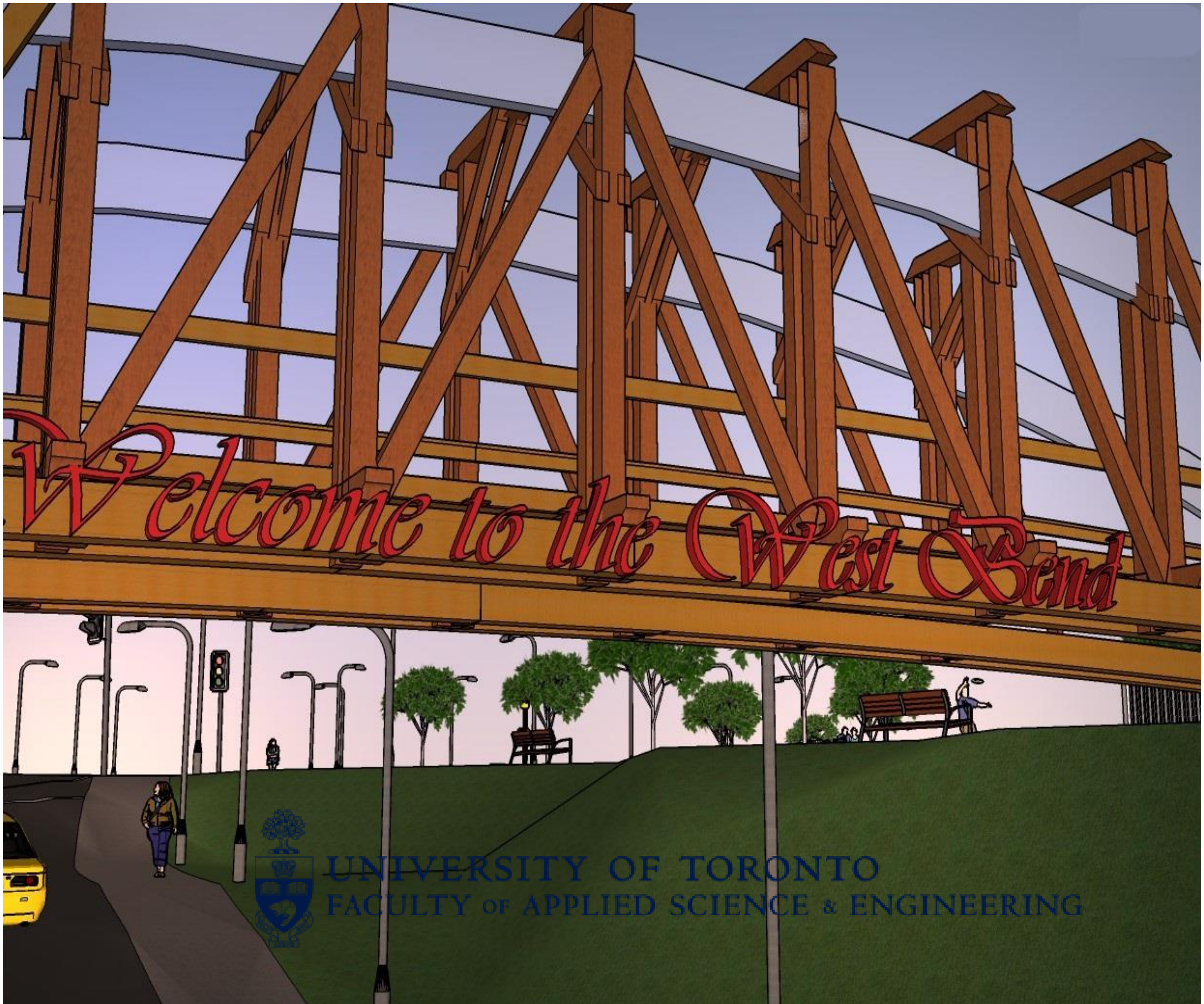

Dundas/Dupont/Annette Intersection Redesign

University of Toronto

Faculty of Applied Science and Engineering

Prepared by: Nikola Kostic, Amy Wang, Adrian Cheung, Susan Lu, Yanbo Wang

4/1/15

West Bend Community Association

Engineering Strategies and Practices

University of Toronto
Faculty of Applied Science and Engineering
APS112 & APS113
Final Design Specification (FDS)

Project #	83	Submission Deadline: April 1, 2015

Project Title	Dupont/Annette/Dundas St. West Intersection Redesign
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Please check off which components have been submitted in this report:
_X FDS (Final Design Specification)

- _X Cover Page
- _X Executive summary
- _X Project Requirements
- _X Detailed Design
- _X Updated Project Plan
- _X Conclusion
- _X Reference List
- _X Appendices

If any of the above components are missing, this report is considered incomplete.

Executive Summary

The current Dundas St. West/Dupont St./Annette St. intersection has failed to regulate modern traffic flow safely and efficiently. Traffic is forced to make dangerous turns with no clear line of sight while pedestrians and cyclists are made to compete with motorized vehicles for road space, producing a dangerous, unwelcoming, stressful environment for users and local residents alike.

In order to succeed in moderate Canadian climatic conditions and amongst a large driving population while addressing the charitable, economic, regulatory, and community concerns of NGOs, businesses, municipal governments, and local residents, the design must perform the following main functions:

- separate and move mass
- control the safe passage of vehicles, cyclists, and pedestrians
- reroute traffic between 4 adjoining roads

Key design objectives include a low maintenance cost of $13,500/year and the causation of no more than 13.8 annual accidents while the strict limits the design must adhere to include:

➢ Cost less than $30 million
➢ Safely handle 29,392 vehicles and 1,962 pedestrians per day
➢ Abide to all relevant laws and bylaws imposed by governmental bodies

The engineering team has developed a proposed design which meets these requirements optimally:
<u>Island Dugout Master Plan</u> - digs a ramp through the central island, regularizes intersection

- gateway bridge constructed and park space expanded to attain aesthetic goals
- outstanding safety due to controlled separation of traffic but pedestrians, cyclists still have to pass through underpass

The *<u>Island Dugout Design</u>* is a cost effective, safe, and accessible design. Total cost is estimated at $608,000 with a total implementation time of just under 2 years. The intersection has been regularized to a 64° intersect angle, with 4 lanes on all adjoining streets where they arrive at the central intersection. Dupont progressively narrows to 2 lanes immediately before entering the underpass. Dedicated bike lanes run East-West on Annette-Dupont and a sharrow exists Northbound on Dundas. Pedestrians and cyclists are elevated above the road surface for the duration of the underpass. Traffic signal timing has been optimized with a 154 second cycle length.

The design satisfies the vital regulations imposed by municipal zoning laws and the federal Highway Traffic Act. Implementation is planned in accordance with the Environmental Protection Act. The following tests are planned to ensure the design is safe and accessible for all users:

- Safety - water resistance test, bridge deck strength test, failure test of asphalt
- Accessibility - signal and marking in full ASTM D713-12 standard compliance, road surface roughness test
- Durability - asphalt surface resistance test

Implementation of the design hinges on obtaining City of Toronto funding, performing a site survey, excavating the island, filling the Dupont ramps, a detailed lane remarking and signal installation, gateway bridge installation, and park expansion - all to ultimately increase community image and safety.

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1.0 Project Requirements

This project is intended to help the West Bend Community Association (WBCA) integrate the historically industrial Dundas St. West/Dupont/Annette intersection into the modern West Bend community.

1.1. Problem Statement

The ability of Toronto's Dundas St. West/Dupont/Annette (DDA) intersection to safely handle traffic is compromised by irregular turns, steep inclines, and a lack of adequate lane separation [1][2]. Furthermore, narrow sidewalks and a stranded pedestrian island have made the intersection an obstacle to foot traffic [3]. These unsafe conditions have resulted in 92 accidents over the last 4 years and decreased residents' confidence in neighbourhood safety [4][3].

The WBCA requires an intersection redesign that will regularize traffic flow and minimize accidents. The design must process 2013.9 vehicles/hour and 134.8 pedestrians/hour and should accommodate users with disabilities [5][6][7][8]. It must keep the number of collisions per year under 13.8 [4]. The design shall preserve a maximal amount of green space and should incorporate existing infrastructure as much as possible. The design must control traffic flow and optimize the passage of vehicles, pedestrians and cyclists. The design must also channel this mass without impeding movement of pedestrians. Mass must be moved without experiencing any plastic deformation.

Fundamentally, the design must separate and move mass, allowing for the free and safe movement of people and their vehicles.

1.2. Identification of Stakeholders

Primary stakeholders include local residents and businesses concerned about community safety and economic development.

Table 1. Stakeholder Interests and Design Impacts

Stakeholder	Interests	Impact on Project Requirements
Local residents, businesses Coffee shops, auto repair chains [3].	• maintaining safe, clean, neighbourhood conducive to business, not foreboding • increasing customer base	*unintended functions:* minimize crime rate, increase transient customer base *objective:* low maintenance, high ease-of use
Municipal Government City of Toronto regulatory bodies. Relevant subsidiaries include Metrolinx Transit [9].	• supporting region's sustainable development • optimize public spending • improving local quality of life • whether design meets all regulations [10]	*constraints:* meet all legal construction requirements, guidelines [10] *objective:* should be cost effective
Toronto Transit Organizations Toronto Transit Commission operates public transit through intersection [11].	• values safety, reliability, efficiency of roads • improve coordination between vehicles to minimize costs, optimize routes [12]	*objective:* should minimize intersection travel time
NGOs Ontario Association of Landscape Architects, streetARToronto Project, Toronto Environmental Alliance, Cycle Toronto [13][14][15].	• develop community, park space • concern regarding protection of city greenbelt • minimize design's carbon footprint • concern for cyclist safety	Consider implied use of design, effect on drivers' decisions. • relevant to safety *objective:* reduce vehicle CO_2 emissions
Commercial Architects Nature Hills, City Gardens, Brown and Storey, may perform aesthetic redesign [16][17][18].	• interest in future area redesigns, manufacturing fencing, walkways, etc.	Consider integrating existing infrastructure.

Engineering Strategies and Practices

1.3. Functions

The main function is to move vehicles between adjoining roads. Listed below are functions the design must perform (supporting functions included for clarity).

1.3.1. Functional Basis

The basic functionality is to separate mass (Appendix A).

1.3.2. Primary Functions

The design will perform the listed basic functions:

- channel movement of mass
    - connect adjoining roads
    - restrict movement to appropriate paths

- control safe passage of vehicles, pedestrians, cyclists
    - separate mass
    - regulate timing of movement of mass

- enable movement of pedestrians
    - receive input information on desired crossing time, location, destination
    - modify path

1.3.3. Secondary Functions

The design will have the following resultant functions:

- allow mass to enter and exit system
    - transport between adjoining roads

- deliver undamaged vehicles as an end product
    - personal vehicles, trucks, bicycles, persons

- channel accumulated rainwater and debris

1.3.4. Unintended Functions

The following functions exist unintentionally:

- lose energy to heat, sound, light
- increase area traffic density
    - improve area businesses' customer base
        - increase number of passersby

1.4. Objectives

The most important objective is safety, due to abnormally high accident rate, while ease-of-maintenance ranks last (Appendix B).

<u>Safe</u>

- fewer than 13.8 accidents annually [4]

<u>Should be accessible to pedestrians, cyclists, disabled</u>

- should handle minimum of 72 cyclists/hour [2]
- handle at least 246 pedestrians/hour [22][5]

<u>Cost-Effective</u>

- should cost less than $19.7 million (Appendix C)[19]
    - minimal expropriation of private property [20]
    - reconstruction should last less than 1.3 years [21]

<u>Durable</u>

- should last minimum of 10 years without major repairs [23][24]

<u>Easy to Maintain</u>

- maintenance costs should not exceed $13,350/year (major repair costs exclusive)[4]
- spaces tidy, accessible: no debris, waste

<u>Environmental Friendliness</u>

- should minimize amount of waste produced
    - by pedestrians, motorized vehicles, nearby facilities
    - car exhaust generated should not exceed 612 kg/hr (Appendix D)[25]
- encourage growth of trees, greenery
    - minimum of 6 trees planted [26]

<u>Harmony of Proportions</u>

- open, welcoming design
- should encourage pedestrian use by optimizing space usage for safety
    - 26% of road space allotted to pedestrians [63]

1.5. Constraints

Key limits are a cost of $30 million and all Ontario Road Standards.

1. Total cost of implementation must be under $30 million [19].

2. Shall abide by city of Toronto by laws (Appendix E), including <u>*Pavement Structural Design Guideline*</u>[27][28], <u>*Pavement Structural Design Matrix*</u>[30], <u>*Ontario Provincial Standards for Roads and Public Works*</u>[31], <u>*Highway Traffic Act*</u>[32], <u>*Motor Vehicle Safety Act*</u>[33], and <u>*Motor Vehicle Transport Act*</u>[34].

3. Must handle 29,392 vehicles and 1,962 pedestrians/day [22][7][8].

Engineering Strategies and Practices

1.6. Service Environment

Service environment is primarily characterized by a continental climate and a large local driving population of 53,277.

Table 2. Virtual Environment

Virtual Environment		**Impact on Design**
Traffic Flow	• Daily motorist, pedestrian volume: 29,392, 1962 respectively [22] • 24 cyclists/hour [2]	-adjust directional capacity for peak times
Traffic Signal Timing	• 110 second cycle length [34][35]	
Accidents and Collisions	• 69 collisions over 4 year period from June. 2010 to June. 2014 [34] ○ 2 collisions involved pedestrians [34]	-separate vehicles
Number of local businesses	• 6 in immediate proximity [2] ○ north and west side	-accommodate parking space

Table 3. Physical Environment

Physical Environment		**Impact on Design**
Climate	• Semi-continental climate characterized by cold winters, humid summers [36]	
Temperature	• Range -24.4 to 36.9℃ [37] ○ Average temperature 8.7℃ [37]	-protect road surface from temperature changes
Precipitation	• Maximum 66.0mm/day [37] • Snowfall maximum 30.6cm/day [37]	-channel rainwater runoff
Humidity	• 47.9% maximum [37]	
Air Quality	• 38 days moderate, 1 day poor air quality per year [38]	-protect residential areas from resultant pollution

Engineering Strategies and Practices

Table 4. Living Environment

Living Environment		**Impact on Design**
Population Density	• 9.5k people/km^2 [39]	-high median age -provisions for elderly pedestrians
Demographics	• 0 - 14%: 12% • 15 - 64%: 75% • 65+: 13% [39]	
Driving Population	• 1.4 drivers/household ○ 53,277 total [5][6][40]	

1.7. Client Ethics and Values

Ethical priorities focus on creating an open, friendly, safe neighbourhood.

The West Bend neighbourhood connects the east and west halves of old Toronto. As such, the WBCA holds a fundamental interest in maintaining their neighbourhood's status as gateway to the Junction-High Park communities.

The design must include special considerations for local residents, including low emissions for local air quality, maintaining a safe space for residents, and improving the area economy [41]. It should also be as open and inviting to foot traffic as possible. This will ensure the WBCA's image of an open, welcoming, safe neighbourhood is preserved.

2.0 Detailed Design: Island Dugout Master Plan

The Island Dugout Master Plan represents the optimal solution; it separates the flow of traffic while maximizing accessibility and minimizing costs. This design regularizes the intersection, such that different types of vehicles do not travel outside of their designated lane. It offers a high degree of safety for pedestrians, cyclists, and drivers. By eliminating the need for bridges or roundabouts and integrating a ramp into the very center of the intersection, the design also scores best in accessibility. Lastly, the design does not require the construction of additional road surfaces other than a single dugout running through the center of the island. This allows for a relatively low cost, easy to implement solution. Therefore, the design delivers a balanced, optimized solution and satisfies all major functions and objectives.

2.0.1. Introduction and Design Overview

Design 1 focuses on updating old infrastructure into a simple, functional four-way intersection. Roads split by the island are reconnected and a ramp is dug up through the center of the island to connect Annette and Dupont.

- **Reducing infrastructure into one central intersection simplifies routing for pedestrians, bikers, and motorists**

Engineering Strategies and Practices

- **Ramp connecting Annette with Dupont enables regularization of intersection without reducing it to a fully standard, unoriginal layout**
- **Integration of the Gateway Bridge emphasis the theme of the West Bend as a gateway to this part of the city**

Figure 1. Regularized intersection of the proposed design. Annette-Dupont runs top-left to bottom-right.

The need to create an open, welcoming intersection that functions as a gateway to the greater West Bend community is the inspiration for this design, which totals $608,000 in construction costs (Appendix F).

The main features of the design include the following:

- intersection is **shifted 37.84m south-east** on Dundas (approximately to the center of the island)
- traffic from **Old Weston road is cut off** from direct access to intersection, instead re-routed to Watkinson Ave. and merged into Dundas
- southbound traffic from Dundas is unaffected beyond relocation of central intersection
- inbound traffic from Annette straightens prior to arriving at intersection by turning onto current Money Mart parking lot
- northbound traffic from Dundas is unaffected beyond relocation of central intersection
- inbound traffic from Dupont continues straight out from underpass and onto a **ramp through center of current island**, splitting island in two
    - halves **connected by the Gateway Bridge**, an arch bridge **spanning Dupont**
        - resembles a modern "gateway" directly into the community (Figure 2)
- all pedestrians, cyclists and traffic converge to regularized central intersection
    - once in underpass, pedestrians and cyclists each have **dedicated lanes** in both directions on **elevated shoulders**
- existing **north and south Dupont ramps filled**, connecting island to currently unused greenspace adjacent to railway

Engineering Strategies and Practices

- **island no longer stranded**
- pedestrian access to greenspace greatly improved

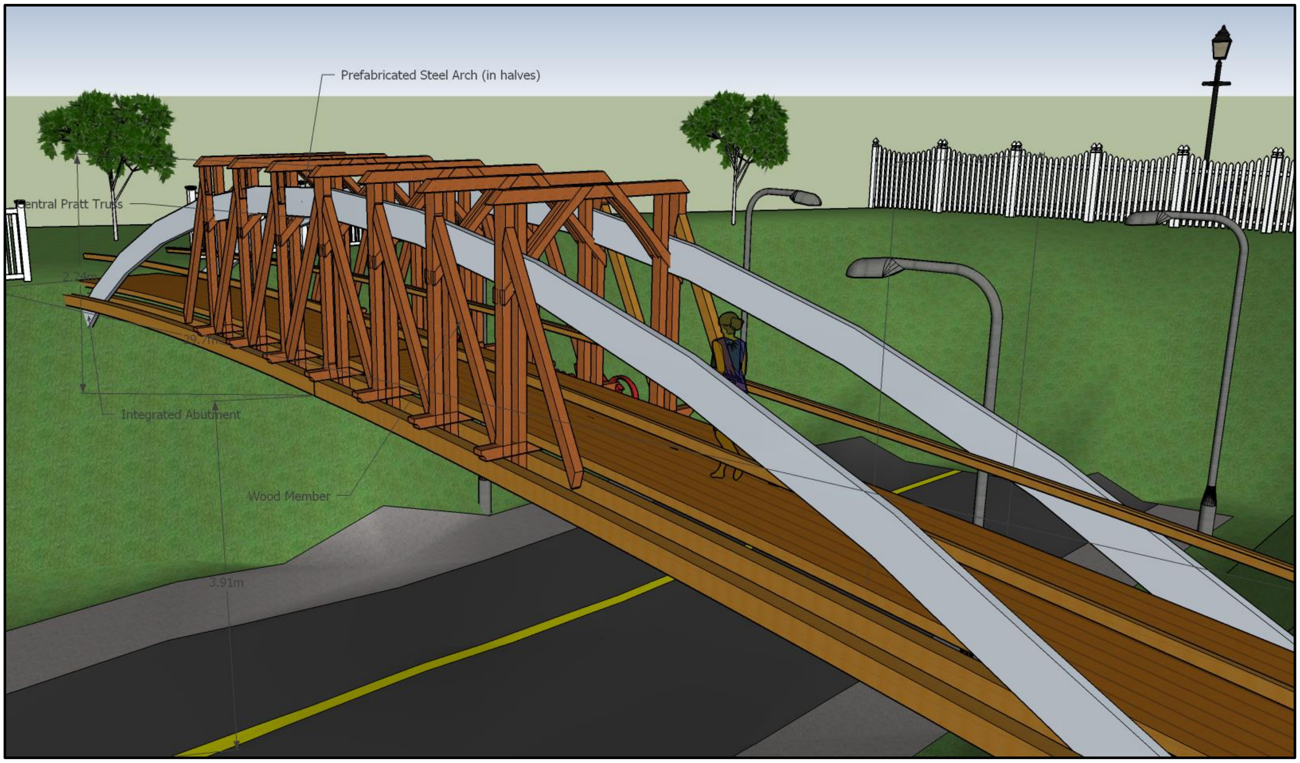

Figure 2. Proposed gateway bridge overview. Labels and dimensions included. Key dimensions include clearance of 3.91m and width of 2.74m.

This design focuses on safety primarily through regularization of the intersection and as much separation of traffic as possible without the construction of a bridge or underpass. The island is repurposed as a walkway which allows pedestrians to cross the new Dupont ramp via the park so that the island has an active role in the intersection rather than being a stranded novelty. The aesthetic sense of the intersection as a gateway is achieved on the island, where a small pedestrian arch bridge is constructed to welcome underpassing motorists into the community. The island is no longer stranded, but instead a fully integrated peninsula connected to greenspace along the Railpath.

Engineering Strategies and Practices

Figure 3. Alternate angle of the central intersection. It has been shifted to the approximate center of the island.

2.0.2. Lane Widths and Other Dimensions

Exact lane widths and street dimensions have been determined according to regulatory restrictions and numerous optimization algorithms issued by the City [121]. The centerline position of the proposed Annette modification and Dupont island ramp has been given in reference to its current position (Figure 12).

