections have in some cases, used similar interfaces overseas to allow a circular movement for cyclists prior to any motor vehicle flow. See case study on protected intersections for timing uses.

Pedestrian Crossing Signal

Figure 2-20 - Pedestrian Crossing Signal
(Ministry of Transportation, 2010)

Figure 2-20 illustrates pedestrian signals can vary slightly from what is depicted. The use is to provide pedestrians sufficient permitted time to cross the roadway.

2.6.2 Boulevard

Arterial road boulevards shall be a minimum of 4.8m in width in accordance with Figure 2-21 and the Thunder Bay – Urban Design Guidelines (2012). The following boulevard characteristics are detailed proceeding section.

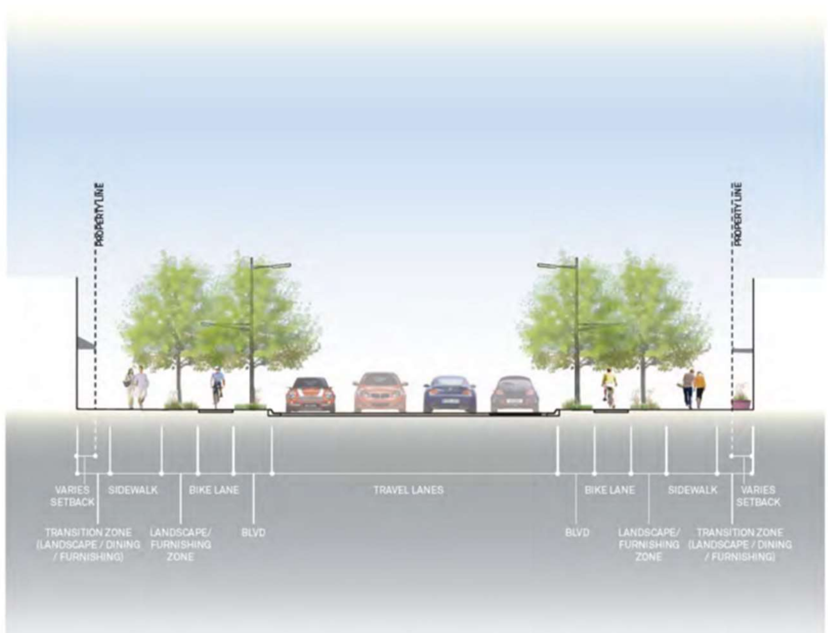


Figure 2-21 - Arterial Road Sample Cross Section (City of Thunder Bay, 2012)

2.6.2.1Greenspace

Based on the Thunder Bay – Urban Design Guidelines new off-road (separated) dedicated cycling lanes on an arterial road shall be separated by a 1.5m landscaped strip incorporating street trees. A 1.8m planting strip shall be implemented between the cycling lane and the adjacent sidewalk, where possible.

Silviculture

The practice of silviculture is the implementation, growth and maintenance of trees. When utilized within the boulevard, it shall be in accordance with the Urban Forest Management Plan – City of Thunder Bay, Ontario, December 2011 edition, to ensure the growth, composition, health and quality of the greenspace. The Following sub-sections will illustrate different silviculture practices.

Planter Boxes

A planter box is a raised rectangular shaped concrete landscape structure designated for trees and/or desired plant features. Planter boxes can be found within medians or in boulevards, typically in the general area of a cities' downtown core. The reason for the gaining popularity of trees in the downtown/urban areas is because, studies, one of which was completed by the University of Washington, have shown that trees increase property value as well as provide a higher sense of safety, which increases pedestrian and cyclist traffic (ReForest London, 2010).

To implement a planter box, the boulevard or median must have sufficient width otherwise the more viable option is a tree pit with grate. Planter boxes typically have drainage tile connecting to the storm sewer and a specific blend of topsoil requirement depending on jurisdiction. Figure 2-22 was taken from the city of London to illustrate the typical cross-section of a raised planter box.

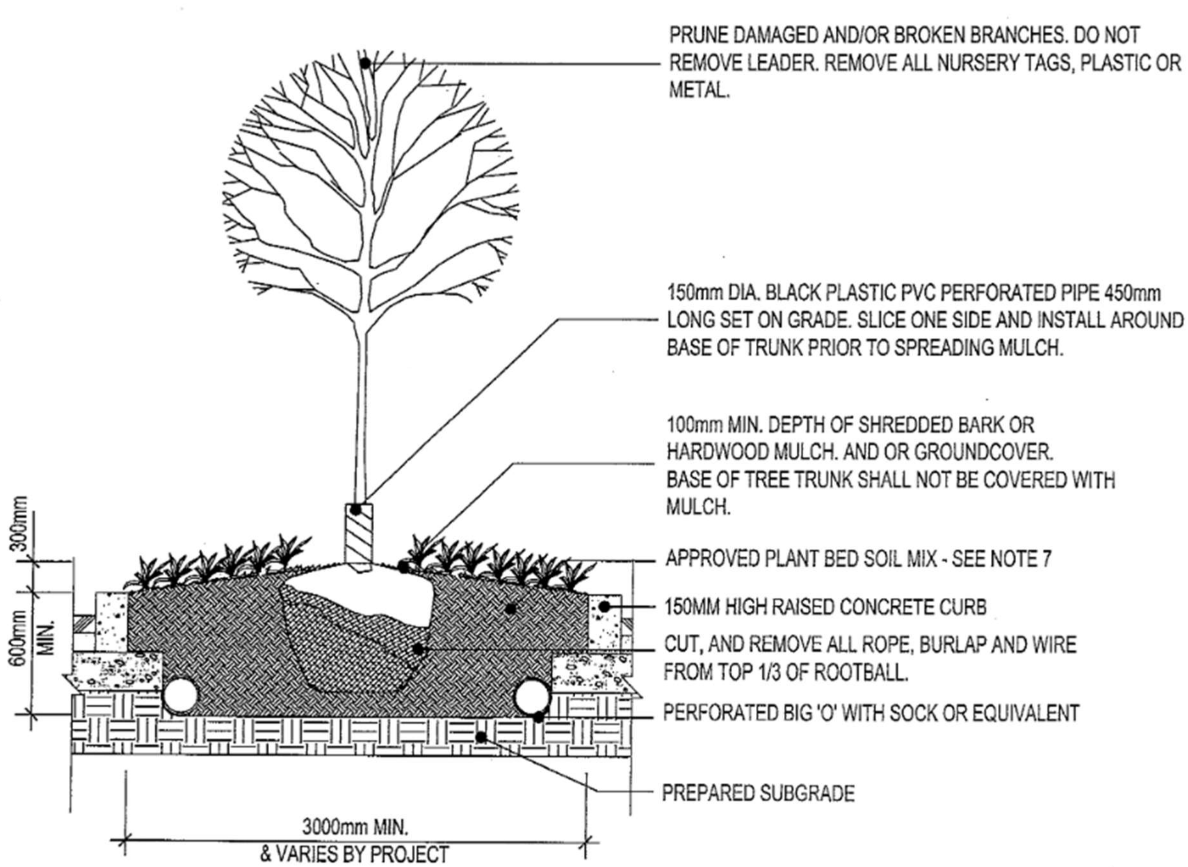


Figure 2-22 - Planter Box Detail (City of London, 2016)

Street Trees

The incorporation of street trees will enhance the greenspace by:

- Reducing Stormwater Runoff
- Energy Consumption Savings; such as climate change, shading and wind reduction
- Aesthetic Value
- Air Quality Improvements
- Carbon Dioxide Reduction (City of Thunder - Urban Forest Management Plan, 2011)

Based on the City of Thunder Bay's Benefit-Cost analysis of the parameters listed above, the Urban Forest Management Plan states the average tree planted has a financial benefit of $85.00/year (City of Thunder - Urban Forest Management Plan, 2011).

The selection of street tree shall be a 60 mm caliper species (City of Thunder - Urban Forest Management Plan, 2011).

The typical street tree pit shall be roughly 1.16m x 2.02m in order to allow for tree growth and accommodate a tree pit grate (City of Thunder Bay Engineering Standards, 2015, DWG. No. M-104-5).

2.6.2.2 Additional Considerations

The remaining considerations will complete the required specifications for boulevard design.

Crossfall and Profile Grade

Crossfall from the back of curb extending to the property line or projected tie in point shall have a slope of 2% draining toward the curb. With the exception of driveways and sidewalk ramps, where the back of sidewalk and driveway lowered for city approved problem driveways to ensure 4% preferred or 6% maximum slope from the front to back of the sidewalk (City of Thunder Bay Engineering Standards, 2015, DWG. No. R-119).

The profile of all boulevard components will match the roadway. With the omission of sidewalk and bikeway ramps as shown in Figure 2-23 (Transportation Association of Canada, 1999).

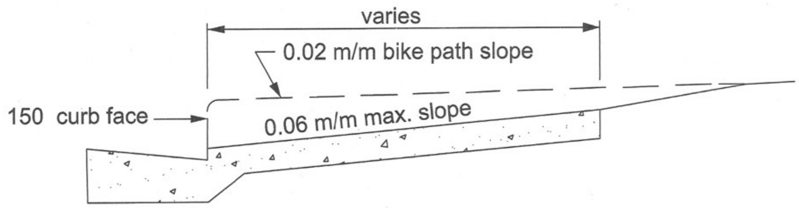


Figure 2-23 – Cross-Section view of Drainage to Curb (Transportation Association of Canada, 1999)

Cycle Track

The width of the cycle track (bike path) will be in accordance with Geometric Guide for Canadian Roads. For a one-way exclusive facility, the width shall be 1.5 m to 2.0 m, in order to give adequate room for bicycle operating space. Figure 2-24 shows additional rider requirements.

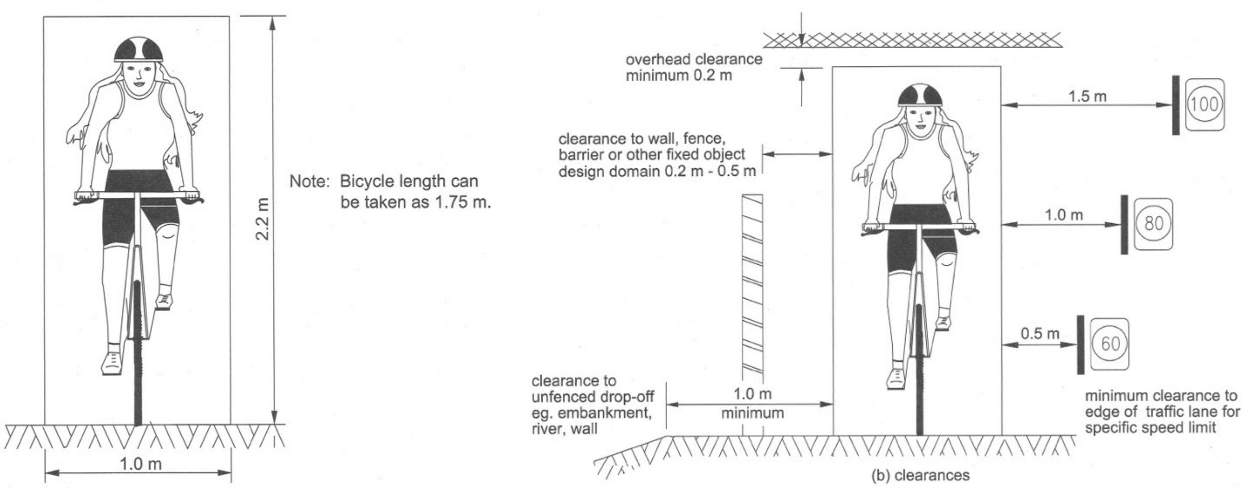


Figure 2-24 - Rider Operating Requirements (Transportation Association of Canada, 1999)

The cycle track is recommended to be 75 mm in depth, composed of asphalt, according to Ontario Provincial Specification Standards (OPSS) 311. Thickness of asphalt will vary depending on expected vehicular traffic crossing. At the most, the thickness shall match that of the adjacent roadway, which is typically 2-40 mm lifts of HL4 asphalt mix, underlined by a minimum of 300 mm composed of Granular ‘B’ for the base material. The depth of base material will typically increase at commercial driveways and where the sub-base material is determined to be unsuitable by the inspector or contract administrator (City of Thunder Bay Engineering Standards, 2015, DWG. No. R-119).

Sidewalk

The sidewalk specification will be in accordance with the City of Thunder Bay Engineering and Development Standards (2015). The sidewalks shall be configured with 30 MPA concrete with 7% (+/- 1.5%) air entrainment. The sidewalk shall be 1.5 m wide with a depth of 130 mm. Base material will be a minimum of 300 mm composed of Granular ‘B’, depth of base material will increase at commercial driveways and where the sub-base material is determined to be unsuitable by the inspector or contract administrator (City of Thunder Bay Engineering Standards, 2015, DWG. No. R-119).

Private Driveways and Entrances

Where private driveways and entrances are located the sidewalk and cycle track will be continuous with no change in crossfall (OPSD 351.010). Cycle track asphalt depth will be continuous across driveways and entrances in order to avoid cracking due to the change in underlying material properties. The sidewalk concrete depth will be increased to a minimum depth of 150 mm for residential driveways and a minimum depth of 200 mm for commercial and industrial driveways (OPSD 310.010). The depth of base material will increase where the sub-base material is determined to be unsuitable by the inspector or contract administrator (City of Thunder Bay Engineering Standards, 2015, DWG. No. R-119). Residential driveways shall be a minimum of 3.0m to a maximum of 6.0m wide (City of Thunder Bay Engineering Standards, 2015, DWG. No. R-125). Industrial and commercial driveways shall have a maximum width of 9.0m at the property line with a maximum of 12m at the road. The minimum radius for curbs shall be 1.5m, with curbs extending at an angle of 60° to 90° to the cycle track (City of Thunder Bay Engineering Standards, 2015, DWG. No. R-127).

Left Turn Restricted Entrance

Where private islands occur sidewalk and cycle track are to remain continuous across the private island with no change in crossfall (City of Thunder Bay Engineering Standards, 2015, DWG. No. R-130). The cross section parameters will be based on a private driveway.

2.6.3 Civil 3D Software

The geometric design software for this project is AutoCAD Civil 3D 2016. It is used in industry for preliminary topographic survey needs, geometric design purposes, and drawing production. It has many features that are used for design and drawing development depending on the quality of the survey and detail of the product required. Some features include alignment, profile, cross sections, cut/fill tool, external referencing and surface creation. Civil 3D does not have knowledge of the specific set of regulations to be followed. The project team should be familiar with design specifications as they apply to the goals of the project.

CHAPTER 3

Methodology

3 Methodology

In this chapter, a breakdown of the system of methods utilized to analyse the complete street will be detailed.

3.1 Site Selection

As previously stated, the Memorial Link is a 5 km proposed complete street section of road that runs from John Street to Miles Street along the Memorial Avenue-May Street corridor. An approximate 690m section along Memorial Avenue from Central Avenue to 13th Avenue was selected for the project. The section under consideration in Figure 3-1 represents some of the challenges associated with the full scope of the project. A few of the challenges within the selected section include:

- Horizontal Curve
- Numerous Driveways and Accesses
- 4 Intersections
- Private Islands
- Dedicated Right Turn Lane

Figure 3-1 - Memorial Avenue from 13th Avenue to Central Avenue

The selected section is used particularly as a means to commute to work, primarily by use of motor vehicles. The selected study area has several commercial buildings that increase the demand of traffic. The Central Avenue and Memorial intersection also happens to be one of the busiest intersections within the project corridor. This section will set out the preliminary steps as well as the sequential steps developed in order to establish the feasibility of a complete street and a preliminary design that serves a benefit to all users from both a safety, operational, geometric and accessibility stand point.

3.2 Field Observations

An onsite field investigation was conducted on November 15th, 2015 to obtain a visual representation of the proposed project. The proposed site was divided into three equal sections starting roughly 100m north of Central Avenue and ending roughly 100m south of 13th Avenue. Photographs were taken in a clockwise pattern starting on the northwest limit and ending on the northeast limit of each specific section. Interest was taken in the current condition of the asphalt, line paint, curb, sidewalk and drainage patterns. It was noted that most private businesses had their own drainage as displayed in Figure 3-2. The emphasis of the site investigation was to gather current information of the study area and to point out any discrepancies from the as constructed drawings. The photographs were required to be taken as soon as possible due to the increased chance of snowfall.

Figure 3-2 - Example of the Existing Private Drainage

3.3 As-Constructed and Survey Observations

The Memorial Link Group provided with as-constructed drawings on the Memorial Avenue study area from Central Avenue to 13th Avenue. These drawings were used to give a starting point to the modifications required in order to incorporate a cycling facility within the projected complete street design. The drawings, which date back to 1977, allowed recognition of an area of study where priority to road reconstruction will be considered.

Based on the drawing files received were determined dimensional parameters with respect to the complete street cross section. It was assumed that the road width was accurately represented throughout the project limits. It was noted that when the existing road was reconstructed the design implemented a storm sewer system that consisted of catchbasin maintenance holes with the mainline sewer running beneath the curb. Due to the lack of information provided regarding minor intersection improvements such as turn lane additions, the assumption that set sewer lines will remain under the existing curb was made. Design solutions will be touched on briefly with regard to existing sewer constraints.

3.4 Data Collection

The data acquired and used for the capacity performance for the road came mainly from three sources: Thunder Bay Police Services, Engineering and Operations department for the City of Thunder Bay and the Memorial Link Group. All the data collected were thoroughly analyzed and the relevant operational data were used for operational and safety analyses.

3.4.1 Collision Data

A request was made to Thunder Bay Police Services to retrieve collision records for the previous three years. Collision reports were obtained along Memorial Avenue, from Central Avenue to Harbour Expressway. With regard to the section of road under consideration, only collision data from Central Avenue to 13th Avenue were analyzed. Collision data were then divided into specific collision type categories relative to each intersection. The type of collision was then analyzed and alternatives to reduce the number of collisions at a particular intersection can be proposed.

3.4.2 Traffic Data

In order to achieve a capacity performance of the road under consideration, volume counts and signal timing data were collected.

3.4.2.1 Traffic Counting

The City of Thunder Bay - Engineering and Operations Division provided the most current traffic volume counts ranging from 2011 to 2015, as well as signal phasing times. Traffic counts contained data from Central Avenue to 13th Avenue with the exception of two streets. No data were available for 10th Avenue and the entrance off of Memorial Avenue to Walmart. At these two locations traffic counts had to be manually conducted using a Traffic Data Collector called TDC-12 developed by JAMAR technologies Incorporated which is depicted in Figure 3-3.

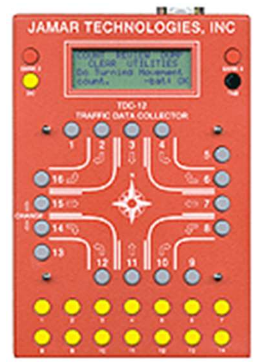


Figure 3-3 - Traffic Data Collector

3.4.2.2 Signal Phase Timing

Signal phase timing were obtained from the City of Thunder Bay – Engineering and operations Division. The signal phasing data were required at 3 intersections, which included Memorial Avenue at Central Avenue, 11th Avenue and 13th Avenue.

3.5 Design Options

The following typical cross-sections have been developed for further analysis. They have been established based on the applicable case studies, the current site constraints such as right-of-way condition being 30m, and/or City standards and specifications. They were developed with specific consideration, outlined in Chapter 2, for the 60% of cyclists that are classified as “interested but concerned” within urban areas (Ministry of Transportation, 2013).

Figure 3-4 – Consists of a curb/grade separated one-way cycle track, along with 5-lanes of traffic. Other features include:

- Greenspace/snow storage between back of curb and cycle track
- Greenspace/snow storage between cycle track and sidewalk
- A sidewalk

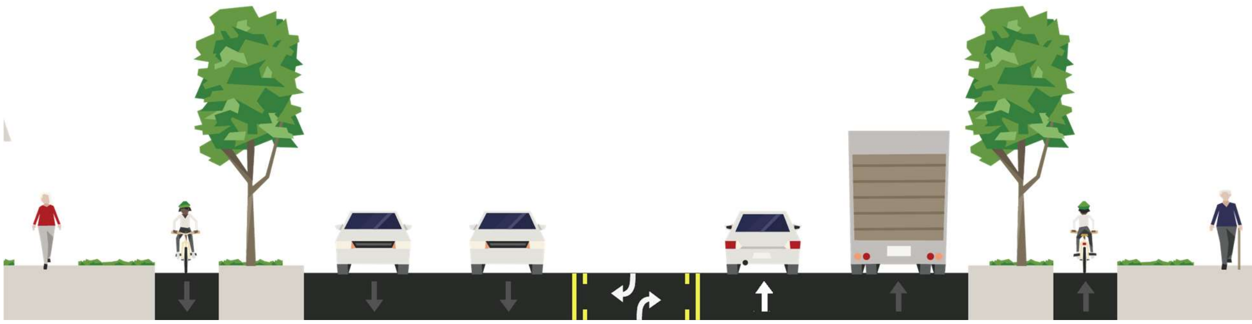


Figure 3-4 - Cross Section 1 with Off Grade One-way Cycle Track

Figure 3-5 – Consists of a median separated one-way cycle track, along with 5 lanes of traffic. Other features include:

- Greenspace/snow storage separated by curb on either side
- A depressed cycle track draining towards the median
- Greenspace between sidewalk and back of curb
- A sidewalk

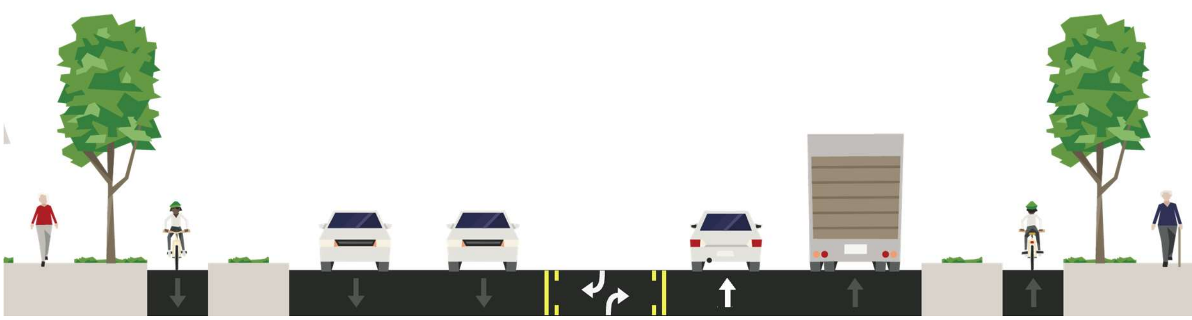


Figure 3-5 - Cross Section 2 with Media Separated One-way Cycle Track

Figure 3-6 – Consists of a removal curb with bollards placed within a buffer zone. This approach is current in Calgary, Alberta and will provide a one-way cycle track, along with 5 lanes of traffic. Other features include:

- Greenspace/snow storage between curb and sidewalk
- Removable curb is elevated in between ends to allow drainage

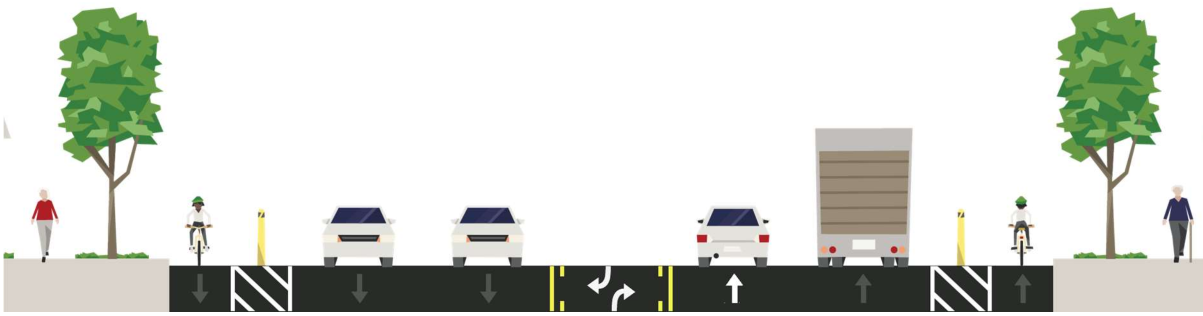


Figure 3-6 - Cross Section 3 with Bollard and Removable Curb Separated One-way Cycle Track

Figure 3-7 – Consists of a painted bike lane with no separation, along with 5 lanes of traffic. Other features include:

- Increased greenspace/snow storage
- A sidewalk

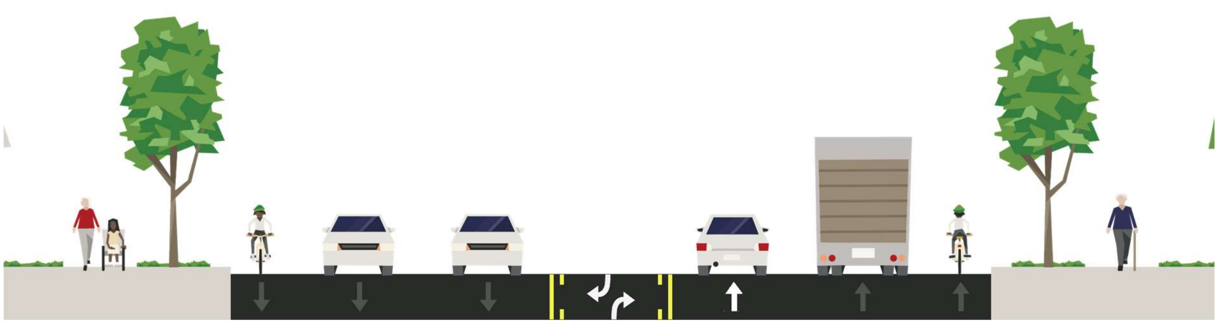


Figure 3-7 - Cross Section 4 Cycle Lane with no Separation

Further analysis is required in order to properly justify the cross-section to be used for Memorial Avenue. The following analysis have been considered for assessment of each cross-section.

