Final Report

Rerouting the TCS Toronto Waterfront Marathon

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Multidisciplinary Urban Capstone Project

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Executive Summary

Partnered with Tata Consultancy Services (TCS) and Canada Running Series (CRS), this MUCP project focused on rerouting the TCS Toronto Waterfront Marathon in pursuit of making the event the most sustainable race in Canada. Building on their Evergreen certification from the Council of Responsible Sports in 2022, TCS and CRS sought to improve upon the existing marathon route to reduce associated traffic congestion and vehicle emissions from road closures and enhance the economic impact of the event with local businesses and communities. Specifically, sustainability, community engagement, and participant experience were identified as the three objective categories to balance and optimize performance across in the development of a new and improved marathon route.

Primary data collected from observation of the 2023 race, case studies of other marathon races, and academic literature informed an understanding of the important features and considerations of an effective marathon route, and contextualized prominent issues faced by the route. This preliminary research, in tandem with feedback and discussion with the community partners and relevant stakeholders including the City of Toronto, informed the development of design guidance for a route evaluation framework. This established the scope of characteristics and set of criteria to generate and evaluate prototype alternative routes.

The route evaluation framework consists of three stages: prototype route generation, evaluation, and ranking. The framework is designed to be flexible, dynamic and can easily adapt to the evolution of relevant characteristics and considerations. Prototype route generation produced potential routes based on the design guidance. Generated routes were evaluated against a suite of metrics through GIS methods and traffic modelling. Metrics, such as emissions, number of subway stations, and number of places of interest, reflect performance across the three objective categories. A calculated composite score represents

the overall performance of a prototype route across metrics. The highest performing prototype is proposed as the new marathon route.

Seven prototypes were generated, evaluated, and compared against each other and the baseline route. The highest performing prototype route had an overall composite score of 1.51, outperforming the 2023 baseline which had a score of 1.38. This prototype route retains the low traffic/road closure impact of the 2023 baseline route while adding new streets to enhance the experience. An additional small loop passing through East Chinatown further adds to the participant experience without creating significant road closure disruption as a larger loop would. Notably, the prototype does not rank the highest in most metrics. Rather, its high composite scores are a result of consistent high performance across the suite of metrics. Its balanced and consistent performance across all three objective categories lead it to emerge as the proposed new route for the TCS Toronto Waterfront Marathon.

Introduction

Background

The TCS Toronto Waterfront Marathon (TWM) is held annually in October. The TWM is considered Canada's premier marathon including 5km, half marathon, and full marathon distances. The TWM is one of the two World Athletics Elite Label races in Canada and is the final event of the Canada Running Series (CRS). Since 2017, the race has served as the Athletics Canada Canadian Marathon Championship and has doubled as the Olympic trials (Ryan, 2022). The 2019 Toronto Waterfront Marathon brought in more than $30 million for the city (Dickinson, 2022).

The TWM is a complex event requiring numerous road closures and reduced lanes to accommodate the race. During the 2022 race, 32 streets were closed or partially closed to vehicle traffic (CBC News, 2022). The closures from the event increased surrounding traffic during the race which increased disruption throughout the city. In response to these issues and in pursuit of the event's goals, there is an opportunity to consider alternative course routes.

Community Partners

Tata Consultancy Services (TCS) is an IT services, consulting, and business solutions organization that has partnered with many of the world's largest businesses in their transformation journeys for over 55 years. In Canada, TCS is among the five largest IT services providers, serving more than 100 of the country's largest companies for 30+ years. In 2022, TCS announced its partnership with Canada Running Series (CRS) to become the new title sponsor and official IT services and technology consulting partner of the TWM through 2026 (Hope, 2022). Together, they have the ambition to continue to elevate the TWM as a marquee event for the city and participants and make it "the most sustainable race in Canada".

Canada Running Series manages running circuits across the nation with 11 events; notably the TCS Toronto Waterfront Marathon, their final and most renowned race in the calendar year. Their races welcome everyone, from Olympians to first-time runners (Canada Running Series, 2024).

Students and Supervisors

This project is a part of the University of Toronto, School of Cities, Multidisciplinary Urban Capstone Project (MUCP) under the supervision of Teaching Assistant Erin Gao and Academic Director Professor David Roberts. There are five project members: Spencer Bezruki and Crystal Chu are architecture students at the John H. Daniels Faculty of Architecture, Landscape and Design; Jia Hao Choo is a computer science and Geographic Information Systems (GIS) student at the Department of Computer Science and Geography; Joshua Der is an economics and environmental studies student at the Department of Economics and School of the Environment; Cody Wang is a kinesiology student at the Faculty of Kinesiology and Physical Education.

Problem Statement

In 2022, the TWM achieved the Evergreen certification from the Council of Responsible Sports, the highest level, for the event's social, environmental, and economic responsibility performance (CRS, 2022). In service of the goal to make the TWM the most sustainable race in Canada, TCS and CRS have identified the opportunity to improve upon the existing marathon route to reduce associated traffic congestion and vehicle emissions from road closures, and enhance the economic impact of the event with local businesses and communities.

Project Requirements

The problem statement, and project goals and objectives are distilled into three objective categories: sustainability, community engagement, and participant experience. These three objectives serve as guiding requirements for our research process, design, and intervention.