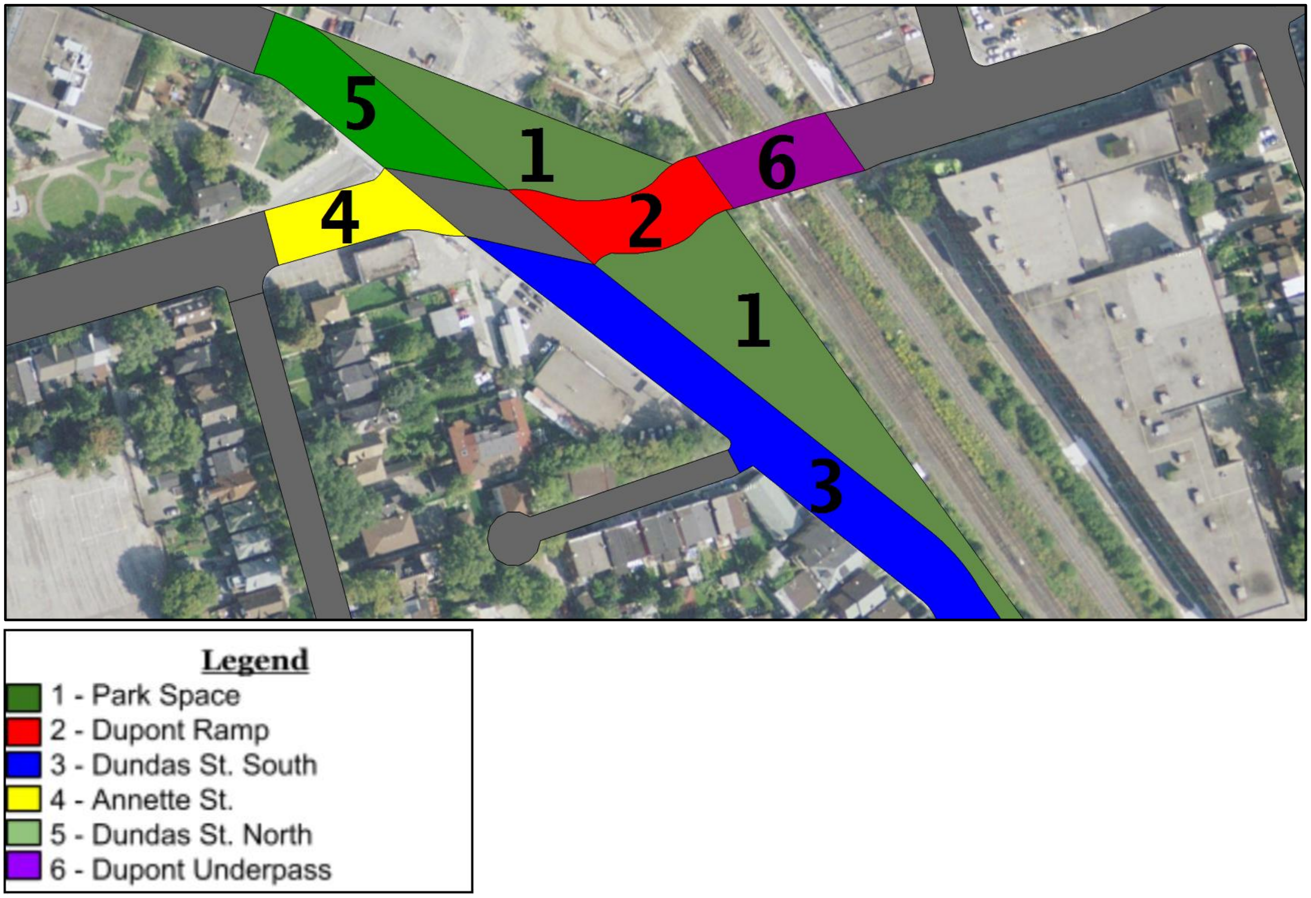

Figure 4. Colour-coded aerial presentation of relevant road surfaces (Appendix G). Legend corresponds with Figures 5 through 10.

Significant modifications include the expansion of Park Space (1) on both sides of the current island, the straightening and shifting of Annette (4), and the introduction of a new 50.44m ramp through the center of the island (2).

By filling the north and south Dupont ramps, the design facilitates the expansion and connection of greenspace with newly created space on either side of the island. This means that the island is no longer stranded between roads on all sides, greatly improving pedestrian access to greenspace.

Engineering Strategies and Practices

2 - Dupont Ramp Cross-section

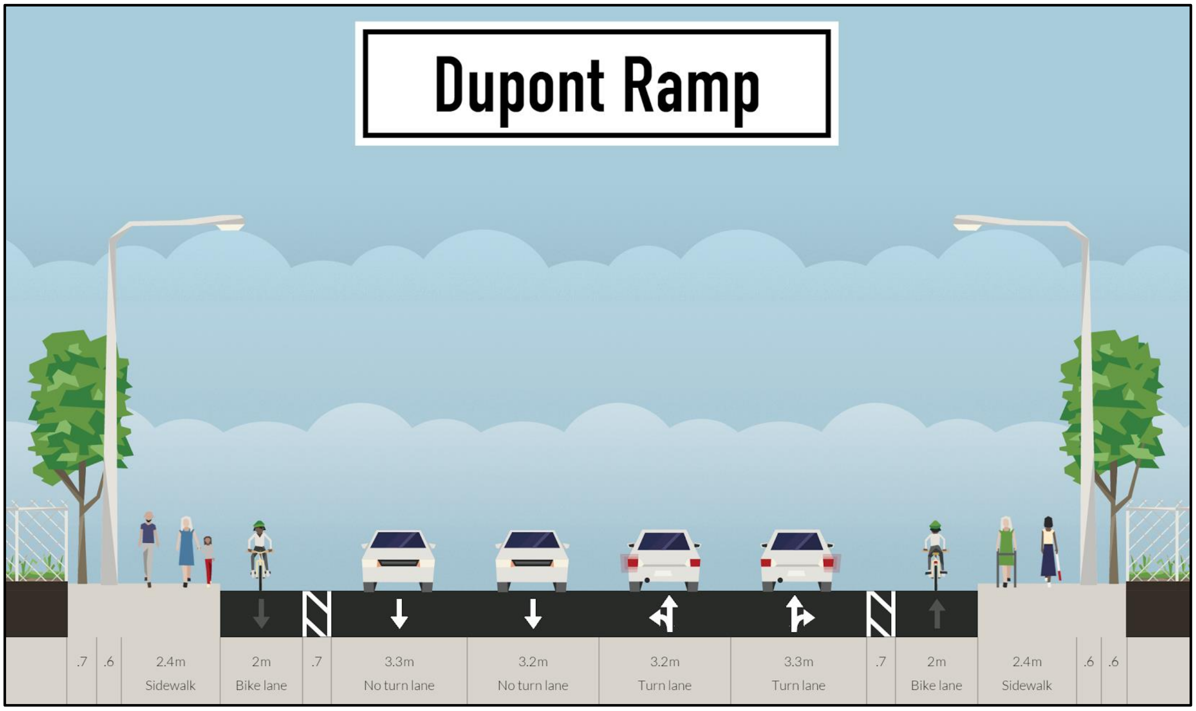

Figure 5. Cross-section of the new island ramp (Figure 4(2)).

2 - Dupont Ramp Slope Profile

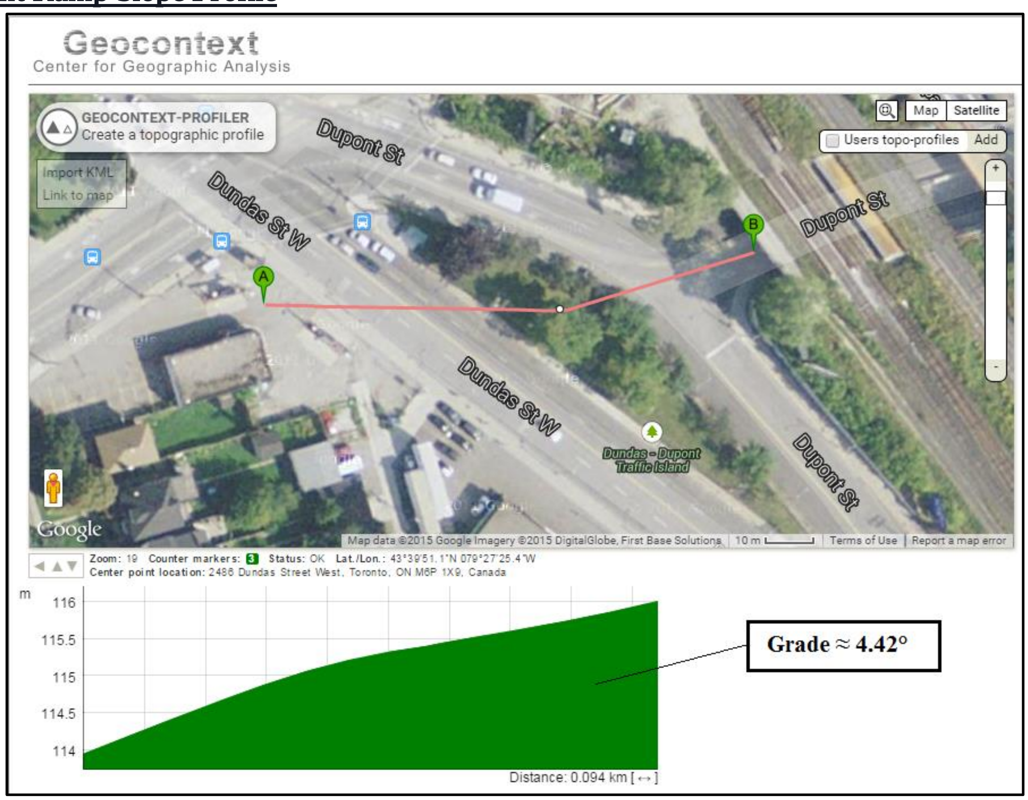

Figure 6. Slope profile of the new island ramp (Figure 4(2)).

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The road layout specified in Figure 5 narrows before reaching the underpass, to the layout is depicted in Figure 7. This was done in order to allow for additional queuing lanes which are required to hold building traffic waiting for the right turn from Dupont to Dundas without delaying the flow of through traffic.

The narrowing occurs immediately prior to entering the underpass. It was positioned here in order to regularize traffic to the constraining width of Dupont proper prior to its eventual merging, ensuring a smooth and safe flow of traffic under the underpass, which is widely regarded as the most dangerous portion of the intersection for pedestrians and cyclists.

There was no substantial benefit to expanding the Dupont underpass to its maximum capacity of 4 lanes because of the eventual constraining 2-lane width of Dupont. However, there was a significant safety benefit to reducing the underpass to 2 lanes because of the need to provide separated lane space for cyclists.

6 - Dupont Underpass Cross-section

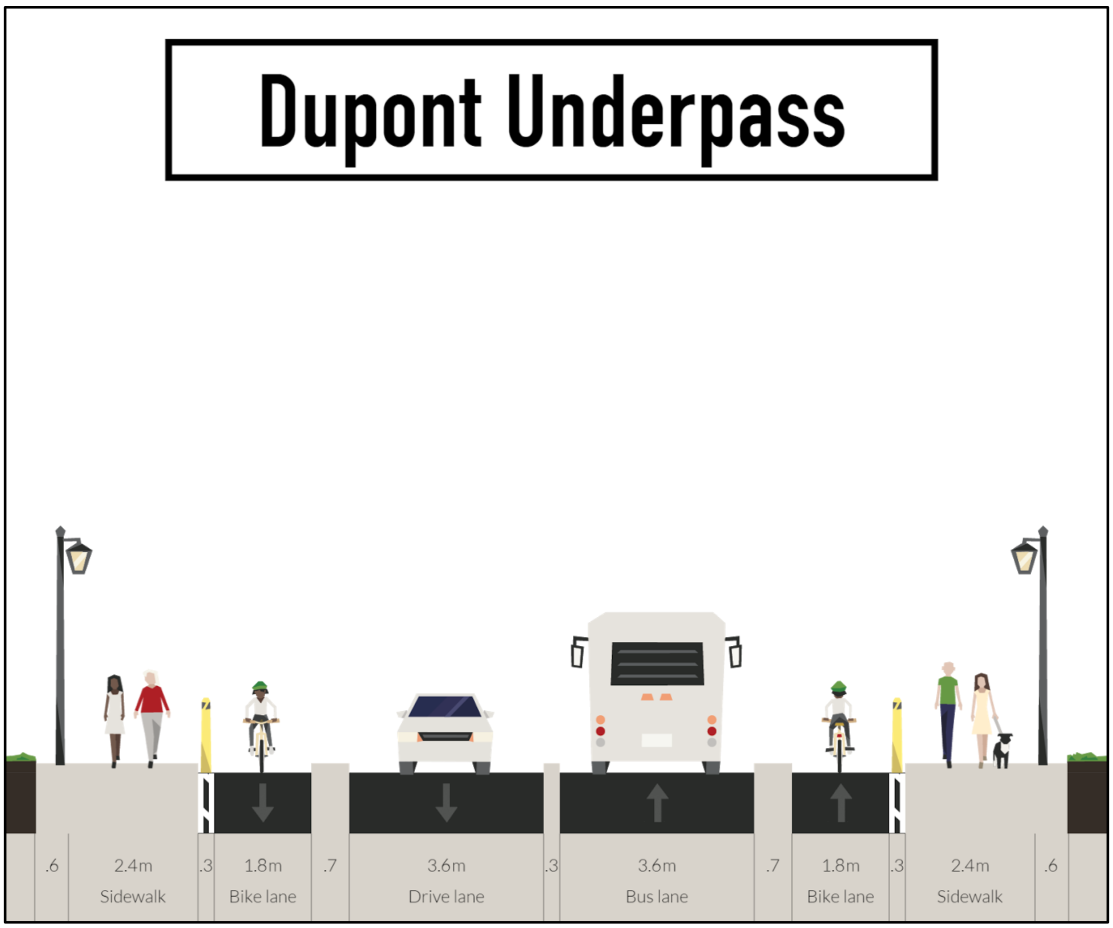


Figure 7. Cross-section of the proposed Dupont Underpass (Figure 4(6)).

Note that both sidewalks are elevated 1.2m above the vertex of the depressed roadway. They are also separated by a fence from the adjacent bike lanes, which have their own elevated shoulder, elevated

0.17m above the aforementioned vertex. The bike lanes are separated by a 0.7 wide median from both curb lanes.

There are two widened vehicle lanes measuring 3.6m in length, one in each direction, to accommodate regular bus traffic safely. These lanes are separated by a 0.3m section of roadway rendered unusable due to support columns positioned there to support the overhead railway.

13 streetlights are used in total (for the area immediately adjacent to the intersection), with 2m between each light. This maximizes the radius of illumination of each light and ensures the greatest lighting coverage. Lights in the underpass are retrofitted with an LED lighting system to fully illuminate the entire tunnel.

3 - Dundas St. (South side) Cross-section

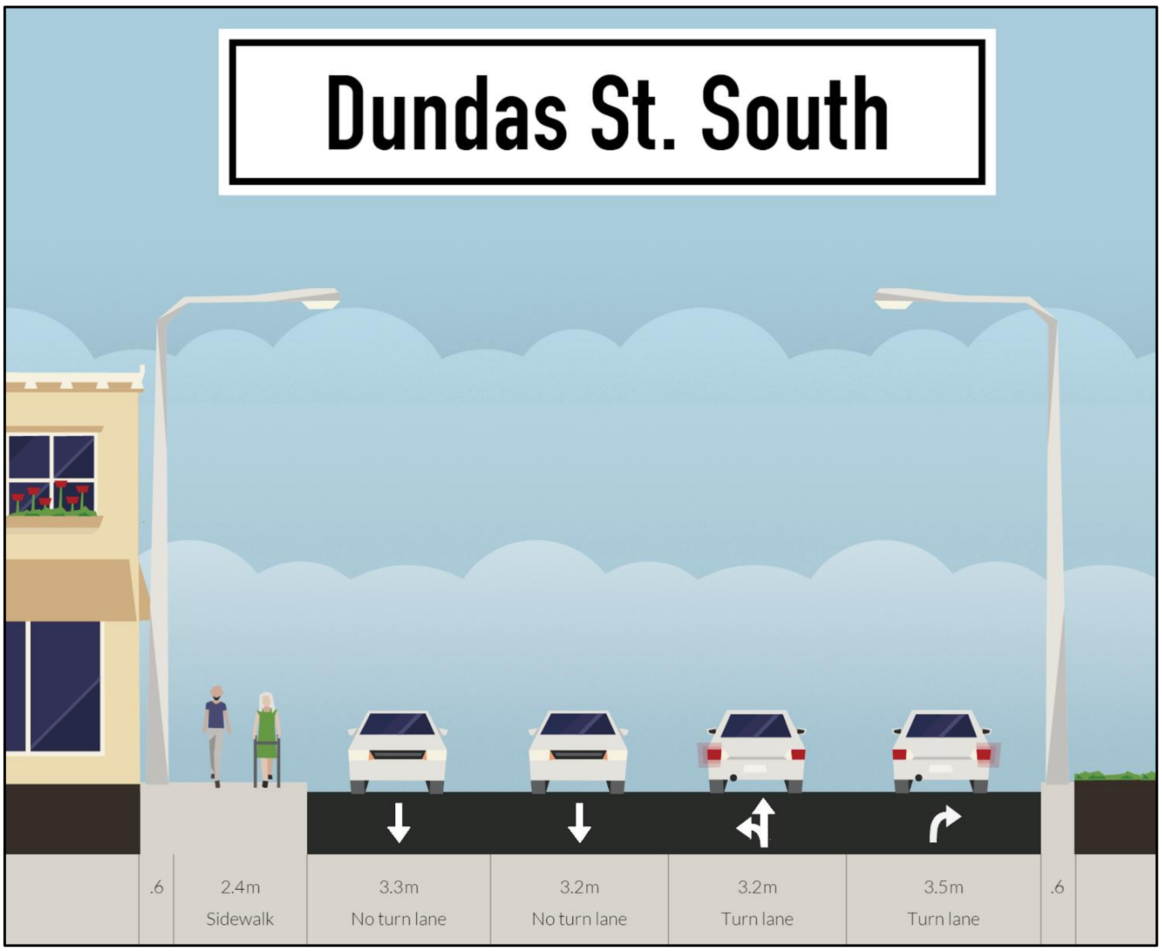


Figure 8. Cross section of the proposed Dundas St. (South side) modifications (Figure 4(3)).

The right curb lane is widened abnormally to ensure it can handle turning traffic from Dundas to Dupont even when space is shared with cyclists in a narrow sharrow configuration. Because this lane replaces the former south Dupont ramp, it is dedicated solely to right turning traffic.

Engineering Strategies and Practices

5 - Dundas St. (North side) Cross-section.

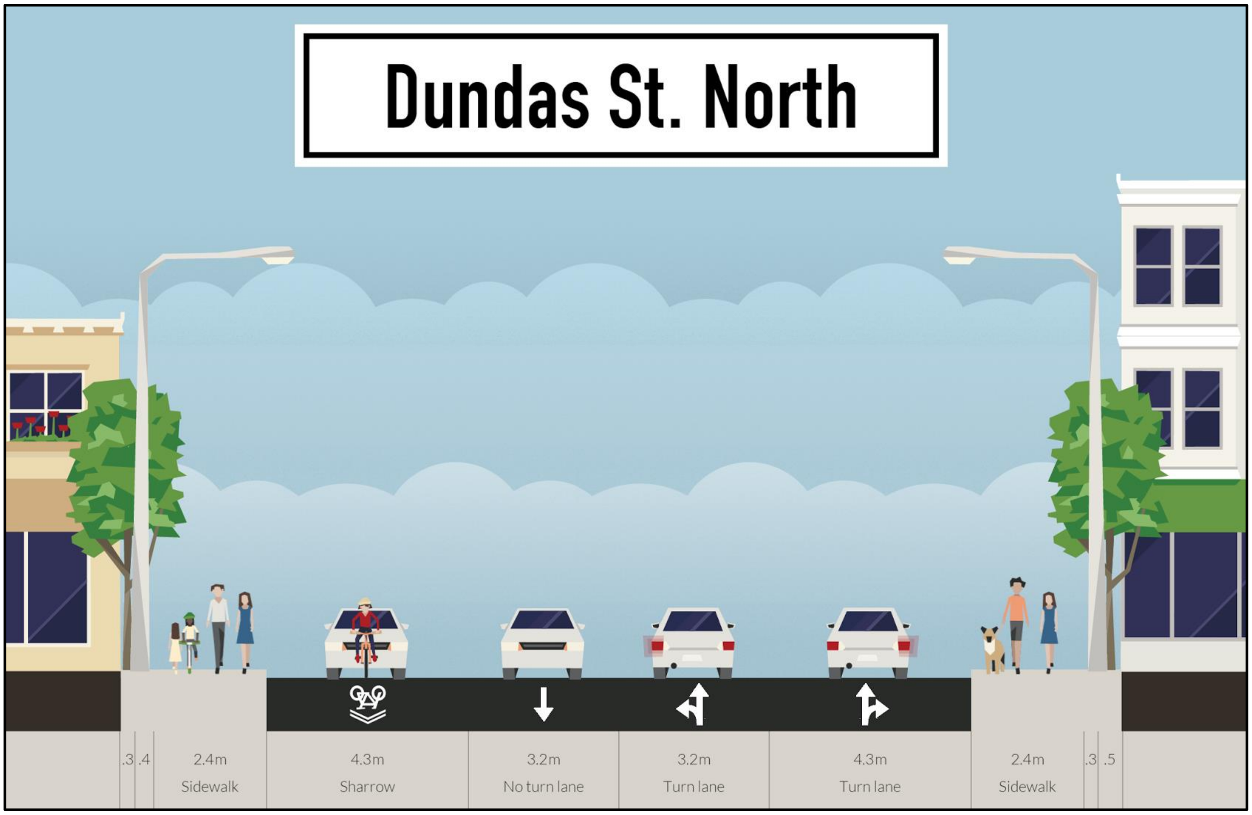


Figure 9. Cross-section of the proposed Dundas St. (North side) modifications (Figure 4(5)).

Note that the modifications in Figure 8,9 refer only to the portion of Dundas immediately adjacent to the central intersection, and as such are limited to only a short distance before merging into the existing Dundas layout.

Both curb lanes have been widened to 4.3m in order to abide by regulations concerning shared road space. This width allows cyclists to pass parked cars without leaving the lane and allows vehicles to pass cyclists without, similarly, encroaching on the adjacent lane.