3.6 Safety Analysis

The safety is the utmost important part of engineering analysis, as it justifies that a particular design will not increase the risk of danger severity and look to improve the overall safety of society as a whole. Safety analysis will be completed based on available collision data and the effects that the proposed changes are projected to have on the collision data. The following subsections will be developed systematically for each respective intersection.

3.6.1 Collision Trends

The collision data will be separated based on location and then trends will be developed based on the nature of the collision (i.e. left turn, rear end, side swipe, etc.). These trends will then be looked at to establish trends with respect to specific details including but not limited to; time of day, month of the year, weather, type of vehicle, condition of driver, road surface condition, pavement marking condition, direction and impact type. Table 3-1 shows an overview of collisions at intersections.

Table 3-1 - Collision Summary (Information obtained from Thunder Bay Police Services)

Intersection	**Month of the Year**												Total Number of Collisions Over A three Year Period
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
Central Avenue	-	-	1	-	-	-	-	1	1	1	-	-	4
10th Avenue	2	-	-	-	-	1	-	1	-	-	1	-	5
11th Avenue	3	1	3	1	1	1	1	4	1	-	-	5	21
12th Avenue	-	-	-	-	-	-	-	-	1	-	-	-	1
13th Avenue	6	2	-	1	-	1	-	-	-	-	3	5	18

The trends developed may reveal a need for improvements. These improvements will be considered and analyzed based on their projected effect on collisions. In order to analyze the possible improvements, crash reduction factors will be used. Typical modifications to existing conditions based on trends include adjustment to intersection signal timings, increased sight distance around curves, and increased storage lengths for turn lanes.

3.6.2 Crash Reduction Factors

The crash reduction factors are used for partial justification of implemented countermeasures. As mentioned in Chapter 2, the required improvements developed based on the collision data may result in the implementation of justifiable countermeasures that will have a positive impact on the number of collisions. Furthermore, one countermeasure may reduce the risk of a low-level collision and have an adverse effect on a high-level collision. Some factors include:

- Adjustment to signal timings at signalized intersections to reduce rear-end collisions (CRF = 17)
- Adjust from protected and permitted phases to strictly protected to reduce angular collisions (CRF = 99)
- Resurface pavement and improve super-elevation to reduce all curve related collisions (CRF = 26 when dry and 51 when wet)

Factors are also to be considered for all changes to the proposed roadway, including those that are not trend based in nature, such as operational changes based on simulation models.

3.6.3 Crash Cost and Economic Analysis

Upon assessment of countermeasures and the effects they have on safety, a crash cost model can be developed. One, two, or all of the following scenarios, listed below, for each intersection will be completed to provide an analysis for the respective scenario:

- A countermeasure decreases the risk of a severe collision and increases the risk of a less severe collision (i.e. rear end), a comparison of both the human capital costs and the direct costs will be completed to provide a quantitative value of the difference in cost of consequence.

- Where countermeasures decrease the risk and have no adverse effect on other forms of collision, the human capital costs and direct costs will be calculated for the collision being prevented and will be considered a cost benefit to society.
- Where accident trends are less severe and are already at an acceptable rate to society, a human capital cost and direct cost will be developed and justified.

Final justification for implementation of countermeasures will be the result of a benefit to cost analysis where applicable. Table 3-2 shows the costs incurred based on the severity of the collision:

Table 3-2 - Costs Associated with Collisions (values provided by the City of Thunder Bay)

Result of Collision	Cost Associated with Collision
Property Damage Only	$2,456
Injury	$8,123
Fatal	$1,234,321

3.7 Operational Analysis

The operational performance of the road works joined together with safety performance, to provide a more convenient driving experience to all users. The operational analysis for the roadway are modeled using Synchro Studio 9.0 and the selection of the cycle facility is justified based on the Decision Support Tool coupled with the Ottawa case study, outlined in Chapter 2.

3.7.1 Lane Reduction

Based on the limited space within the right-of-way to implement a complete street, there is a definite need for reduced lane widths. Within Synchro 9.0 the effects of a reduction in lane width will be modelled to determine the effect that reductions have on the following performance parameters:

- Level of service
- Volume to capacity ratio
- Delay times

Minimum lane width constraints shall be based on NACTO guidelines (2015) and research published by NACTO. It is also important to consider the safety analysis and see the impact that lane width reductions may have on the safety performance.

3.7.1.1 Bus Route Consideration

In addition to lane reductions, bus routes within the limits of the segment will be considered in order to allow for sufficient widths where buses are going to be in operation.

3.7.2 Sensitivity Analysis

Sensitivity analysis will be completed to ensure that the proposed lanes will meet future traffic demands, should changes in zoning cause for different breakdowns of vehicular traffic in the coming years. This will measure how sensitive the intersections are with respect to changes in heavy vehicle percentages and will once again be justified on the basis of the performance parameters set out previously.

3.7.3 Right-Turn Requirement

At the intersection of Central Avenue and Memorial Avenue, there is a northbound channelized right turn lane. It will assess whether there is a need for this turn lane and/or whether it can be reduced in storage length. Simulation will be developed using traffic counts given by the city and additional sub hourly counts completed. This simulation will include the commercial property on the east side of Memorial Avenue, which has a private access entrance, such to more accurately model the uses of the channelized lane. The measure of impact that the turn lane has at the Central Avenue intersection and the commercial entrance will be based on the performance parameter outputs of LOS, Delay and the v/c Ratio.

3.7.4 Optimization

Once all of the above operational characteristics have been considered, the simulation will be optimized to improve the intersection performances. This may result in adjustments to signal timings based on the semi-actuated setup that is currently in operation. The existing signal timings are as displayed in Table 3-3.

Table 3-3 - Existing Signal Timings

Existing Condition Signal Timing	**Central Avenue**										
	Time (sec)	EBL	EBT	WBL	WBT	NBL	NBT	NBR	SBL	SBT	SBR
	Minimum Initial	7.0	10.0	7.0	10.0	7.0	10.0	10.0	7.0	10.0	10.0
	Minimum Split	12.0	36.0	12.0	36.0	12.0	34.0	34.0	12.0	35.0	35.0
	Total Split	17.0	37.0	17.0	37.0	17.0	49.0	49.0	17.0	49.0	49.0
	Maximum Green	12.0	31.0	12.0	31.0	12.0	43.0	43.0	12.0	43.0	43.0
	11th Avenue										
	Time (sec)	EBL	EBT	WBL	WBT	WBR	NBL	NBT	SBL	SBT	
	Minimum Initial	10.0	10.0	7.0	10.0	10.0	10.0	10.0	5.0	10.0	
	Minimum Split	38.0	38.0	12.0	38.0	38.0	38.0	38.0	10.0	38.0	
	Total Split	39.0	39.0	15.0	39.0	39.0	51.0	51.0	15.0	51.0	
	Maximum Green	33.0	33.0	10.0	33.0	33.0	45.0	45.0	10.0	45.0	
	13th Avenue										
	Time (sec)	EBL	EBR	NBL	NBT	SBT					
	Minimum Initial	10.0	10.0	10.0	10.0	10.0					
	Minimum Split	36.0	36.0	31.0	31.0	31.0					
	Total Split	50.0	50.0	70.0	70.0	70.0					
	Maximum Green	44.0	44.0	64.0	64.0	64.0					

3.7.5 Cycling Facility

The decision support tool will be used in order to justify the type of cycling facility. If separation is recommended, it will also provide logical reasoning in deciding the form of separation (within step 2). The 3 step system to be followed can be found in Chapter 2 and is outlined by the following:

- Step 1: A pre-selection nomograph – used to guide the designer for an initial/expected facility type

- Step 2: A decision tree – used to answer questions in more detail, to confirm the compatibility of the pre-selected facility
- Step 3: A summarization process – to justify your thinking

3.7.5.1 Access and Cost Considerations

The next step to be considered for operation is only required should a separated cycling facility be implemented. It consists of an overlook of the entire site and uses engineering judgement to further justify the use of a particular separation method. It is a qualitative measure of effectiveness based on the number of accesses that allow vehicular crossing of the cycling facility as well as the cost of implementation and maintenance relative to other options.

3.7.6 Intersection Selection

There are two main options for intersections containing a cycling facility, the protected intersection and the queue box method. Do to the modeling limitations, Synchro is incapable of modeling how a cyclist will cross an intersection. The intersection treatments will be selected based on case studies. In depth justification and reasoning will be provided due to the lack of modeling and standard implementation processes.

3.8 Geometric Analysis

Upon completion of the operational and safety analysis, the physical constraints of the site will be considered and as a result the following possibilities will need to be looked into:

- Super Elevation
- Minimum Curve Radii
- Turning Movements
- Stopping Sight Distance (both straight and within curve)

3.9 Additional Considerations

Mention of additional specifications that will be followed and items that may not require specific analysis however will enhance the user experience will be mentioned as the preliminary design approaches some conclusive results.

CHAPTER 4

Data Analysis and Results

4 Data Analysis and Results

This section of the report will evaluate the four possible cross-sections described in the methodology and will systematically explain the processes involved in the preliminary design in order to establish a plan view drawing and proposed cross-section, that is suitable for the section of Memorial Avenue. It will also specify additional characteristics such as lane widths, intersection treatments, drainage, service/utility relocations, recommended construction practices and boulevard breakdowns.

4.1 Safety Analysis

Safety analysis will be conducted in an intersection specific fashion. The analysis will address measures that are standard with infrastructure renewal and measures that shall be modeled in order consider the effects they may have on operational characteristics of the roadway.

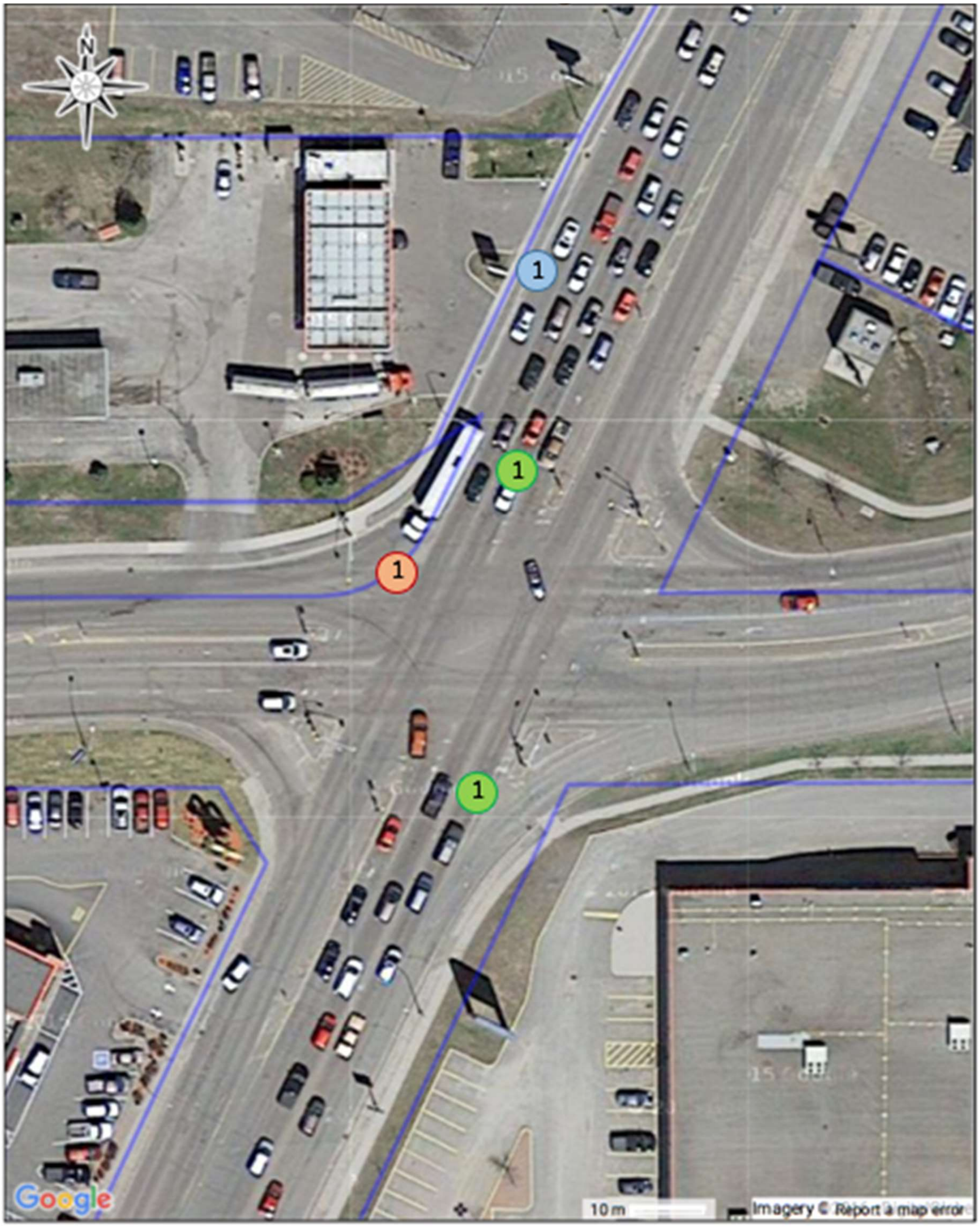
4.1.1 Collision Data Analysis

The process of safety analysis begins with assessment of collision data. Collision diagrams are developed to determine trends. Diagrams are shown in Figures 4-1 to 4-5, and they depict trends within reasonable proximity to the nodes. The following legend has been developed and is referenced throughout the collision diagrams. Collision diagrams are represented in Figures 4-1 to 4-5.

Legend

Note: Numbers written inside the symbols indicates the amount of collisions occurring within reasonable distance to the node, over a 3 year period.

- Denotes estimated location of side swipe collision
- Denotes estimated location of angular collision
- Denotes estimated location of collision with infrastructure
- Denotes estimated location of rear-end collision
- Denotes estimated location of collision with pedestrian or cyclist



Memorial Ave. & Central Ave.

Figure 4-1 - Collision Diagram (Memorial Ave. and Central Ave.)

Memorial Ave. & 10th Ave.

Figure 4-2 - Collision Diagram (Memorial Ave. and 10th Ave.)

Memorial Ave. & 11th Ave.

Figure 4-3 - Collision Diagram (Memorial Ave. and 11th Ave.)

Memorial Ave. & 12th Ave.

Figure 4-4 - Collision Diagram (Memorial Ave. and 12th Ave.)

Memorial Ave. & 13th Ave.

Figure 4-5 - Collision Diagram (Memorial Ave. and 13th Ave.)

4.1.2 Countermeasure Justification

For a complete list of collisions and the specific conditions associated with each, see Appendix C. The following is a breakdown of trends and how they relate to specific countermeasures, and recommended implementations. In addition to this, it should be mentioned that some clear observations were made, that collisions were more common under wet/winter conditions. Where collisions occurred but had little to no implications that a trend was developing, it will be considered an outlying situation for analyses purposes.

4.1.2.1 Central Avenue

As seen below in Table 4-1 the intersection is relatively safe, in the past 3 years there have been a total of four collisions.

Table 4-1 - Collision Summary for Memorial and Central Ave.

<table>
<tr><th colspan="6">Summary*of*Collision*Data</th></tr>
<tr><th colspan="2" rowspan="2">Central*Ave.</th><th colspan="4">Movement</th></tr>
<tr><th>SBT</th><th>SBR</th><th>NBL</th><th>NBT</th></tr>
<tr><td rowspan="3">Collision* Type</td><td>Side*Swipe</td><td>1</td><td></td><td></td><td>1</td></tr>
<tr><td>Infasructure</td><td></td><td>1</td><td></td><td></td></tr>
<tr><td>Angle</td><td></td><td colspan="2">1</td><td></td></tr>
</table>

Two of which were side swipe collisions in opposing directions. They are classified as ‘property damage only’ (PDO) collisions and are not considered a trend. However, countermeasures will be investigated to see if implementation may effect both approaches. Countermeasures for side swipe collisions that have no injuries or fatalities are as follows:

- Reduce Speed Limit – The crash reduction factor is -5
- Improve Pavement Markings – The crash reduction factor is 18 with standard error of 22 (U.S. Dept. of Trans. Fed. Highway Admin., 2008)

The overall performance of the roadway by reducing the speed limit will not be justified based on these collisions not appearing to be a reoccurring trend and the fact that according to the crash reduction factors it has a negative impact. In addition to this, at least one of the descriptions of the scenarios suggest that driver misjudgment was a factor.

Improved pavement markings will be completed regardless of safety implications due to the process of project reconstruction and thus will result in increased awareness of lane allowances and merge boundaries. Self-reporting collision records throughout the extents of the project often commented on the relatively poor condition of pavement markings. Thus, making the expected countermeasure reduction factor not fall below zero, a conservative value of 5 will be used for calculation purposes. Based on Equation 2-1, the anticipated total collisions and total benefit of the countermeasure are as follows:

$$Total\ Anticipated\ Accidents = (1 - CRF)\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Anticipated\ Accidents = (1 - 0.05)\ \times\ 2$$

$$Total\ Anticipated\ Accidents \cong 2$$

$$Total\ Benefit = CRF\ \times\ Collision\ Cost\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Benefit = 0.05\ \times\ 2456\ \times\ 2$$

$$Total\ Benefit = \$245.60$$

Since pavement marking replacement is a standard process in the reconstruction process, this serves no additional cost. Therefore, there is no additional cost to the implementation and will be recommended by way of standard practice.

4.1.2.2 10th Avenue

As seen below in Table 4-2, the primary type of collision occurring in this section is the northbound rear end.

Table 4-2 - Collision Summary for Memorial and 10th Ave.

Summary*of*Collision*Data					
10th*Ave.		Movement			
		SBT	EBL	SBL	NBT
Collision Type	Side*Swipe			1	
	Rear*End				3
	Angle		1		
	Pedestrian	1			

The rear end collisions are property damage only and typically occurred in the winter months. Below are countermeasures for a rear end collision with property damage only at an un-signalized intersection:

- Option 1 – Install pavement condition warning signage (slippery when wet) – The crash reduction factor is 5 for all conditions and 20 for wet conditions
- Option 2 – Improve pavement friction – The crash reduction factor is 13 (U.S. Dept. of Trans. Fed. Highway Admin., 2008)

These counter measures will be assessed below using Equation 2-1 and 2-2:

Option 1 – Signage:

$$Total\ Anticipated\ Accidents = (1 - CRF)\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Anticipate\quad Accidents = (1 - 0.05)\ \times\ 3$$

$$Total\ Anticipated\ Accidents \cong 3$$

$$Total\ Benefit = CRF\ \times\ Collision\ Cost\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Benefit = 0.05\ \times\ 2456\ \times\ 3$$

$$Total\ Benefit = \$368.40$$

$$Benefit\ to\ Cost\ ratio = \frac{Total\ Benefit}{Cost}$$

Where the total cost based on other signage costs is estimated to be $100,

$$Benefit\ to\ Cost\ ratio = \frac{368.40}{100.00} = 3.68$$

Over the course of 3 years, the total benefit of the sign is a savings of $368.40 and the benefit to cost ratio is well above 1 meaning that it will serve a benefit to society over 3 years. It will have an increased benefit for every additional year of use.

Option 2 - Improve Pavement Friction using Equation 2-1 and 2-2:

$$Total\ Anticipated\ Accidents = (1 - CRF)\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Anticipated\ Accidents = (1 - 0.13)\ \times\ 3$$

$$Total\ Anticipated\ Accidents\ = 2.61 \cong 3$$

$$Total\ Benefit = CRF\ \times\ Collision\ Cost\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Benefit = 0.13\ \times\ 2456\ \times\ 3$$

$$Total\ Benefit = \$957.84$$

$$Benefit\ to\ Cost\ ratio = \frac{Total\ Benefit}{Cost}$$

Where the total cost of implementation is the cost to add surface texture to asphalt. The cost is expected to be well beyond the $368.40 that would serve as benefit to the intersection. Therefore, the benefit to cost ratio will not be calculated as it will be well below 1.

Based on the analysis located at the 10th Avenue intersection, the implementation of pavement condition signage is recommended as a countermeasure for the trending rear end accidents.

4.1.2.3 11th Avenue

This intersection proved to have a variety of issues as shown on the Table 4-3. This intersection is within a horizontal curve, which is believed to be a major factor.

Table 4-3 - Collision Summary for Memorial and 11th Ave.