Sustainability focuses on improving the event's environmental impact. The TWM already has strong performance in waste management and scope 1 and 2 emissions (operation emissions and emissions from purchased energy) (CRS, 2022). However, associated traffic congestion emissions due to the event's road closures is an additional frontier to improve the sustainability of the TWM. Notably, associated event emissions are an important category of the Evergreen certification. Specifically, the relevant certification criterion is "Carbon Footprints" which awards points such as for the percentage of carbon footprint offset, and initiatives like working with transit services to provide free transit (Council of Responsible Sports, n.d.). Figure 1 shows traffic congestion on the west end of the current route. The sustainability objectives focus on improving the route to reduce traffic congestion and its associated emissions due to road closures on race day.

Figure 1: Traffic congestion on the west end of the route (Figure by authors with data provided by Canada Running Series)

Community engagement focuses on increasing the TWM's economic impact and community connection. Promoting and celebrating the city's local community and culture are important for TCS and CRS. In 2023, the #ChooseTOCelebrate program was introduced to engage with various neighbourhoods during the event through encouraging local businesses and communities to take part in cheer sites and special promotions (Canada Running Series, 2023). Community is also a key criterion for the Evergreen certification, which award points based on clear measurement of economic impact and number of community-building initiatives implemented such as making a donation to the community, involving community volunteers, and promoting local businesses (Council of Responsible Sports, n.d.). The community engagement objectives focus on how the route can foster economic impact for local businesses, highlight the city's landmarks and cultural neighbourhoods, and enhance the spectator experience.

Participant experience focuses on ensuring an enjoyable route for all runners, wheelchair athletes, and walkers. There is a particular focus on the east end of the marathon route due to low spectatorship in this part of the route coinciding with the "runner's wall" at 32 - 38 km where participants are exhausting all of their energy and need the energy of the crowd as motivation. Figures 2 and 3 show that most cheer sites are clustered around downtown areas, as opposed to the east end of the routes which are long but have few cheer sites and attractions. Route improvements with respect to participant experience will be considered by changing elevation profiles, terrain, and atmosphere.

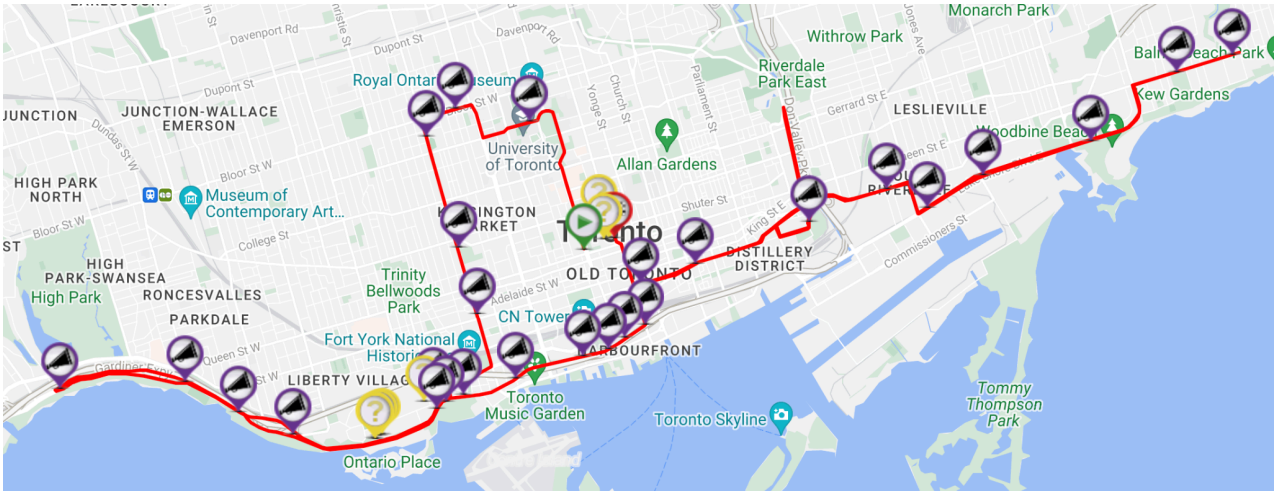


Figure 2 - Cheer sites along the full marathon route in 2023 (Canada Running Series, 2023b)

Figure 3 - Lack of attractions on the east end of the route (Figure by authors with data provided by Canada Running Series)

Design Proposal

Primary data from observing the 2023 TWM, case studies of other marathons, and academic literature guided the exploration, analysis, and selection of design alternatives. This formed a design proposal which, following critique and feedback, set the guidance for the final intervention.

Observation of the 2023 TCS Toronto Waterfront Marathon

Collection of primary data from observation of the 2023 race further contextualized the problem and provided insight to better understand the scope and relevant considerations to effectively improve the marathon route. Notably, shown in figure 4, the east end of the route had visibly less cheer sites and crowds compared to the west end of the route. Additionally, many pedestrians were observed to have difficulty walking through sidewalks and crossing roads due to the busy foot traffic during the race.

Figure 4: Images taken in the west-end (left) and east-end (right) of the 2023 route

Design Alternatives

A range of design alternatives were explored to narrow the scope and identify a set of guidelines for the development of an improved marathon route. To frame the discussion of alternatives relevant to route design, it was important to consider the constraints regarding what parts of the current route are to be unchanged. From discussions with our community partners, the start and end point of the route were not to be changed. The route must start on

University Ave. facing the TCS Toronto Office. The finish line must be near Nathan Phillips Square due to the space requirement of the post-race area setup. The elevation profile must be maintained or reduced to have a flat route. Considering these identified constraints, design alternatives are separated into three categories: points of focus, race course features, and race course structure.