4 - Annette St. Cross-section

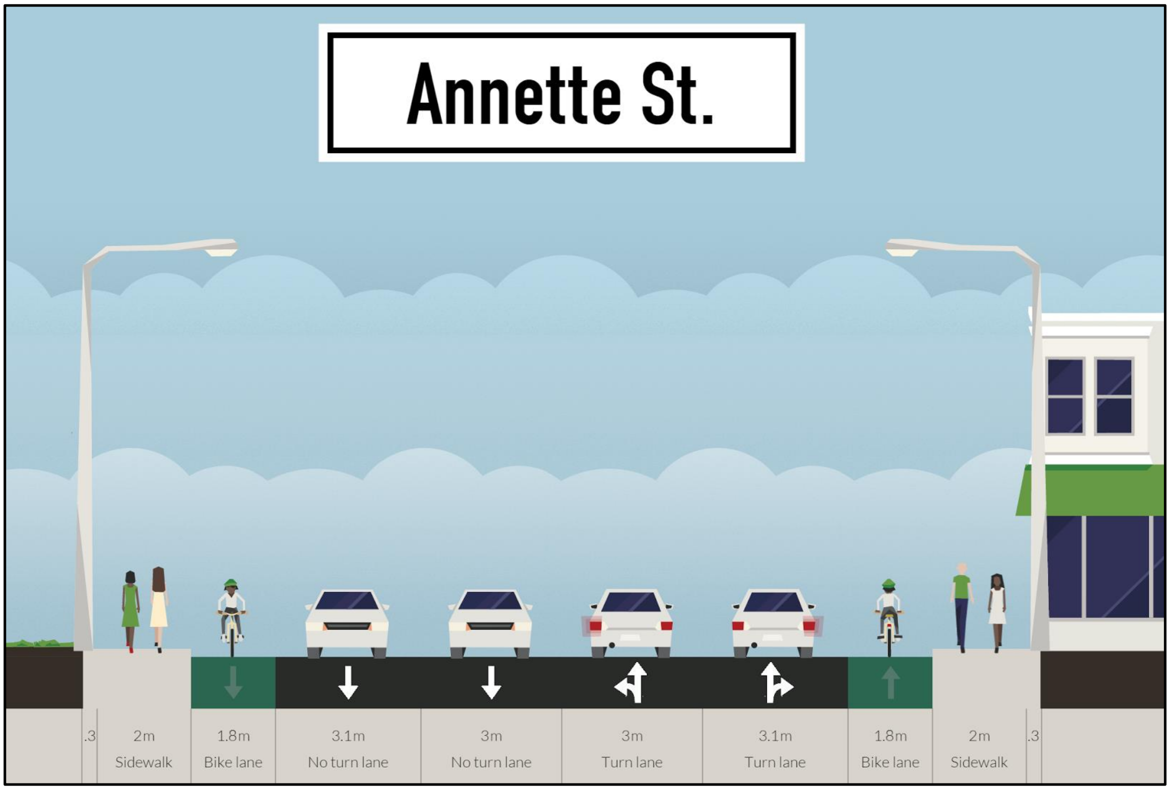


Figure 10. Cross-section of the proposed Annette St. modifications (Figure 4(4)).

The expansion of Annette St. to 4 lanes with dedicated bike lanes requires the expropriation of 365.7m^2 of Money Mart's northern parking lot. It has been straightened and its centerline now runs 37.84m south-east of its former position. It intersects Dundas St. at a 63.5 degree angle.

Due to the need to minimize expropriation of Money Mart's property and thus lower costs, Annette's curb lanes deviate 6.25% below optimal width at 3.1m while its through lanes are at the legal minimum of 3m, 6.45% below optimal width.

Bike lanes have been afforded the optimal lane space identical to that on the Dupont island ramp, allowing for smooth and regular flow through the intersection. Sidewalks deviate 18.18% below optimal width but pedestrians have access to greenspace directly adjacent on the north side of Annette and empty former parking space on the south side, ensuring that they can never be pinned by rushing traffic.

2.0.3. Satisfaction of Major Functions and Objectives

The design greatly simplifies turns and creates a simple four-way intersection. Cars are allowed to enter and exit via straightened roads with a continuous, clear line of sight. Pedestrians and cyclists are still required to pass through the underpass, but are afforded elevated shoulders for adequate separation.

- **Improved safety**
  - Pedestrians face only one crossing travelling from Annette to Dupont

- Minimizes distance pedestrians must walk while level with a busy road
- Bike lanes do not swerve through car lanes and are consistently kept on the side
- Turns around sharp corners of island are eliminated
  - Maximum 63.5 degree turn
  - approximately 90 degree turns maintained from Dundas to Dupont and Dundas to Annette
- All vehicles must adhere to traffic lights to cross intersection
- Clear line of visibility, easy to predict path of vehicles and other users

- **Greater accessibility**
  - Central ramp at 4.42% average grade
    - Below 5% maximum universal access grade requirement [62]
  - Sidewalk ramps constructed for wheelchair access (Figure 11)[62]
  - No stairways used

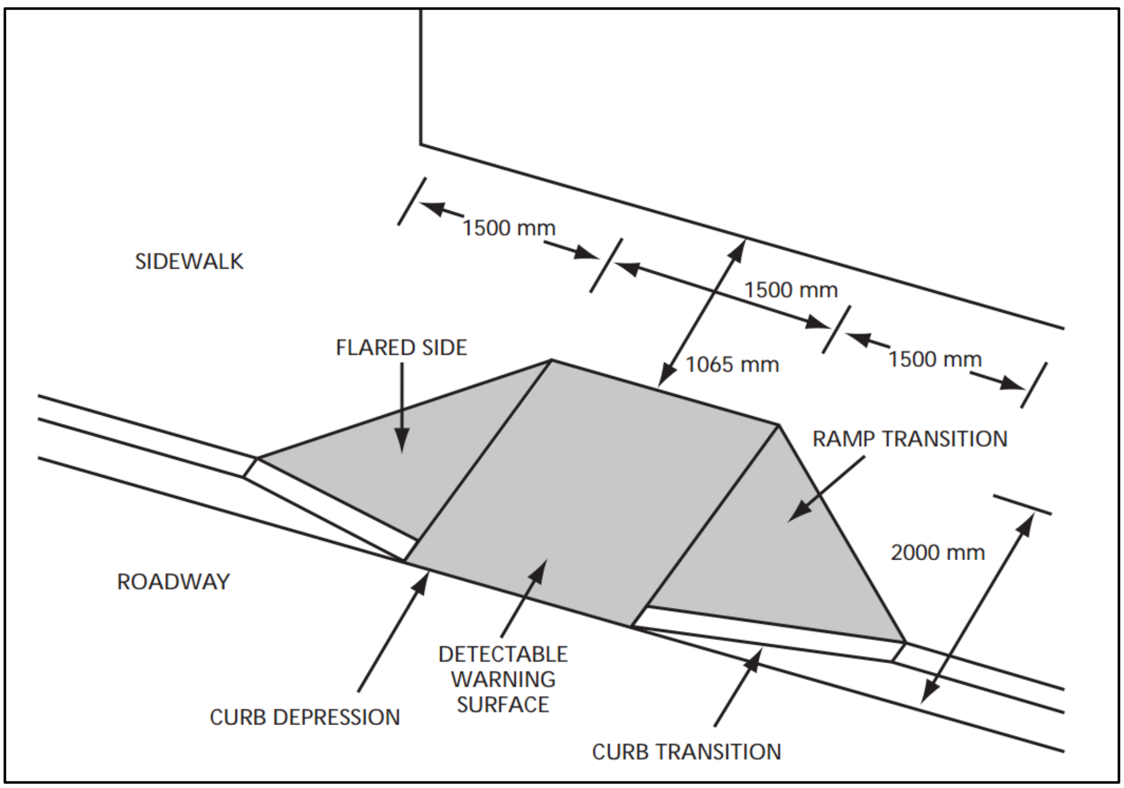


Figure 11. Accessibility standards in sidewalk ramp construction. Taken from [62].

- **Cost-effective and easy to implement**
  - Total construction costs at $608,000
    - Below both objective and constraint values
    - Increased from original CDS estimate due to added detail, more features
  - Estimated total implementation time of under 2 years
    - Approximately meets objective of 1.3 - 1.5 years
- **Durable**
  - Asphalt service life of 25 years

- Pedestrian bridge to last 90 years with regular maintenance
- **Easier to maintain**
    - Less road surface
    - Parallel park triangular layout optimized for ease-of-maintenance in cutting grass, garbage collection, etc.
- **Environmentally friendly**
    - 4697.9m^2 of new integrated park space
        - connected with Gateway Bridge (Figure 14)
    - More than 6 trees planted
- **Road use proportions in correspondence with aesthetic and functional holistic goals**
    - 35.64% pedestrian space (sidewalks and walkways)
        - Exceeds objective of 25%
    - Legal requirements met universally
    - Space usage optimized ideally on all adjoining roads (excluding Annette)
        - Optimized for safety, traffic flow

See Figure 12 for a detailed schematic of all relevant dimensions and specifications.

Engineering Strategies and Practices

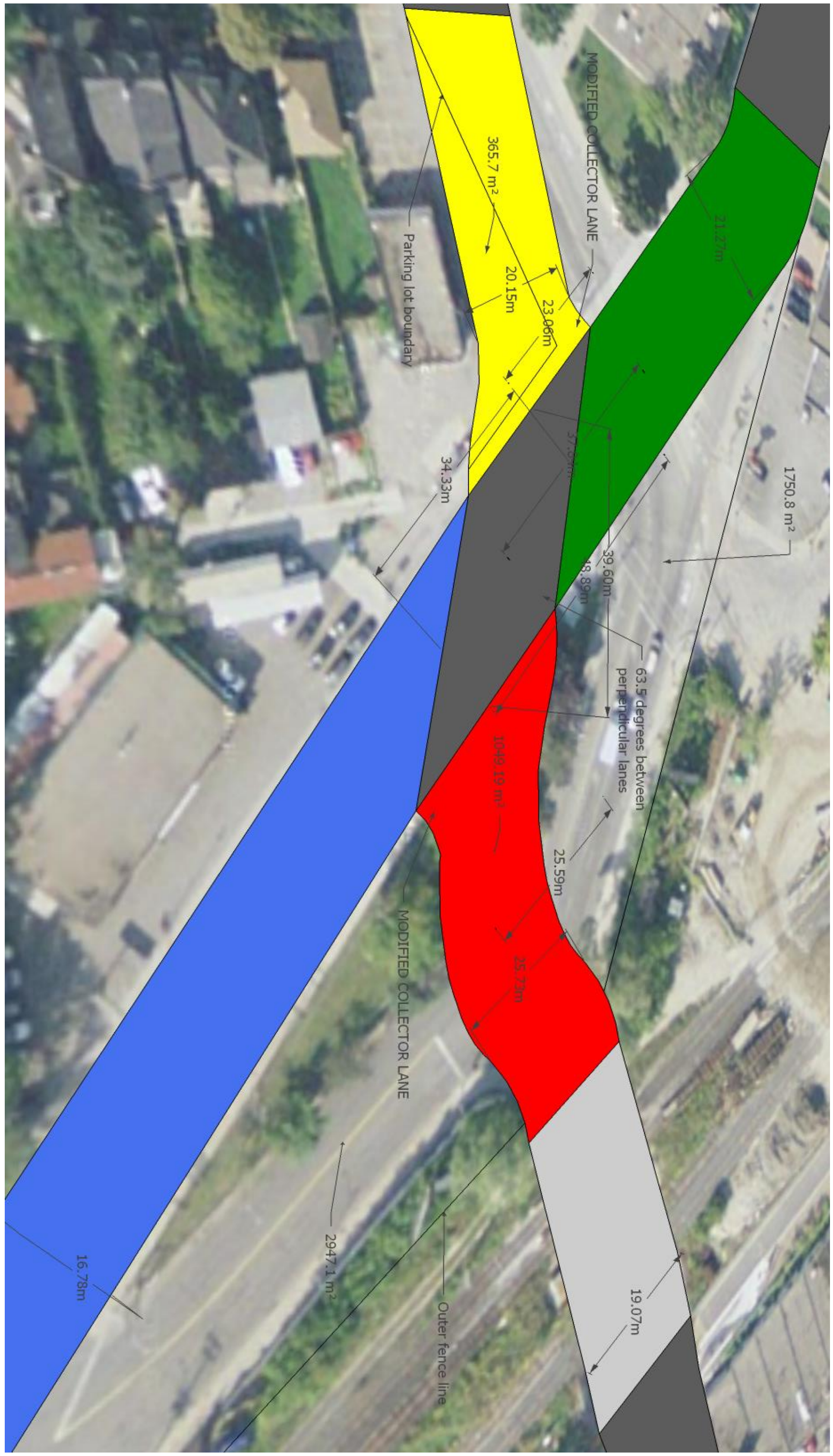


Figure 12. Detailed schematic of street widths, intersect angles, areas, and other dimensions related to the intersection.

2.0.4. Objective Tradeoffs

- Straightening of road connecting Annette and Dupont increases accessibility but also cost
  - must expropriate northern portion parking lot (365.7m^2) from Money Mart

- Decreased accessibility in order to lower cost
  - pedestrians still required to travel through underpass

- Regularization of Dupont following underpass requires removal of dedicated Dupont north and south ramps
  - increased safety at the cost of efficiency

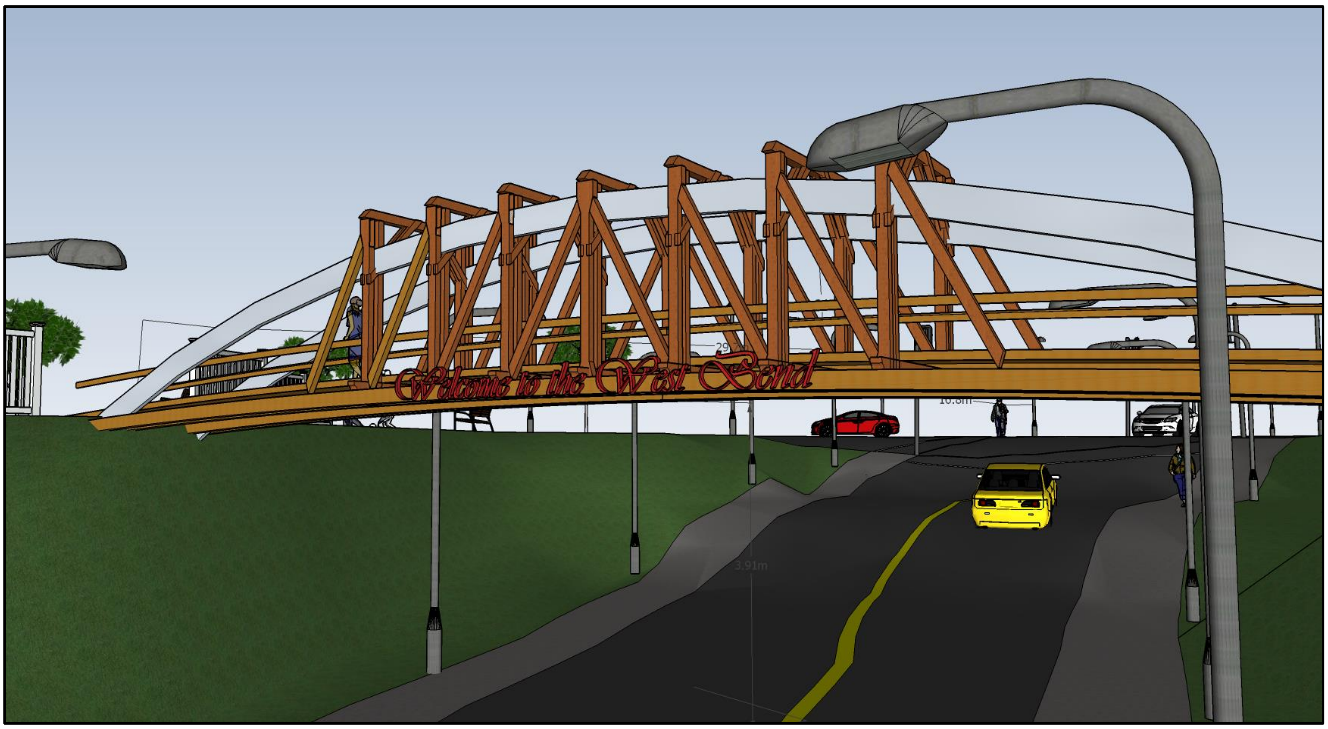


Figure 13. The Gateway Bridge. Its inscription reads: “Welcome to the West Bend”.

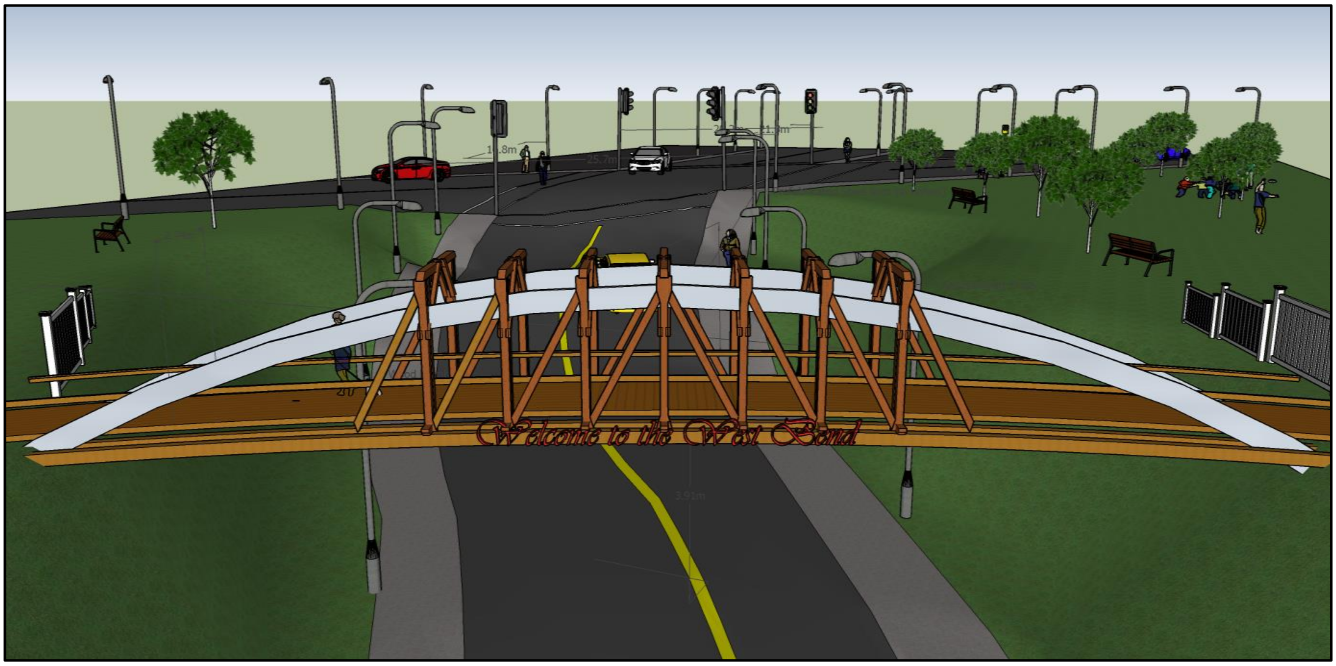


Figure 14. Centered view of the Gateway Bridge with the intersection in the background.

2.0.5. Traffic Signal Light System

Traffic signal timing represents a significant part of the optimization process for traffic flow through an intersection. Since Old Weston Road is removed from the intersection, the signal system in this design regulates one less street. The remaining signals have been optimized by increasing the average cycle length from 110s to 154s and modifying the effective green and red times in a two phase flow traffic model.

2.0.5.1. Physical Layout and Positioning

For regularity, the new four-way intersection will employ four sets of identical signal lights. Figure 14 illustrates the general schematic of each set.

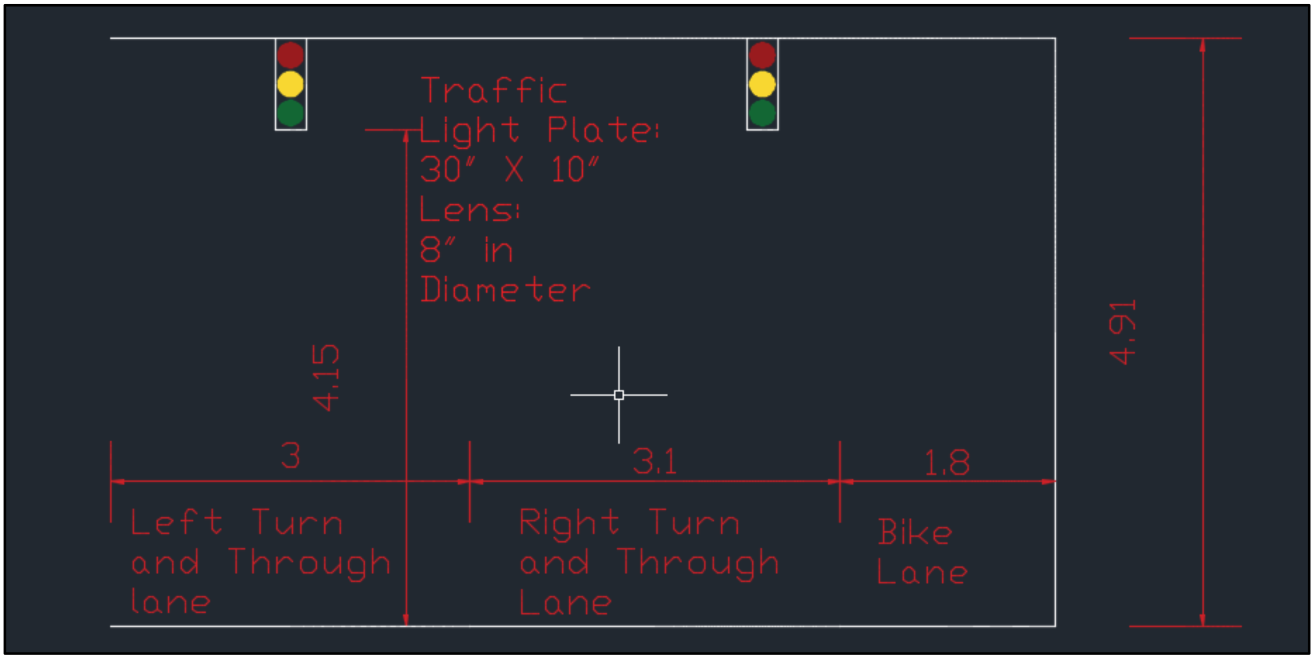


Figure 15. Schematic of the traffic light system controlling the Dupont and Annette intersection. Average lane widths used.

The traffic light setup on Dundas is identical, aside from a slightly shorter overhead extension due to the difference in road width. More precisely, due to the absence of bike lanes on Dundas, the length of the overhead support will be only 6.7m. The spacing of the traffic lights themselves will also be adjusted such that every traffic light will be set up in the middle of the lane it controls to optimize visibility for drivers and cyclists.