<table>
<tr><th colspan="8">Summary of Collision Data</th></tr>
<tr><th colspan="2" rowspan="2">11th Ave.</th><th colspan="6">Movement</th></tr>
<tr><th>SBT</th><th>SBL</th><th>NBT</th><th>EBL</th><th>SBT</th><th>EBR</th></tr>
<tr><td rowspan="3">Collision-Type</td><td>Rear End</td><td>4</td><td></td><td>8</td><td></td><td></td><td></td></tr>
<tr><td>Angle</td><td></td><td colspan="2">4</td><td colspan="3">2</td></tr>
<tr><td>Infastructure</td><td>1</td><td></td><td>2</td><td></td><td></td><td></td></tr>
</table>

Trends included angular, rear end, and infrastructure related collisions. The ideal countermeasure would be to move the intersection out of the horizontal curve, however this is not realistic. As a result, countermeasures should be implemented to address both the rear end and the infrastructure (Property Damage Only) while separate countermeasures address the angular collisions (Injury related). Countermeasures for signalized intersections are as follows:

- Angular - Adjust protected and permitted phases to strictly protected - Crash reduction factor is 99
- Rear Ends and Infrastructure - resurface pavement and improve super-elevation - Crash reduction factor is 26 and 51 when wet (U.S. Dept. of Trans. Fed. Highway Admin., 2008)

The countermeasures are assessed below using Equation 2-1 and 2-2:

Angular:

(Based on most angular cashes causing injury to persons)

$$Total\ Anticipated\ Accidents = (1 - CRF)\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Anticipated\ Accidents = (1 - 0.99)\ \times\ 4$$

$$Total\ Anticipated\ Accidents\ = 0.04 \cong 0$$

$$Total\ Benefit = CRF\ \times\ Collision\ Cost\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Benefit = 0.99\ \times\ 8123\ \times\ 4$$

$$Total\ Benefit = \$32{,}167.08$$

$$Benefit\ to\ Cost\ ratio = \frac{Total\ Benefit}{Cost}$$

Where the total cost is strictly based on adjustment to the existing signal, which is essentially zero since the signal already provides a permitted and protected phase. As well as the cost associated with additional signage to communicate the change in operation to the driver. This sign would be roughly $100.

$$Benefit\ to\ Cost\ ratio = \frac{32167.08}{100.00} = 322$$

Based on this, the safety benefit is clear. However, it should be modelled to see the operational effect of changing the signal types.

Rear Ends and Infrastructure Related Collisions, calculated based on Equation 2-1 and 2-2:

$$Total\ Anticipated\ Accidents = (1 - CRF)\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Anticipated\ Accidents = (1 - 0.26)\ \times\ 15$$

$$Total\ Anticipated\ Accidents\ = 11.1 \cong 11$$

$$Total\ Benefit = CRF\ \times\ Collision\ Cost\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Benefit = 0.26\ \times\ 2456\ \times\ 4$$

$$Total\ Benefit = \$2554.24$$

$$Benefit\ to\ Cost\ ratio = \frac{Tota\ \ Benefit}{Cost}$$

Where the implementation is required regardless of safety analysis in order to meet current geometric design standards and thus poses no additional cost to the project. Therefore, the implementation will be made and serve two purposes.

4.1.2.4 12th Avenue

This intersection proved to have no real trends. It acts more like a driveway then a roadway and thus has less activity. The one accident occurred just south of the intersection as a result of a turn movement to cross lanes from a private driveway.

4.1.2.5 13th Avenue

The trends developed for 13th Avenue show that rear ends are a major concern particularly in the southbound direction, as shown in Table 4-4.

Table 4-4 - Collision Summary for Memorial and 13th Ave.

Summary of Collision Data						
13th Ave.		Movement				
		SBT	EBL	EBR	SBL	NBT
Collision Type	Rear End	12				3
	Angle	1				
	Pedestrian	1		1		1

Pedestrian and cyclist conflicts were not a trend however, enhanced pavement markings at crosswalks and a designated cycle facility should reduce these. The countermeasures for rear end collisions at signalized intersections with property damage only are as follows:

- Option 1 - Adjust signal timing (yellow or all red phases) - Crash reduction factor is 17 for rear end related collisions
- Option 2 - Install pavement condition warning signage (slippery when wet) The crash reduction factor is 5 for all conditions and 20 for wet condition
- Option 3 - Improve pavement friction - The crash reduction factor is 13 (U.S. Dept. of Trans. Fed. Highway Admin., 2008)

The countermeasures are assessed below using Equation 2-1 and 2-2:

Option 1 - Adjust Signal Timing:

$$Total\ Anticipated\ Accidents = (1 - 0.17)\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Anticipated\ Accidents = (1 - .17)\ \times\ 15$$

$$Total\ Anticipated\ Accidents\ = 12.45 \cong 13$$

$$Total\ Benefit = CRF\ \times\ Collision\ Cost\ \times\ Current\ Number\ of\ Collision\ Type$$

$$Total\ Benefit = 0.17\ \times\ 2456\ \times\ 15$$

$$Total\ Benefit = \$6262.80$$

$$Benefit\ to\ Cost\ ratio = \frac{Total\ Benefit}{Cost}$$

Since the adjustment to signal timing is strictly based on a one time operator change, the total cost associated with set changes is essentially zero. Therefore, there is significant benefit for very minimal cost, indicating that implementation is justified by economic analysis, however, calculations must be performed to confirm the validity. In the city of Thunder Bay all red time is standard at all intersection at 2 seconds, and will not be adjusted. Below is a calculation for the yellow time which is currently 4 seconds. The calculation is in imperial so changes to speed are required 60 km/h is the same as 37.28 mph.

$$y = 1 + \frac{1.47S_{85}}{2a + (64.4 \times 0.01G)}$$

Where,

S_{85} = 37.28 + 5 = 42.28 mph

a = 10 ft/s^2 based on The Institute of Transportation Engineers (ITE)

G = 0 (Conservative value)

$$y = 1 + \frac{1.47(42.28)}{2(10) + (64.4 \times 0.01(0))}$$

$$y = 4.11\,\mathrm{sec} = use\ 4.5\ seconds$$

Based on the calculation and the knowledge that most of the collisions occur in winter months, additional timing to the yellow light should be added for safety implications. The time should be adjusted to 4.5 seconds to give an extra half second during winter months for drivers to react. This will be confirmed with respect to operational analysis later on.

Options 2 and 3 have previously been calculated and based on additional collisions occurring, the total benefit will increase, therefore it should be mentioned that a pavement condition sign be installed in addition the timing change to further inform the drivers. As well, the improved surface friction will be limited to the natural improvements associated with replacement of existing asphalt. Improved pavement friction without specifying modifications to mix design are considered temporary in nature and will therefore not be considered as a long term benefit.

4.1.3 Summary of Safety Analysis

Based on the above analysis and practical applications countermeasures can be broken down into 'to be implemented' and 'to be confirmed by operational analyses. The countermeasures to be implemented are as follows:

- Install pavement condition warning signage (slippery when wet) for north and southbound traffic at 10th Avenue.
- Resurface pavement and improve super-elevation within horizontal curve, including 11th Avenue
- Improve pavement markings throughout (in particular side swipe locations at Central Avenue)

The countermeasures to be confirmed by operational analysis are as follows:

- Adjust yellow signal timing at 13th Avenue to 4.5 seconds
- Adjust protected and permitted phases for southbound left turn to strictly protected at 11th Avenue, timing to be set based on operational analysis

4.2 Operational Analysis

The following subsections will cover all operational considerations such as additional field counts, simulation development, simulation results and additional analysis for cycling facility selection.

4.2.1 Field Counts

The field counts taken were over one 15-minute interval around peak afternoon time of 4 pm. The time interval does not coincide with the exact peak hour traffic counts provided by city staff. Adjustments are made below to both the Walmart entrance and the 10th Avenue intersection in order to make the 1 hour interval constant.

Step 1 - Count traffic

Figure 4-6 illustrates the current condition for Memorial Avenue and Walmart from 4:45 pm to 5:00 pm. Figure 4-7 depicts the traffic count data obtained in the field for the intersection at 10th and Memorial Avenue from 4:15 pm to 4:30 pm; See Appendix D (Operational Analysis), for complete traffic count forms.

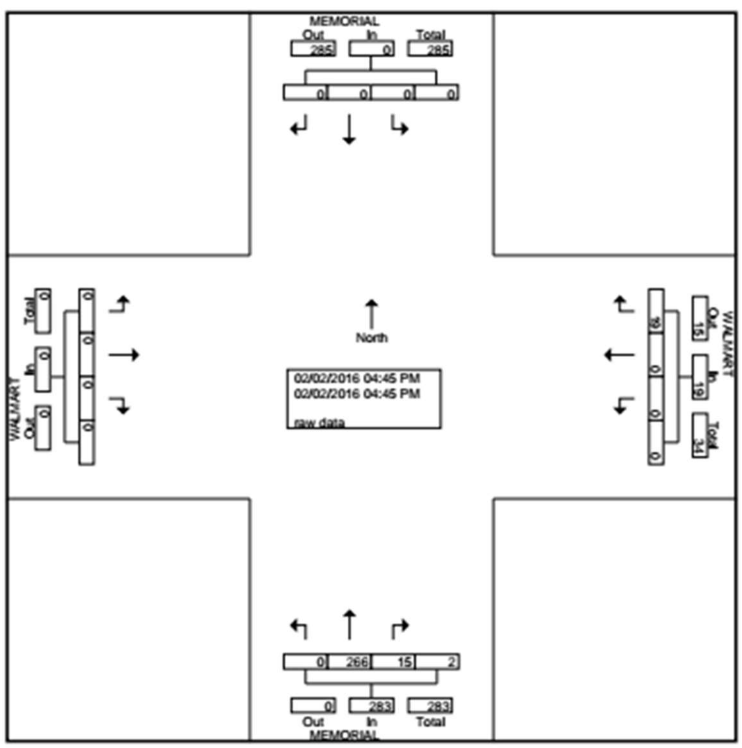


Figure 4-6 - Memorial Ave. and Walmart Raw Traffic Data

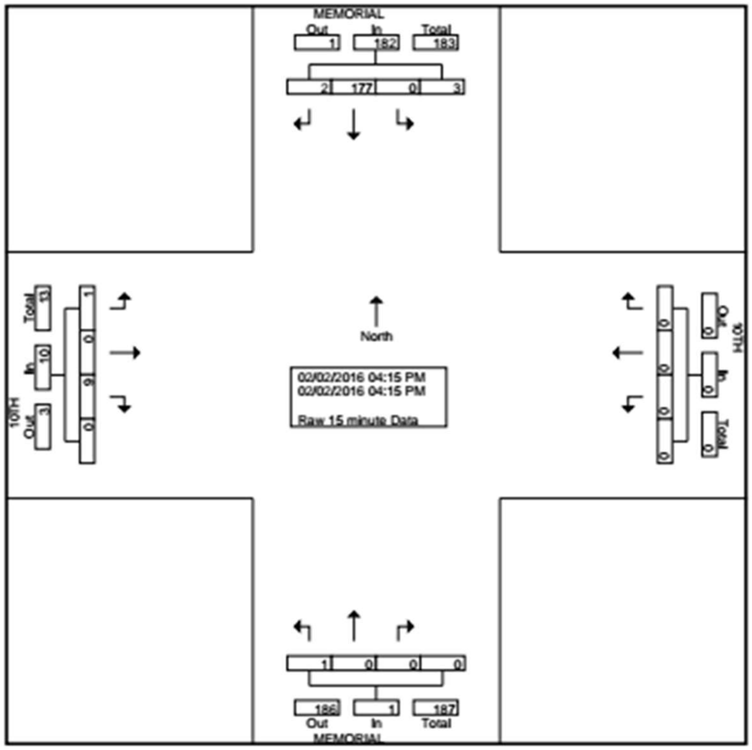


Figure 4-7 - Memorial Ave. and 10th Ave. Raw Traffic Data

Step 2 - Develop boundary conditions from data provided for afternoon peak hour for each section and create multiplier factors.

Note: All counted data are multiplied by 4 to convert to 1-hour interval

Walmart Entrance

All Vehicle Entering Northbound Intersection at Central = 982

From count at Walmart Northbound Straight = 1064

Multiplier factor

$$MF = \left(\frac{NB\ Central}{NB\ Walmart}\right)$$

10th Avenue

All Vehicle Entering Southbound Intersection at 11th Avenue = 841

From count at 10th Avenue Southbound Straight = 708

Multiplier factor

$$MF = \left(\frac{SB\ 11th\ Ave.}{SB\ 10th\ Ave.}\right)$$

$$MF = \left(\frac{982}{1064}\right)$$

$$MF = 0.923$$

$$MF = \left(\frac{841}{708}\right)$$

$$MF = 1.188$$

Step 3 - Calculate factored turn values for field counts

$$Turn\ Direction\ Volume = Field\ Count\ \times\ MF$$

Note: All field data are multiplied by 4 to convert to 1-hour interval

Walmart Entrance

$$NB\ Right = 60\ \times\ 0.923 \cong 54$$

$$WB\ Right = 76\ \times\ 0.923 \cong 71$$

$$NB\ Th = 982$$

$$Pedestrian = 8\ \times\ 0.923 \cong 8$$

10th Avenue

$$EB\ Right = 36\ \times\ 1.188 \cong 43$$

$$EB\ Left = 4\ \times\ 1.188 \cong 5$$

$$SB\ Right = 8\ \times\ 1.188\ \cong 10$$

$$NB\ Left = 4\ \times\ 1.188 \cong 5$$

$$SB\ Th = 841$$

$$Pedestrian = 12\ \times\ 1.188 \cong 15$$

The factored counts will be used for all operational purposes.

4.2.2 Simulation Comparison

The City of Thunder Bay specifies that design hours for a roadway that is considered a major retail roadway shall be taken as weekday PM peak hours and weekend peak hours. Due to limited data available only weekday PM peak hours could be completed within the time constraints of the project. Using these data, a thorough comparison of the existing road conditions and proposed conditions were completed in Synchro. In order to complete the comparison a model was created in the software and parameters were inputted. A plan view image of Central Avenue to 13th Avenue from Bing maps was placed into Synchro (Appendix D). Using icons and tools within the software an animated model was created which consisted of links and nodes representing stretches of road and intersections. With this given data, lane configurations and lane volumes were implemented using data collected previously. Given the signal phase diagrams it was established that intersections have a control type of actuated uncoordinated. Table 4-5 shows a breakdown of the phases for turning movements.

Table 4-5 - Existing Turning Movement Phases

	EBL	WBL	WBR	NBL	NBR	SBL	SBR
Control Type Central Ave	Perm+Prot	Perm+Prot	Permitted	Perm+Prot	Permitted	Perm+Prot	Permitted
Control Type 11th Ave	Permitted	Perm+Prot	Permitted	Permitted	N/A	Perm+Prot	N/A
Control Type 13th Ave	Permitted	Permitted	Permitted	Permitted	N/A	Permitted	Permitted

From as-constructed drawings lane widths of the existing road were gathered and also implemented. Signal phasing data were then inputted next, with times for initial green, initial split, yellow and all red. Combining all of this information into the input parameters of Synchro a detailed existing conditions were created. Furthermore, in order to complete data analysis, several comparisons were done with respect to current conditions.

4.2.2.1 Lane Reductions

In order to add a separated bicycle facility on Memorial Avenue lane reductions on the road must be considered. Shown in Appendix D the current existing lane width from Central to 13th Avenue is 3.7m. The proposed section incorporates a lane width of 3.0m for through and left turn lanes and 3.3m for a bus route lane. Currently there are three bus routes that travel through the Memorial Avenue - May Corridor which are:

- 3M - Memorial to Waterfront - 15 minutes between mid-day stops (weekdays and Saturdays)
- 8 - James to Intercity/College - 30 minutes between mid-day stops (weekdays and Saturdays)

- 9 - Junot to Intercity - 30 minutes between mid-day stops (weekdays and Saturdays)

Since these bus routes run the entire length of Memorial Avenue, the 3.3m lane is to give the bus operator additional comfort. Due to Synchro limitations all lane widths are required to be held constant across the entire roadway, so a lane width of 3.0m was inputted. Although no simulation was complete for 3.3m bus lanes, data analysis shows virtually no decrease in Level of Service from 3.7m widths to 3.0m. With this information it was assumed that a 3.3m bus lane would be adequate. The NACTO guidelines (2015) recommends not to go below 3.0m, for more details on the NACTO findings see Chapter 2. Table 4-6 shows the signalized intersection comparisons for different lane widths.

Table 4-6 - Effects of Lane Width Reductions

Signalized Intersection	Existing Condition 3.7 meters			Proposed Condition 3.0 Meters			Worst Case 2.8 Meters		
	LOS	v/c	Delay	LOS	v/c	Delay	LOS	v/c	Delay
Central	D	1.04	35.9	D	1.04	36.7	D	1.04	36.9
11th	C	0.69	22.5	C	0.74	23.6	C	0.76	24.0
13th	A	0.41	5.0	A	0.44	5.3	A	0.45	5.4

A worst case scenario was completed with a minimum lane width of 2.8m. As can be seen in the table above, the Level of Service still remains unchanged but according to the study completed by Sprinkle Consulting, referenced in Chapter 2, negative effects arise at lane widths less than 3.0m. It was found that the existing condition of the road is already at capacity and that reducing the lanes down to 3.0 m had no effect on the Volume to Capacity ratio and very little change to the Total Delay. Based on the analysis of outputted data from Synchro the reduction of lanes has no effect on the Level of Service, however improvements are still necessary to stabilize traffic flow.

4.2.2.2 Heavy Vehicle Sensitivity Analysis

A comparison was done using Synchro with different percentages of heavy vehicle traffic. Calculations were completed to find the current Heavy Vehicle Percentages of the existing road, the result can be seen in Table 4-7. In order to have a better understanding of how the flow of traffic would change, the percentages used are: 5%, 10%, 15%, 20% and 30%. Table 4-8 below shows the comparison of results.

Table 4-7 - Existing Heavy Vehicle Percentages

Signalized Intersection	Existing Heavy Vehicle Pecentages (Values in %)											
	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Central	0.0	3.0	4.0	1.0	3.0	2.0	2.0	2.0	3.0	1.0	2.0	3.0
11th	2.0	2.0	5.0	3.0	0.0	2.0	6.0	2.0	1.0	2.0	2.0	6.0
13th	0.0	-	0.0	-	-	-	3.0	2.0	-	-	2.0	0.0

Table 4-8 - Heavy Vehicle Sensitivity Comparison

Signalized Intersection	3.0m with Current HVP			3.0m Width and HVP 5%			3.0m Width and HVP 10%			3.0m Width and HVP 15%		
	LOS	v/c	Delay	LOS	v/c	Delay	LOS	v/c	Delay	LOS	v/c	Delay
Central	D	1.04	36.7	D	0.98	38.1	D	1.12	41.4	D	1.16	43.9
11th	C	0.74	23.6	C	0.77	24.3	C	0.81	25.8	C	0.85	27.6
13th	A	0.44	5.3	A	0.45	5.4	A	0.52	7.2	A	0.5	5.9

As can be seen in the table, for the signalized intersections there is no change in the Level of Service provided. The Delay Time is greater with every increase in percentage for heavy vehicle traffic which makes sense since larger vehicles require more time to maneuver in urban areas. For the comparison of Volume-to-Capacity ratios the current Heavy Vehicle Percentage along with the proposed 3.0m lane width has reached its maximum capacity and produces unstable flow, it seems to drop as flow increases to a uniform 5% heavy vehicle, this may mean that timings were initially established with set estimation of 5%. As the Heavy Vehicle Percentages become 10% or greater there are noticeable increases in the Volume-to-Capacity ratio and the Total Delay. Given the location of the study area, the Heavy Vehicle Percentage should not have a heavy vehicle sensitivity of greater than 10%. Although it is not anticipated, should heavy vehicle traffic increase dramatically a new simulation should be run to adjust signal timings accordingly.

4.2.2.3 Right-Turn Lane

A right-turn assessment was completed on Memorial Avenue northbound right onto Central Avenue to see if additional width could be added to the boulevard, by removing the right-turn lane. In order to see if the right-turn lane could be removed a comparison was done in Synchro between the implementation of a right-turn lane versus no right-turn lane. As seen in Table 4-9, the results of the comparisons showed that there is virtually no change in the Level of Service or Volume-to-Capacity ratio for the through movement, however when the right-turn movement is removed the vehicles in the right-turn lane are significantly affected by the through movement vehicles, causing a decrease in LOS and an increase in v/c Ratio and Delay, outlined in Table 4-9. Due to the simulation run the values given justify a need for a northbound right-turn lane at Central Avenue to be present.

Table 4-9 - Northbound Right-Turn at Central Avenue Investigations

Signalized Intersection	3.0 Meters - Separate Right-Turn						3.0 Meters - No Right-Turn		
	NBT			NBR			NBT		
Central	LOS	v/c	Delay	LOS	v/c	Delay	LOS	v/c	Delay
	C	0.7	31.0	A	0.06	0.2	C	0.7	31.8

During a site visit it was noted that during weekday afternoon traffic, through vehicles in the queue at the Memorial/Central Avenue intersection backed up to the private Walmart entrance. Due to this observation it proved self-evident that the right-turn lane was required to reduce delays. A model for weekend peak hour would likely better show the use of the right-turn lane. It was assumed that the right-turn lane was added to ease the flow of vehicles making a right hand turn onto Central Avenue East while through traffic would remain stable.

4.2.2.4 Traffic Signals

In order to provide greater influence of the Total Delay and Volume-to-Capacity ratios the optimization tool within Synchro was utilized for the proposed 3.0m lane widths and the current Heavy Vehicle Percentages. Table 4-10 below shows the results.

Table 4-10 - Signal Timing Optimization Comparison

Signalized Intersection	Proposed Condition			Optimization		
	3.0 Meters			3.0 Meters		
	LOS	v/c	Delay	LOS	v/c	Delay
Central	C	1.04	31.9	C	0.84	32.3
11th	C	0.81	21.7	C	0.71	22.3
13th	A	0.5	6.7	A	0.43	5.1

Like the previous comparisons the Level of Service remains unchanged from the existing condition of 3.7m lanes. Although due to the slight increase in the Total Delay, however, the v/c ratios have decreased significantly. This is especially clear on Central Ave where the v/c ratio is below 1.0, which indicates that traffic is below capacity making traffic flow more stable and less congested. This comparison proves that a lane width of 3.0m will be sufficient in providing the driver the same Level of Service and only a minimal increase to the Total Delays.

4.2.2.5 Growth Factor

The City of Thunder Bay has experienced minimal population growth over the last several years. For these slight increases in growth, it was assumed a growth factor of 1% over a 10 year period. The selected growth factor of 1% was inputted into Synchro to see how the performance parameters would change over the course of 10 years. Table 4-11 shows the findings of the 10 year growth factor.

Table 4-11 - Growth Factor Comparison (2016 to 2026)

Signalized Intersection	Optimization			Optimization-Growth Factor		
	3.0 Meters			3.0 Meters		
	LOS	v/c	Delay	LOS	v/c	Delay
Central	C	0.84	32.3	C	0.86	33.2
11th	C	0.71	22.3	C	0.71	22.1
13th	A	0.43	5.1	A	0.43	5.1

The table above shows that a growth factor of 1% will not decrease the performance of the roadway. It is projected that over the course of 10 years the small impacts of Total Delay and Volume-to-Capacity ratios will lead to no major issues of the proposed design 3.0m reduction in the lane widths, making the proposed design feasible over the long term.