Points of Focus

The existing route is segmented to identify the points of focus for redesign. Informed by primary data observation from the 2023 race, most of the problems are identified to be in the east end of the route. Specifically, the current east side of the route features less populated areas which leads to substantially less spectators and cheer sites compared to the west end of the route. The east side of the route also features fewer local businesses and landmarks since it is outside the main downtown areas. Further, according to the re-opening times of the 2023 Marathon, the streets in the east end were closed the longest during the time of day when traffic may be busier, with some major roads (like Bay St./Wellington St.) being closed for more than 8 hours starting at 8am (Canada Running Series, 2023). Therefore, the east end of the route performs significantly worse in all three objective categories due to long road closures, lack of cheer sites, and lack of businesses and major landmarks. However, there are also some issues in the west end of the route, specifically near the finishing line. Significant crowding issues lead to low walkability and barriers to public transit station access. This can worsen community engagement in terms of spectator experience. This discussion is summarised in the Pugh Matrix below in figure 5 below:

	Rerouting West end	Rerouting East end
Sustainability	0	+1
Community Engagement	0	+1
Participants Experience	+1	+1
Total	**1**	**3**

Figure 5: Pugh Matrix for Points of Focus Alternatives

Race Course Features

Race course features are the different features that can be included in the route contributing to performance in the three objective categories. First, it is important to consider choosing between prioritizing places of interests in Toronto, or local businesses and retail areas coverage. Note that it is common to have overlap between the two, such that there will be places that feature places of interest that also have local businesses or retail stores. However, this section primarily concerns how ties should be broken if they arise.

A study for the Thailand Bangsaen21 Half Marathon shows that there is a positive relationship between availability of tourist attractions and runners' satisfaction (Boonsiritomachai & Phonthanukitithaworn, 2018). Therefore, focusing on covering major places of interest in Toronto will help with the storytelling of the route, which will increase participant satisfaction. The current route features many Toronto landmarks, such as the CN Tower and Gooderham Building. Therefore, maintaining or increasing the number of places of interest should not cause significant changes to road closure or sustainability performance.

Alternatively, prioritizing covering local businesses or retail areas can increase spectatorship, as identified in our primary data observation. The areas with the highest spectatorship or highest performing cheer sites at the 2023 race were located in these business-dense areas like Bay Street. Hence, prioritizing covering business areas helps

improve participant experience. Also, since most of the current route already covers business-dense streets, road closure and sustainability performance will not be significantly affected when maintaining or increasing the coverage of businesses and retail areas. However, it is crucial to recognise this might still lead to issues with overcrowding as was observed in the 2023 race. This may inhibit walkability and access to public transit stops due to the overcrowding. Therefore, prioritizing local businesses coverage could help with community engagement in terms of the local businesses economy, but could adversely affect community engagement in terms of access to public transit and walkability for spectators and pedestrians. Hence, the gains and losses in terms of community engagement with this alternative offset each other. A summary for choosing between prioritizing covering places of interests and covering local businesses/retail areas can be found in column 1 & 2 of the Pugh Matrix in figure 7.

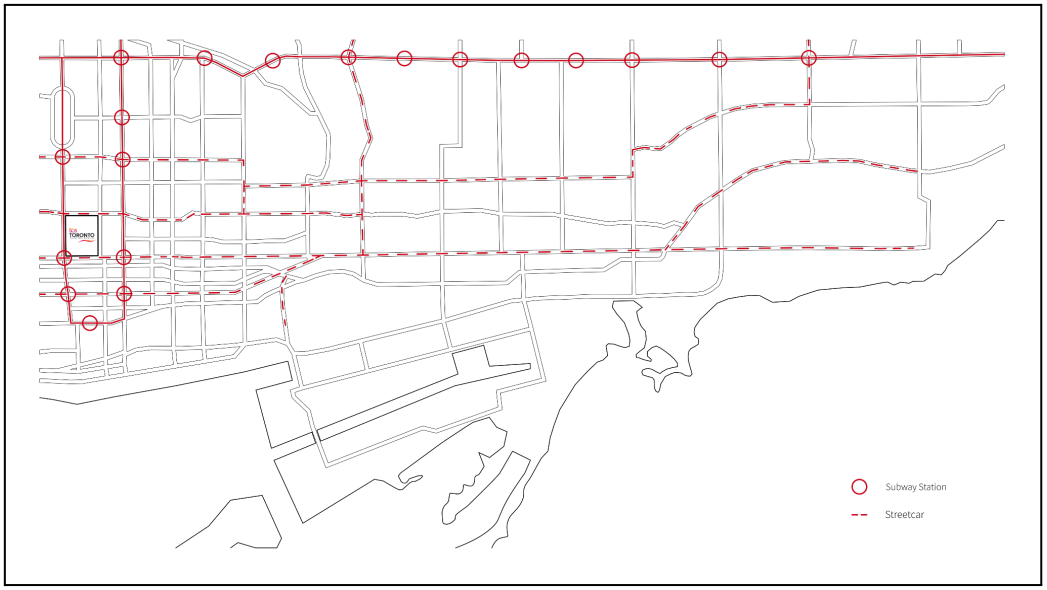


Figure 6: Existing TTC Streetcar network and Subway lines

Inclusion of semi-enclosed spaces presents another route feature design alternative. Semi-enclosed spaces refer to places that are easily overcrowded, for example a small neighbourhood street. This is a relevant consideration as Wong et. al. (2013) show that semi-enclosed places that can be crowded at times can lead to herd effects where people

move closer to each other. Herd effects in small areas can reduce air circulation and increase temperature and vapour pressure leading to higher temperature and humidity (Wong et. al, 2013). This will result in a reduction in spectator experience and participant performance as conditions in semi-enclosed spaces fail to meet the minimal level of thermal comfort (Wong et. al, 2013) thus affecting community engagement and participants' experience. This discussion is summarised in column 3 of the Pugh Matrix in figure 7.