Engineering Strategies and Practices

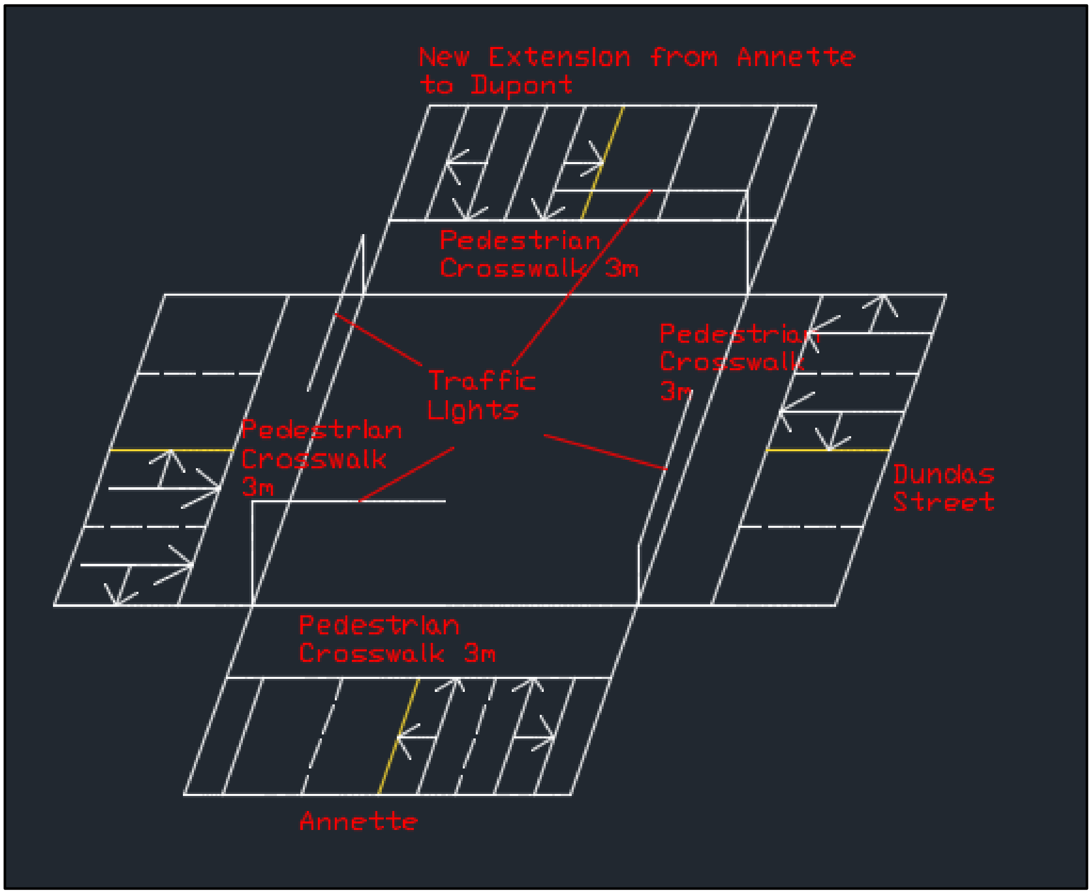


Figure 16. Placement of traffic lights in the new lane arrangement.

As shown, four new traffic lights will be positioned on the corner of each street. The arrows represent the permissible directions in which the vehicles can travel while in their designated lanes.

2.0.5.2. Phases and Timing of Traffic Signals

Traffic signal timing is essential to the effective transport of mass. Designing a traffic light system requires the consideration of both safety and efficiency.

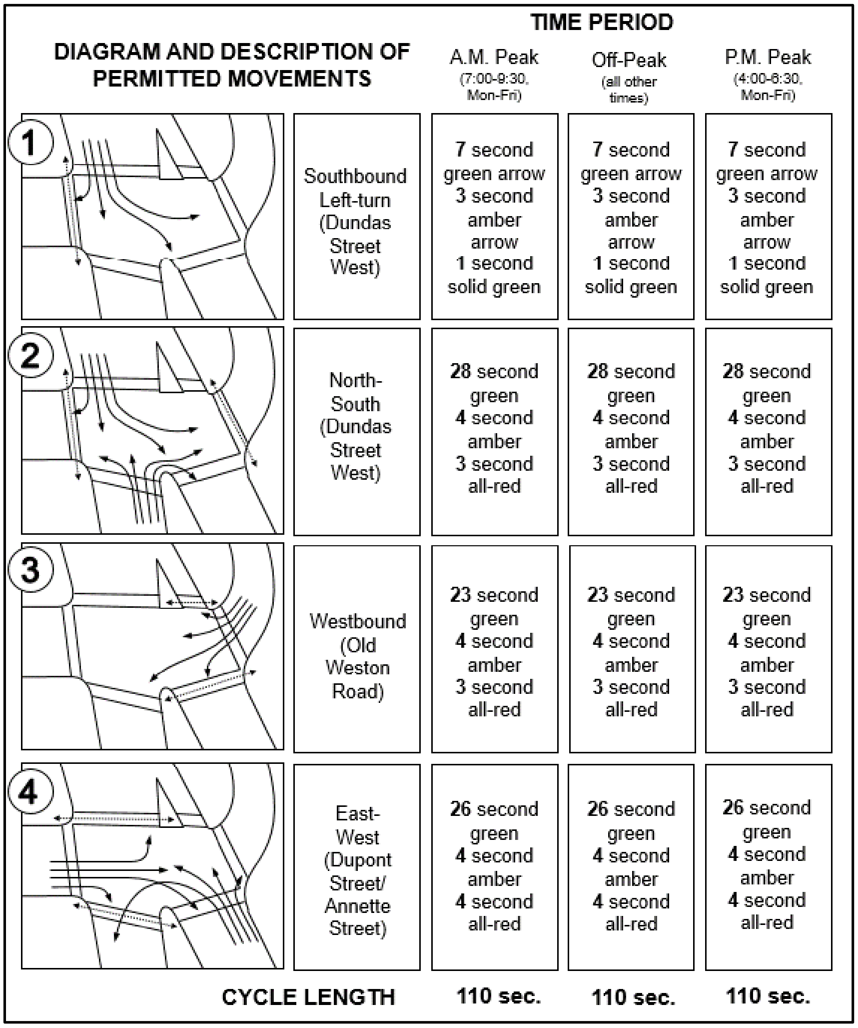


DIAGRAM AND DESCRIPTION OF PERMITTED MOVEMENTS		TIME PERIOD A.M. Peak (7:00-9:30, Mon-Fri)	Off-Peak (all other times)	P.M. Peak (4:00-6:30, Mon-Fri)
1	Southbound Left-turn (Dundas Street West)	7 second green arrow 3 second amber arrow 1 second solid green	7 second green arrow 3 second amber arrow 1 second solid green	7 second green arrow 3 second amber arrow 1 second solid green
2	North-South (Dundas Street West)	28 second green 4 second amber 3 second all-red	28 second green 4 second amber 3 second all-red	28 second green 4 second amber 3 second all-red
3	Westbound (Old Weston Road)	23 second green 4 second amber 3 second all-red	23 second green 4 second amber 3 second all-red	23 second green 4 second amber 3 second all-red
4	East-West (Dupont Street/ Annette Street)	26 second green 4 second amber 4 second all-red	26 second green 4 second amber 4 second all-red	26 second green 4 second amber 4 second all-red
	CYCLE LENGTH	110 sec.	110 sec.	110 sec.

Figure 17. Current traffic signal timings for peak and off-peak hours for the DDA intersection.

The following baseline times were calculated using a strictly physics-based approach, using the acceleration of the slowest vehicles crossing the intersection to maintain a suitable margin of safety. Optimization was not considered.

Table 5. Baseline Signal Times (Appendix H)

Phase	**Green Timing**	**Yellow Timing**	**Red Timing**	**Pedestrian Green**	**Pedestrian Red**
Dundas Northbound - Southbound	**Green Light 72s**	**Yellow Light 3s**	**Red Light 82s**	**Pedestrian Green: 75s**	**Pedestrian Red: 85s**

Dupont Eastbound - Annette Westbound	Green Light 82s	Yellow Light 3s	Red Light 72s	Pedestrian Green: 85s	Pedestrian Red: 75s

Note that the amber timing, by legal standards, is universally 3s. A cycle length of 154s was calculated using the total green light cycle time.

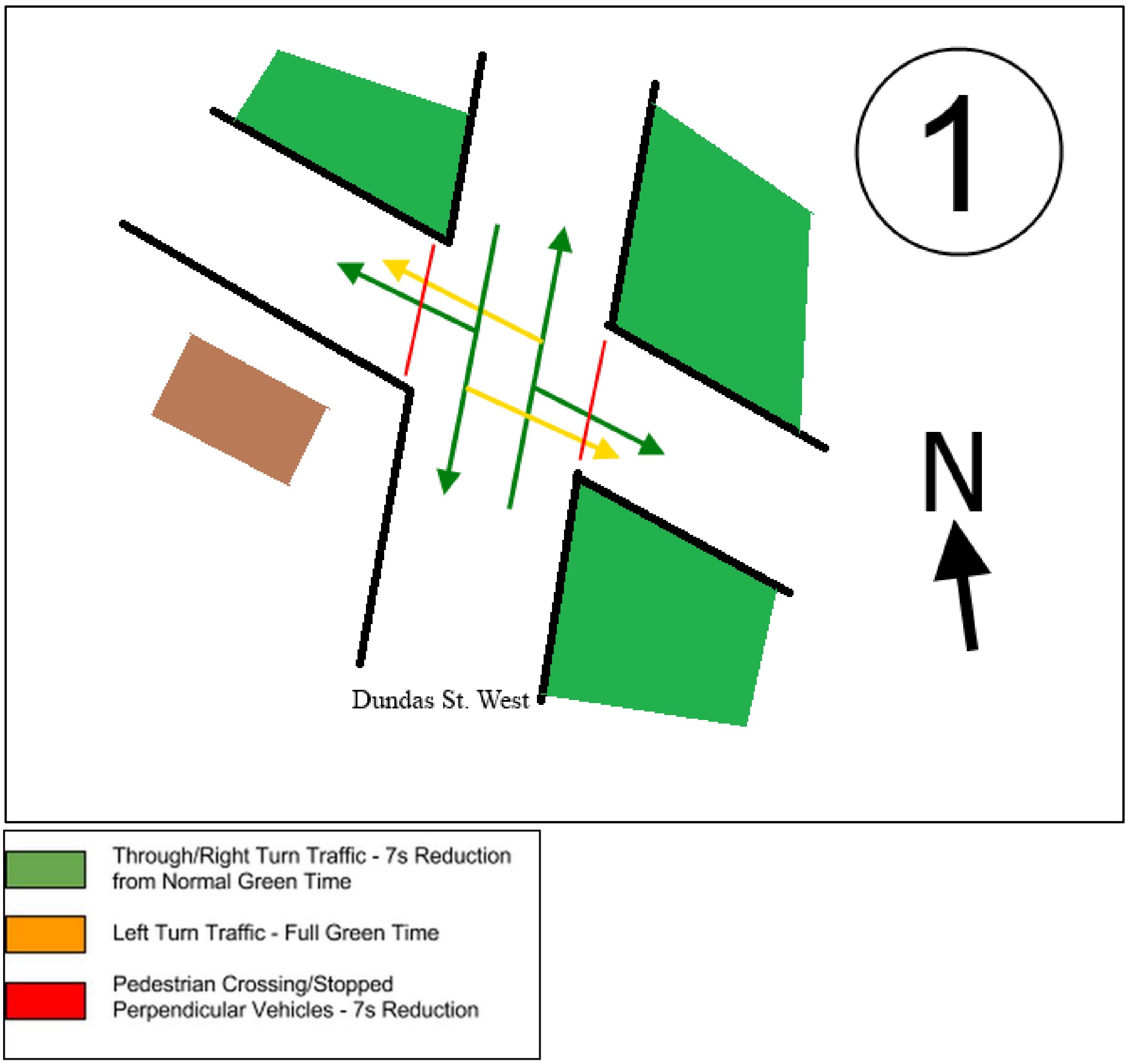


Figure 18. Phase 1 of the traffic light timing system. Note that the various sub-phases are broken down by colour.

Engineering Strategies and Practices

As indicated in Figure 18,19, two main signal phases exist, with each phase further modified into two subphases through the introduction of a 7s dedicated left turn period from Dundas to Dupont, and Annette to Dundas inserted 7s prior to the end of each phase.

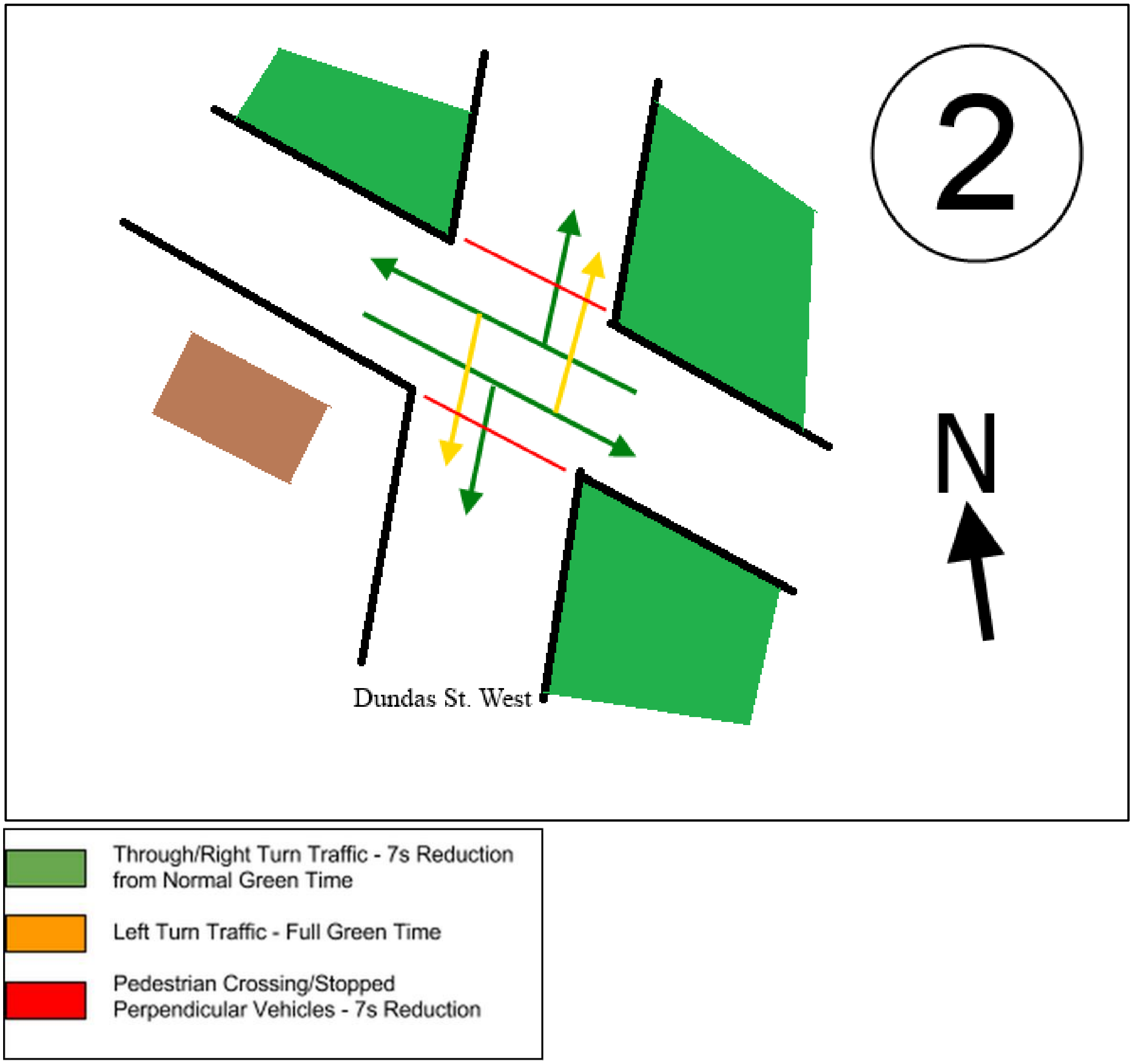


Figure 19. Phase 2 of the traffic light timing system.

The decision to dedicate 7s explicitly for left turning traffic was made in order to accommodate the current provisions that exist for turns southbound from Dundas to Dupont. This guarantees a minimal clearance of traffic for these turns in every cycle.

This pattern was extended to all left turns in order to standardize turning procedures at the intersection as well as to future-proof the intersection with an increased left turn capacity as the driving population continues to grow.

Optimization of Signal Timing:

$$D_t = \sum_{a}^{b} d_i$$

$$D_t = \frac{\lambda_a r_a^2}{2\left(1-\rho_a\right)} + \frac{\lambda_b (C - r_a)^2}{2\left(1-\rho_b\right)}$$

$$D_t = \frac{0.0775 r_a^2}{2\left(1-0.158\right)} + \frac{0.0585(154 - r_a)^2}{2\left(1-0.357\right)}$$

$$D_t = \frac{0.0775 r_a^2}{1.684} + \frac{0.0585(154 - r_a)^2}{1.286}$$

SETTING $D_t' = 0$

$$r_a = 76.554s = g_b$$

$$C = r_a + g_a$$

$$154 = 76.553 + g_a$$

$$g_a = 77.447s = r_b$$

where D represents the total delay of the intersection (sum of all queues across all lanes over the time period they occur) and optimization was performed by minimizing this delay. All rounding is rounded up to the nearest second. See Appendix I for the derivations of the remaining variables.

This yields the following optimized green and red light values:

Table 5. Optimized Signal Times

Phase	**Green Timing**	**Yellow Timing**	**Red Timing**	**Pedestrian Green**	**Pedestrian Red**
1. **Dundas Northbound - Southbound**	**All Green Light 71s** **Left Green 7s**	**Yellow Light 3s**	**Red Light 77s**	**Pedestrian Green: 74s**	**Pedestrian Red: 80s**
2. **Dupont Eastbound - Annette Westbound**	**All Green Light 71s** **Left Green 7s**	**Yellow Light 3s**	**Red Light 78s**	**Pedestrian Green: 73s**	**Pedestrian Red: 81s**

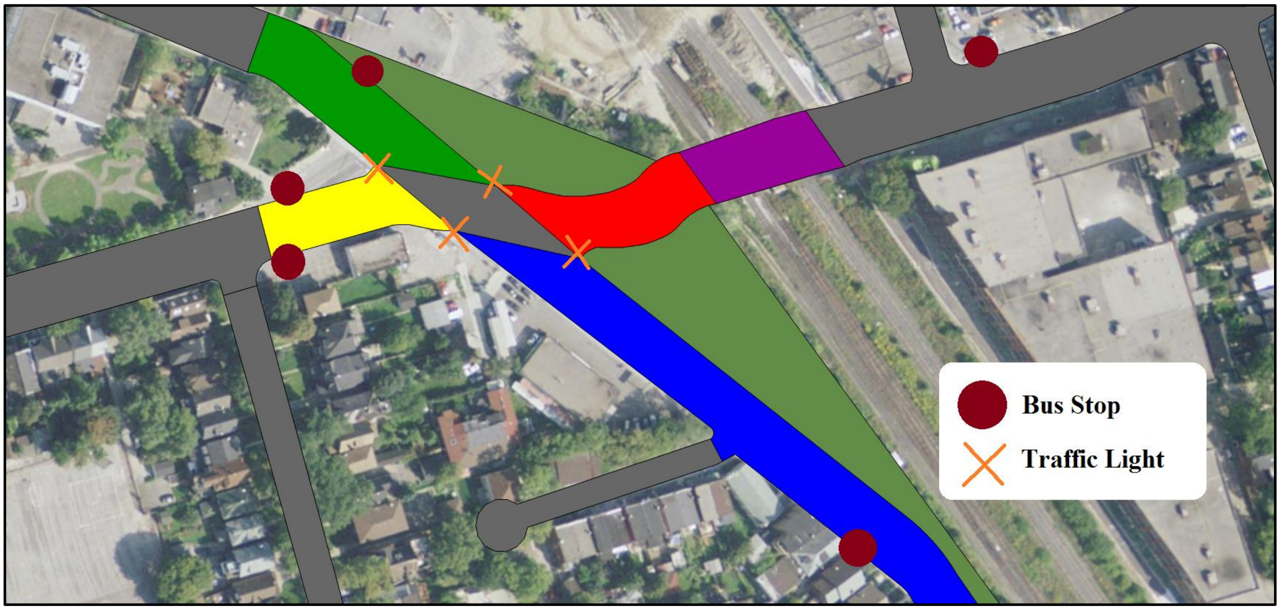


Figure 20. Positioning of bus stops and traffic lights around the intersection.

Traffic lights have been positioned in order to maximize visibility for drivers, particularly for drivers moving west on the new Dupont ramp, where visibility was previously compromised by the rise of the road.

All bus stops have been preserved in order to minimize disruptions to the TTC`s current route network in the area. However, in order to prevent delays at the intersection, all stops have been moved slightly away and positioned after crossing the intersection. This ensures that turning traffic is not slowed by stopped busses. Note that the two bus stops on Annette and the one stop on Dundas north are built on the section of roadway that has been expanded to 4 lanes. This guarantees two lanes for the uninterrupted flow of through traffic, even when buses are stopped at all stops simultaneously.

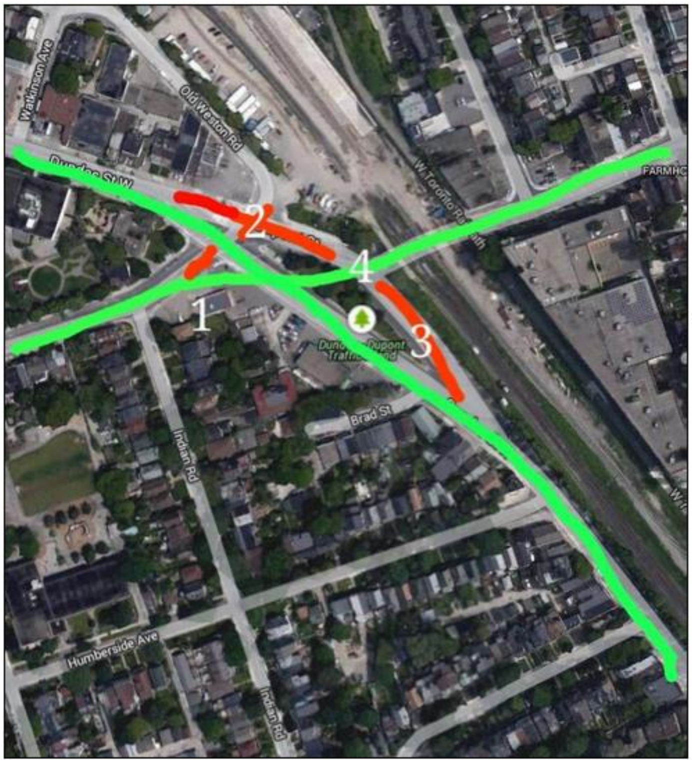
2.0.6. Cost Estimate

The majority of expenses go towards heavy equipment rental, which represents 40% of the total cost. Other costs include the pouring of concrete foundations and paving road surfaces. To meet aesthetic objectives, construction of the Gateway Bridge and adjoining park consumes 30% of the total cost. See Section 2.7 for details.