4.2.2.6 Safety Recommended Simulations

A safety analysis comparison was done using the proposed condition of 3.0m lane widths and making changes to the Yellow times and turn-types mentioned in section 4.2.3 The Yellow time at 13th Avenue was increased from 4.0 seconds to 4.5 seconds for north and southbound traffic. This increase is expected to assist in the reduction of rear-end collisions at the intersection especially during the winter months. Also for the left-turn on 11th Avenue heading southbound the current turn type was changed from protected/permitted to just a protected left-turn phase. This protected left-turn, once adapted to, is expected to eliminate the collisions occurring by way of the turning manoeuver meeting through traffic. Again these intersections were optimized to see the effects it would have on the road before confirming the required implementation. As shown in Table 4-12 there is no change in the Level of Service from the proposed condition.

Table 4-12 - Safety Recommended Changes Comparison to Optimized Signal Timings

Signalized Intersection	Proposed Condition 3.0 Meters			Optimization 3.0 Meters			Optimization- Safety 3.0 Meters		
	LOS	v/c	Delay	LOS	v/c	Delay	LOS	v/c	Delay
Central	C	1.04	31.9	C	0.84	32.3	C	0.84	32.3
11th	C	0.81	21.7	C	0.71	22.3	C	0.71	23.3
13th	A	0.5	6.7	A	0.43	5.1	A	0.43	5.3

From the previous comparison of optimizing the intersections, adding additional safety requirements still brings the Volume-to-Capacity ratio below 1.0 therefore preventing congestion. Also, the Total Delay does not change drastically from the addition of safety measures. From the data presented, it can be recommended that these safety considerations be implemented without compromising the operational performance of the roadway section.

4.2.3 Cycling Facility Investigations

For selection of the cycling facility, the Book 18 (Highway Capacity Manual, 2010) 3-Step process is as follows:

Step 1 – Pre-selection using the nomograph (Figure 4-8)

Establish values for operating speed and traffic volumes to be used on the axis.

$$85th\ Percentile\ Speed = Poste\quad Speed\quad 5\ mph$$

$$85th\ Percentile\ Speed = Posted\ Speed\quad 8.05\ km/h$$

$$85th\ Percentile\ Spee\qquad 60 + 8.05\ km/h$$

$$85th\ Percentile\ Speed \cong 68\ km/h$$

The AADT from Central Avenue to 13th Avenue is well over 15000 veh/day

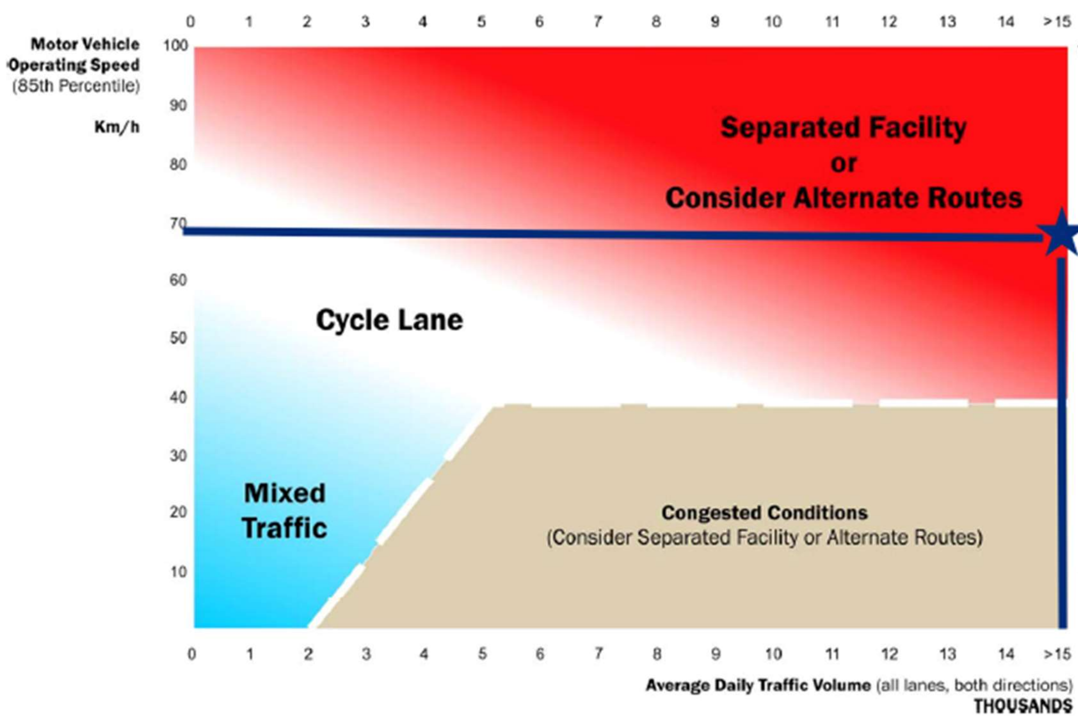


Figure 4-8 – Pre-selection Nomograph for Cycling Facility

The pre-selection tool suggests either a separated cycling facility or alternate routes.

Step 2 – Site Specific Questions

The questions broken down into Table 4-13 and rules/considerations have been taken from the Feasibility Selection Tool Document (MMM Group, 2011) as they pertain to the section. See Appendix A for a complete look at the questions and all possible responses.

Table 4-13 - Site Specific Questions Relating to Cycling Facility Selection

Roadway Characteristics	Site Specific Observation	Response
Motor Vehicle Operating Speed	High (65 to 80 km/h)	Suggesting physical *separation* of the two modes is most appropriate.
Motor Vehicle Volumes	High (two-way daily average volume greater than 10,000 vpd)	Physical *separation* of motor vehicle and bicycle traffic (i.e. separated facility) may be most appropriate.
Function of Road	Both mobility and access	Some level of formal bicycle facility (cycle lanes or *separated* facility) is appropriate
Vehicle Mix	Bus stops are located frequently along the route	Facilities should be designed to minimize and clearly mark conflict areas between cyclists and busses/pedestrians at stop locations.
On-Street Parking	Not permitted	Opportunities to provide wide curb lanes or cycle lanes, as well as their appropriateness should be explored.
Intersection/Access Density	Numerous low volume driveways and/or un-signalized intersections are encountered	Wide curb lanes or cycle lanes may be more appropriate than *separated* facilities as motorists are more likely to be aware of cyclists on the roadway than adjacent to the road
Available Space		Not considered since reconstruction
Anticipated Users	Basic/novice cyclists (recreational)	This group generally prefers routes on residential, neighbourhood streets with light traffic and low speeds. Wide curb lanes, cycle lanes, and *separated* facilities should be considered.

Table 4-13 - Site Specific Questions Relating to Cycling Facility Selection

Level of Bicycle Use	Presently low bicycle volumes (< 10 per hour)	Wide curb lanes may be adequate.
Function of Route Within Network	New route provides district level access to a neighbourhood, city region, suburb, etc.	New route provides district level access to a neighbourhood, city region, suburb, etc. Cycle lanes and *separated* facilities should be considered to encourage cycling for all users.
Type of Roadway Improvement Project	Reconstruction	Major roadway reconstruction provides an opportunity to improve provisions for cyclists through increased roadway width or off-road space with considerable cost savings.

Step 3 - Rationalize Findings

Both the nomograph and the questions generally lead to the conclusion that separation is the best alternative. Some anomalies are addressed below:

- On-Street Parking - Since there is no on-street parking there may be an opportunity to have a curb lane cycling facility. Due to the operating speed, volume of traffic through the section of concern, and the projected skill level being a novice/interested but concerned ridership, outlined in Chapter 2, as a group the decision was made that a curb lane is not justifiable.
- Intersection and Access Density - Since there are numerous accesses, drivers are more aware of cyclists when they are physically on the roadway. Countermeasures can be developed to build awareness such as traffic control signage or green paint where a vehicle will cross the cycling facility. *The bottom line is that to build awareness and/or command respect of motor vehicles a cycling facility must be used.* This is the most effective way to improve safety. Public surveys are common for determining which type of facility is preferred by potential users.
- Recommendation - Remain a separated facility based on the Decision Support Tool questions developing the conclusion. Also supported by Winnipeg,

Manitoba, a community who has begun building awareness through applying green paint across accesses along separate facilities.

There are limited alternative routes for cyclists that provide a direct access to the downtown cores. Within the Memorial-May corridor cyclist trips can consist of commuter, destination (shopping) or hobby trips. It seems to be an ideal location for a facility to be utilized and therefore a cycling facility is relevant. Prioritization of the right-of-way is safety, and thus a separate facility is to be designed. Site conditions such as vehicular volumes, speeds, and function reinforce a need for a separate facility. This will provide the most comfort and hopefully make cycling more appealing to a greater diversified cyclist skill level.

The type of separation will be addressed in the next portion of this section. It is clear at this point that cross-section 4 is no longer going to be in consideration due to the cycling facility having no separation.

4.2.4 Buffer Zone Selection

The form of separation will be picked based on knowledge of the site specific characteristics. The following forms of separation will be looked at: grade/curb, planter/median, and bollard/removable curb. For more details on the background see Chapter 2.

The first form of separation is curb separation which would have a greenspace strip according to the urban design guidelines of 1.5m in addition to the width of curb. This appears in cross-section alternative 1. This typically provides the highest level of comfort to a cyclist as there is a grade separation coupled with a lateral separation.

The second form of separation is median or planter box separated. This appears in cross-section alternative 2. Planter boxes require additional maintenance costs and therefore are not recommended. In addition, the upfront cost of implementing a median does not constitute a benefit. Considering the challenges associated with breaks in medians for the numerous accesses along the section. A median is generally preferred where there is little to no need for motor vehicles to cross the facility.

The third form of separation is bollard with or without removable curb. This resembles the pilot project in Calgary as well as the existing facility in Thunder Bay. It also appears in cross-section alternative 3. Bollards are a very current approach, however the breaks in bollards are typically in the neighbourhood of 20m and can become less effective where additional breaks allow drivers to cross the cycling facility for driveway entrances. This form of separation serves the most benefit where there is no motor vehicle crossings.

Based on the above breakdowns, a curb separated one-way cycle track will be provided with a 1.5m greenspace from back of curb to cycle track. **Cross-section alternative 1** should be implemented based on the available data. The following sections will further develop additional justification for preliminary redesign.

4.2.5 Intersection Type Comparison

Table 4-13 and Figure 4-9 have been developed to assist in selecting a logical decision on the uses of each intersection treatment. Since simulation processes show limited connectivity between cyclists and motor vehicle traffic, this comparison coupled with engineering judgment will be used.

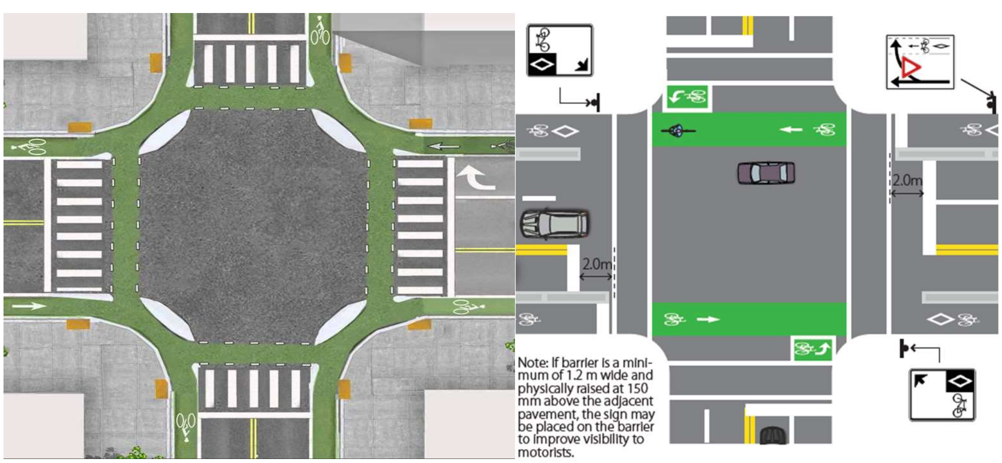


Figure 4-9 - Intersection Treatments (ALTA, 2015 and Ministry of Transportation, 2013)

Table 4-14 - Intersection Treatment Comparison (ALTA, 2015 and Ministry of Transportation, 2013)

Protected Intersection	Queue Box Treatment
Key Features: • Installation of corner safety Islands. • Vehicles must stop at a greater distance behind the cross walk making cyclists and pedestrians more visible. • Cycle facility shifts toward sidewalk for increased buffer at intersections. • Placement of green paint for cyclists for greater visibility. • Introduction of cyclists and pedestrian signal movement only.	Key Features: • Vehicles must stop at a recommended 2 m behind the stop bar for the cyclist. • Placement of green paint for cyclists for greater visibility. • Cyclists follow vehicular traffic signals for movement. • Two-stage left-turn movement.
Right-Turn Movement: • Vehicles wishing to make a right-turn movement must slow their speed. • Drivers have better control of the vehicle. • Where larger vehicles on Central and 11th Avenues turning right, installation of a corner apron can be installed for greater maneuverability. • Increased setback of cyclist zone allows vehicles more reaction time. • Cyclists making right turns have the maneuverability without disrupting the traffic or other cyclists waiting in the queue area. • Cyclist will become more aware of pedestrians waiting at crosswalks.	Right-Turn Movement: • Vehicles should slow speed. • Unprotected for bicycles, however, it is a simple manoeuver that leaves little vulnerability. • Bicycles and Vehicles can make movement on a red light. • Motor vehicles need to be aware of straight through cyclists during green phases.

Table 4-14 - Intersection Treatment Comparison (ALTA, 2015 and Ministry of Transportation, 2013)

Through Lane Movement: • Reduces the amount of rear-end collisions on 11th Avenue, forcing vehicles to reduce speed and stop earlier. • Cyclist has no through movement, cyclists must have a slight jog from the separated bicycle facility to cross the intersection. • A clear and distinct separation of cyclists and pedestrian on the crosswalk.	Through Lane Movement: • Optimal, no deviation for cyclist or motor vehicles from their path of travel. • Cyclists become exposed without buffer zone.
Left-Turn Movement: • Reduces collisions by introducing a protected left turn movement only. • Protected intersection acts as a round-a-bout for cyclists, providing that no cyclist has to make a left turn. • Painted cyclist crosswalk becomes more visible to drivers making left-turn movements.	Left-Turn Movement: • Two-stage sequence, straight through movement, pulling into queue box. • Cyclists sit in queue box and proceed to complete movement as phasing changes on the signals. • Queue boxes are protected strictly based on phasing. • If users override then the cyclists may resort to crosswalk.

General Comments for Protected Intersections

As pedestrians and cyclists approach the protected intersection the area behind the corner safety islands will be on grade with the roadway to add additional comfort for the cyclists waiting for their turn or through movement. For Central Avenue where cyclists and pedestrians first have to get across the medians, these also will be on grade with the roadway as to not interrupt the bicycle traffic flow.

Summary of Decision Process

Based on the comparative table above, the protected intersection has been selected for signalized intersections. With recent breakthroughs in North America, this style of intersection is gaining popularity and has received very positive feedback from users. It is expected that intersection treatments such as this will provide the comfort level required to increase ridership within the corridor. Where minor intersections occur such as 10th and 12th Avenue, there will be no setback or safety island and a modification of the straight through movement of the current approach will be used.

The Memorial Avenue - May Corridor is a reconstruction design. Therefore, for both treatments engineering judgment must be taken into account. Some signal phases or construction designs may not be able to be implemented due to limitations of the existing right-of-way.

4.3 Geometric Analysis

All characteristics such as lane widths developed in this section become design constraints for drawing production within Civil 3D. The geometric calculations performed are to ensure that drivers have the distance required to bring their vehicle to a stop as well as calculations for the minimum radius required for the safe operation at design speed. In order to calculate stopping sight distance and minimum radii, the coefficient of friction is required.

4.3.1 Friction Coefficients

In a straight stretch of road, the friction force that is the longitudinal friction factor (f) is assumed to be the default value of 0.348 (Roess, 2011). In a horizontal curve, the frictional coefficient is a vector resultant of the lateral and longitudinal factors. The lateral factor (f_2) is 0.15 according to the Geometric Guide for Canadian Roads (1999). These values are default; detailed design should look into specific characteristics that have effect on the frictional values. The following value is calculated as the vector resultant of the assumed values using Equation 2-8:

$$f_2 = \sqrt{f^2 - {f_1}^2}$$

$$f_2{}^2 = f^2 - f_1{}^2$$

$$f_1 = \sqrt{f^2 - f_2{}^2}$$

$$f = \sqrt{0.348^2 - 0.15^2}$$

$$f = 0.314$$

4.3.2 Stopping Sight Distance

The stopping sight distance will be checked for both scenarios applied to the site. They will be used as measurement checks within the drawing file.

4.3.2.1 Straight

Analyses of any straight portion were taken using Equation 2-6. An assumed gradient of zero was used since the grade of the road is relatively flat. The friction coefficient will be longitudinal and 0.348, the speed used will be the design speed of 70 km/h. The reaction time is assumed to be 2.5 seconds. For more information on these values see Chapter 2.

$$d_s = 0.278Vt + \frac{s_i{}^2 - s_f{}^2}{254(f \mp g)}$$

$$d_s = 0.278(70)(2.5) + \frac{70^2 - 0^2}{254(0.348 \mp 0)}$$

$$d_s = 104.1\ m$$

4.3.2.2 In Radius

Stopping sight distance uses is slightly greater through a horizontal curve and can be taken with slight modification by using the friction force vector previously established (f_1 = 0.314) along with all values previously mentioned. Equation 2-10 was used as follows:

$$d_{s-rad} = 0.278Vt + \frac{V^2}{254f_1}$$

$$d_{s-rad} = 0.278(70)(2.5) + \frac{70^2}{254(0.314)}$$

$$d_{s-rad} = 110\ m$$

4.3.3 Minimum Radius and Super-Elevation

The minimum radius is the tightest curve possible for a vehicle to not be overcome by centrifugal or centripetal forces. It has been documented that within the existing curve there is super-elevation in place. During the design, super-elevation was assessed and was determined to be required. Through calculations coupled with the super elevation tool in Civil3D, it is evident that a 6% super elevation is required. By Transportation Association of Canada stipulations this is within the allowable for an urban road.

For the minimum radius, Equation 2-7, maximum super-elevation is taken as 6%, f_{max} is taken as the lateral coefficient of friction (0.15) and the design speed is again 70 km/h.

$$R_{min} = \frac{V^2}{127(e_{max} + f_{max})}$$

$$R_{min} = \frac{70^2}{127(0.06 + 0.15)}$$

$$R_{min} = 183.7\ m$$

The radius used for design was applied to the centreline of the north bound driving lane (tightest lane on radius) and it was set to a value of 184m such to allow all other traffic lanes to have radii larger than the minimum.

Please see Appendix E for a screen shot to show the full taper leading up to and at the end of the transformation from super elevation to normal crown as it pertains to the Memorial Avenue control station alignment.

4.4 Additional Considerations

In addition to the analyses above, the following additional aspects that do not require calculations are going to be implemented into the preliminary design. The findings will be implemented within Civil3D.

4.4.1 Accessibility for Ontarians with Disabilities Act

Tactile Plates will be suggested at intersections where pedestrians will cross. In addition, pedestrian signal indicators will be recommended at all crossings in an effort to make crossing the street more feasible to the visually impaired based on the AODA Act.

4.4.2 Greenspace

Street trees with grates will be planted on both sides of the roadway within the 1.5 m greenspace at intervals of 50m, where possible. The recommended street tree to be utilized is a 60 mm caliber tree according to Thunder Bay Engineering Specifications. The selection of the street tree species is to be decided by a licenced Urban Design Planner. Planter boxes will not be used due to lack of space available for proper implementation.

4.4.3 Specifications

Additional specifications and guidelines will be followed as they apply to sidewalks, cycling facilities, curb, asphalt, pavement markings, driveways, etc. For a complete list of the references see Section 2.4.

4.5 Results

From the data calculated, simulated, and selected above, the following results can be developed in support of the proposed cross-section and the plan view preliminary design:

Safety Comments

The current state of the road is relatively safe. Recommended improvements based on the limited data available can be broken down into associated cost with construction and additional cost to construction.

Associated Cost with Construction

- Paint proposed markings for a more visible lane movement in accordance to Figure 2.13
- Make design improvements to super elevation in accordance with Appendix E
- Improve surface asphalt condition by re-pavement

Additional Cost to Construction

- Install pavement condition warning signage for north and southbound traffic at 10th Avenue
- Adjust yellow signal timing for north and southbound traffic at 13th Avenue to 4.5 seconds (confirmed feasibility by simulations)
- Adjust southbound left protected and permitted phases to strictly protected left turn phase (confirmed feasibility by simulations)

Operational Comments

All required changes were able to be made without an effecting the Level of Service of each intersection. The analysis was limited to weekday afternoon peak hour and should be modeled at weekend peak hours as well to confirm the overall feasibility (beyond the data available). Figure 3-1 shows the design cross section with a typical 2% crossfall draining towards the curb and can be broken down as follows:

- Lane widths for driving lane should be 3.3 m to provide additional space for bus routes
- Lane widths for passing lanes and two way left turn lane should be 3.0 m
- The boulevards should include

- 1.5 m greenspace from back of curb to cycle track
  - 1.5 m separated one-way cycle track
  - 1.8 m greenspace between cycle track and sidewalk
  - 1.5 m sidewalk
- Where additional turn lanes are developed, greenspace between cycle track and sidewalk is eliminated on both sides of the roadway

In addition to the above cross sectional specifications Table 4-15 shows the traffic signal changes also as a result of simulations. Changes are required to all intersections with regard to Maximum Green times and Total Split times in order to stabilize the flow of the proposed roadway.