The final race course feature design alternative concerns the re-opening of roads. Currently, there are some sections of the route where participants travel the same section of road in a two-way fashion. This allows roads to be reopened behind the last participant while the opposite direction of the road remains closed with participants. However, this leads to traffic travelling alongside participants which can be disruptive and unsettling. Thus, the alternatives with regards to roads reopening are either keeping this feature or preventing this from occurring by avoiding traffic and participants interaction. Keeping the current strategy for road reopening sacrifices participant experience. However, it has the benefits of reducing road closures time for some sections of the road which could reduce traffic congestion and increase sustainability performance. Alternatively, changing the road opening strategy such that participants never intersect with traffic would increase the participant experience at the cost of longer road closures. However, from the 2023 race, the Canada Running Series (CRS) identified that the marginal gains to reopening two-way roads independently in each direction did not outweigh the adverse effects of traffic proximity on participant experience. Thus, more weight is given to the gains in participant experience. This result is summarised in column 4-5 in the Pugh Matrix in figure 7 below:

	Prioritizing Attractions Coverage	Prioritizing Local Businesses / Retail Coverage	Featuring Semi-enclosed Spaces	Allowing runners' section to intersect with traffic	Avoiding runners' section to intersect with traffic
Sustainability	0	0	0	1	-1
Community Engagement	0	0	-1	0	0
Participants Experience	+1	+1	-1	-1	+2
Total	**1**	**1**	**-2**	**0**	**1**

Figure 7: Pugh Matrix for Race Course Features Alternatives

Race Course Structure

There are two significant alternatives related to marathon race course structure: race course style and elevation. Race course style refers to where the route starts and ends, and how it traverses its location. There are three main race course styles: loop, one-way, and out-and-back. Race courses have dominant styles but often include sections which feature different styles. For example, many loop race courses include sections of out-and-back and some one-way race courses include sub-loops. Elevation refers to how flat the route is. Routes with a lot of elevation gain consist of more uphill sections.

Table 1 consists of selected prominent marathon races comparing their race course structure. All of the selected marathons are either a loop or one-way race course style. Both styles offer advantages and disadvantages. Notably, one-way routes are advantageous for their ability to reopen roads behind the last participants allowing sections of cities to be reopened faster, reducing traffic congestion and increasing sustainability performance compared to loop routes which may enclose sections of cities for longer.

Among the six Abbott World Marathon Majors, the race course styles are split evenly between loops and one-ways. The Boston Marathon is a historic one-way route which starts in Hopkinton, a town outside of Boston and follows a route through other towns leading to the finish in Boston (B.A.A., 2023b). The TCS New York City Marathon is also a renowned one-way route starting in Staten Island and traversing the five boroughs before finishing in Central Park (NYRR, 2023). In contrast, the Bank of America Chicago Marathon and the BMW Berlin Marathon are loop routes which use prominent city parks as start and end points (Bank of America Chicago Marathon, 2023; BMW Berlin Marathon, 2023).

However, the Abbott World Marathon Majors all only include the marathon distance. Events which include a half marathon distance (and also a 5k distance) require additional logistical considerations to the race course style to hold the distances concurrently. As such, one-way routes are less conducive as they require multiple start and/or finish points to be added to accommodate the different distances. Loop routes are better suited to hold multiple distances as sub-loops and turn off points can be easily included to achieve the shorter distances while maintaining a common start and finish point. The common start and finish points also notably eliminate travel to different starting points. These logistical advantages contribute to greater participant experience. Loop routes also allow the race course to be more central within cities, improving community engagement (via greater proximity and coverage of places of interest and local business). In table 1, of the selected marathon races, those including multiple distances all use a loop style route.

Elevation gain presents challenges to participants as running uphill requires more exertion, detracting from participant experience. Generally an unpleasant feature of routes for participants in the moment, elevation and hills can also provide a point of pride and triumph upon completion. Heartbreak Hill at mile 20 (km 32) of the Boston Marathon (B.A.A., 2023b) and the many hills and the uphill Central Park finish of the TCS New York City

Marathon (NYRR, 2023) contribute to these routes having the most elevation gain of the Abbott World Marathon Majors. This also leads to their notorious status and popularity by creating a sense of community around those hills which increases community engagement. On the other hand, flat races with little elevation gain have greater participant experience from their lack of hills and opportunity for participants to chase faster times and personal bests. The Bank of America Chicago Marathon is regarded for its flat elevation profile and lends itself to fast times. In the 2023 Bank of America Chicago marathon, Kelvin Kiptum broke the marathon world record with a time of 2:00:35 (McAlister, 2023). The California International Marathon also advertises its net downhill elevation profile with a net elevation of -112m (CIM, 2023). Flat elevation profiles also contribute to attracting valuable elite talent seeking fast routes. Elevation may also have relevance to facilitating reopening road closures. Routes with more elevation gain increase the difficulty which manifests in slower finish times. Intuitively (although not necessarily robust or causal), routes with more elevation generally have slower average finish times. Longer average finish times may delay how quickly roads can be reopened.

The evaluation of the race course style, and elevation gain type design alternatives with respect to the three main objective categories are summarised in a Pugh Matrix in figure 9.