2.0.7. Conclusion

This design enables the idea of having a single intersection by digging out the center of the island to create a ramp. It ensures the safety of pedestrians, bikers, and vehicles by reorienting bike lanes and eliminating unnecessary turns. Lastly, the design liberates and integrates island green space for beautification of the intersection to deliver a solution that satisfies all major functions and objectives.

Engineering Strategies and Practices



Legend

1. Expropriated portion of northwestern Money Mart parking lot
2. Old Weston Rd. connection severed and North Dupont ramp filled
3. South Dupont Ramp filled
4. Ramp dug up through center of Dupont traffic island, connecting Annette and Dupont and enabling significant intersection regularization

Figure 21. Aerial view of proposed design renovations.

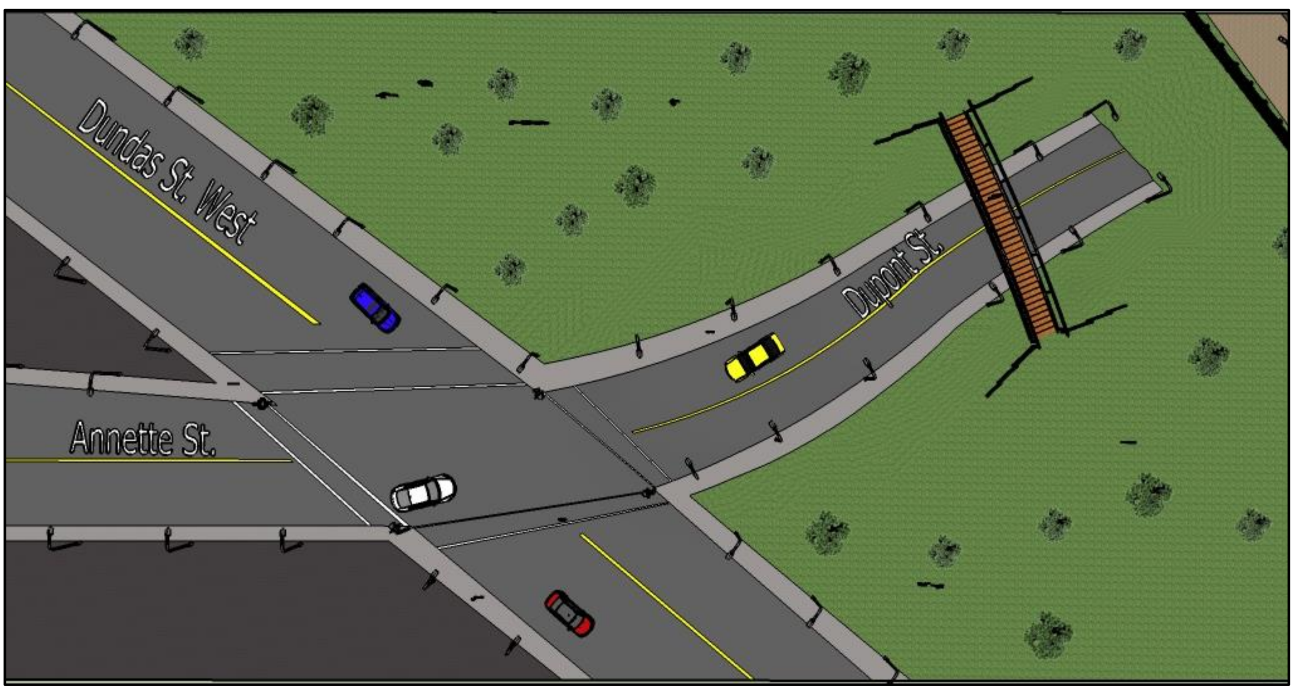


Figure 22. Software rendition of Figure 21.

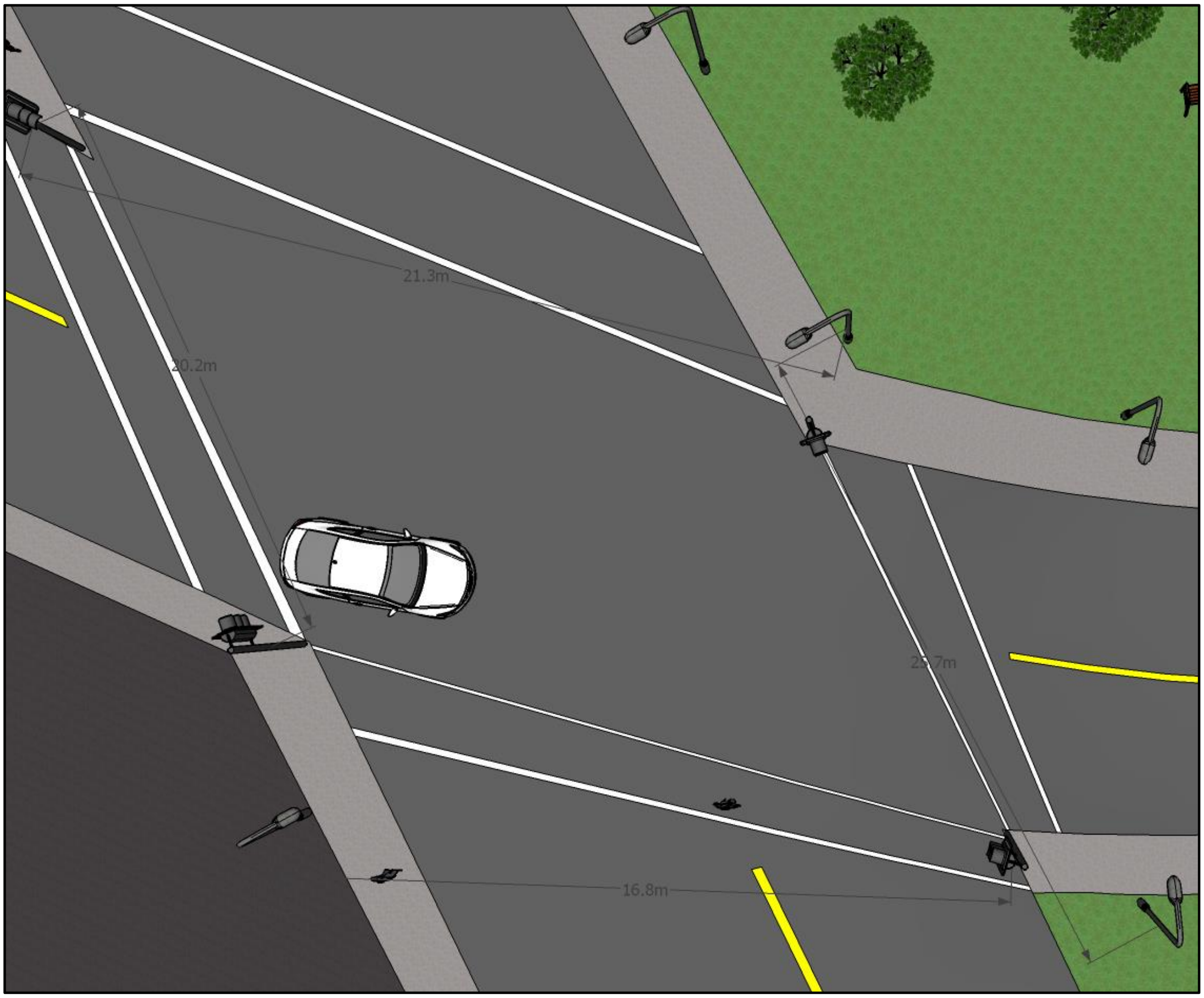


Figure 23. Close-up with dimensions of the central intersection.

2.1. Regulations, Standards, and Intellectual Property

The design must follow all regulations and standards while abiding to Federal and international intellectual property (IP) rules in order to be successful. Municipal building codes have a significant impact on this design while intellectual property considerations are minimal due to the generic and unpatentable nature of the technologies used in its implementation.

2.1.1. Governmental Regulations

Primary regulations include municipal zoning laws and building codes as well as higher level legislation such as the federal Highway Traffic Act.

Environmentally, construction of the design must comply with the Environmental Protection Act of Ontario [122]. This limits the amount of noise and pollutant output that can be tolerated during construction. Adherence to this regulation limits working hours (Appendix E) and increases costs.

A listing of less important regulatory standards can be found in full in Appendix E.

2.1.2. Industry Standards

Road vehicles - Collision classification
This standard classifies the different types of vehicle collisions. The design mandates consideration of the most common types in order to avoid them in a road environment [123].

Commercial road vehicles - Dimensional codes
This standard provides dimensions for commercial vehicles. These dimensions were used to verify all vehicles will be able to operate safety within the design [124].

Road vehicles - Objective rating metric for non-ambiguous signals
This standard provides a set of metrics used to rank signal lighting and timing. The design team considered these industry standards when choosing appropriate street lamps [125].

Road construction and maintenance equipment - Road milling machinery and asphalt pavers (commercial specifications)
This standard shows the characteristics of industry standard road milling machinery. During the heavy equipment selection process, it provided guidance on proper equipment choices [126][127].

It also contains the characteristics of industry standard asphalt paver. This mix must adhere to strict testing procedures outlined in Section 2.2 [128].

2.1.3. Intellectual Property

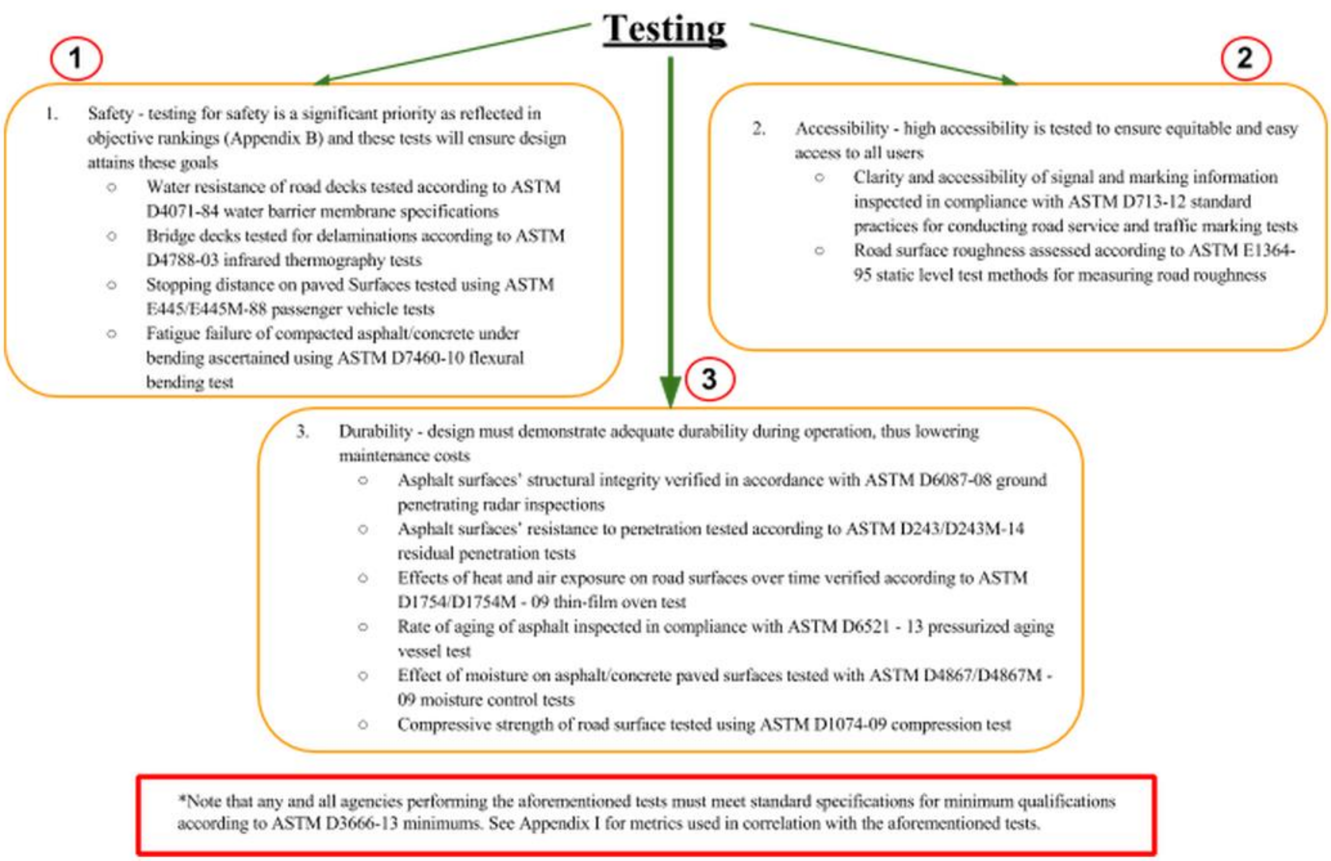
The relevance of intellectual property in this design is extremely limited. Since traditional asphalt mixing and road paving techniques have become common knowledge within the industry, they fail the novelty, utility, and nonobviousness requirements and are thus no longer patentable [129][130][131]. Furthermore, the large collection of prior art in the field means that the design does not require novel techniques for full implementation, some of which have indeed been patented [132][133][134][135].

For the purposes and implementation procedures of this design, none of the referenced patents are required (Section 2.3). Foreseeably, no patent or intellectual property concerns exist for the ultimate implementation of this design.

However, noteworthy patents whose use can be explored following initial implementation of the design have been listed in Appendix J.

2.2. Testing

The following standardized tests can be used to test the design against objective metrics. The specifics of these metrics have been documented in Appendix K. Preliminary testing will be done on the top 3 objectives for which standardized ASTM testing procedures exist.



2.3. Implementation Requirements

Implementation of the design will require large scale collaboration with city authorities, general contractors, and architectural firms.

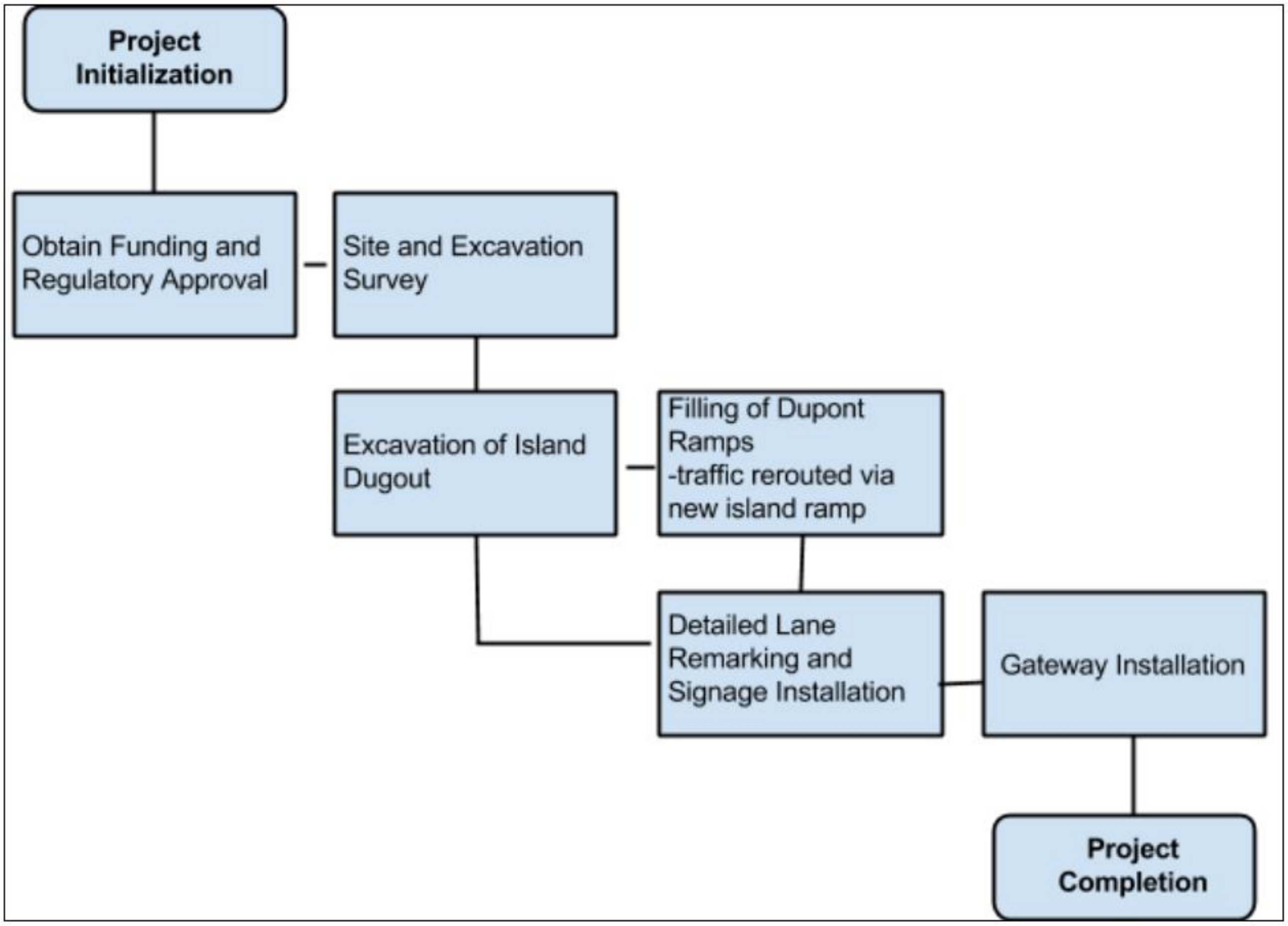


Figure 24. Simplified overview of the proposed design implementation process.

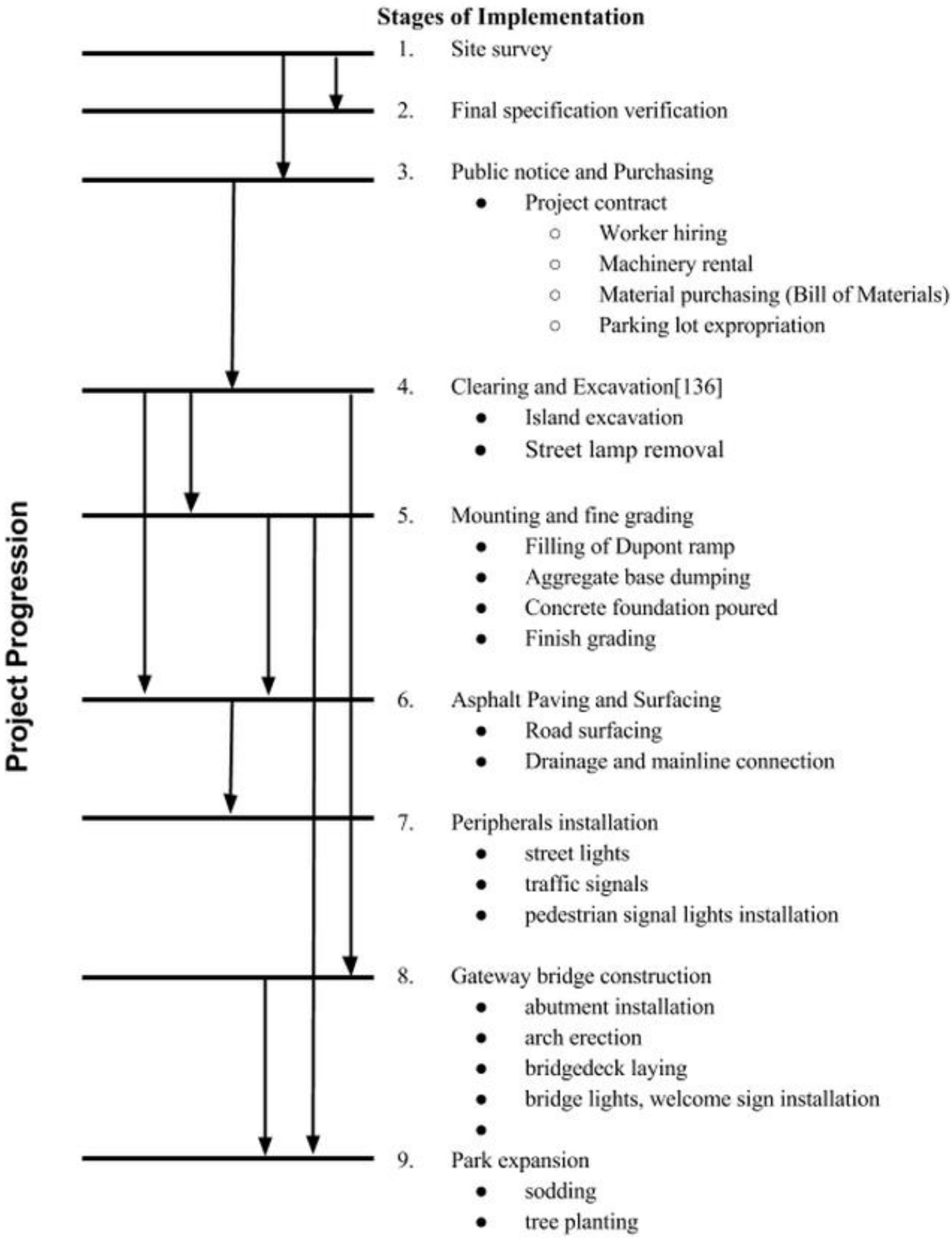


Figure 25. Simplified vertical Gantt chart of the project implementation process.

Implementation will be managed in stages in order to minimize disruptions to traffic during construction. Consequently, coordination in timing of the island ramp construction and Dupont ramp filling is instrumental in preserving acceptably smooth traffic flow during implementation and represents the greatest foreseeable challenge in this process.

As indicated in Figure 25, construction of the island ramp will occur first while the current Dupont ramps are used to handle traffic. Once the island ramp has all its basic installations complete and is opened, the current Dupont ramps will be filled (in layers) and park expansion can proceed. Other tasks, such as gateway bridge construction, can occur simultaneously (represented in the figure by arrow heads from different levels arriving at the same line).

2.4. Life Cycle and Environmental Impact

Goal Definition and Scoping

The preliminary Life Cycle Assessment (LCA) focuses on the key materials and processes involved in the production, on-site delivery, and application of the main construction materials, namely concrete and asphalt. These materials form the basis of modern day roadway and bridge construction.

The production processes for items not integral to the primary function of a road (to move mass), such as fencing, lighting and road signage, have been deemed beyond the scope of this LCA.