Table 4-15 - Signal Timing Changes from Existing to Proposed

Existing Condition Signal Timing		Central Avenue									
	Time (sec)	EBL	EBT	WBL	WBT	NBL	NBT	NBR	SBL	SBT	SBR
	Minimum Initial	7.0	10.0	7.0	10.0	7.0	10.0	10.0	7.0	10.0	10.0
	Minimum Split	12.0	36.0	12.0	36.0	12.0	34.0	34.0	12.0	35.0	35.0
	Total Split	17.0	37.0	17.0	37.0	17.0	49.0	49.0	17.0	49.0	49.0
	Maximum Green	12.0	31.0	12.0	31.0	12.0	43.0	43.0	12.0	43.0	43.0
Proposed Signal Timing		Central Avenue									
	Time (sec)	EBL	EBT	WBL	WBT	NBL	NBT	NBR	SBL	SBT	SBR
	Minimum Initial	7.0	10.0	7.0	10.0	7.0	10.0	10.0	7.0	10.0	10.0
	Minimum Split	12.0	36.0	12.0	36.0	12.0	34.0	34.0	12.0	35.0	35.0
	Total Split	23.0	47.0	12.0	36.0	16.0	46.0	46.0	15.0	45.0	45.0
	Maximum Green	18.0	41.0	7.0	30.0	11.0	40.0	40.0	10.0	39.0	39.0
Existing Condition Signal Timing		11th Avenue									
	Time (sec)	EBL	EBT	WBL	WBT	WBR	NBL	NBT	SBL	SBT	
	Minimum Initial	10.0	10.0	7.0	10.0	10.0	10.0	10.0	5.0	10.0	
	Minimum Split	38.0	38.0	12.0	38.0	38.0	38.0	38.0	10.0	38.0	
	Total Split	39.0	39.0	15.0	39.0	39.0	51.0	51.0	15.0	51.0	
	Maximum Green	33.0	33.0	10.0	33.0	33.0	45.0	45.0	10.0	45.0	
Proposed Signal Timing		11th Avenue									
	Time (sec)	EBL	EBT	WBL	WBT	WBR	NBL	NBT	SBL	SBT	
	Minimum Initial	10.0	10.0	7.0	10.0	10.0	10.0	10.0	5.0	10.0	
	Minimum Split	38.0	38.0	12.0	38.0	38.0	38.0	38.0	10.0	38.0	
	Total Split	38.0	38.0	12.0	50.0	50.0	57.0	57.0	13.0	70.0	
	Maximum Green	32.0	32.0	7.0	44.0	44.0	51.0	51.0	8.0	64.0	
Existing Condition Signal Timing		13th Avenue									
	Time (sec)	EBL	EBR	NBL	NBT	SBT					
	Minimum Initial	10.0	10.0	10.0	10.0	10.0					
	Minimum Split	36.0	36.0	31.0	31.0	31.0					
	Total Split	50.0	50.0	70.0	70.0	70.0					
	Maximum Green	44.0	44.0	64.0	64.0	64.0					
ProposedSignal Timing		13th Avenue									
	Time (sec)	EBL	EBR	NBL	NBT	SBT					
	Minimum Initial	10.0	10.0	10.0	10.0	10.0					
	Minimum Split	36.5	36.5	31.5	31.5	31.5					
	Total Split	39.0	39.0	81.0	81.0	81.0					
	Maximum Green	33.0	33.0	74.5	74.5	74.5					

Intersection Comments

Based on the comparative analysis of the current standard approach and the protected intersection approach, it has been established that the protected intersection approach be used for major intersections while current approach straight through movements be maintained for minor locations.

Geometric Considerations

Throughout the horizontal curve, super elevation is required at a maximum of 6%. The existing roadway is super elevated, however the exact crossfall is unknown. Civil3D simulations as well as Geometric Guide for Canadian Roads calculations both stipulate 6%.

Additional Comments

Beyond the scope of simulations, the following recommendations are being made based on considerations to accommodate special population groups and environmental concerns.

- Implementation of metal tactile plates at pedestrian crossings for the visually impaired complimented by locator tone for pedestrian signal.
- Street Tree box and grate implemented within greenspace area between back of curb and cycle track
- Green surface treatment should be used at all intersections and driveways where vehicles cross the cycle track

Based on the above discussion a proposed drawing for plan view, as well as pavement markings, has been developed. See Appendix F for the reduced preliminary drawings.

4.6 Field Specific Considerations

The following considerations are important acknowledgements that further outline the challenges associated with the surface redesign within the specific section and indicates how they should be implemented.

4.6.1 Pre & Post Construction Survey

Due to the location of the building at 920 Memorial Avenue (Play It Again Sports), being directly on the property line, a Pre and Post Construction Survey is recommended to identify whether the adjacent building has been affected or damaged as a result of construction work. The survey should focus on structural damages such as foundation settlement that may result in interior or exterior cracking of the buildings components. In order to monitor the building, vibration monitors and crack gages will be required to perform the survey.

4.6.2 Drainage and Profile

The nature of this project is focused strictly on surface works with regard to the feasibility of a cycle track within Memorial Avenues right-of-way. When designing a road profile one must consider the drainage as a priority. Since this project does not include storm sewer redesign, it is difficult to make changes to the current low points. Two hypothetical cases have been considered:

- *Scenario A –* The existing storm sewer is left in the ground
- *Scenario B –* The sewer system is replaced

For Scenario A, the storm sewer exists as a curb line storm sewer with catchbasin maintenance holes on both sides of the road, if the width or alignment changes, the maintenance holes should be benched to fill in the sumps and to provide minimum head losses. Existing catchbasin lids should be replaced with storm sewer lids according to the Ontario Provincial Specification Standards (2015) and cores should be made at the existing maintenance holes such that curb inlet catchbasins can be placed to the edge of pavement as curb setbacks at the same stations as existing. This effectively maintains the same drainage practices and allows the profile to mimic the existing.

For scenario B, the storm network is replaced. This will require a detailed drainage and sewer analysis. From here, the profile can change freely and a network can be established with a single storm sewer within the roadway.

For the purpose of this design, the assumption is that catchbasin stations remain unchanged and therefore drainage areas are minimally disturbed.

4.6.3 Retaining Wall

As a result of the location of the sidewalk on the southeast of Memorial Avenue and Central Avenue a retaining wall will be required to provide stability to the embankment due to the elevation change. A typical concrete retaining wall with footing will be used with accordance to Thunder Bay Engineering Standards Drawing M-105-1. The height of the concrete retaining wall will be contingent on survey data.

4.6.4 Relocation of Services, Appurtenances and Utilities

Throughout the section the following items will require relocation and should be accommodated within greenspaces:

- Hydro Posts – Between curb and cycling facility
- Watermain Valves – In either greenspaces or 0.3 m off property line
- Fire Hydrants – 0.3 m off property line
- Encroaching Private Parking Lots (Municipal No. 915) – Set limits to property line

CHAPTER 5

Summary, Conclusions and Recommendations

5 Summary, Conclusions and Recommendations

5.1 Summary

Amalgamation of vehicular, pedestrian and cyclist traffic within a complete street is becoming ever increasingly popular in cities around the world. Challenges of implementation of complete streets are typically caused by the space and restriction demands proposed by the existing right-of-way. This project was conducted to determine the feasibility of a complete street with an emphasis on a cycle track along Memorial Avenue in Thunder Bay, Ontario.

A literature review was established, highlighted by case studies from the cities of Calgary, Ottawa, Thunder Bay and Vancouver. These case studies were utilized to gain exposure to cities that have already taken the initiative to implement complete streets into their respective communities. A total of four alternative cross sections were developed based on the literature review. The discovery of the cycling facility selection decision support tool developed as an initiative by the City of Ottawa, was utilized in assessing the proposed cycling facility cross sections, resulting in the elimination of all non-separated cycling facilities.

For the alternative cross sections, safety and operational analyses were assessed. The safety analysis was separated into a three-part process. Firstly, trends were developed, then countermeasures were established, followed by an economic analysis. Then operation of the roadway was analysed by the use of the simulation software, Synchro 9.0. With the utilization of Synchro 9.0, lane widths, number of lanes, signal timing and traffic volumes were experimented with in order to establish a level of service. Once the roadway was deemed suitable, the remaining three alternative cycling facilities were presented. Figure 5-1 illustrates the bollard, planter/median and off-grade in boulevard separated facilities.

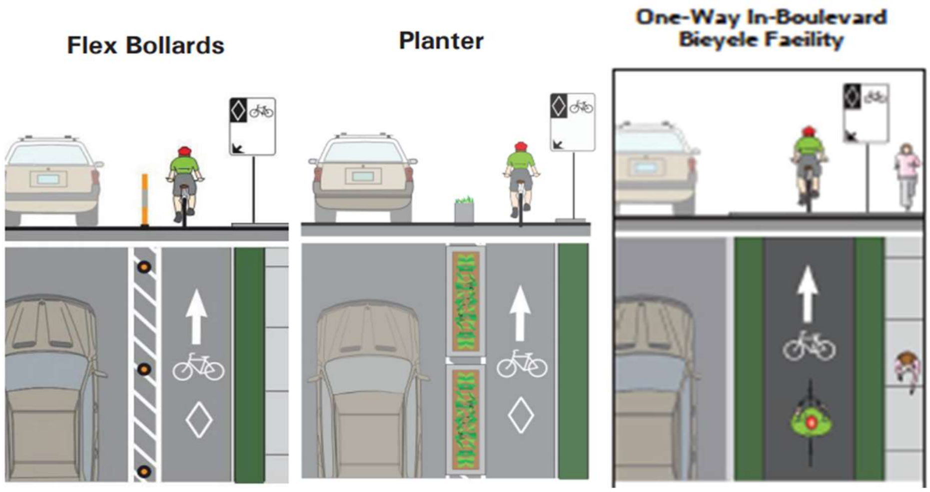


Figure 5-1 - Alternative Cycling Facilities (Ministry of Transportation, 2013)

5.2 Conclusions

The proposed cross-section is depicted in Figure 5-2 and the proposed plan view can be found in Appendix F. These designs can be recommended due to:

- The improved experience of all road users
- The successful operational performance simulations developed
- The improvements to safety considerations established by economic analysis

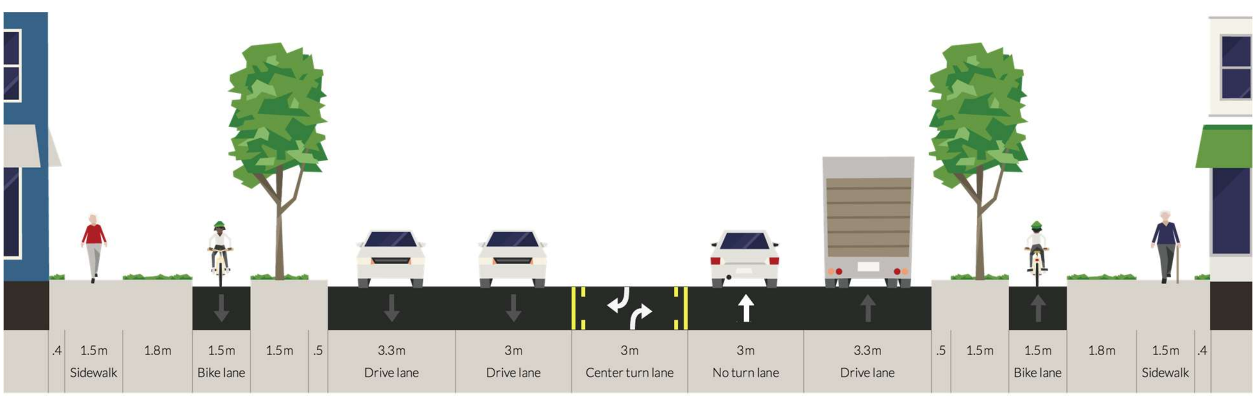


Figure 5-2 - Proposed Typical Cross Section

The above proposed cross-section includes the following:

- 2% typical crossfall on the roadway

- 3m lane widths with the exception of the outside lane being 3.3m to accommodate the bus route
- 1.8m greenspace between the bike lane and the sidewalk, can be removed when an additional lane is needed

The following additional features have been implemented into the simulation programs or the preliminary drawings that were developed in Civil 3D for the 690m section of Memorial Avenue from Central Avenue to 13th Avenue.

- Adjustment to signal timings per simulation findings
- Implementation of protected intersections
- Installing tactile plates and locator tones
- Wherever motor vehicles cross the cycle track, green surface treatments will be applied

5.3 Recommendations

Due to time constraints the preliminary design and findings have some limitations. To address these limitations, it is recommended that more in depth research be completed on the protected intersections. In the coming years more information may become available through NACTO and should be looked into. In addition to this, the following recommendations highlight the limitations of results:

- A simulation model for weekend peak hour traffic, should be developed due to the commercial land uses being predominant throughout the proposed section
- Traffic counts should be completed for all private driveways to improve model accuracy
- A detailed topographic survey should be completed for the existing condition to provide additional information of surface profile as well as location of existing utilities and appurtenances
- A simulation program that can further analyze cycling facilities should be looked into

Some recommended additional analyses that were not completed are as follows:

- Consideration of restricted accesses
- Consideration of removing two way left turn lane
- Storm, sanitary, and watermain redesign
- Vertical alignment changes and relocation of catchbasins
- Detailed utility relocation
- Retaining wall at the southeast corner of Memorial Avenue and Central Avenue
- Pre-construction survey for 920 Memorial Avenue to assess existing building condition

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APPENDIX A

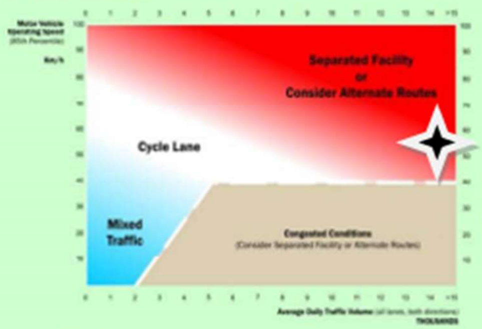
Cycling Facility Selection

Step One
Pre-select the facility type

Street and Section:

Memorial Avenue

Cycle Facility
Pre-selection Nomograph



Traffic Volume:

15,000+ Vehicles
Date and source:

Motor vehicle operating speed:

68 km/hour
Date and source:

Nomograph Result:

Separated Facility

Step Two
A more detailed look

Traffic Speed: High 65-80 km/hr

Function of Road: Mobility and Access

Vehicle Mixture: Bus stop located frequently along route

No on-street parking

Level of Bicycle Use: Low bicycle volumes

Motor Vehicle Volumes: High (2-way daily average volume greater than 10,00vpd)

This view shows the following relevant factors:

Describe Your Site:
The Table In Appendix D has descriptors from the following categories:

- Speed
- Volume
- Function
- Vehicle Mix
- On-street parking
- Intersection/access density
- Collision history
- Available space
- User skill
- User density
- Route function
- Project type
- Costs/funding

Check all that apply.

Select Rules:
From the column next to each checkmark, extract each rule.

Photo

This view shows the following relevant factors:

Attach additional sheets if more documentary photos and data are required.

Step Three
Develop your rationale

On-Street Parking - Since there is no on-street parking there may be opportunity to have a curb lane cycling facility.

Intersection and Access Density - Since there are numerous accesses, drivers are more aware of cyclists when they are physically on the roadway.

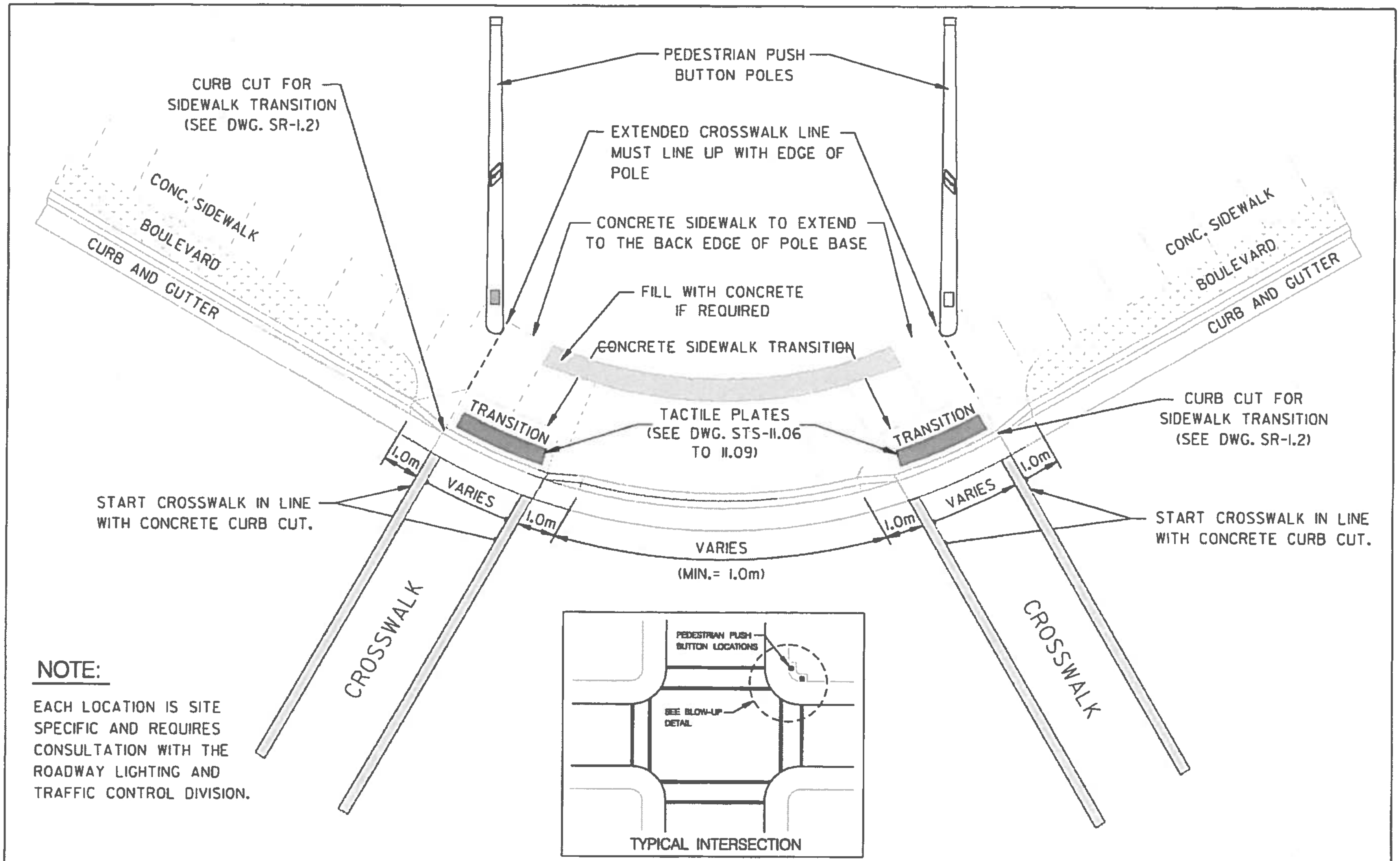
Countermeasures can be developed to build awareness such as traffic control signage or green paint where a vehicle will cros the cycling facility. *The bottom line is that to build awareness and/or command respect of motor vehicles a*

Roadway Characteristics	Rules / Considerations
Motor vehicle operating speeds (85th percentile)	
Very low (less than 30 km/h)	Bicycles and motor vehicles operate at approximately the same speed. Formal bicycle facilities may not be necessary.
Low (30 to 50 km/h)	Speed differential between bicycles and motor vehicles is within 20 km/h, suggesting integration of the two modes as mixed traffic (in standard or wide curb lanes) may be appropriate.
Moderate (50 to 65 km/h)	Exclusive operating space for both bicycles and motor vehicles, in the form of wide curb lanes, cycle lanes, or separated facilities is recommended. Traffic calming and enforcement may be considered to manage motor vehicle volume and speed.
High (65 to 80 km/h)	Speed differential between bicycles and motor vehicles exceeds 40 km/h, suggesting physical separation of the two modes is most appropriate (i.e.
Very high (greater than 80 km/h)	Typical of rural highways and major urban thoroughfares, separated facilities with a buffer between the roadway and the bicycle facility are most appropriate. Alternatively, a parallel bicycle route should be explored.
Motor vehicle volumes	
Low (two-way daily average volume less than 3,000 vpd)	Mixed traffic may be appropriate if vehicle speeds are also low. Curb lanes should be as wide as possible.
Moderate (two-way daily average volume 3,000 to 10,000 vpd)	Some level of formal bicycle facility (cycle lanes or separated facility) is recommended.
High (two-way daily average volume greater than 10,000 vpd)	Physical separation of motor vehicle and bicycle traffic (i.e. separated facility) may be most appropriate.
Hourly one-way volume in the curb lane exceeds 250 vph	Some level of formal bicycle facility (cycle lanes or separated facility) is recommended.
Function of street/road/highway	
Access (local roads, residential streets)	Mixed traffic may be appropriate if speeds and volumes are low. Curb lanes should be as wide as possible.
Mobility (arterials, major collectors)	Some level of formal bicycle facility (cycle lanes or separated facility) is appropriate.
Both mobility and access (many collectors, other roads and streets)	Some level of formal bicycle facility (cycle lanes or separated facility) is appropriate.
Motor vehicle commuter route	Separated bicycle facilities should be considered to minimize conflicts with aggressive drivers on the roadway.
Vehicle mix	
More than 30 trucks or busses per hour are present in a single outside lane	Separated bicycle facilities may be preferred by many cyclists. If wide curb lanes or cycle lanes are considered, additional width should be provided as a
Bus stops are located frequently along the route	Facilities should be designed to minimize and clearly mark conflict areas between cyclists and busses/pedestrians at stop locations.
On-street parking	
Parallel on-street parking is not permitted	Opportunities to provide wide curb lanes or cycle lanes, as well as their appropriateness should be explored.
Parallel on-street parking is permitted in localized areas along the route	Consistent cycle lanes may prove difficult to provide as available roadway width is likely to change where parking is provided. Wide curb lanes may be an acceptable solution.
Parallel on-street parking is permitted but demand is low	Opportunities to remove, restrict, or relocate parking in favour of providing cycle lanes should be considered.
Parallel on-street parking is permitted but turnover is low	Cycle lanes may be appropriate. Additional buffer space between bicycle and parking lanes should be provided.
Parallel on-street parking is permitted; turnover and demand is high	Separated bicycle facilities or alternate routes may be most appropriate. Cycle lanes are not desirable in this situation due to frequent conflicts with parking
Perpendicular or diagonal parking is permitted	On-road facilities are not appropriate unless parking is reconfigured or removed. Alternate routes or opportunities to provide a separated facility should be
Intersection/access density	
Limited intersection and driveway crossings are present along the route	Separated facilities or cycle lanes are well suited to routes with few driveways and intersections.
Numerous low volume driveways and/or unsignalized intersections are encountered	Wide curb lanes or cycle lanes may be more appropriate than separated facilities as motorists are more likely to be aware of cyclists on the roadway than adjacent to the road.
Numerous high volume driveways and/or unsignalized intersections are present along the route	Separated facilities are generally not preferred in this situation; cycle lanes or wide curb lanes may be more appropriate. Crossings should be designed to minimize conflicts; additional positive guidance/warning measures should be considered to warn cyclists and motorists of conflicts.
Major intersections with high speed and traffic volumes are encountered	Consider provision of cycle lanes, advance stop lines, and exclusive bicycle signal phases at major intersections; consider hook/indirect left turn treatments if there is significant bicycle left turn demand conflicting with through motor vehicle traffic. If a separated facility is being considered, crossings should have bicycle traffic signals with exclusive phases and conflicts should be clearly marked.