Table 1: Comparison of Prominent Marathon Race Course Structures

Event	Race Distances	Race Course Style	Elevation Gain (m) (42k)	Average Marathon Finish Time
TCS Toronto Waterfront Marathon	42k, 21k, 5k	Loop	148	4:07:29[2022]
Boston Marathon*	42k	One-way	263	3:42:29
Bank of America Chicago Marathon*	42k	Loop	74	4:21:03
TCS New York City Marathon*	42k	One-way	301	4:40:04
TCS London Marathon*	42k	One-way	124	4:26:51
BMW Berlin Marathon*	42k	Loop	74	-
Tokyo Marathon*	42k	Loop	60	-
California International Marathon	42k	One-way	0	3:59:25[2022]
TCS Amsterdam Marathon	42k, 21k, 8k	Loop	108	-
Eugene Marathon	42k, 21k	Loop	151	3:57:48
Ascension Seton Austin Marathon	42k, 21k, 5k	Loop	309	4:33:06
Portland Marathon	42k, 21k	Loop	266	4:28:42

Notes:

*: Abbott World Marathon Majors

Race distances and race course styles are retrieved from event websites (see References)

Elevation gains are retrieved from Strava (2023) or FindMyMarathon.com (2023)

Average marathon finish times are retrieved from MarathonGuide.com (2023) and are from 2023 results unless noted otherwise.

Figure 8: A topographic view of the area of study

	Race Course Style		**Elevation Gain**	
	Loop	One-way	Flat	Hills
Sustainability	0	+1	0	-1
Community Engagement	0	-1	0	+1
Participant Experience	0	-1	0	-1
Total	Baseline	-1	Baseline	-1
Notes: Alternatives currently used in the 2023 route are scored 0 in each category and marked “baseline”. Scores of non-baseline alternatives are relative to the baseline.				

Figure 9: Pugh Matrix for Race Course Structure Alternatives

Design Review & Critique

Our final intervention will be a framework that can be used to evaluate alternative routes resulting in a proposed new route. The discussion of the design alternatives, points of focus; race course features; and race course structure, in previous sections inform the selection of the alternatives that set design guidelines for the final deliverable. These

decisions on alternatives underwent a critique and feedback from our community partners and supervisors to form the final set of design guidelines.

For points of focus, rerouting the east end of the route will be the primary focus. The Pugh Matrix in figure 5 illustrates that focusing on the east end of the route will facilitate the greatest performance gains by addressing all three objective categories. This will only affect the process of rerouting and designing alternative routes. The evaluative framework will still be applied to entire routes to evaluate overall performance. The focus on the east end of the route was reaffirmed by our community partners as a priority.

For race course features, informed by columns 1 and 2 in the Pugh Matrix in figure 7, balance will be targeted between covering landmarks and attractions, and business areas in Toronto as both contribute to improving performance in the objective categories differently. Specifically, landmarks can help with storytelling aspects of the route. On the other hand, business areas can help with attracting more spectators, improving cheer site atmosphere, and contributing towards the local economy. Both are valid and important, hence striving for a balance between the two can help us to maximise participant experience.

Our framework will be designed such that semi-enclosed areas are avoided by internalizing this consideration in the creation of potential reroutes. This affects both community engagement and participant experience, as summarised in the Pugh Matrix in figure 7, as small streets that can easily become overcrowded adversely affect participant performance and spectator experience.

Columns 4 and 5 of the Pugh Matrix in figure 7 inform the decision to avoid road reopening that creates participant proximity with traffic. Participants seeing and potentially interacting with traffic during the race negatively affect their experience, detracting from participant experience. This approach implies some roads will be closed for longer which works against the sustainability objective. However, as mentioned, our community partners

identified the priority of participant experience in this case, citing the marginal gains to faster road reopenings and traffic congestion reduction, supporting this selection.

Route structure alternative selections are guided by the Pugh Matrix in figure 9. The existing loop style route will be retained as the alternative one-way style's worse performance in community engagement and participant experience outweigh greater performance in sustainability. As mentioned, our community partners have also stated the requirement for Nathan Phillips Square as the start and finish points of the race which requires a loop route.

The existing flat elevation profile will also be retained. Although there are community engagement improving opportunities with a feature hill in the route, this is outweighed by advantages to participant experience of a flat, fast route and sustainability through faster average finish times. Our community partners have reiterated this selection for maintaining the elevation or reducing it further if possible. They add the additional justification of attracting elite talent through the possibilities of faster time in a flat course as a valuable asset for their operations. Note, by the requirements to finish at Nathan Phillips Square, the Bay St hill at the finish of the race will be in all proposed re-routed routes. Though, this hill does not detract significantly from participant experience as it is offset by the energy from the large crowds of spectators in this area.

To summarize, the final intervention will be a framework to produce a new route that is a flat, loop style course that features an overhauled east end, features a range of Toronto places of interests and businesses, avoids semi-enclosed areas, and does not interact with vehicle traffic.

Route Evaluation Framework

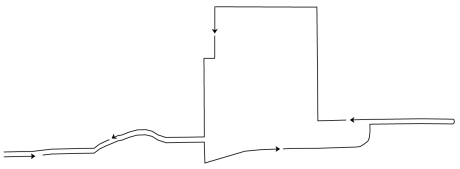
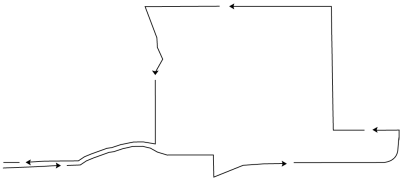
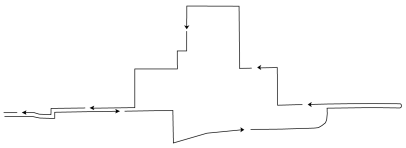
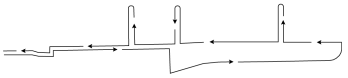
A route evaluation framework is developed to systematically analyze and measure the performance of different potential marathon routes. The framework is grounded in quantitative comparison with a transparent methodology to ensure objective and comparable evaluation. The development of the framework follows the guidance of the design choices finalized in the design review and critique. There are three stages in the framework: prototype generation, prototype evaluation (using GIS methodology and traffic modelling), and prototype ranking and scoring.