It has been split into two sub-LCAs for clarity: production and transport/application.

Inventory Analysis

Bitumen distillation and concrete mixing represent the central procedures involved in the production LCA [75][76][77]. An evaluation of vehicle and construction machinery emissions forms the basis of the transport/application LCA [78].

The mass and energy inputs and outputs to each process have been documented as part of Figure 26 and 27.

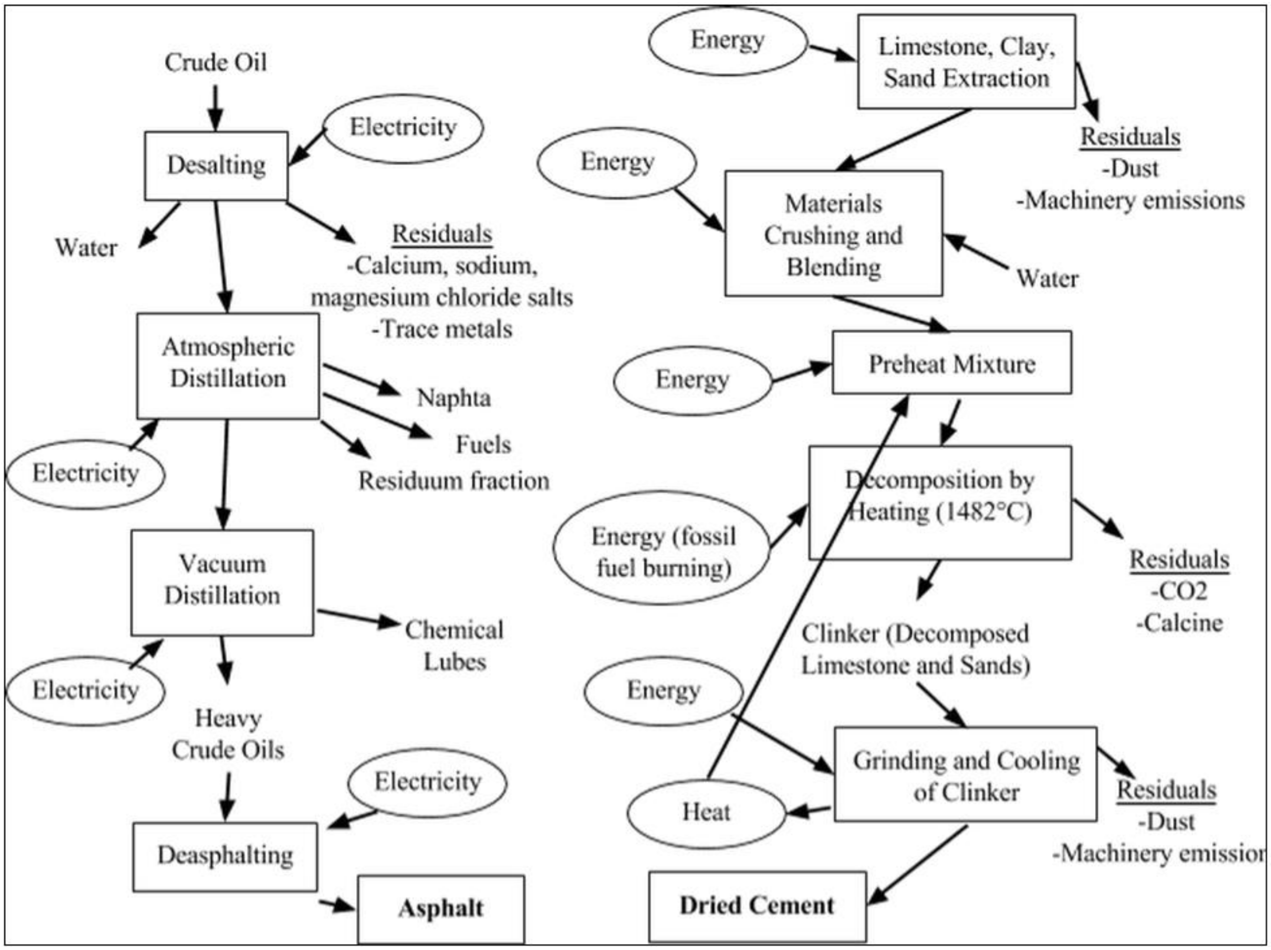


Figure 26. Life cycle assessment diagram (LCAD) for the main roadway and bridge construction materials.

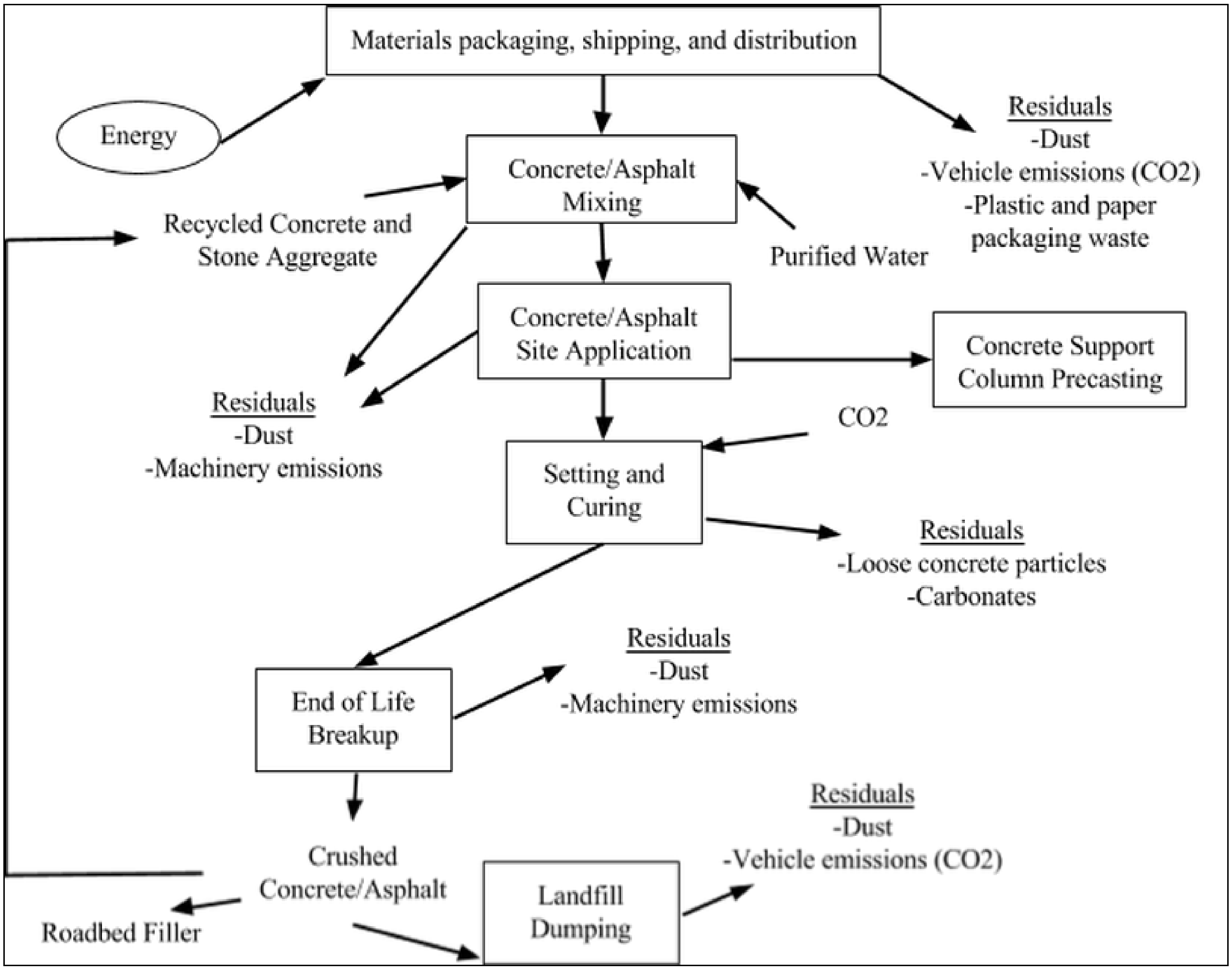


Figure 27. LCAD for various transport and construction efforts on site.

Impact and Improvement Analysis

The results of this analysis have been summarized in Table 6, following the principles of the three R's - to reduce, reuse, and recycle.

Table 6. Environmental Impacts

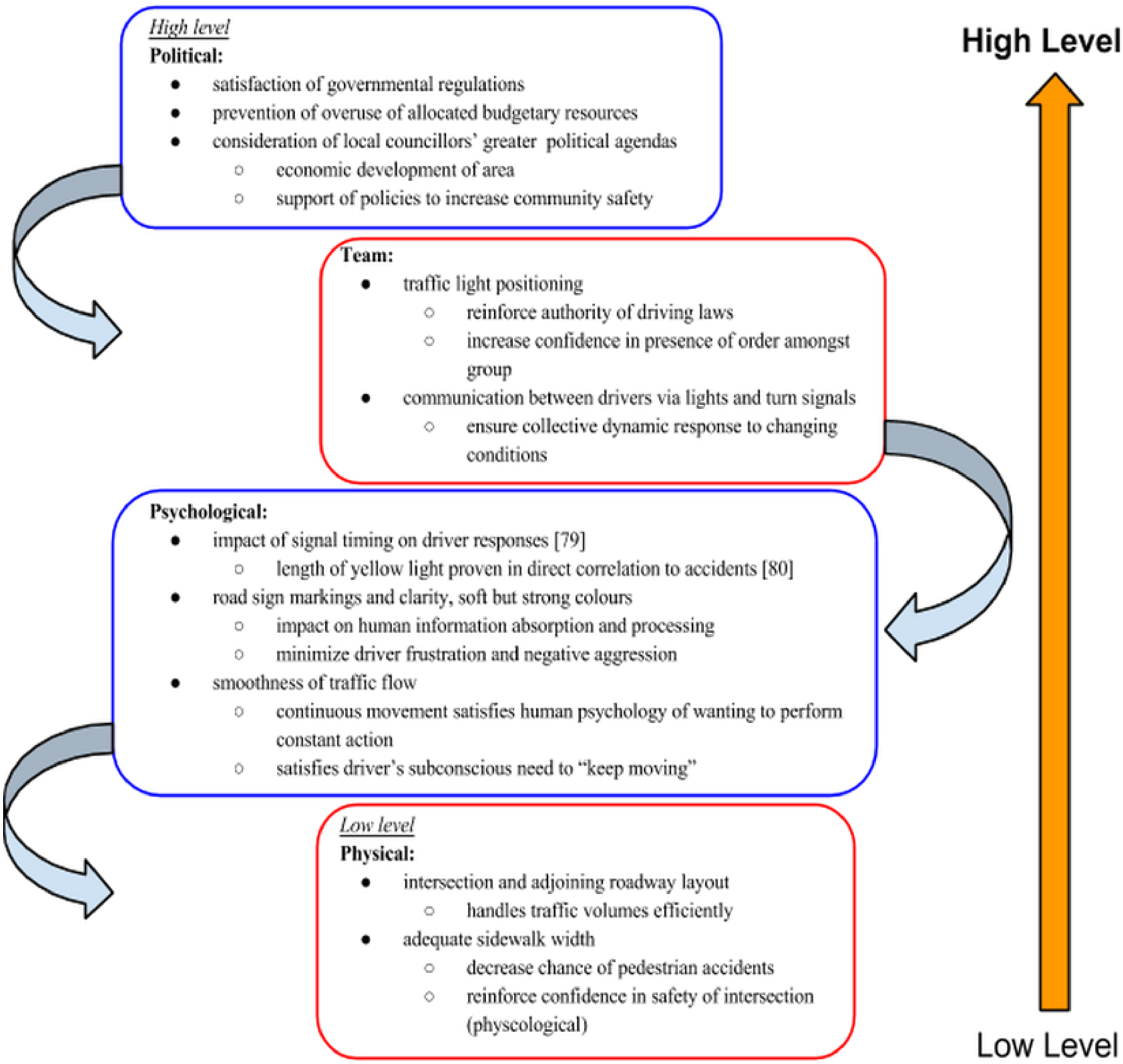
Design Production/Operation Element	**Potential Environmental Impact**	**Impact Mitigation**
During asphalt production	• Hazardous residuals disposal • High electricity consumption • Pollutant wastewater discharge	Reduce: • Avoid unnecessary electricity usage. Manage idling equipment to minimize operation during downtime Reuse:

<table>
<tr><td></td><td></td><td>Collect residual minerals, salts and trace metals for sale to and reuse by relevant factory processes
<u>Recycle:</u>
Direct wastewater to water treatment plants for clean water recycling into public system</td></tr>
<tr><td><u>During cement production</u></td><td>Safe potassium sulfate disposal
Electricity usage</td><td><u>Reuse:</u>
Ship potassium sulfate to industrial sulfur production plants</td></tr>
<tr><td><u>During road/bridge construction</u></td><td>Road closure generating excess exhaust by idling vehicles
Raising of excess dust
at intersection
by transport vehicles
Excess noise generation
impact on local wildlife
Emission of CO_2, SO_2, other biohazardous materials (particles below PM2.5)[82]
Accumulation of biologically harmful waste polymers, scrap metals, acidic fluids
Damage to roadside vegetation</td><td><u>Reduce:</u>
Cover exposed dirt piles to reduce dust
provide protective equipments to workers
<u>Reuse:</u>
Use dugout soil from island to fill other site ramps
Replant viable dug up plants
<u>Recycle:</u>
Recycle scrap metals, non-elastomer polymers, paper products</td></tr>
<tr><td><u>Lifetime Operation</u></td><td>Noise generation
Greater exhaust pollution due to increased traffic</td><td><u>Reduce:</u>
Consult municipal authorities to encourage use of fuel efficient vehicles. Excessively old cars should not be permitted on roads
Encourage commute by foot and TTC</td></tr>
</table>

Engineering Strategies and Practices

2.5. Human Factors

The human tech ladder explains technological relationships humans experience ranging from individual physical and psychological needs to high level organizational systems. Listed below are essential human factors relating to this design:



2.6. Social Impact

Key social impacts of this design include its increasing of community safety, both in terms of traffic accidents and crime rates, as well as the design's ability to reclaim currently unused green space on the island and integrate it into the greater intersection, significantly increasing use of communal spaces. The latter carries greater social impact in terms of community growth and bonding while the former influences primarily practical social concerns.

Significant efforts have been placed throughout the design process to maximize positive social impacts, however, balancing them amongst stakeholders has led to several tradeoffs. Most significantly, the design's requirement to expropriate the north-eastern portion of the Money Mart parking lot in order to regularize the intersection has led to large improvements in safety and accessibility for local residents and commuters. However, this business will nonetheless experience a loss of parking space for customers and thus experience a negative impact.

This impact has been balanced by increasing the overall number of passersby through the intersection, and thus the number of potential customers, in order to offset the loss of revenue due to inconvenienced customers who no longer have as much room to park.

Conversely, the design has a double positive social impact on the TTC and local NGOs. By increasing the efficiency of the intersection and reducing idling times, CO_2 emissions have been lowered while speeding up transit through the crossroads. This works to satisfy both local environmental NGOs and the TTC.

Lastly, the design offers a boost to the community's image and cultural significance within Toronto. By increasing the intersection's openness and reinforcing it as a gateway into the Western half of old Toronto through the construction of the gateway bridge atop the island dugout, it bolsters community consensus to create a less foreboding and more welcoming environment.

2.7. Economics

Table 7. Costs of Design Implementation

Capital Costs	**Operating Costs* (Fixed and Variable)**	**Disposal Costs**

• concrete application costs[81]
• asphalt application
• sewer line modification
• integrating electrical systems to main power grid
• traffic signal lights and roadway signage procuration
• potted vegetation
• bus shelters, water features, guardrails
• site survey
	• construction workers' wages
	
	• equipment rental
	  ○ excavator
	  ○ road roller
	  ○ crane
	  ○ totalling station
	  ○ bulldozer, dump trucks
	  ○ levelling set/measuring instruments
	
	• maintenance of road
		• waste management costs (disposal of asphalt, concrete) when decommissioned
		
		• grafting or eliminating existing vegetation
		
		• re-modifying underground sewer lines
		
		•
		• filling island ramp

- gateway bridge construction - park expansion	- winter maintenance - pothole filling - erosion prevention - maintenance of park - watering - grass cutting, tree trimming - garbage collection	

*operation of the design will overlap with construction (primarily capital) costs, and some have therefore been merged

External (Indirect) Costs and Benefits borne by society:

Costs

- economic losses in productivity due to increased commute time during construction
- cost dealing with pollutants (dust, noise, hazardous wastes) during construction
- treatment of wastewater runoff

Benefits

- increases jobs available for skilled workers
- economic benefits due to greater commuter flow

Cost breakdown of the design:

Heavy Machinery: Design implementation requires many different types of heavy machinery, including a dozer, hydraulics excavator, articulated trucks, asphalt roller, smooth drum roller, and a hydraulics breaker. The estimated cost to rent each piece of equipment for time periods between 1-15 months is $199,400.

\+

Stone pitched foundation: After removing the existing asphalt road, stone pitched foundation is used in conjunction with surfacing materials such as asphalt to stabilize the roadbed foundation. 0.533 tonnes of stone pitching are required to cover one square meter of road. The material cost for the 962.598 tonnes of pitching stone required is $75,039.

\+

Asphalt: The new roadway is to be paved with asphalt. This requires 140,616 tonnes of asphalt. Two layers of asphalt are laid: a bottom layer 50mm thick and a top layer of 25mm. In total, the estimated cost of asphalt required is $31,570.

\+

Sidewalk: The cost of constructing approximately 200m of brand new sidewalk is estimated at $14,627.

\+

Parking lot expropriation: The design requires the expropriation 365.7m^2 (Figure 11) of parking lot from Money Mart. This will cost $20,822.

\+

Peripherals: 8 traffic signal lights will be used in the intersection, and 11 additional street lamps will be planted. Pedestrian traffic lights, bridge lighting, and underpass illumination will also be included. The total cost for these items is $22,999.

\+

Gateway bridge: By benchmarking, the cost of a 29.7m long, 2.74m wide wood and steel gateway bridge is $146,159.

\+

Park expansion: A park with an area of 4687.9m^2 will be established. The cost, including sodding and planting trees, is estimated at $54,355.

=

Total cost of the design : $607,561 (Appendix H)

3.0 Updated Project Management Plan

Following finalization of the Final Design Specification (FDS) on April 1st, the team will prepare for the final presentation on April 27th. The presentation outline and preparation of visual aids will be done by April 24th. During the next team meeting on April 8th, the team will assign final presentation components to each participating team member.

4.0 Conclusion and Recommendation

The Island Dugout proposed design has been thoroughly detailed in this document and the engineering decision process used to arrive at the aforementioned design can be seen in Appendix L. Lane diagrams have been developed in accordance with regulatory standards and optimization algorithms for all four adjoining streets. Traffic signal timing has been redone to ensure optimal traffic flow, and an accurate total cost estimated was produced.

The WBCA is now invited to further advance the design specified in this document to municipal authorities and investors.

Figure 28. Grand overview of the proposed intersection, with the Gateway Bridge in the foreground.

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Note: All Google Sketchup scenery objects (trees, vehicles, people) used in the models contained in this document were obtained from Google's online public 3D Warehouse of Sketchup objects. Available: https://3dwarehouse.sketchup.com/

Appendix A: The Black Box Method

The black box method, as referenced in Section 1.3.1, is an idea generation technique that works through enabling the functional decomposition of various inputs and outputs into the fundamental categories of mass, energy, and information. It is employed within a strictly solution-independent thinking space.

The black box method was employed as shown in Figure 1 in order to create a clear functional basis for the design:

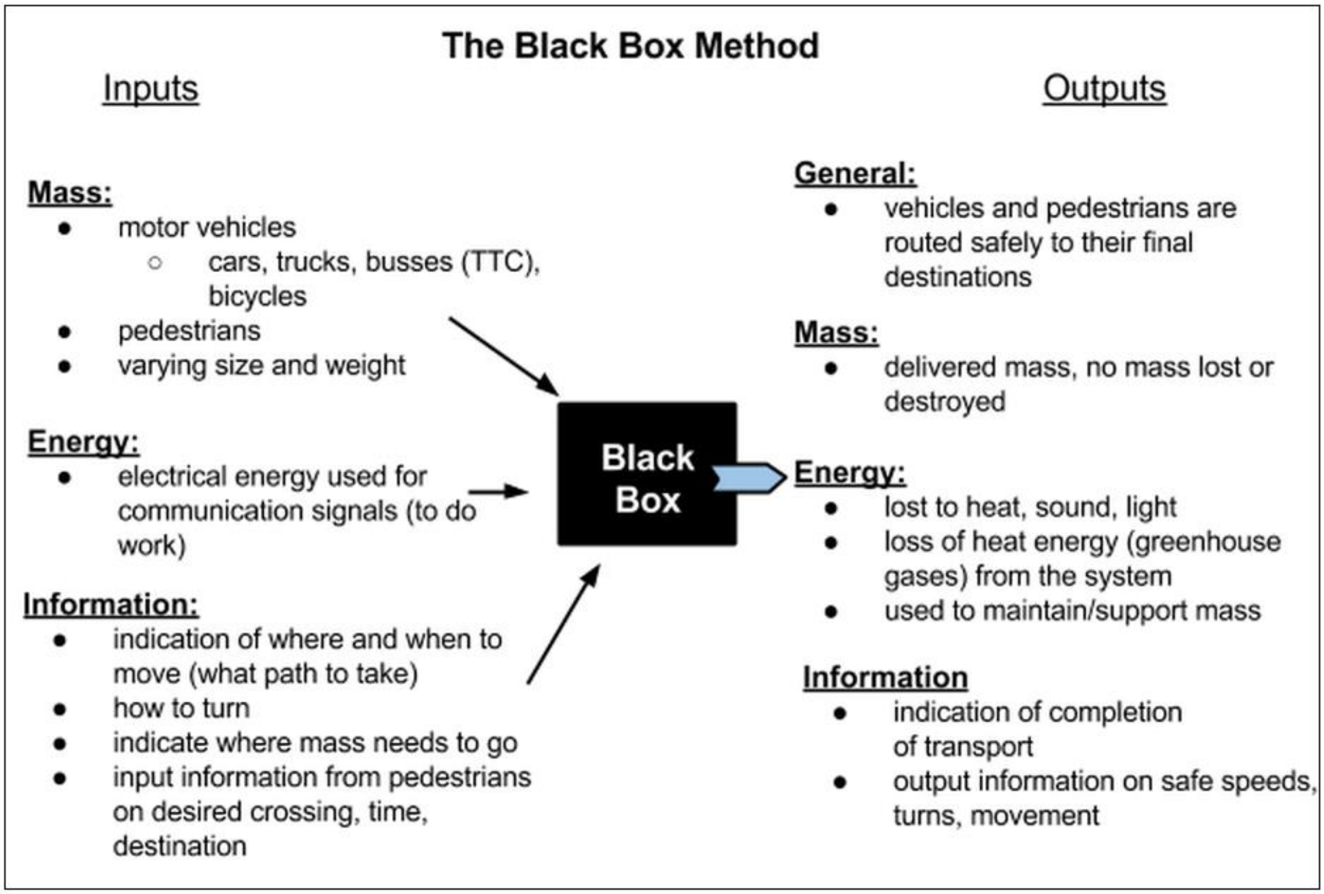

Figure 1. Group exploration of the Black Box method in defining the basic function of the design.