Collision history	
Bicycle collisions are relatively frequent along the route	A detailed safety study is recommended. Alternate routes should be considered. Separated facilities may be appropriate to address midblock conflicts. If on-road facilities are considered, the operating/buffer space provided to cyclists should be enhanced.
Bicycle collisions are relatively frequent at specific locations	Localized design improvements should be considered to address contributing factors at high-collision locations (often near intersection and driveway
Noticeable trends emerge from bicycle collisions	Proposed facility and its design should attempt to address noticeable collision trends (refer to the FHWA's BIKESAFE as one potential source of safety countermeasures).
Conflicts exist between cyclists and other modes (i.e. motor vehicles, pedestrians)	Facilities and crossings should be designed to minimize conflict between different types of users and the conflict area should be clearly marked.
Available Space	
Sufficient curb-to-curb width exists to adequately accommodate motorists and cyclists	Redistribute roadway space to accommodate cycle lanes or wide curb lanes by narrowing/eliminating parking lanes, narrowing travel lanes, eliminating unnecessary turn lanes, etc.
Sufficient curb-to-curb width exists, but pinch points are created where turn lanes are developed at intersections	Cycle lanes may be discontinued (with appropriate positive guidance/warning measures) upstream of intersections to encourage cooperative merging of cyclists and motorists into a single traffic lane through intersections. Sharrow markings can be used to denote desirable cyclist path through narrow intersections. Refer to TAC Bikeway Traffic Control Guidelines for Canada for design recommendations.
Physical barriers are created by steep grades, rivers, freeways, railways, narrow bridges, etc.	Separated facilities should be considered to bypass or overcome barriers.
Curb-to-curb width is not adequate to provide adequate operating space for both motorists and cyclists	Provide separated facilities adjacent to the roadway or within independent right-of-way, widen roadway platform to accommodate cycle lanes or wide curb lanes, or examine alternate routes. If on-street parking is present, explore opportunities to eliminate or reduce parking.
Sight distance is limited at intersections, crossing locations, or where cyclists and motor vehicles share limited road space	Improve sightlines by improving roadway geometry or removing/relocating roadside furniture and vegetation; provide adequate space for cyclists either on or off the roadway. Design intersection crossings to minimize and clearly mark conflicts and restrict parking in close proximity to intersections.
Anticipated users (skill, trip purpose)	
Experienced/advanced cyclists (commuters/utilitarian)	This group generally prefers direct, continuous facilities with minimal delay as is generally provided by the arterial road network. Wide curb lanes may be
Basic/novice cyclists (recreational)	This group generally prefers routes on residential, neighborhood streets with light traffic and low speeds. Wide curb lanes, cycle lanes, and separated facilities should be considered.
Child cyclists	This group generally requires separated facilities free of conflicts with motor vehicle traffic. Separated facilities should be considered near schools, parks, and neighborhoods.
Level of bicycle use	
Presently low bicycle volumes (< 10 per hour)	Wide curb lanes may be adequate.
Presently high bicycle volumes (>50 per hour)	Cycle lanes may be appropriate. Provided width should accommodate bicycle volumes during peak periods both mid-block and at intersections.
Significant bicycle traffic generators are nearby	Latent bicycle demand may exist if there are employment centres, neighborhoods, schools, colleges, parks, recreational and shopping facilities along the route. Cycle lanes and separated facilities should be considered to accommodate anticipated levels of cyclists.
Function of route within bicycle facility network	
Parallel bicycle routes already exist with bicycle facilities present	Redundancy of bicycle routes may provide an opportunity to provide different types of bicycle facilities within the same travel corridor, providing options for cyclists with different skill levels and trip purposes.
New route provides a connection between adjacent existing facilities	Facility selection should provide continuity with adjacent bicycle facilities to the extent possible.
New route provides district level access to a neighbourhood, city region, suburb, etc.	Cycle lanes and separated facilities should be considered to encourage cycling for all users.
Type of Roadway Improvement Project	
New construction	Appropriate bicycle facilities should be planned and integrated with design and construction of new roads and communities.
Reconstruction	Major roadway reconstruction provides an opportunity to improve provisions for cyclists through increased roadway width or off-road space with considerable cost savings.
Retrofit	Affordable solutions may be limited to redistributing existing road space.
Costs/Funding	
More than one type of bicycle facility appears appropriate	Benefit/cost analysis of alternatives should be conducted. Refer to NCHRP Report 552 - Guidelines for Analysis of Investments in Bicycle Facilities.
Funding levels are not available to provide preferred type of facility	Consider alternate routes or focus on cost-effective improvements to existing facilities such as improved maintenance, pavement/drainage rehabilitation, and removal of barriers. Poorly designed or constructed facilities may result in increased safety risks for cyclists and are unlikely to encourage additional

APPENDIX B

Tactile Plate Standards



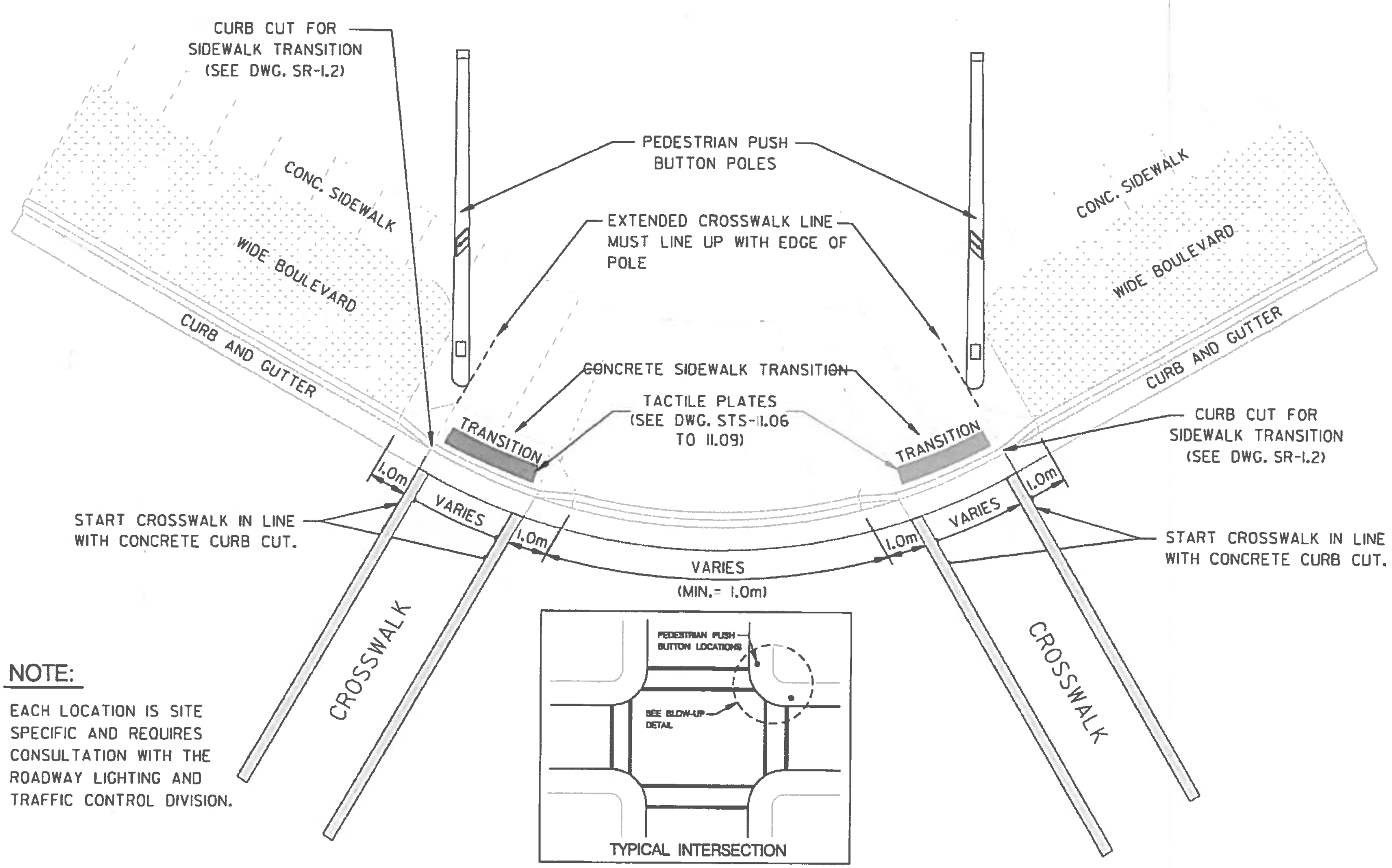
NOTE:

EACH LOCATION IS SITE SPECIFIC AND REQUIRES CONSULTATION WITH THE ROADWAY LIGHTING AND TRAFFIC CONTROL DIVISION.

CITY OF LONDON STANDARD DRAWING

SIDEWALK TRANSITION LOCATIONS AT NEW SIGNALIZED INTERSECTIONS

DWG: STS – 11.01	DATE 2014 08 23	for APPROVED BY CITY ENGINEER:	NTS



NOTE:

EACH LOCATION IS SITE SPECIFIC AND REQUIRES CONSULTATION WITH THE ROADWAY LIGHTING AND TRAFFIC CONTROL DIVISION.

CITY OF LONDON STANDARD DRAWING

SIDEWALK TRANSITION LOCATIONS AT NEW SIGNALIZED INTERSECTIONS

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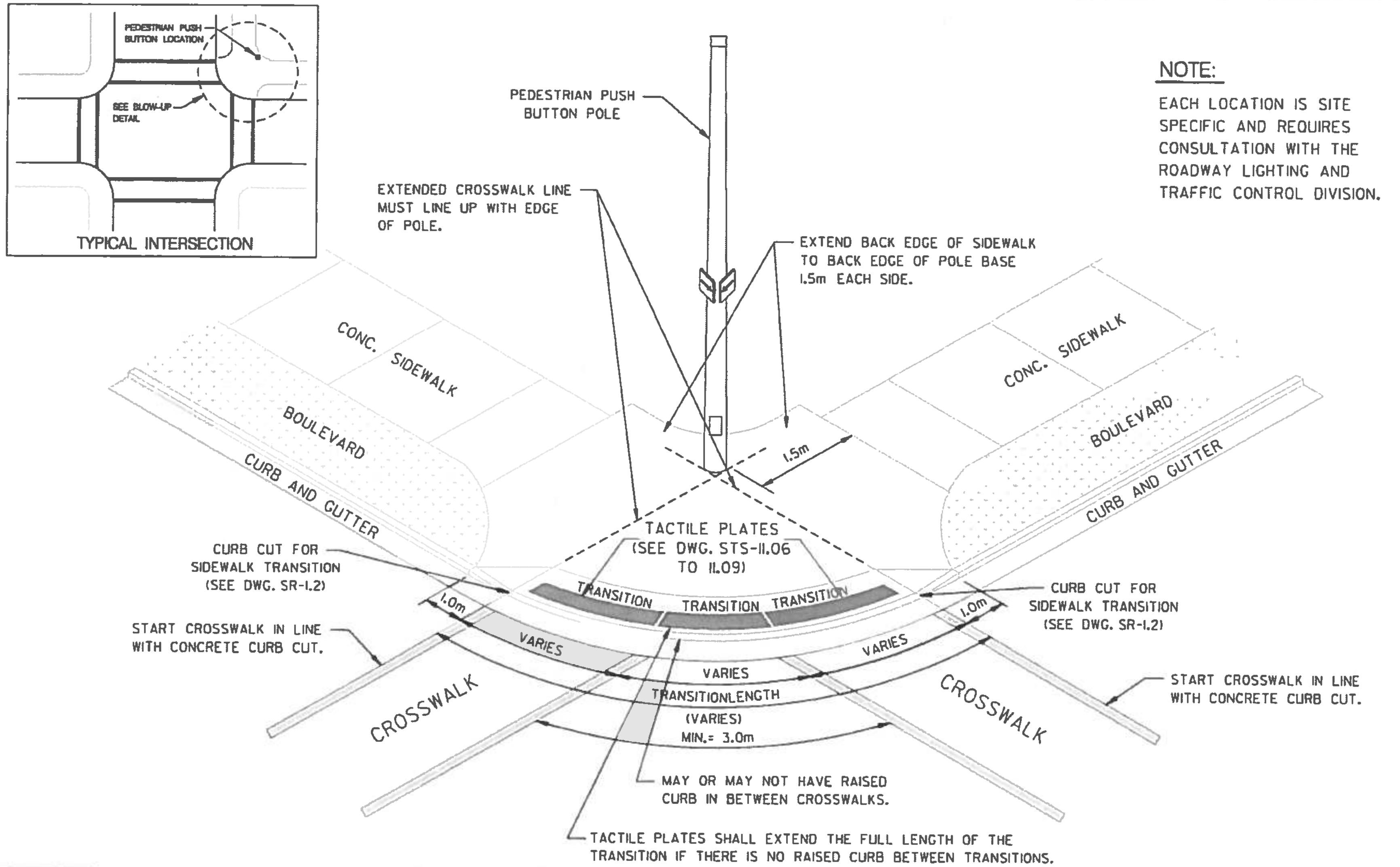


NOTE:

EACH LOCATION IS SITE SPECIFIC AND REQUIRES CONSULTATION WITH THE ROADWAY LIGHTING AND TRAFFIC CONTROL DIVISION.

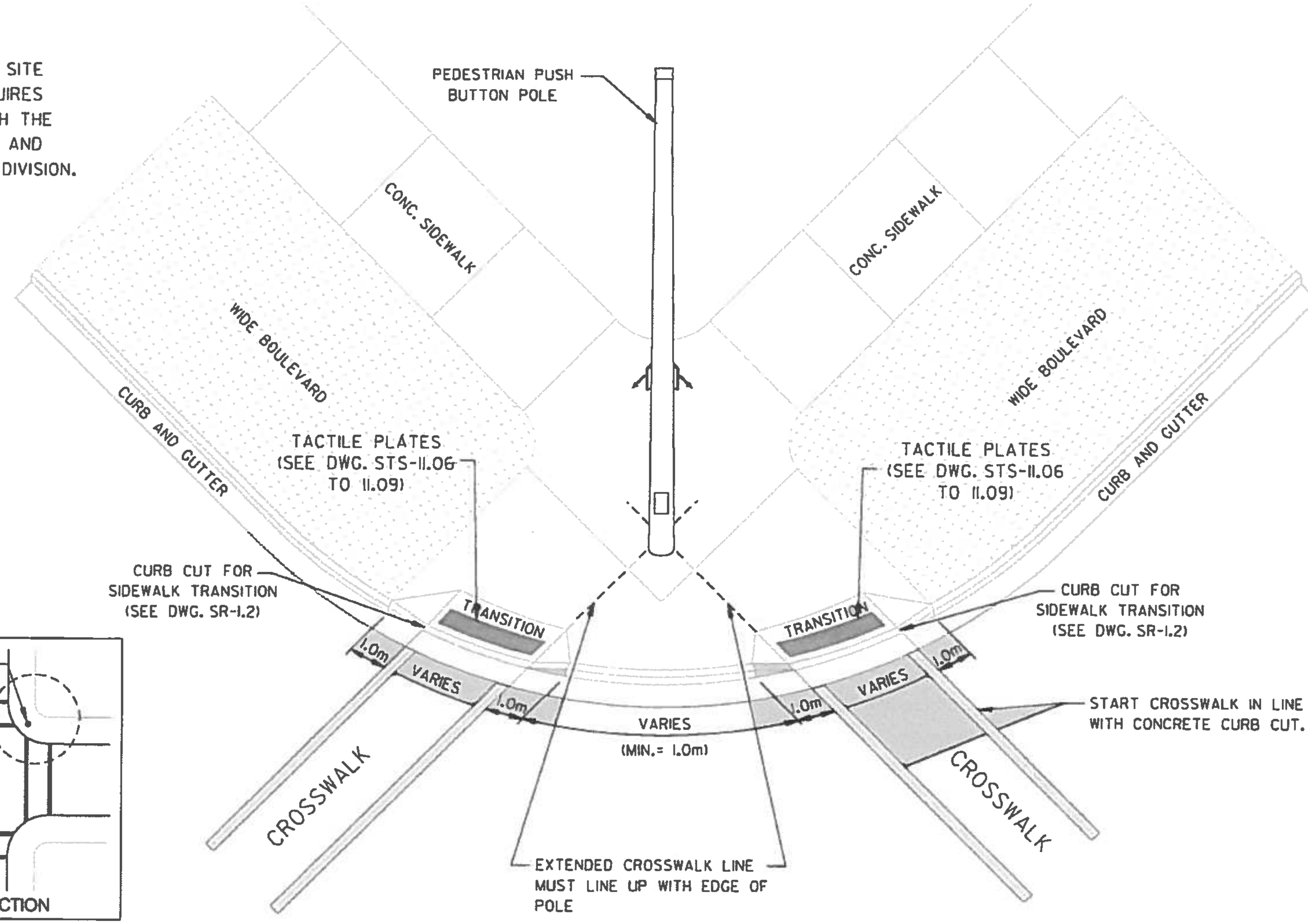
CITY OF LONDON STANDARD DRAWING

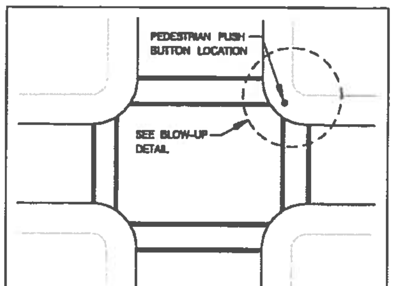
SIDEWALK TRANSITION LOCATIONS AT NEW SIGNALIZED INTERSECTIONS

DWG: STS – 11.03	DATE 2014 08 21	APPROVED BY CITY ENGINEER:	NTS

NOTE:

EACH LOCATION IS SITE SPECIFIC AND REQUIRES CONSULTATION WITH THE ROADWAY LIGHTING AND TRAFFIC CONTROL DIVISION.





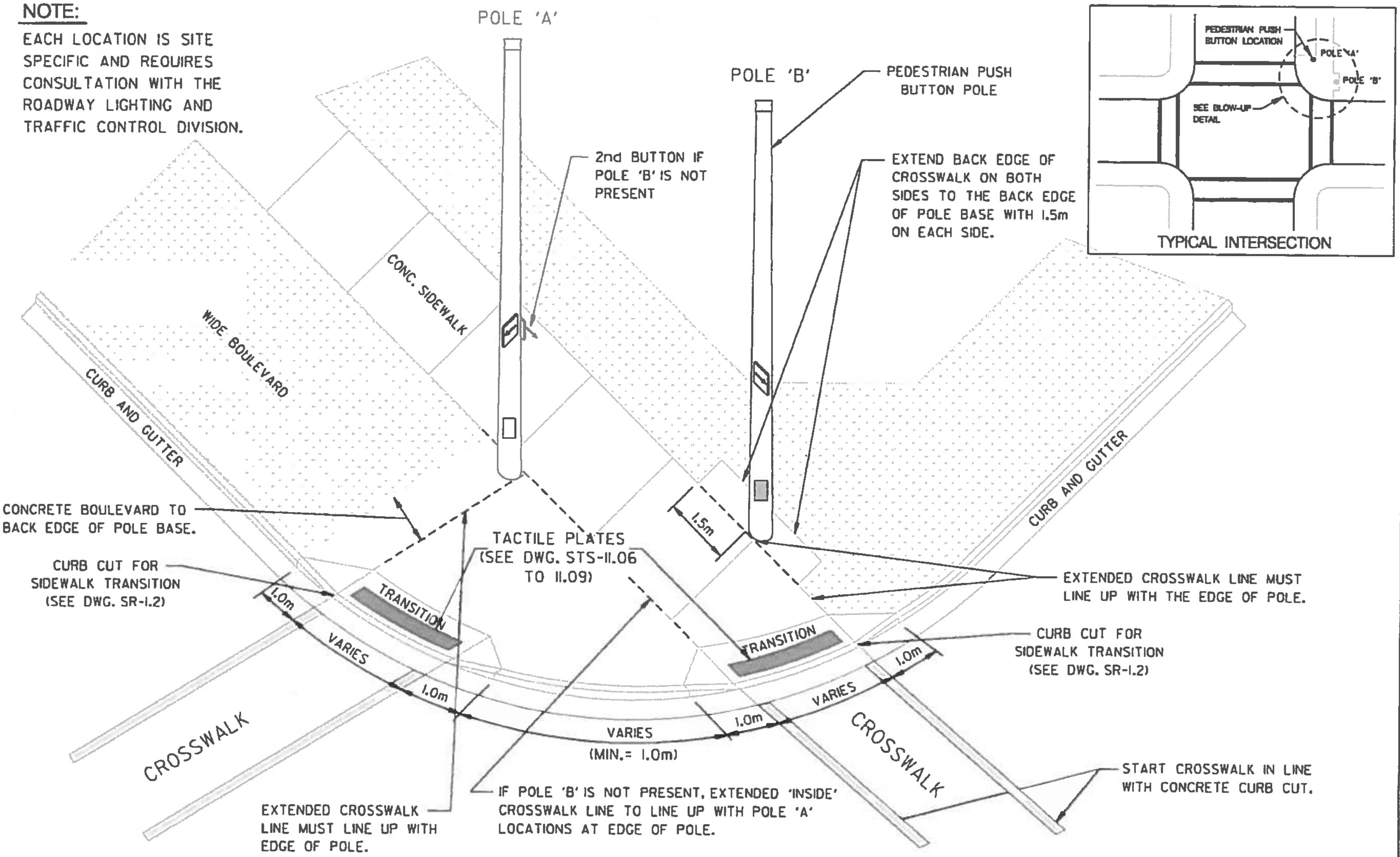
TYPICAL INTERSECTION

CITY OF LONDON STANDARD DRAWING

SIDEWALK TRANSITION LOCATIONS AT NEW SIGNALIZED INTERSECTIONS

DWG: STS – 11.04	DATE 2014 08 23	APPROVED BY CITY ENGINEER:	NTS

NOTE:
EACH LOCATION IS SITE SPECIFIC AND REQUIRES CONSULTATION WITH THE ROADWAY LIGHTING AND TRAFFIC CONTROL DIVISION.