Prototype Generation

A prototype is a potential alternative marathon route. Prototypes vary in their east-end routes following the identification of the west-end (half-marathon portion) of the route to remain unchanged. Prototypes are 42.2km in length (the marathon distance) and start and end at Nathan Phillips Square. Two sets of prototypes were generated. The exploratory generation-1 prototypes aimed to calibrate the model by exploring the performance of extreme routing decisions. Informed by generation-1, generation-2 prototypes were refined and are candidates for the final proposed route.

Generation-1 prototype routes were not intended to be final candidates for the proposed route. Rather, they tested extreme route features to give insight to the performance of certain characteristics. Table 2 shows the east-ends of generation-1 routes. Prototypes 1.1 and 1.2 are variations of large loops, significant departures to the out-and-back nature of the baseline 2023 route. The loops serve to explore the performance of traversing north and including Danforth in the route. Prototypes 1.3 and 1.4 explore unconventional features. Stacked turns in 1.3 forming a quasi-loop and multiple out-and-back sections within a smaller loop in 1.4 attempt to test options which mimic a full loop with reduced impact on the areas enclosed by the road closures.

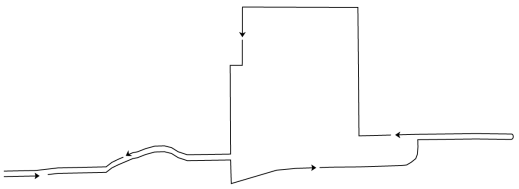
Table 2: Generation-1 Prototype Routes East-Ends

1.1	1.2
	
1.3	1.4
	

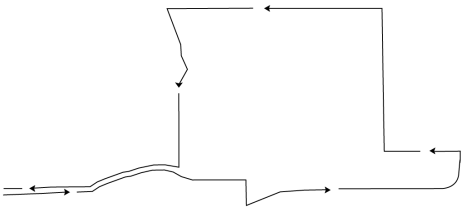
Following initial analysis, and feedback and discussion with community partners, generation-2 prototype routes were the evolution of generation-1. The east-ends of generation-2 prototype routes are shown in table 3. Prototypes 1.1 and 1.2 were carried over from generation-1 to include full loop route options and retain points of comparison. The key issue with loop prototypes is their disruptive enclosure of the area inside the loop. Generation-2 routes were developed to address this. Prototypes 2.1 and 2.2 traverse Broadview Ave, and Danforth Ave in 2.2, refining the concept in 1.4 using out-and-backs to limit road closure impacts. Prototypes 2.3 and 2.5 draw on the quasi-loop 1.3 to include smaller loops as a middle ground. Prototype 2.4 is a full out-and-back option extending up Kingston Rd. This set of generation-2 prototypes routes comprise the candidates with the highest performing to be selected as the final proposed route.

Table 3: Generation-2 Prototype Routes East-Ends

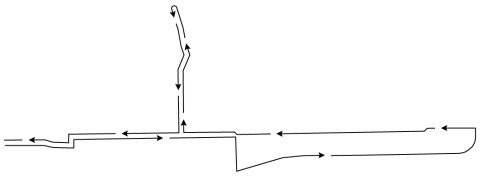
1.1



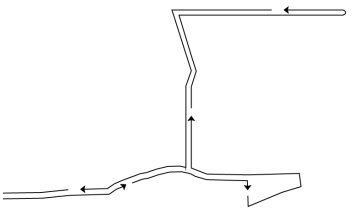
1.2



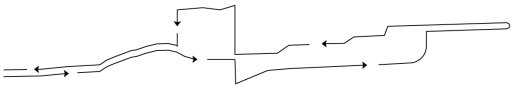
2.1



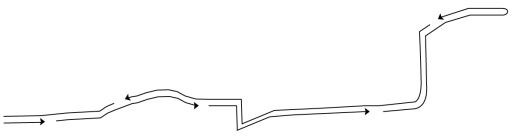
2.2



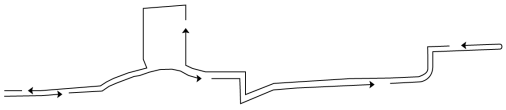
2.3



2.4



2.5



Prototype Evaluation

Metrics

Prototypes are evaluated against a suite of metrics. Effective metrics serve as quantitative proxies to measure real impacts. In this context, real impacts are how different route characteristics affect performance in the three objective categories. The suite of metrics is summarized in table 4. These metrics aim to capture the real performance of the relevant route characteristics in each objective category as identified in the guidance from the design process. The full suite of metrics is calculated for each prototype route and the 2023 baseline route.

The elevation gain, sharp turns, and wide turns metrics, in the participant experience category, are calculated manually as a result of being internalized within the prototype. They are summarized in box 1. These metrics are manually extracted from the prototypes via their GPS exchange format (GPX) files using navigation and route planning application Komoot.