Appendix B: Pairwise Objective Comparison

This appendix shows the key results of a pairwise comparison procedure, where key design objectives were compared in order to rank their relative importance. The results of this comparison indicate the following order of relative objective importance:

Safety > Accessibility > Cost-Effectiveness > Harmony of Proportions > Durability > Environmentally Friendly > Low Maintenance

Safety earned the highest relative objective importance due to the abnormally high number of accidents experienced at the DDA intersection, indicating a need to address this issue as a priority. This objective was followed by accessibility, based on the diverse range of users and community members requiring ease-of-access to the interaction. This earned it a respective high rating among objectives. Cost-effectiveness was also an important objective, as it relates closely to the implementation and feasibility of the project. The design must be able to make use of the limited available budgeting resources while achieving its goals.

Durability, environmental friendliness, and ease-of-maintenance were less important objectives due to their lesser impact on the functional basis of the design. However, there was a need to produce a durable design that would function well with limited maintenance while reducing pollutant and greenhouse gas emissions that could degrade the local environment, fundamentally opposing core client values of a clean, friendly, open neighbourhood.

Table 1. Pairwise Objective Comparison Chart

Pairwise Comparison Chat	Cost-Effectiveness	Safety	Accessibility	Durability	Low Maintenance	Environmentally Friendly	Harmony of Proportions	Total
Cost-Effectiveness		0	0	1	1	1	1	4
Safety	1		1	1	1	1	1	6
Accessibility	1	0		1	1	1	1	5
Durability	0	0	0		1	1	0	2
Low Maintenance	0	0	0	0		0	0	0
Environmentally Friendly	0	0	0	0	1		0	1
Harmony of Proportions	0	0	0	1	1	1		3

Figure 2. Table indicating results of pairwise comparison between main objectives. Green indicates a point awarded to the horizontal component, while orange indicates the opposite. Red boxes represent logically incorrect fields and blue boxes represent the total, showing relative importance of the horizontal component.

Appendix C: Estimated Budget and Related Projects

This appendix relates to cost estimates made by scaling similar existing City of Toronto infrastructure projects. The following estimates provide a low to high-end budget range, capped by Section 1.5's monetary constraint (constraint 1).

Project 1 - Highland Creek Village Transportation Master Plan

Budget: between $200,000 to $250,000 [42][43][44]

A similarly sized, but less complex, intersection redesign provides a low-cost estimate (scale factor 2) for the project [45]. The work done includes road surface renewal, merging ramp construction, and signal redesign, offering a base template for the DDA interaction budget.

Project 3 - Danforth Avenue Improvements

This project involves a different infrastructure renewal, dealing primarily with a single road compared to an intersection [46]. For this reason, its budget was not considered as an accurate base estimate for the DDA redesign. However, the project is considered for its template on construction time, labour involved, and local impact [47].

Project 4 - Fort York Pedestrian and Cycle Bridge and Ordnance Master Plan

Budget: $19.7 million [48]

A more extensive project of similar complexity, involving an intersection and bridge redesign (scale factor 1.5) [48]. This provides the absolute limit for the budget of the design, indicating the maximal feasible budget allocated to a project of the size and complexity of the DDA.

This recent infrastructure project will therefore be used for the high-end budget limit and corresponding constraint.

Appendix D: Calculation for Maximal Car Exhaust

This appendix contains the calculations involved with the determination of the maximum allowed CO2 car emissions for the design.

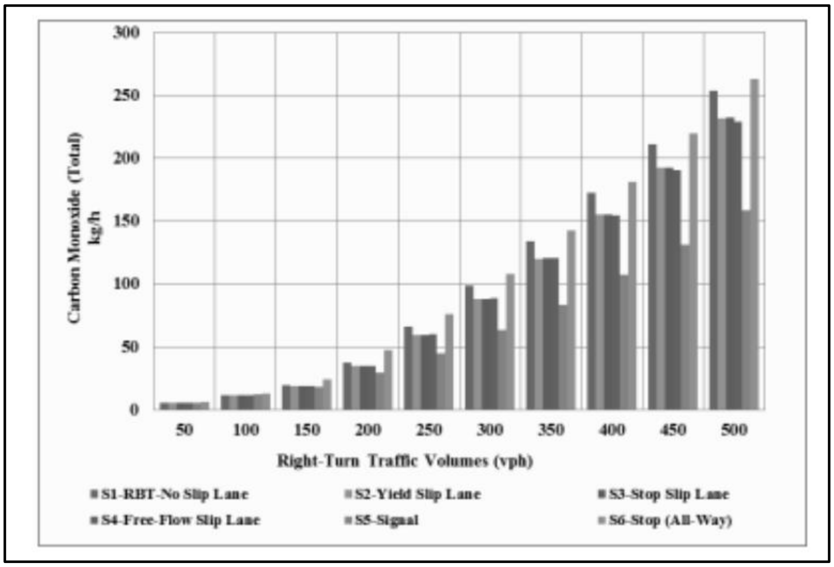

Figure 2. Graph of emissions vs. traffic volumes for average intersection turns. Taken from [25].

<u>Calculations</u>

Average Car Volume of Intersection: 29,392 vehicles/day/24hrs = 1225 vehicles/hr

Estimating a linear relationship: at 500 vehicles/hr, maximum car exhaust is 250 kg/hr

500 vehicles/250 kg/hr = 1225 vehicles/***x*** kg/hr

***x* = 612 kg/hr**

Therefore, 612 kg/hr is approximately the maximum car exhaust, on average, per hour permissible for this intersection. Note that this provides only a rough estimation, and therefore a flexible limit as the distribution of cars in real world application is not even.

Appendix E: Relevant Municipal By-laws, Provincial Laws, and Federal Legislation

1. City of Toronto Construction Requirements [27]

- Consult with your neighbors before working on a project
- Communicate with your neighbors and keep them well informed
- Remove the waste and clean up after you complete the project
- Consult with Street Occupation Permit before starting a demolition, construction or renovation project
- Construction should only be done during Monday to Friday 7:00 to 19:00 and Saturdays 9:00 to 19:00
- Construction must be safe for both the workers and users. Please ensure the construction is safe by complying with the bylaw. Failure to comply may result in fine:
    - Construction must not interfere with any neighboring services, including underground lines
    - Protect the trees and shrubs prior to construction
    - The construction site must be closed with protective fencing to prohibit public access (Toronto Municipal Code - Construction Fence Bylaw - Chapter 313)
    - If the construction involves the alteration of overhead power lines in anyways, remember to contact Toronto Hydro.
    - Portable toilets must not be placed anywhere near the neighboring homes and must be hidden
    - Garbage and bins must be kept away from the neighboring properties
    - No construction vehicles are allowed on private neighboring properties
    - No burning of construction waste of any sort
    - Idling construction vehicles are not allowed. Nor should any dangerous goods and equipments be left unattended.
    - Ensure all the construction workers are properly equipped

2. City of Toronto By-law with Regards to Trees and Plants

Private Tree By-law: Toronto Municipal Code, Chapter 813, Article III regulates planting of trees and other vegetation, pertinent to the green space on the Dundas traffic island involved in the intersection redesign [49][50].

3. City of Toronto By-law with Regards to Noise

The “Noise” By-law states that no noise shall be heard in public areas Monday to Friday before 7am and after 7pm, and before 9am and after 7pm on Saturday [28].

4. City of Toronto By-law with Regards to Zoning Information [52][53]

This by-law provides information for different zones and residential areas:

Engineering Strategies and Practices

Setback to Adjacent Buildings	For most Residential buildings: the zoning by-law requires a setback to adjacent buildings of 1.2 meters for adjacent building walls with any openings, and 0.9 meters for adjacent building walls without openings

6. City of Toronto Development Charges By-law

The city of Toronto has a set of by-law for determining the costs of constructions of private properties [54][55].

7. City of Toronto developed many programs to ensure traffic safety

These programs regulate traffic flow and safety with respect to signals and road conditions [56].

8. Pavement Structural Design Matrix [30]

Major Arterial	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
Non-Truck Routes (5% Commercial Vehicles)	40 mm HL-1 110 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 500 mm Total	40 mm HL-1 90 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 480 mm Total	40 mm HL-1 125 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 515 mm Total	40 mm HL-1 100 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 490 mm Total	40 mm HL-1 135 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 525 mm Total	40 mm HL-1 110 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 500 mm Total	40 mm HL-1 145 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 535 mm Total	40 mm HL-1 120 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 510 mm Total	40 mm HL-1 155 mm HL8 (HS) 50 mm Granular A 300 mm Granular B * 545 mm Total	40 mm HL-1 125 mm HL-8 (HS) 50 mm Granular A 300 mm Granular B * 515 mm Total
Truck Routes (7.5% Commercial Vehicles)	40 mm HL1 130 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 570 mm Total	40 mm HL1 110 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 550 mm Total	40 mm HL1 150 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 590 mm Total	40 mm HL1 130 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 570 mm Total	40 mm HL1 155 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 595 mm Total	40 mm HL1 135 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 575 mm Total	40 mm HL1 160 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 600 mm Total	40 mm HL1 145 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 585 mm Total	40 mm HL1 170 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 610 mm Total	40 mm HL1 150 mm HL8 (HS) 50 mm Granular A 350 mm Granular B * 590 mm Total
Truck Routes (10% Commercial Vehicles)	40 mm HL-1 150 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 590 mm Total	40 mm HL-1 125 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 565 mm Total	40 mm HL-1 160 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 600 mm Total	40 mm HL-1 135 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 575 mm Total	40 mm HL-1 170 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 610 mm Total	40 mm HL-1 145 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 585 mm Total	40 mm HL-1 175 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 615 mm Total	40 mm HL-1 155 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 595 mm Total	40 mm HL-1 185 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 625 mm Total	40 mm HL-1 165 mm HL-8 (HS) 50 mm Granular A 350 mm Granular B * 605 mm Total

Minor Arterial	20,000		25,000	
	30 MPa	50 MPa	30 MPa	50 MPa
Non-Truck Routes (4% Commercial Vehicles)	40 mm HL-1 95 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 435 mm Total	40 mm HL-1 80 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-1 105 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-1 85 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 425 mm Total
Truck Routes (7.5% Commercial Vehicles)	40 mm HL-1 135 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 475 mm Total	40 mm HL-1 110 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 450 mm Total	40 mm HL-1 140 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 480 mm Total	40 mm HL-1 120 mm HL-8 (HS) 50 mm Granular A 250 mm Granular B * 460 mm Total

Composite Pavements	All Traffic & Subgrade
Major Arterial	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
Minor Arterial - Bus/Truck Route	40 mm HL-1 50 mm HL-8 (HS) 250 mm PCC Concrete 150 mm Granular 'A' 490 mm Total
Local Collector - Bus/Truck Route	50 mm HL-1 of HL-3 200 mm PCC Concrete 150 mm Granular 'A' 400 mm Total
Local Collector - Non Bus/Truck Route	50 mm HL-1 or HL-3 150 mm PCC Concrete 150 mm Granular 'A' 350 mm Total

Collector	5,000		7,500		10,000		15,000	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
Comm./Ind. (5% Commercial Vehicles)			40 mm HL3 105 mm HL-8 50 mm Granular A 250 mm Granular B * 445 mm Total	40 mm HL-3 75 mm HL-8 50 mm Granular A 250 mm Granular B * 415 mm Total	40 mm HL-3 115 mm HL-8 50 mm Granular A 250 mm Granular B * 455 mm Total	40 mm HL-3 85 mm HL-8 50 mm Granular A 250 mm Granular B * 425 mm Total	40 mm HL-3 125 mm HL-8 50 mm Granular A 250 mm Granular B * 465 mm Total	40 mm HL-3 95 mm HL-8 50 mm Granular A 250 mm Granular B * 435 mm Total
Residential (3% Commercial Vehicles)	40 mm HL-3 70 mm HL-8 50 mm Granular A 250 mm Granular B * 410 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 85 mm HL-8 50 mm Granular A 250 mm Granular B * 425 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 95 mm HL-8 50 mm Granular A 250 mm Granular B * 435 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total		

Local	2,500		3,000		4,500	
	30 MPa	50 MPa	30 MPa	50 MPa	30 MPa	50 MPa
	Local Residential (3% Commercial Vehicles)		Local Industrial (10% Commercial Vehicles)		Local Throughway (3% Commercial Vehicles)	
	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 80 mm HL-8 50 mm Granular A 250 mm Granular B * 420 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total	40 mm HL-3 60 mm HL-8 50 mm Granular A 250 mm Granular B * 400 mm Total

Notes: AADT

Subgrade

* Subbase is Granular B - Type II as specified in OPSS 1010

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Figure 3. Graphical matrix for use with pavement structural design. Taken from [30].

9. Major Capital Infrastructure Coordination

This office is a part of the Toronto council which addresses deficiencies and flaws in the plan and implementation of large city of Toronto infrastructure projects, such as the DDA intersection redesign [17].

10. Ontario Provincial Standards

These standards explain establish legal and regulatory guidelines for the project [57].

Engineering Strategies and Practices

11. Government of Canada Motor Vehicle Safety Act

This legislation explicitly deals with the safety of motor vehicles, a major component of the redesign [33].

12. Government of Canada Highway Traffic Act

This Highway Traffic Act defined permissible modifications to road surfaces and intersections [34]. It will play a significant role in navigating the legal constraints of the DDA project.

13. Must accommodate all types of motorized/non-motorized vehicles and pedestrians

a. Minimum head clearance: 4.15 meters [60]
b. Minimum lane width: 2.8 meters [60]
c. Must permit the passage of vehicles up to 23 meters in length [60][61]
d. Must be accessible to all pedestrians, regardless of their age, gender, race, religious belief, and health conditions [7][8][62]
e. Pedestrian sidewalks must be at least 3 meters wide and clearly marked by 0.1 meter lines [60]
f. All curb lanes must be at least 3.3m allowing for passages of all TTC buses [137]
g. All bike lanes must be at least 1.5m wide[138]
h. Shared curb lanes (vehicles and cyclists) must be at least 4.3m wide [137]

Table 2. Minimum lane width specifications and other influencing factors. Taken from [137].

						Parking		Transit		Cycling					Posted Travel Speed			Land Use				Other	
			Minimum/Constrained	Target	Maximum	Off Peak On Street Parking	24-Hour Parking Lane	Streetcar Tacks	Bus Route	On-Street Bike Lane	Buffered On-Street Bike Lane	Moderate Cyclist Volumes	High Truck Volume/ Designated Truck Route	High Pedestrian Activity	Less than 40 km/h	40-50 km/h	Greater than 50 km/h	Residential	Commercial	Industrial	Institutional (school, park)	Horizontal Curves	No Buffer Between Sidewalk and Curb Lane
Through Lane	Collector and minor arterial		2.8	3.0	3.3	=	=	+[1]	=	X	X	X	+	-	-	=	+	-	=	+	-	+	=
	Major arterial			3.2	3.6																		
Curb Lane	Dedicated cycling Facility not present	All road classifications	2.8	4.3	4.3	+	+[2]	X	+[3]	X	X	+	+[4]	-	-	=	+	-	=	=	=	+	+[5]
	Dedicated cycling facility present	Collector and minor arterial		3.2	3.3					+[6]	-[7]	X											
		Major arterial			3.6																		
Two-way Left Turn Lane			2.7	3.0	3.2	=	=	X	+	=	=	=	+	-	-	=	+	-	=	+	-	+	=

[1] A through lane containing streetcar tracks must be at least 3.1m wide.
[2] Recommended lane width does not include width of parking space. Increase beyond the target width is intended to reduce risk of "dooring" for cyclists in the bike lane.
[3] On designated TTC bus routes, the target lane width for all lanes used by TTC buses is 3.3m, where possible.
[4] Where a bike lane is present on a road with high truck volumes the curb lane should be widened to the maximum width, where possible.
[5] Wider curb lane in such conditions is preferred in order to add more space between vehicles and pedestrians. However, if the project scope allows for moving the curbs and adequate width for cycling facility is already provided, it is best to increase the width of the boulevard and create a buffered sidewalk rather than widening the curb lane.
[6] When bike lane is present, consider widening bike lane to target width before widening curb lane
[7] Where a bike lane with a minimum buffer of 0.7m is present, the right of way is constrained and posted speed is 40 km/hr or less, a minimum curb lane width of 3.0 m wide may be permitted, regardless of TTC bus route designation.

Appendix F: Cost Estimate for Proposed Design - Island Dugout Master Plan

Machinery Cost:

The design requires many different types of heavy road machinery such as bulldozers, hydraulics excavator, articulated trucks, asphalt roller, smooth drum roller, and a hydraulics breaker.

Dozer D39EX: ($4,200 per month) X 15 months = $63,000
Hydraulics Excavator GH6: ($4,700 per month) X 8 months = $37,600
Articulated trucks HM-300: ($12,000 per month) X 6 months = $72,000
Smooth drum roller 3307: ($4,000 per month) X 1 month = $4,000
Hydraulics breaker PC88: ($3,800 per month) X 6 months = $22,800 [152]

Total Heavy Machinery Rental Cost = $199,400

Cost to remove existing intersection (labour fuel included, machinery is separate):

1. Removing Existing Asphalt:
Width of the road = 12.9m (3 lanes + 2 bike lanes)
Area of road removed = 302m X 12.9m = 3,896sqm

Cost to remove the asphalt road = 3,896sqm X $4.06/sqm = $15,818 [82]

2. Stripping of Topsoil:
Cost to remove the topsoil = 3,896sqm X $1.80sqm = $7,013 [82]

3. Removing the concrete sidewalk:
Length of sidewalks removed = 604m
Average width of sidewalks = 1.5m [83]
Area of sidewalks removed = 604m X 1.5m = 906sqm

Cost to remove concrete sidewalks = 906sqm X 9.39$/sqm = $8507 [82]

Total Cost to Remove Existing Intersection = $31,338

Stone Pitching Foundation Material Cost:

Plant and labour cost = $10.23 per tonne
Plant and transportation = $0.17 per tonne
Material cost = $67.55 per tonne
Total cost = $77.95 per tonne
Tonnes of Stone Pitching required = (12.9m X 140m) X 0.533 tonne = 962.598 tonnes

Total Cost for Stone Pitching Foundation = $75,034

Asphalt Material Cost (two-coat hot asphalt thickness of 75mm - bottom coating 50mm, and top coating 25mm):

0.062 (top) + 0.115 (bottom) tonnes of Asphalt is needed per square meter of road

0.22 hours of labour is required to lay and roll one square meter of roll
Material cost: $41.32 per tonne of Asphalt
Material cost (0.177 tonnes):$7.31 per square meter

Cost to hire the roller, the driver, fuel and oil ($18.78 per hour): $4.13 per square meter
Cost for labour ($11.27 per hour): $2.48 per square meter

Total cost: $13.92 per square meter

Bottom coating 50mm, and top coating 25mm:
0.062 tonnes of Asphalt required per square meter

Width of road = 16.2m (4 lanes + 2 bike lanes)
Length of road = 140m

Total Cost for Asphalt Surfacing = (16.2m X 140m) X $13.92 = $31, 570

<u>Cost to mix, labour and pour the concrete sidewalk:</u>
Length of sidewalk built = 200m
Width of sidewalk = 1.525m
Area of sidewalk constructed = 200m X 1.525m = 305sqm

Cost to construct the concrete sidewalk = 305sqm X $47.96/sqm = $14,627 [82]

<u>Traffic Lights Installation Cost:</u>
Engineering Design cost = $2,415 to $3,675

Construction Cost for Traffic Lights = $13,650 to $26,250 [85]

<u>Cost of Parking Lot Expropriation:</u>
Amount of land required = 365.7sqm
Average net value of Industrial and Commercial/Retail Property in Neighbourhood = $56.94 per sqm [84]

Cost to purchase the parking lot = 365.7sqm X 56.94$ = $20,822

<u>Cost of Maintenance:</u>
Cost to maintain traffic lights = $252 to $305 per year [85]

<u>Installing Streetlights [153][154][155]:</u>
Total high efficiency street lamps to be installed: 41m/2 street lamp = 11
$1500*11 = $16,500

Cost to Install Street Lamps = $16,500

<u>Installing Bridge Lighting [156]:</u>
Pedestrian bridge light: 2/5m
6 * 2 * $136.62 = $1639.44

Cost to Install Pedestrians Bridge Lighting = $1639.44

<u>Gateway Bridge Construction [157]:</u>
Length: 29.7m
Width: 2.74m

$1500/linear foot
$1500 * 29.7m * 3.2808 = $146,159.64

Cost to build Gateway Bridge = $146,159.64

<u>Park Space Expansion [158][159][160]:</u>
Area of the park: 1750.8m^2 + 2947.1m^2 = 4697.9m^2
Sodding price: $0.98/ft^2
Sodding the park: 4697.9 * 0.98 * 10.7637 = $49,555.45
Tree planting: PINE-Austrian Pine * 5 + SPRUCE-Colorado Blue Spruce * 5 + SPRUCE-Glacier Blue Colorado Spruce * 5 = $100 * 5 + $160 * 5 + $50 * 5 = $1,550
Planting labour price: $110/hr * 2hr/tree * 15 trees = $330

Total Cost of Park Creation = $54,405.45

<u>Cost Breakdown Summary:</u>
Total Road Machinery Cost = $199,400
Total Cost to Remove Existing Intersection = $31,338
Total Cost for Stone Pitching Foundation = $75,039
Total Cost for Asphalt Surfacing = (16.2m X 140m) X $13.92 = $31, 574
Cost to Pour the Concrete Sidewalk = 305 sqm X $47.96/sqm = $14,627 [82]
Construction Cost for Traffic Lights = $13,650 to $26,250 [85]
Cost to Purchase the parking lot = 365.7sqm X 56.94$ = $20,822
Cost to Install Street Lamps = $16,500
Cost to Install Pedestrians Bridge Lighting = $1639.44
Cost to Build Gateway Bridge = $146159.64
Total Cost of Park Expansion = 54,405.45

<u>Grand Total: $607,560.53</u>

Appendix G: Intersection Maps and Site Visualization

This appendix contains relevant site maps, key elements of which were verified during the site visit performed by the team on January 28, 2014.