CITY OF LONDON STANDARD DRAWING

SIDEWALK TRANSITION LOCATIONS AT NEW SIGNALIZED INTERSECTIONS

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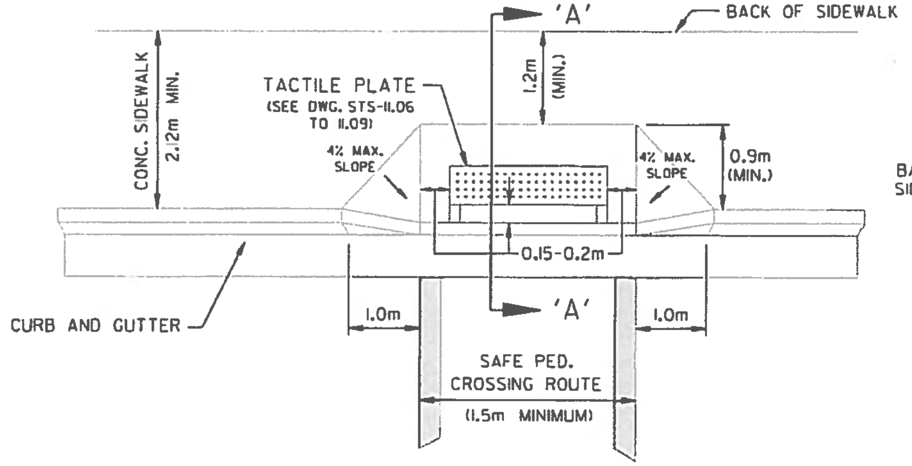
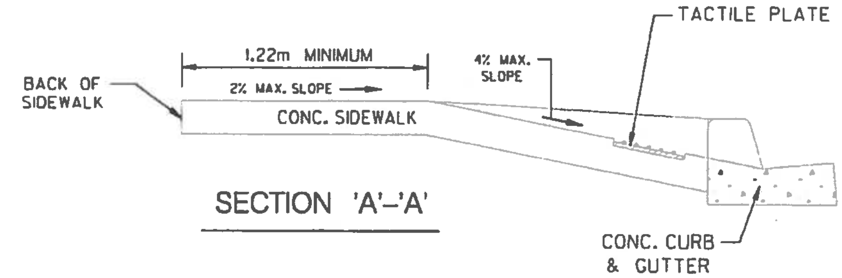
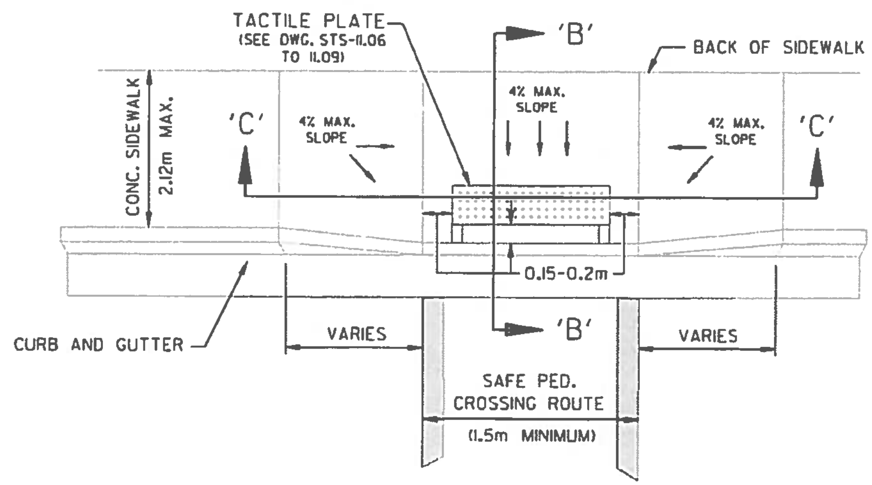


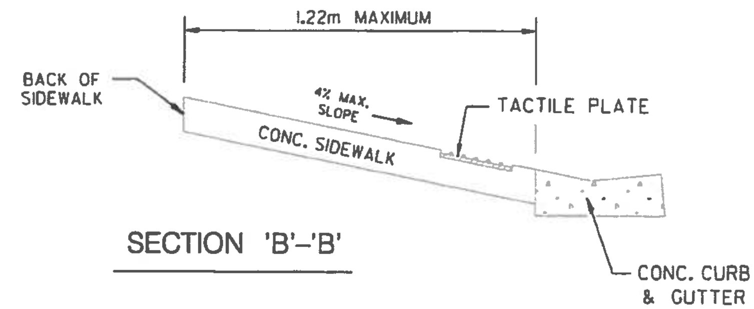
MID-BLOCK TRANSITION DETAIL



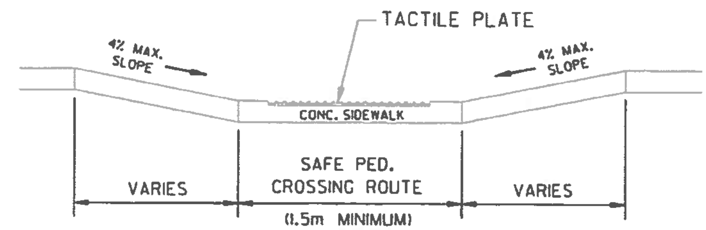
SECTION 'A'-'A'



NARROW SIDEWALK DETAIL



SECTION 'B'-'B'



SECTION 'C'-'C'

CITY OF LONDON STANDARD DRAWING

TACTILE PLATE LOCATION DETAILS AND CROSS-SECTIONS

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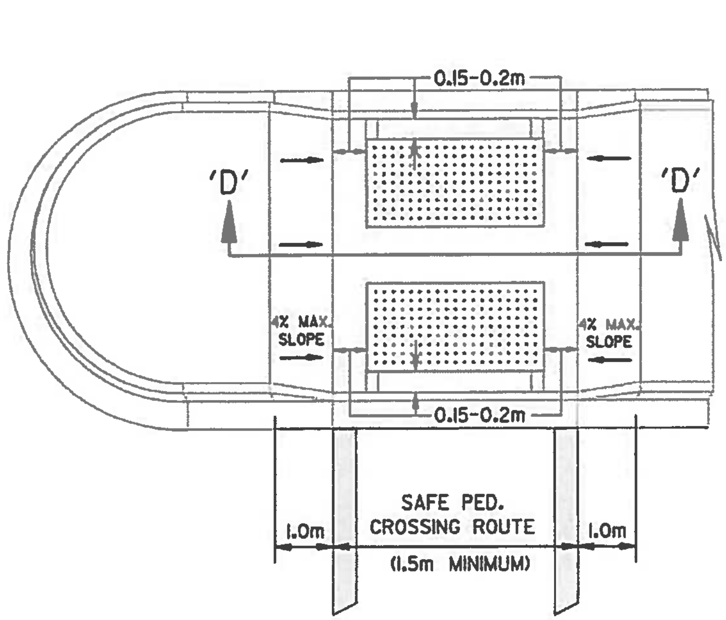
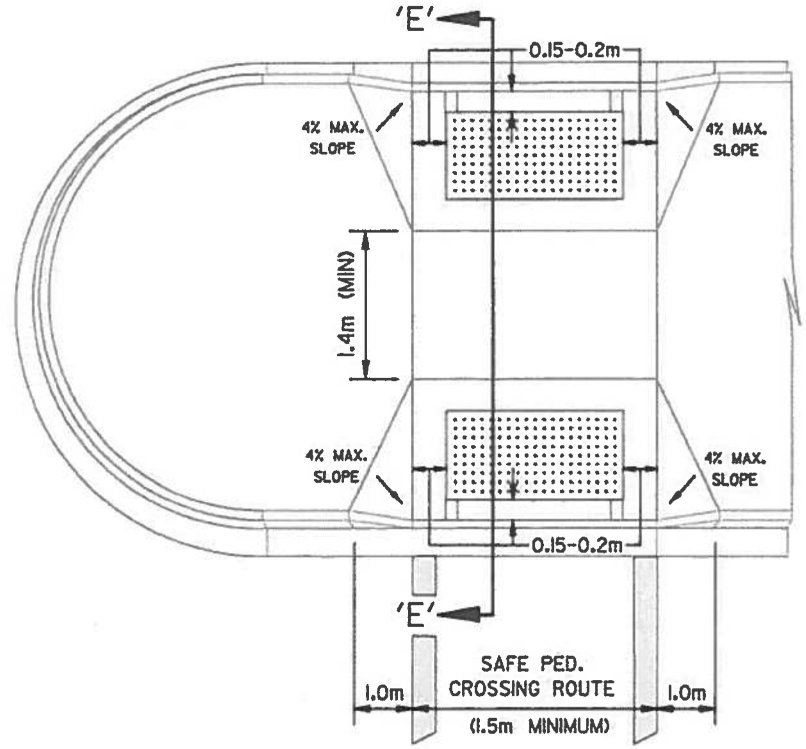
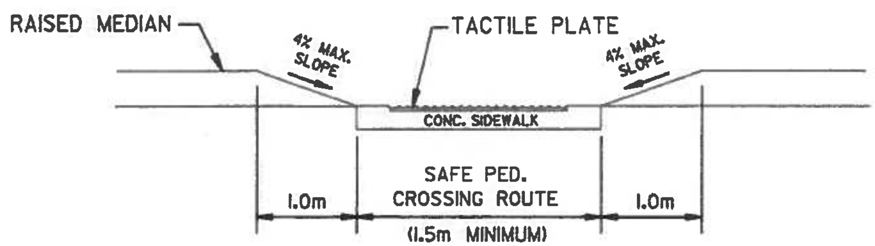


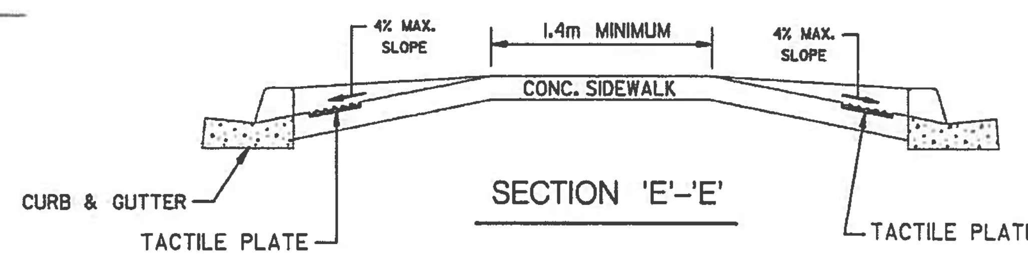
CURB RAMP AT MEDIAN
(NARROW ISLAND)



CURB RAMP AT MEDIAN
(WIDE ISLAND)



SECTION 'D'–'D'

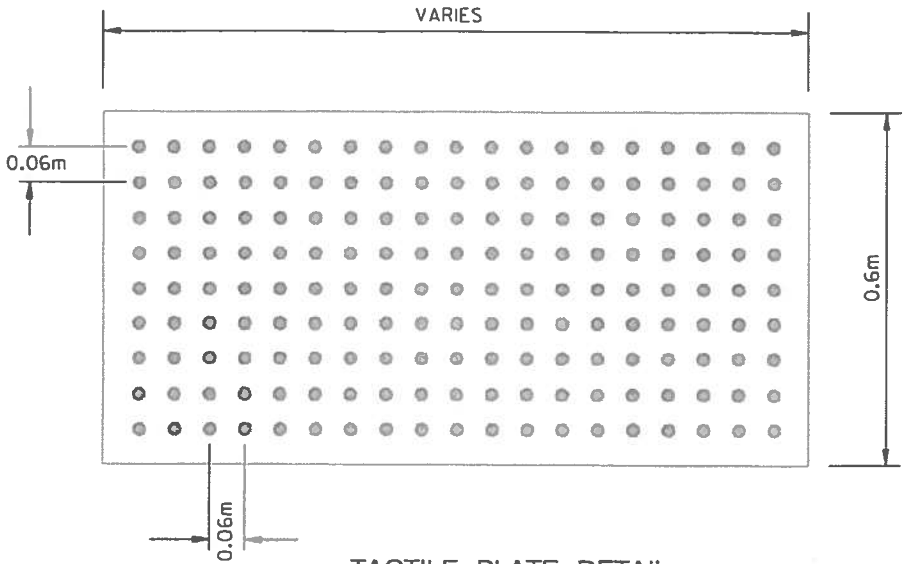


SECTION 'E'–'E'

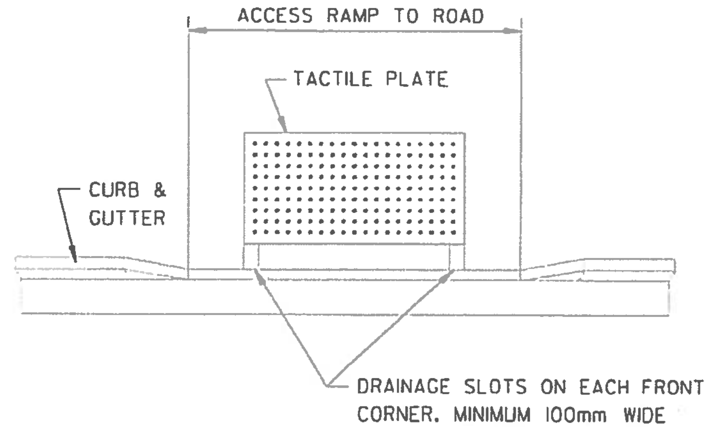
CITY OF LONDON STANDARD DRAWING

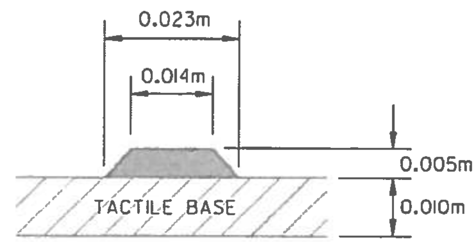
TACTILE PLATE – ISLAND LOCATIONS AND CROSS-SECTIONS

DWG: STS – 11.07	DATE 2012 08 23	APPROVED BY CITY ENGINEER:	NTS

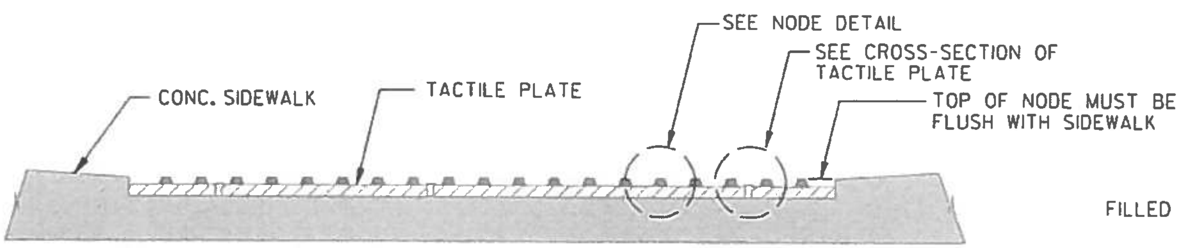


TACTILE PLATE DETAIL

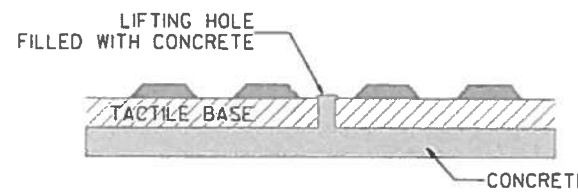




NODE DETAIL



SECTION THROUGH TACTILE PLATE



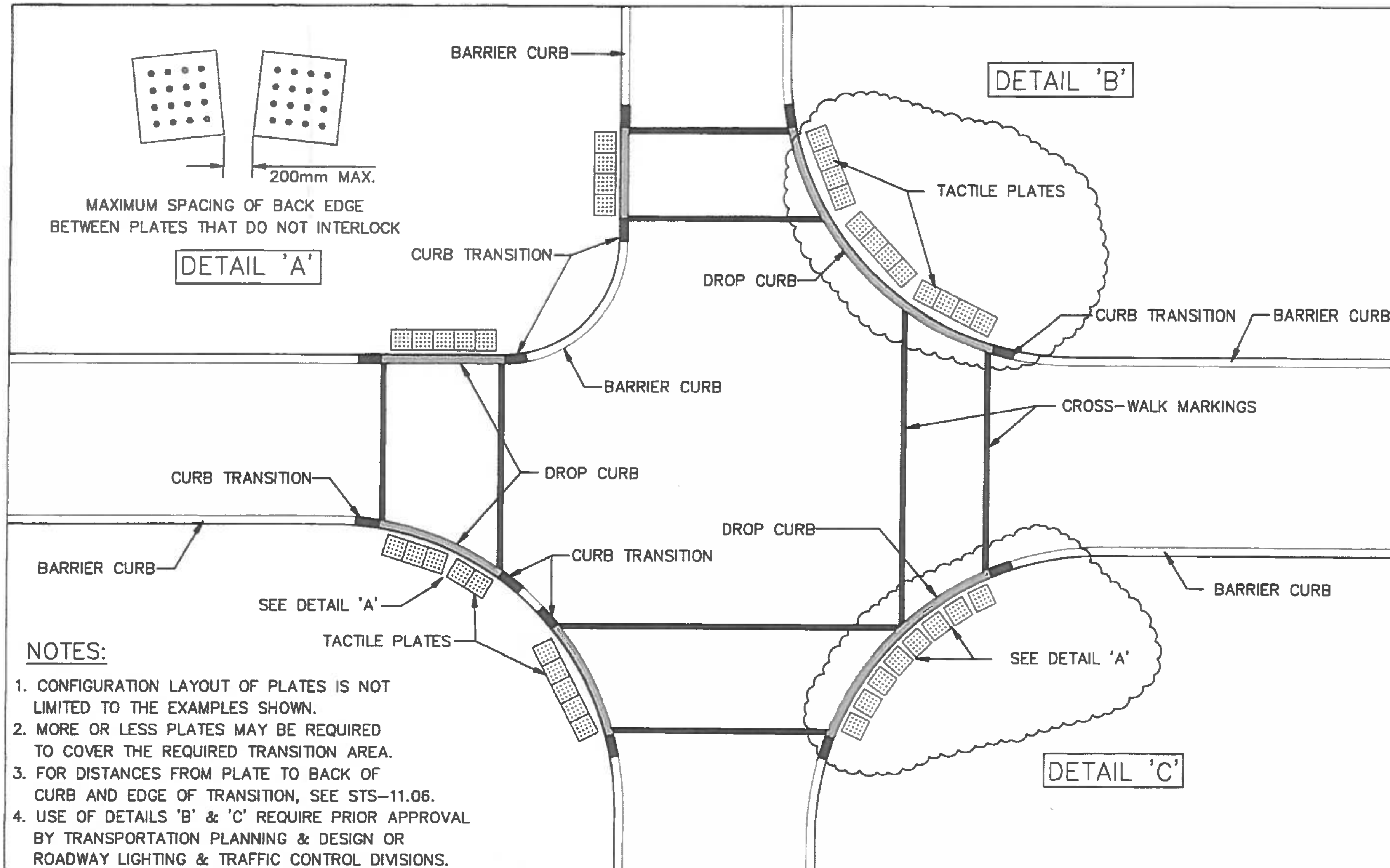
CROSS-SECTION OF TACTILE PLATE

NOTE: CONCRETE MUST PROTRUDE THROUGH ALL LIFTING HOLES AND BE WIPED FLUSH. ANY HOLES SHALL BE FILLED WITH CONCRETE CAULKING.

CITY OF LONDON STANDARD DRAWING

TACTILE PLATE DETAILS AND SECTIONS

DWG: STS – 11.08	DATE 2014 08 21	APPROVED BY CITY ENGINEER:	NTS



NOTES:

1. CONFIGURATION LAYOUT OF PLATES IS NOT LIMITED TO THE EXAMPLES SHOWN.
2. MORE OR LESS PLATES MAY BE REQUIRED TO COVER THE REQUIRED TRANSITION AREA.
3. FOR DISTANCES FROM PLATE TO BACK OF CURB AND EDGE OF TRANSITION, SEE STS-11.06.
4. USE OF DETAILS 'B' & 'C' REQUIRE PRIOR APPROVAL BY TRANSPORTATION PLANNING & DESIGN OR ROADWAY LIGHTING & TRAFFIC CONTROL DIVISIONS.

CITY OF LONDON STANDARD DRAWING

TACTILE PLATE LAYOUT

DWG: STS – 11.09	DATE 2015 02 26	APPROVED BY for CITY ENGINEER: [signature]	NTS

APPENDIX C

Safety

Officer On-Scene Reports

Intersecting Street	Time of day	Month	Weather	Type of Vehicle	No. of vehicles	Direction	Lane	Description
13th Ave.	2:26 PM	January		Passenger veh	3	NB	passing	Failing to notice vehicles stopping, rear ended
13th Ave.	1:10 PM	January		Passenger veh	2	SB	through	Stopping at yellow, vehicle behind unable to make stop
13th Ave.	1:30 PM	January		Passenger veh	2	SB	passing	stopping at yellow/red, vehicle behind unable stop
13th Ave.	7:04 PM	April		Passenger veh	2	SB + EBL	passing and left	SB driver went through red light, causing T Bone collision
13th Ave.	11:59 AM	June		Passenger veh and bicycle	2	EBR + NB	turn lane and sidewalk	Driver stopped at red light, proceeded to make right turn, was struck on passenger car door by northbound cyclist on sidewalk
13th Ave.	11:25 AM	November		Passenger veh	2	SB	passing	first vehicle waiting for red light, second vehicle is hit by behind
13th Ave.	2:09 PM	December		Passenger veh	2	SB	passing	first vehicle stopped for congestion ahead, second vehicle rear ended
13th Ave.	11:59 AM	January		Passenger veh	2	SB	passing	vehicle hit from behind on red light
13th Ave.	4:51	November		Passenger veh	4	SB	through	Stopped for city bus, vehicles rear ended causing chain reaction, damages involved
13th Ave.	10:57 PM	December		Passenger veh and pedestrian	1	NB veh	through	vehicle in car lane, pedestrian crosses without right of way could have been making right turn
13th Ave.	3:17 PM	January		Passenger veh	2	SB	through	stopping for city bus, driver attempts to switch lanes and car coming behind rear ends
13th Ave.	11:37 AM	December		Passenger veh	3	SB	through	all stopping for red light, unable to make stop, 2 cars rear ended

Intersecting Street	Time of day	Month	Weather	Type of Vehicle	No. of vehicles	Direction	Lane	Description
12th Ave.	7:56 PM	September		Passenger veh	2	NB	suicide/passing	vehicle turning out of driveway clips side of car passing through, vehicle hit, ends up in suicide lane

Intersecting Street	Time of day	Month	Weather	Type of Vehicle	No. of vehicles	Direction	Lane	Description
11th Ave.	9:53 AM	March		Passenger veh	1	SB	Passing	Vehicle veers away from traffic cone, hits street pole
11th Ave.	11:29 AM	August		passenger veh	2	SBL + NB	Left + through	car turning misjudged gap in traffic. T Bone collision
11th Ave.	11:50 AM	December		Passenger veh	2	SBL + NB	Left + Passing	vehicle turning lost traction and was struck by straight through
11th Ave.	8:00 AM	April		Passenger veh	1	SB	Passing	vehicle could not keep control in slush, could not go into through lane, hit median sign
11th Ave.	3:30 PM	September		Passenger veh	2	NB	Passing	first vehicle stopping for traffic ahead, second vehicle rear ends
11th Ave.	8:00 AM	January		Passenger veh	2	SB + EB	Passing	Vehicle going SB failed to stop at red light, then EB traveled forward and hit the side on green
11th Ave.	2:11 PM	March		Passenger veh	2	SBL + NB	Left + through	Vehicle turned when unsafe to do so
11th Ave.	11:50 AM	June		Commercial veh	1	WBR	right	vehicle making right turn, hopped curb and hit light post
11th Ave.	6:56 PM	August		Passenger veh	2	SB + EB	through	vehicle proceeds SB through red, and is struck by EB vehicle proceeding through green
11th Ave.	5:40 PM	December		Passenger veh	2	SBL + NB	left + passing	Vehicle turning left cut off NB vehicle which collided with side of
11th Ave.	2:55 PM	December		Passenger veh	2	NB	through	vehicle stopped at red and was rear ended by vehicle in behind

Intersecting Street	Time of day	Month	Weather	Type of Vehicle	No. of vehicles	Direction	Lane	Description
10th Ave.	9:40 AM	June		Passenger veh	2	NB	Passing	Construction zone, merging into passing lane, collided into rear of vehicle
10th Ave.	3:20 PM	August		Passenger veh	2	SBL + SB	Left + Passing	vehicle stopped waiting to turn left and is side swiped by distracted driver
10th Ave.	12:23 PM	January		Passenger veh	2	SBL+EBL	Left + Left	vehicle SB waiting in turn lane, then vehicle turning from 10th drove into
10th Ave.	3:25 PM	January		Passenger veh	5	NB	Passing	Series of rear ended accidents
10th Ave.	1:39 PM	July		Passenger veh and pedestrian	1	SB	Through	Lost control went up on the sidewalk hit pedestrian (approx. 50 km/h)

Intersecting Street	Time of day	Month	Weather	Type of Vehicle	No. of vehicles	Direction	Lane	Description
Central Ave.	10:57 PM	March		Passenger veh	1	SB	Through	lost control, hit esso entrance, impaired
Central Ave.	1:12 AM	September		Passenger veh	2	SB	Through + Passing	through lane attempting to get to passing lane, side swipes vehicle
Central Ave.	9:56 PM	August		Passenger veh	2	NBL+SB	Left + Through	turned left and didn't have the space to do so