Box 1: Description of Manual Metrics

Metric	**Description**
Elevation Gain↓	This metric is the total amount in metres ascended in the route.
Wide Turns↓	Wide turns cost approximately 3 seconds in race time. This metric counts the number of wide turns in the route.
Sharp Turns↓	Sharp (or hairpin) turns cost approximately 5-10 seconds in race time. This metric counts the number of sharp turns in the route.

↓Route performance is increasing in the minimization of this metric

GIS analysis and traffic modelling, and their associated metrics, are discussed further in subsequent sections.

Table 4: Summary of Prototype Evaluation Metrics

Sustainability

Metric	Methodology	Data Source
Number of high traffic intersections	GIS Analysis	Toronto Open Data: Traffic Volumes at Intersections for all Modes
Traffic Emissions	Traffic Modelling	PTV VISSIM
Vehicle Delay	Traffic Modelling	PTV VISSIM
Stopped Delay	Traffic Modelling	PTV VISSIM

Community Engagement

Metric	Methodology	Data Source
Business Improvement Areas Coverage	GIS Analysis	Toronto Open Data: Business Improvement Areas
Number of Trapped Condominiums	GIS Analysis	Toronto Open Data: Property Boundaries
Number of Residential Zones	GIS Analysis	Toronto Open Data: Zoning By-law
Number of Subway Stations	GIS Analysis	Toronto Open Data: TTC Routes and Schedules

Participant Experience

Metric	Methodology	Data Source
Number of Places of Interest	GIS Analysis	Toronto Open Data: Places of Interest and Toronto Attractions
Elevation Gain	Manual	Internalized in Prototype
Sharp Turns	Manual	Internalized in Prototype
Wide Turns	Manual	Internalized in Prototype

GIS Analysis

The majority of our metrics are calculated using GIS analysis, they are described below in box 2.

Box 2: Description of GIS Analysis Metrics

Metric	Description
Number of high traffic intersections↓	A high traffic intersection is defined as an intersection in downtown Toronto with above average car traffic in the *Traffic Volumes at Intersection for All Modes* data from Toronto Open Data. This metric counts the number of high traffic intersections within a 100m of the route.
Business Improvement Areas Coverage↑	This metric sums up the total areas of business improvement areas covered within 100m of the route.
Number of Trapped Condominiums↓	This metric counts the number of condominiums inside the area enclosed by the route.
Number of Residential Zone↓	This metric counts the number of residential zones intersecting within 100m of the route.
Number of Subway Stations↑	This metric counts the number of TTC subway stops that are within 100m of the route.
Number of Places of Interest↑	This metric counts the number of places of interest that are within 100m of the route.

↑Route performance is increasing in the maximization of this metric
↓Route performance is increasing in the minimization of this metric

The GIS program and scripts used to calculate these metrics can be found in a GitHub repository. In the *Scripts* folder, *Model.py* is a script used to define the GIS model for analyzing and calculating each metric for a route. *Runner.py* is a script that facilitates running the model for multiple routes at a time. Detailed instructions to run the program are provided in the ReadMe section of the repository. Note, these scripts are written based on methods

provided by ArcGIS Pro libraries requiring an active ArcGIS Pro license for the script to work.

The GIS program and scripts are designed to be flexible. Adding, modifying, or removing metrics as needs and demands evolve is an intentional feature. For example, the number of business zones was previously included as a GIS analysis metric. However, it was replaced by the Business Improvement Areas (BIA) coverage given BIA coverage is a more robust metric than simple zoning counts as zonings may be rezoned or have ambiguous uses in the case of mixed use zoning.

Traffic Modelling

Traffic modelling was used to calculate the stopped and vehicle delays and emissions metrics in the sustainability objective category. PTV VISSIM, a multimodal traffic simulation software, was used to conduct the traffic modelling. A traffic network, shown in figure 10, was built to recreate the roads and intersections around Queen St East, Eastern Ave, Broadview Ave, and Carlaw Ave. Access to PTV VISSIM was limited to a student trial version which restricts the traffic network size to 1km by 1km. Given this limitation, this network was selected as it is a high traffic area with variation in how it is affected by the prototypes.

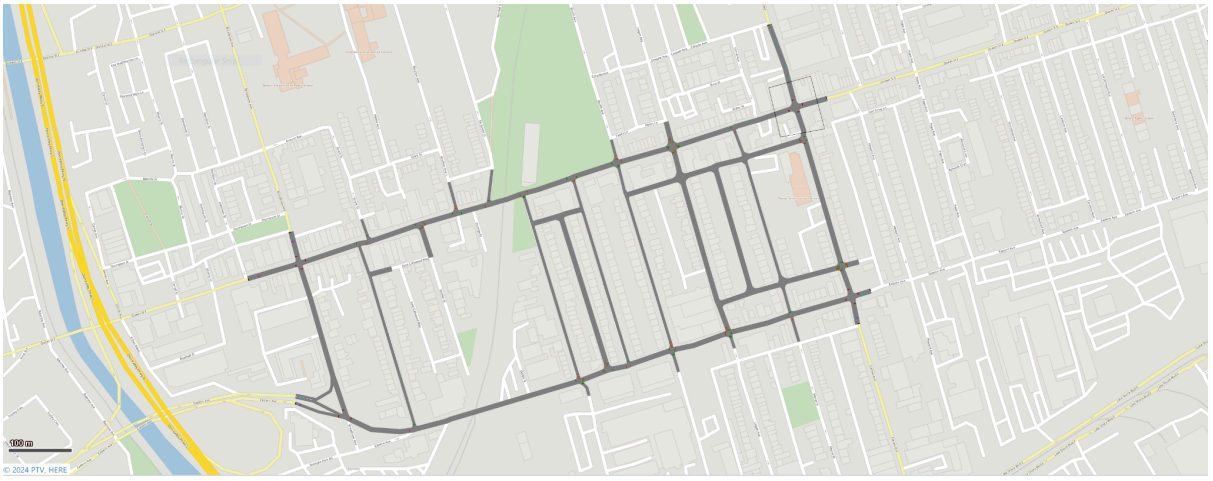


Figure 10: PTV VISSIM Network

Using the network, the traffic at the Queen St East and Broadview intersection was simulated. By varying the routing and volume of traffic through the network to reflect the different road closures of their respective prototypes. PTV VISSIM calculates data on the traffic simulation. The traffic modelling metrics are described in box 3. These metrics capture the effects of associated road closures on traffic congestion and emissions.