Most notable are the East-West Dupont St. Annette St. bike lanes (Figure 3), which run in both directions over even the narrowest sections of the intersection, and the existing sewer mains that are buried direction below the intersection (Figure 8). These must be considered should excavation be required, and could potentially add cost.

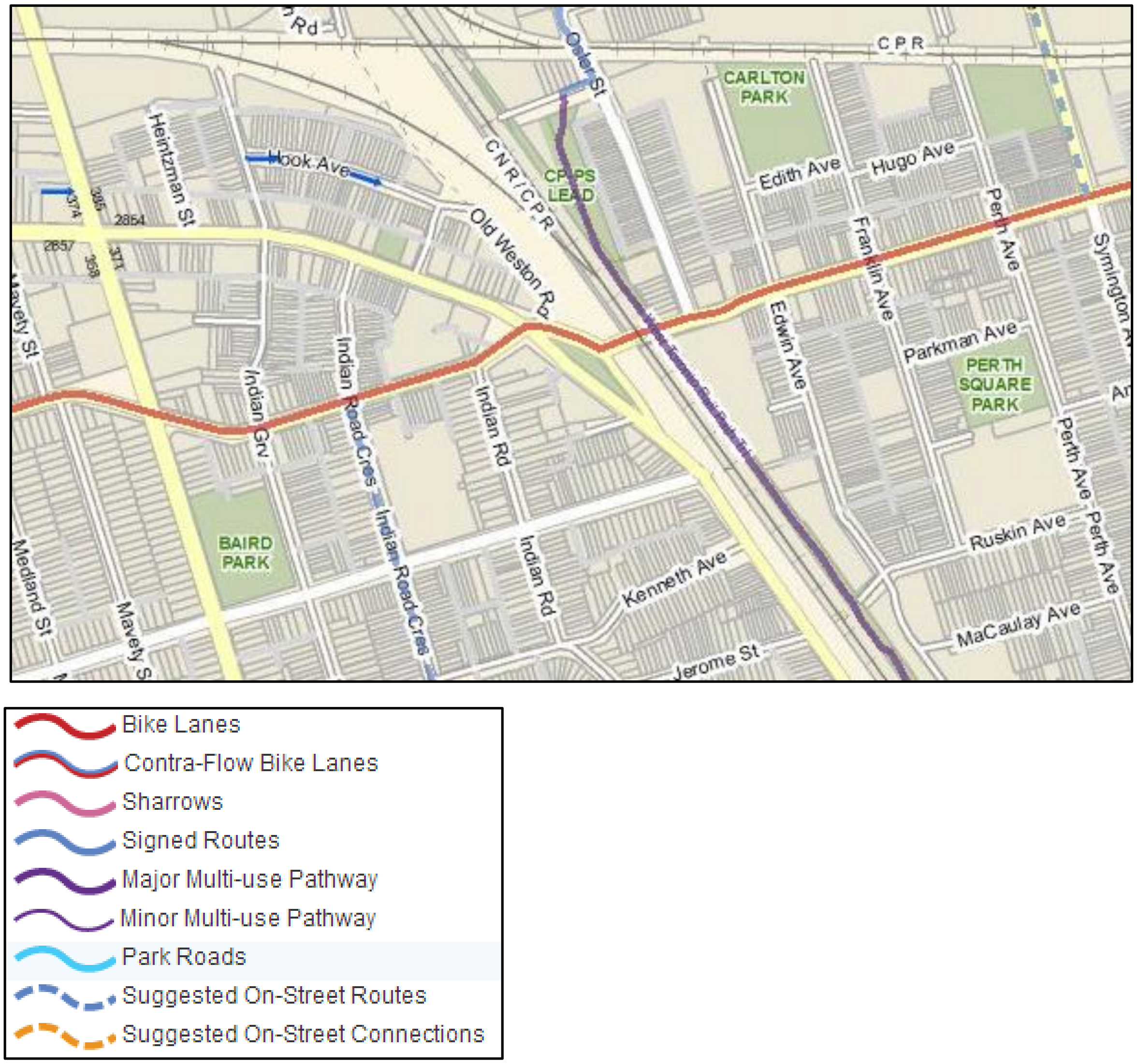

Figure 3. Bike lanes currently installed surrounding the DDA intersection. Taken from [58].

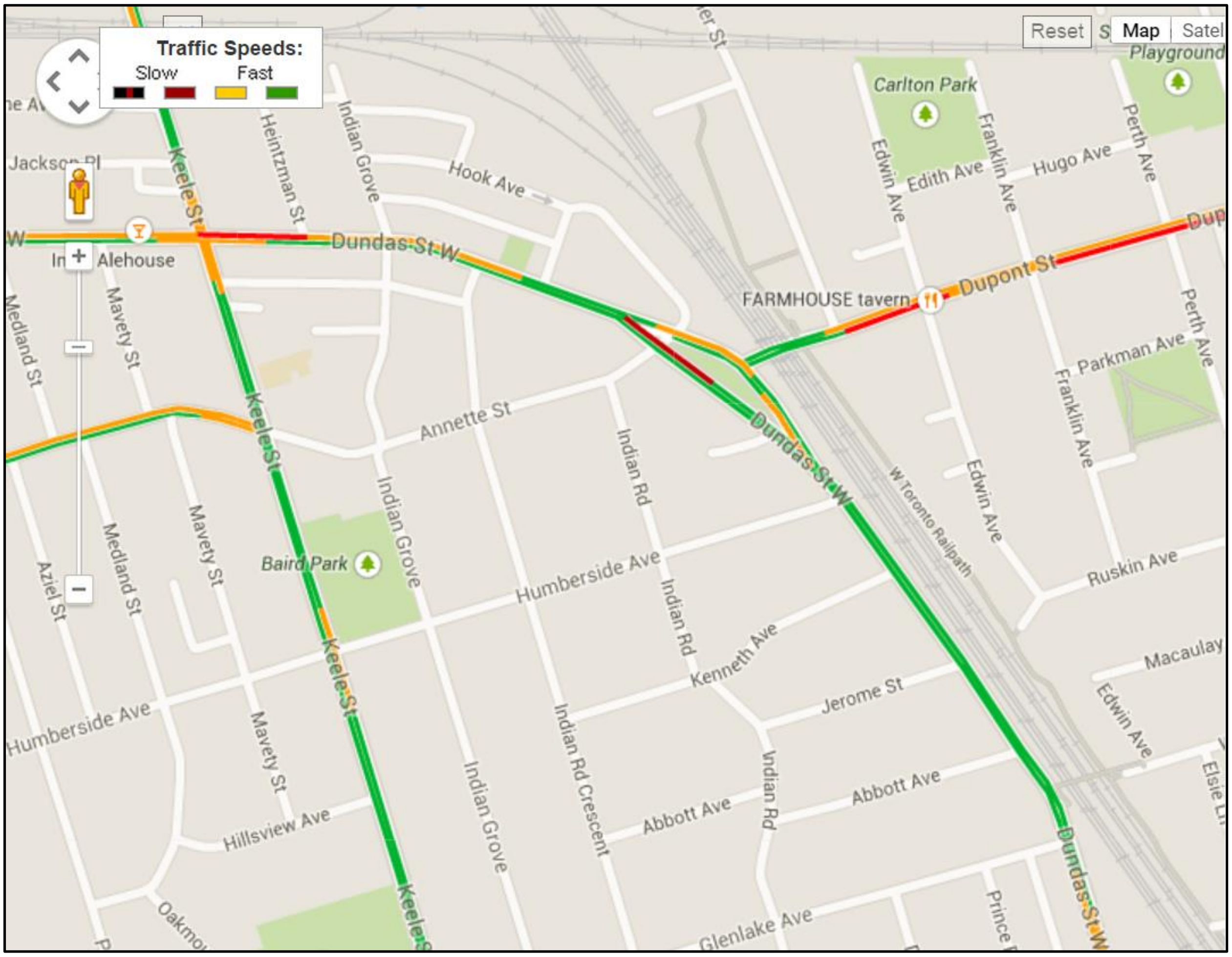

Figure 4. Average speed of motorized vehicles through the DDA Intersection choke points. Taken from [59].

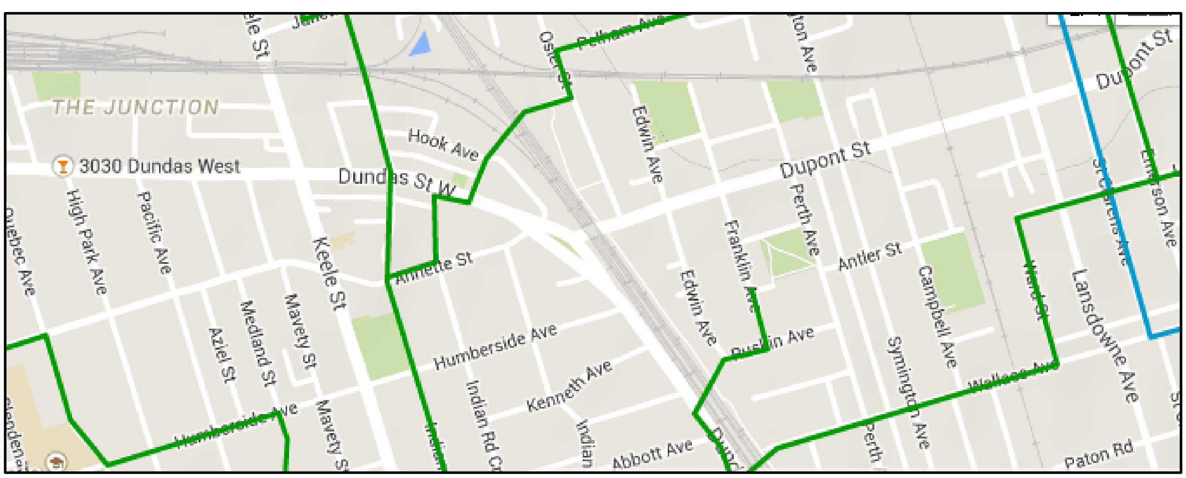

Figure 5. Underground sewage system near the DDA Intersection. Taken from [51].

Appendix H: Physics-Based Signal Timing Calculation

Signal Timing on Dundas

1. Green Signal Timing:
The new Dupont extension consists of two through lanes, two curb lanes, and two bike lanes.

Width of Dupont (distance Dundas vehicles need to travel) = 34.33m (Figure 11)
Average acceleration of trucks (slowest moving vehicles): 1.49 m/s^2 [139]

Calculate the final speed first, then determine the time it takes for one truck to cross:
distance = 34.33m acceleration = 1.49 m/s^2 Vi = 0 *Vf = ?*
Vf^2 = Vi^2 + 2ad Vf = sqrt(0 + 2*1.49 m/s^2*34.33m) Vf = 10.12m/s
a = Vf-Vi/t t = Vf-0/a t= 10.12m/s / 1.49 m/s^2 t = 6.79s
Thus it takes 6.79s for a truck to clear the intersection completely.
A single car will take less time (margin of safety).

According to predefined constraints, the design needs to handle 29392 vehicles per day or 1225 vehicles per hour.
1225 vehicles/hr/60 = 20 vehicles/min
In this case it takes 6.79s to cross the intersection for one vehicle. The intersection must allow 20 vehicles to pass in a minute.

Benchmarking with pedestrian light is used to set the effective green light time:
Disabled pedestrians walk 1m/s [140]

Dupont is 34.33m wide. Therefore, it takes 35s for a disabled pedestrian to walk across. For a margin of safety (x2), allow time for two trips.
Total time of pedestrian light = 2*35s +2s of delay time = 72s

72s/6.79s/vehicle = Approximately 10.60 cars can pass per lane per green light, or 21 cars in total.
Want to set the green light on Dundas so that 20 vehicles can pass per minute:
Although 21/72s is slightly less than 20/60s, since the acceleration data is used for trucks, which are slower than the average car, assuming that not all traffic is comprised of trucks, the error is negligible.
Therefore **72s**.

2. Yellow Signal Timing:
Yellow signal timing is standardized for all traffic signals. **All yellow signals will last 3.0s [141]**

3. Red Signal Timing:
Same as the green signal timing on Dupont and Annette: **82s**.

4. **Pedestrian Signal Timing** will correspond to the signals setup for vehicles. 3 seconds of extra yellow signal timing will be added to allow extra time for pedestrians to cross. Pedestrian signals will be

accessible pedestrian signals (APS), which produce audible signals for both visually impaired and deaf-blind users [142]

The pedestrian signal chosen is a LED pedestrian countdown signal system. It consists of a panel that counts down how many seconds remain for the pedestrian to complete the crossing. In this system, **the signal will count down from half of the total allocated time, rounded to the nearest 5 seconds, or 40s [143]**

5. Signal timing for left turn vehicles will be the same as vehicles traveling straight. Vehicles turning left must wait for straight going vehicles, traveling in the opposite direction, before proceeding. See *Ontario Highway Traffic Act* in Appendix E for details of this crossover procedure. To ensure a minimum of turning vehicles passes during each cycle, the signal for through vehicles will end at 7s early relative to their regular time while the turn signal remains green. This reduction was chosen in order to match current optimization of this turn, which remains the same in terms of traffic quantity in the proposed design. The majority of users consist of through and right-turning traffic (Appendix G).

6. Signal timing for right turn vehicles also uses the same timing for vehicles traveling straight.

Signal Timing on Dupont and Annette

1. Green Signal Timing:
The new extension of Dupont will intersect Dundas at approximately 63.9 degrees. Refer to Figure 2, the intersection resembles a parallelogram.

Width of Dundas portion =39.60m

Following a similar calculation process to the one described above:
For pedestrians: Total time = 2 *40s = **82s**
For Vehicles: Benchmark with pedestrians:

distance = 39.60m	acceleration = 1.49 m/s^2	Vi = 0	*Vf = ?*
Vf^2 = Vi^2 + 2ad	Vf = sqrt(0 + 2*1.49 m/s^2*39.60m)	Vf = 10.86m/s	
a = Vf-Vi/t t=Vf-0/a	t= 10.86m/s / 1.49 m/s^2	**t = 7.29s for one truck**	

Need 29 vehicles per minute:
82s/7.29s= 11.25 vehicles or approximately 23 vehicles for two lanes.

23/82 is still slightly less than 20/60 but the same rationale holds true here. **82s of green light will be used for signals on Dupont.**

2. Yellow Signal Timing:
All yellow signals last 3s.

3. Red Signal Timing:
Same as the green signal timing on Dundas: **72s**.

4. Pedestrians and turning vehicles, as explained above, obey the same shared and 7s reduction in timing principle.

Table 3. Summary of Signal Timing Calculations

Dundas Northbound - Southbound	**Green Light 72s**	**Yellow Light 3s**	**Red Light 82s**	**Pedestrian Green: 75s**	**Pedestrian Red: 85s**
Dupont Eastbound - Annette Westbound	**Green Light 82s**	**Yellow Light 3s**	**Red Light 72s**	**Pedestrian Green: 85s**	**Pedestrian Red: 75s**

Appendix I: Traffic Signal Optimization

This appendix refers to the optimization calculation summarized in 2.0.5.2. It explains how the values for the variables used to calculate the total intersection delay time were obtained.

Variables:

- arrival rate λ and a departure rate μ
- ρ = Arrival Rate divided by Departure Rate
- r = Red Time
- g - Effective Green Length
- C = Cycle Length

Phase 1 is referred to with subscript *a*
Phase 2 is referred to with subscript *b*

Based on an analysis of Figure 16 in Section 2.0.5.2., it was determined that the current percentage of cycle time allocated to Dundas traffic was 57.38% (excluding Old Weston Road as it is to be disconnected from the intersection)

Therefore, it can be extrapolated that, since the intersection is currently operating at capacity, approximately 57% of vehicles passing through the intersection arrived on Dundas

From current data, 0.544 vehicles/second pass through the intersection:

- 0.57 x 0.544 vehicles/second = 0.310 vehicles/second across Dundas
- 0.43 x 0.544 vehicles/second = 0.243 vehicles/second across Annette/Dupont

Smooth traffic flow is obtained when $\mu = 7\lambda$ [161]

Based on average traffic flow patterns during rush hour (Appendix G, Figure 4), this occurs on Dundas but not on the Annette/Dupont crossing

For Dundas:
$(\lambda+\mu)/2$ = x vehicles handled per second
$(\lambda+7\lambda)/2$ = 0.310 vehicles/second
λ = 0.0775 vehicles/second
Then, $\mu = 7\lambda$ x 0.9 safety factor so **μ = 0.543 vehicles/second**

$\rho_a = \lambda_a / \mu_a$
ρ_a = 0.0775 vehicles/second / 0.543 vehicles/second
$\rho_a = 0.158$

Similarly for Phase 2 (b), using (λ+μ)/2 = 0.234 vehicles handled per second, where μ = 3.5λ (traffic flow half a slow, no longer smooth based on rush hour traffic data), and a safety factor of 0.8 (less accurate farther from ideal conditions):

λ = 0.0585 vehicles/second
μ = 0.164 vehicles/second
ρ_b = 0.357

Appendix J: Future Relevant Design Patents

This appendix refers to the additional patents referenced in section 2.1.3, whose use may be desirable in the longer-term future of the design operation as improvements and repairs are made according to a regular maintenance schedule.

It is important to note that such use will likely require the payment of licensing fees and other associated costs.

Patents which may be for the design in the future are listed below:

- Method and composition for road construction and surfacing: US 8104991 B2 [144]

    - This patent includes methods for improving the strength and durability of roadways looking at the composition perspective.
- Road construction machine, leveling device, as well as method for controlling the milling depth or milling slope in a road construction machine: US 7946788 B2[145]
  This patent deals particularly with techniques for operating different road paving machines.
- Road construction methods and apparatus: US 3423859 A[146]
    - Patent dives deeper into the machine perspective. In fact, it mainly introduces an improved design of a road paving machine that performs with greater efficiency.
- Method of actuating a wireless sensor of road construction equipment US 8646167 B2[147]

Design of a wireless sensor which can easily be mounted on a road construction machine to detect at the same time reducing battery usage.

- Reinforced concrete road construction: US 3437017 A [148]

    - Methods on how to pave concrete surfaces are detailed in this patent.
- Road construction: US 2746365 A[149]

    - Patent focuses on improvements to current road pavement methods. It focuses on how to minimize excess water accumulation on roads.
- Digital system for controlling traffic signals: US 3784971 A[150]
    - This patent focuses on the logistics of traffic controlling systems. It details on connection mechanisms of traffic controlling systems and differentiates various controllers.
- Traffic signal system for blind people US 4253083 A[151]

    - Tetsuaki Imamura internally designed an internal circuit for pedestrian lights. It integrates sound into the pedestrian light so visually impaired pedestrians can safely cross streets.

Appendix K: Test Metrics

Table 4. Metrics for tests outlined in Section 3.9

Objectives	Test	Metric Scale
Safety	• Calculate road capacity and traffic volumes passing through intersection, in accordance to Canada Road Safety Measures 2015 [85] • Approximate time required for 23m vehicle to pass an intersection and verify traffic signal system allows vehicle to pass in this time • Measure minimum height of overhead structures to verify minimums	• permit safe passage of vehicles up to 23 meters in length [60] • overhead clearance>=4.15m [60]
Accessibility	• Verify car lanes satisfies minimum lane width [60] • Measure sidewalk to verify whether it follows City of Toronto Accessibility Design Guidelines [68]	• lane width>=2.8m[60] • sidewalk>=1.8m [68] • pedestrian sidewalk clearly marked by 0.1m lines [68]
Cost-effectiveness	• Calculate cost of design verify under objective metrics	• cost<$19.7 million [19]
Durability	• Perform soundness test by submerging asphalt, concrete in sodium sulfate or magnesium sulfate solution for 15 minutes [84] ○ tests must follow ASTM road and paving test standards	• Maximum loss in sodium sulfate is 18%, in magnesium sulfate is 12% [118] • last at least 10 years [23][24]
Maintainability	• Calculate maintenance cost of design	• maintenance <=$13350/yr
Environmental Friendliness	• Check whether design requires alteration of any underground water mains or major electrical power lines • Benchmark amount of greenhouse gas generated by measuring traffic flow (Appendix D)	• Carbon dioxide<=612kg/hr (Appendix D) • Trees>=6 [26]
Harmony of	• Measure space designated for	• 26% road space

Proportions	pedestrians, calculate percentage under total road space	for pedestrians [27]

Appendix L: Engineering Team Design Generation and Selection Processes

This appendix describes some of the essential processes involved in the engineering team's design generation and selection processes.

Primary tools used in approaching the design space include significant functional decomposition, benchmarking against numerous large city infrastructure projects, and structured and unstructured collaborative brainstorming. Structural decomposition was used to break up the problem into modular components, increasing creativity amongst solutions. Obstacles encountered during the design generation process centered on the inability to effectively differentiate between designs using the graphical decision matrix, resulting in the need to have multiple iterations which modified and diversified the designs in question.

Table 2. Prioritized Objectives

Objective	Rank	Weight
Safety	1	25%
Accessibility	2	20%
Cost-Effectiveness	3	15%
Harmony of Proportions	4	10%
Durability	5	10%
Low Maintenance	6	7%
Environmental Friendliness	7	5%
Total	N/A	100%

Table 3. Weighted Decision Matrix

Design	Island dugout	Regularization with Pedestrian/ Cyclist bridge	Central Roundabout	Davenport and Keele Expansion	Dundas Street Suspension	Island Ramp
Safety	70%	90%	50%	80%	50%	90%
Accessibility	60%	70%	60%	50%	50%	70%
Cost-Effectiveness	80%	70%	80%	5%	60%	90%

Durability	40%	50%	80%	70%	90%	70%
Harmony of Proportions	80%	60%	90%	50%	90%	60%
Low Maintenance	90%	60%	90%	10%	90%	60%
Environmentally Friendly	40%	60%	50%	40%	50%	50%
Total	71.6%	66.4%	64.1%	45.7$	55.1%	63.4%

Note that due to the similarity and compatibility of Designs 1 and 6, they were merged into one design for the top five designs.

Furthermore, the similarity of Design 2 and 3 does not indicate lack of diversity as one might initially suspect, but actually represents a similarity of tradeoffs between two unique designs. In other words, each set of tradeoffs is different but has been accurately weighed to be of equal value.