Self Reports

Intersecting Street	Time of day	Month	Type of Vehicle	No. of Vehicle	Weather	Light	road surface condition	road pavement marking	Driver Action	Drive Condition	Direction	impact type	Vehicle Action
13th Ave.	7:40 PM	November	Passenger Veh	2	snow	dark	slush	exists		had been drinking	SB	rear end	slowing/stopping
13th Ave.	1:15 PM	February	Passenger Veh	4	snow	daylight	loose snow/ice	obscured	slid on ice	normal	NB	rear end	slowing/stopping
13th Ave.	3:35 PM	January	Passenger Veh	2	clear	daylight	ice	obscured	following to close	normal	NB	rear end	going ahead
13th Ave.	8:10 PM	February	Passenger Veh	2	clear	dark	slush/ice	obscured	following to close	normal	SB	rear end	going ahead/turning right
13th Ave.	1:15 PM	December	Passenger Veh	2	snow	daylight	ice	obscured	careless driving	normal	SB	rear end	slowing/stopping
13th Ave.	12:15 PM	December	Passenger Veh	2	clear	daylight	slush/ice	obscured	speed to fast for conditior	normal	SB	rear end	slowing/stopping
Intersecting Street	Time of day	Month	Type of Vehicle	No. of Vehicle	Weather	Light	road surface condition	road pavement marking	Driver Action	Driver Condition	Direction	impact type	Vehicle Action
11th Ave.	2:25 PM	March	Passenger Veh	2	clear	daylight	wet/packed snow	exists/obscured	driving properly	normal	NB	rear end	going ahead
11th Ave.	12:20 PM	February	Passenger Veh	2	snow	daylight	packed snow	obscured	speed to fast for conditior	normal	NB	rear end	slowing/stopping
11th Ave.	12:30 PM	January	Passenger Veh	2	clear	daylight	dry	obscured	driving properly	normal	NB	rear end	stopped
11th Ave.	5:00 PM	December	Passenger Veh	2	clear	dusk	ice/wet	exists/obscured	following to close	normal	NB	rear end	going ahead
11th Ave.	2:00 PM	August	Passenger Veh	2	mist/rain	daylight	wet	exists	driving properly	normal	SB	rear end	stopped
11th Ave.	5:25 PM	May	Passenger Veh	2	clear	daylight	dry	exists	looked away for a second	normal	NB	rear end	going ahead
11th Ave.	8:20 PM	December	Passenger Veh	2	clear	dark	wet	exists	following to close	normal	NB	rear end	slowing/stopping
11th Ave.	5:15 PM	August	Passenger Veh	2	clear	daylight	dry	exists	following to close	inattentive	SB	rear end	stopped
11th Ave.	3:03 PM	July	Passenger Veh	2	rain	daylight	wet	exists	following to close	normal	SB	rear end	going ahead
11th Ave.	4:45 PM	January	Passenger Veh	2	clear	daylight	ice	obscured	-	normal	SB	rear end	slowing/stopping
Intersecting Street	Time of day	Month	Type of Vehicle	No. of Vehicle	Weather	Light	road surface condition	road pavement marking	Driver Action	Driver Condition	Direction	impact type	Vehicle Action
10th Ave.	10:30 AM	November	Passenger Veh	3	snow/freezing rain	daylight	ice	obscured	following to close	normal	NB	rear end	slowing/stopping
Central Ave.	4:35 PM	October	Passenger Veh	2	clear	daylight	dry	exists	driving properly	normal	NB	side swipe	changing lanes

APPENDIX D

Simulations and Additional Files

See the disk provided for access to Appendix D

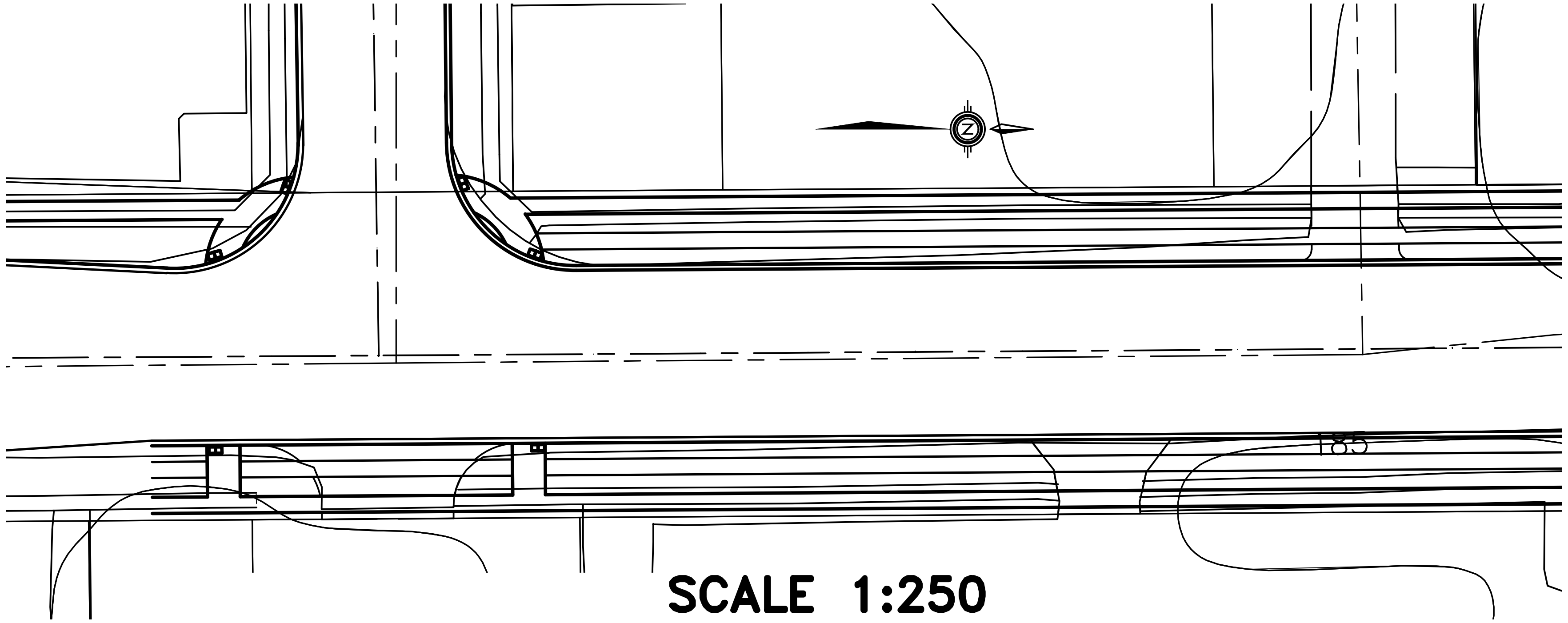
APPENDIX E

Super Elevation Calculation

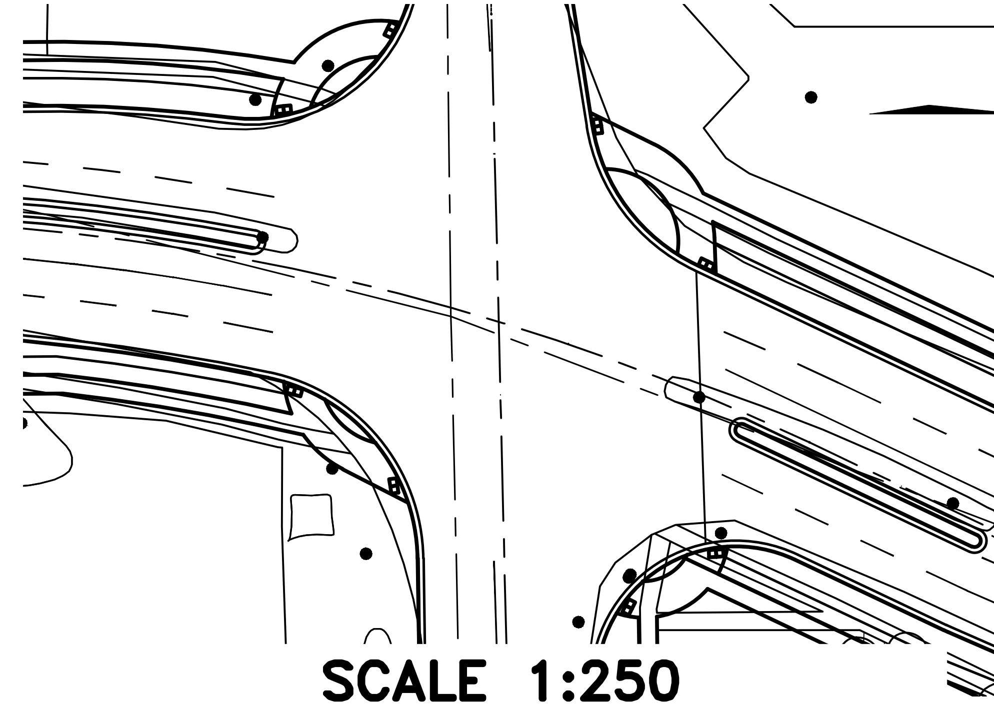
Superelevation Curve	Start Station	End Station	Length	Left Outside Lane	Curve Smoothing(L...	Left Inside La...	Curve Smooth...	Right Inside Lane	Curve Smoothi...	Right Outside La...	Curve Smoothing
Curve.1											
Transition In Region	10+96.51m	11+48.51...	52.000m								
Runout	10+96.51m	11+09.51...	13.000m								
End Normal Cro...	10+96.51m			-2.00%	20.000	-2.00%	20.000	-2.00%	20.000	-2.00%	20.000
Level Crown	11+09.51m			0.00%	20.000	0.00%	20.000	-2.00%	20.000	-2.00%	20.000
Runoff	11+09.51m	11+48.51...	39.000m								
Level Crown	11+09.51m			0.00%	20.000	0.00%	20.000	-2.00%	20.000	-2.00%	20.000
Reverse Crown	11+22.51m			2.00%	20.000	2.00%	20.000	-2.00%	20.000	-2.00%	20.000
Begin Curve	11+35.51m										
Begin Full Super	11+48.51m			6.00%	20.000	6.00%	20.000	-6.00%	20.000	-6.00%	20.000
Transition Out Region	12+08.58m	12+60.58...	52.000m								
Runoff	12+08.58m	12+47.58...	39.000m								
End Full Super	12+08.58m			6.00%	20.000	6.00%	20.000	-6.00%	20.000	-6.00%	20.000
End Curve	12+21.57m										
Reverse Crown	12+34.58m			2.00%	20.000	2.00%	20.000	-2.00%	20.000	-2.00%	20.000
Level Crown	12+47.58m			0.00%	20.000	0.00%	20.000	-2.00%	20.000	-2.00%	20.000
Runout	12+47.58m	12+60.58...	13.000m								
Level Crown	12+47.58m			0.00%	20.000	0.00%	20.000	-2.00%	20.000	-2.00%	20.000
Begin Normal C...	12+60.58m			-2.00%	20.000	-2.00%	20.000	-2.00%	20.000	-2.00%	20.000

APPENDIX F

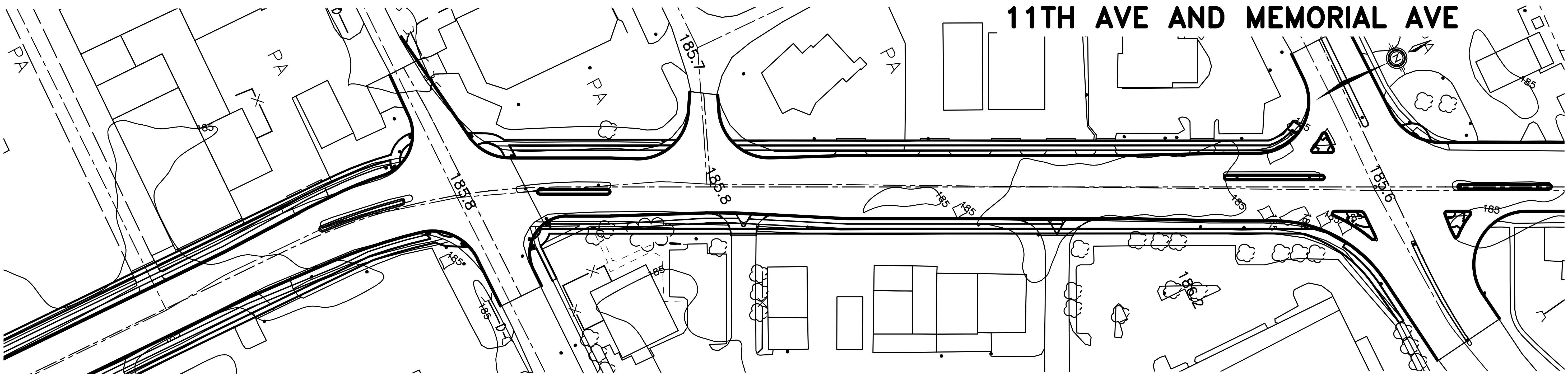
Reduced Preliminary Drawings



SCALE 1:250
MEMORIAL AVENUE – STA 1+105 TO SOUTH LIMIT



SCALE 1:250
PROTECTED INTERSECTION AT
11TH AVE AND MEMORIAL AVE



SCALE 1:500
MEMORIAL AVENUE – NORTH LIMIT TO STA 1+070

Z:\Eng\

ALL DIMENSIONS AND ELEVATIONS ARE IN UNITS OF METRES UNLESS OTHERWISE NOTED.
ALL PIPE DIAMETERS ARE IN UNITS OF MILLIMETRES UNLESS OTHERWISE NOTED.

	NAME	DATE
DRAWN BY	LRG	MAR. 2016
TRACED BY		
CHECKED BY	JRC	MAR 2016
APPROVED BY	SRI	MAR 2016
APPROVED BY		
SCALE	HORIZ. VARIES VERT.	

CITY OF Thunder Bay Superior by Nature

ENGINEERING DIVISION

TITLE
MEMORIAL AVENUE
PLAN VIEW
CENTRAL AVENUE TO 13TH AVENUE

MANAGER, ENGINEERING DIVISION

FILE NO.

SIZE E

SHEET NO. 03 OF ___ SHEETS

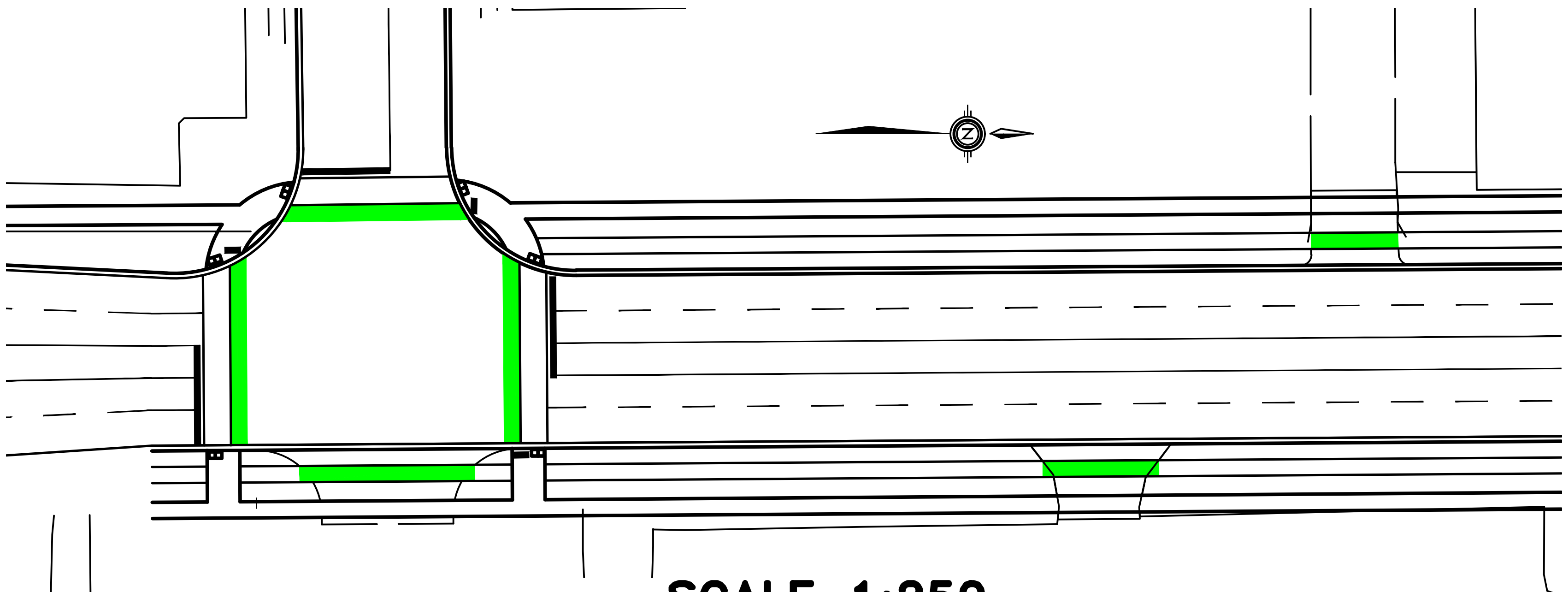
CONTRACT NO. :

WORK CHECKED BY THE FOLLOWING UTILITIES	UTILITY	T.B. HYDRO	TBAYTEL	UNION GAS	SHAW CABLE	
	CHECKED BY					
	DATE					

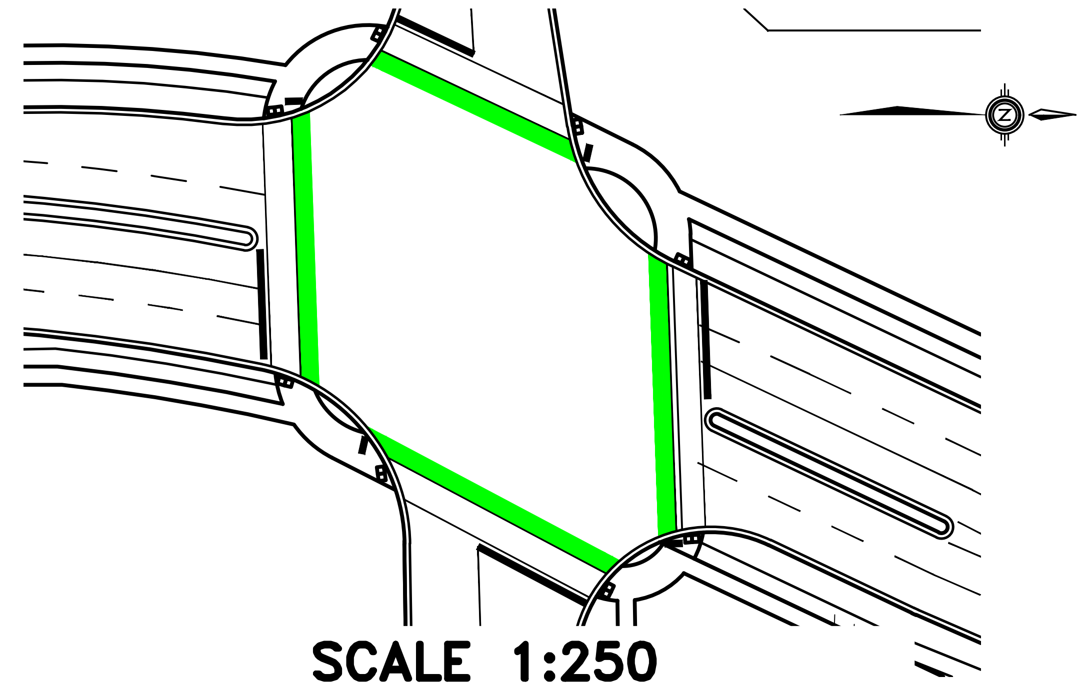
REVISION: C | B | A

APPROVED BY M.O.E.
SEWER–CERT. NO. ____
WATER–CERT. NO. ____

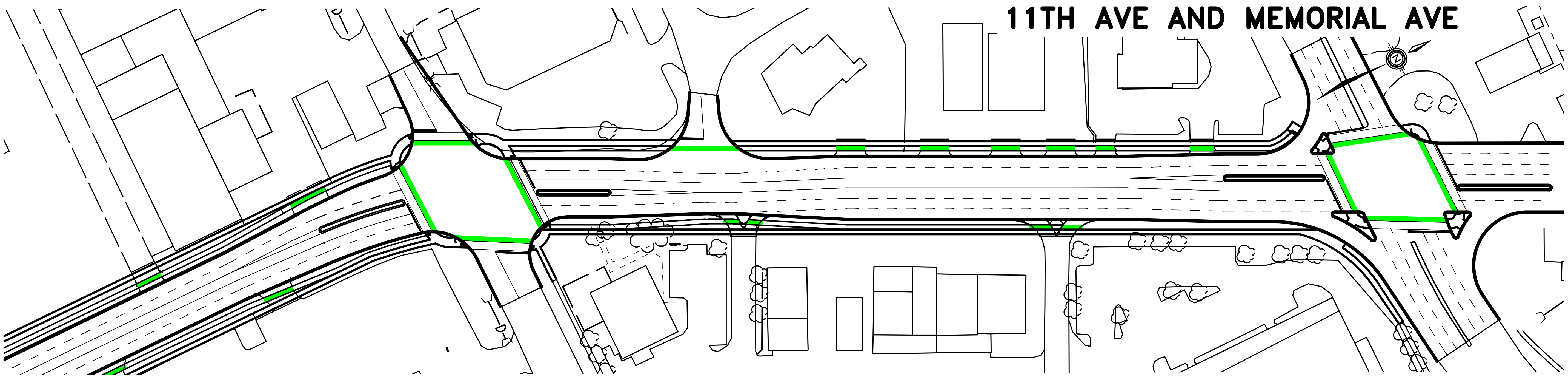
BENCH MARKS
GEODETIC DATUM



SCALE 1:250
MEMORIAL AVENUE – STA 1+105 TO SOUTH LIMIT



SCALE 1:250
PROTECTED INTERSECTION AT
11TH AVE AND MEMORIAL AVE



SCALE 1:500
MEMORIAL AVENUE – NORTH LIMIT TO STA 1+070

Z: \Eng\

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	NAME	DATE
DRAWN BY	LRG	MAR. 2016
TRACED BY		
CHECKED BY	JRC	MAR 2016
APPROVED BY	SRI	MAR 2016
APPROVED BY		
SCALE	HORIZ. VARIES VERT.	

CITY OF Thunder Bay Superior by Nature — ENGINEERING DIVISION

TITLE: **MEMORIAL AVENUE**
PAVEMENT MARKINGS
CENTRAL AVENUE TO 13TH AVENUE

MANAGER, ENGINEERING DIVISION — FILE NO. — SIZE E

WORK CHECKED BY THE FOLLOWING UTILITIES	UTILITY	T.B. HYDRO	TBAYTEL	UNION GAS	SHAW CABLE	
	CHECKED BY					
	DATE					

C | B | A | REVISION

APPROVED BY M.O.E.
SEWER-CERT. NO. ______
WATER-CERT. NO. ______

BENCH MARKS
GEODETIC DATUM

SHEET NO. 03 OF ___ SHEETS

CONTRACT NO. :