Box 3: Description of Traffic Modelling Metrics

Metric	**Description**
Traffic Emissions↓	This metric is the simulated average carbon monoxide, nitrogen oxides, and volatile organic compounds (CO, NOx, VOCs) emissions in grams measured at the Queen St E and Broadview Ave intersection.
Vehicle Delay↓	This metric is the simulated average vehicle travel time delay compared to a theoretical ideal travel time in seconds at the Queen St E and Broadview Ave intersection.
Stopped Delay↓	This metric is the simulated average time a vehicle is stopped in seconds measured at the Queen St E and Broadview Ave intersection.

↓Route performance is increasing in the minimization of this metric

Prototype Ranking and Scoring

Upon collection and calculation of the suite of metrics, the routes are ranked by their performance in each metric relative to each other. This ranking process is automated using the *Ranking.py* script. Specific instructions to run the script can be found in the ReadMe section of the repository. As in the GIS Scripts, the ranking script is designed to be flexible, easily accommodating any metric additions in the future. The ranking script is independent of the GIS scripts such that it does not require an active ArcGIS Pro license to work. Any results and data can be ranked as long as the input format matches the script requirements. This is designed to separate metric and ranking calculations and reduce redundant computations

given changes affecting only one of the elements. This also facilitates a key flexibility feature of the program: weighting.

Ranking weights allow the prioritization of metric performance to flexibly capture and align with goals and objectives. By default, all metrics have a weight of 1 if no weights are provided. For assignment, a weight is inputted for each metric prior to running the ranking script. Weights can take on any values but it is recommended to pass a set of weights with justified support and reasoning to maintain interpretable results.

Table 5 contains the weights assigned used in this evaluation to rank the performance of the generation-2 prototypes.

Table 5: Metric Weights

Metric	Weight
Number of high traffic intersections	0.50
Traffic Emissions	0.20
Vehicle Delay	0.15
Stopped Delay	0.15
Business Improvement Areas Coverage	0.25
Number of Trapped Condominiums	0.25
Number of Residential Zones	0.25
Number of Subway Stations	0.25
Number of Places of Interest	0.25
Elevation Gain	0.25
Sharp Turns	0.25
Wide Turns	0.25

Metrics within each objective category are convexly weighted (weights are non-negative and sum to 1). This is to give equal weight to each objective category overall. Metrics in the community engagement and participant experience objective categories all have equal weights (4 metrics in each objective category all with weights of 0.25). In the sustainability objective category uneven weights are used. Given the limitations of traffic modelling as discussed, half of the weight (0.5) has been assigned to high traffic intersections which is based on more robust historical data. Of the remaining weight, 0.2 is assigned to emissions reflecting the greater importance with respect to sustainability, and 0.15 to both delay metrics.

Ranking and scoring follow a maximization rule, higher ranks and scores correspond to higher performance. However, not all metrics are inherently maximizing metrics, for example emissions. To address this, minimizing metrics are converted to maximizing metrics before ranking simply by multiplying their results by -1. Each route's performance is ranked relative to the other routes in each metric. The highest performing route receives the largest value. Routes with identical performance (that is, they have the same metric value) receive the same rank value.

Composite scores are calculated as a weighted average of metric rank. Using the weights assigned, composite scores for each objective category (weighted average of metrics in the respective objective category) and an overall composite are calculated. When no weights are passed, the composite scores are simple averages of metric ranks.

Results & The Proposed Route

Composite scores for the generation-2 prototype routes and the 2023 baseline route are reported in table 6.

Table 6: Composite Score Results

Route	Sustainability	Community Engagement	Participant Experience	Overall Composite Score
Baseline	1.95	0.94	1.25	1.38
Prototype 1.1	0.5	1.38	1.44	1.10
Prototype 1.2	0.5	1.56	1.63	1.23
Prototype 2.1	1.13	1.13	1.44	1.23
Prototype 2.2	1.13	1.44	0.94	1.17
Prototype 2.3	**1.48**	**1.31**	**1.75**	**1.51**
Prototype 2.4	1.7	1.19	1.25	1.38
Prototype 2.5	1.5	0.75	1.31	1.19

Larger composites score indicate higher performance

Prototype 2.3 is the highest scoring route with an overall composite score of 1.51 and emerges as the final proposed route for rerouting the TWM. Notably, prototype 2.3 does not rank the highest in most metrics. Rather, its high composite scores are a result of consistent high performance across the suite of metrics.

Figure 11 overlays prototype 2.3 with the 2023 baseline route. By following a similar outbound route to the baseline and adding a minimal loop, prototype 2.3 is able to retain the low traffic/road closure impact of the 2023 baseline while adding new streets and not returning in a full out-and-back to enhance the experience. An additional small loop passing through East Chinatown further adds to the participant experience without creating significant road closure disruption as a larger loop would.

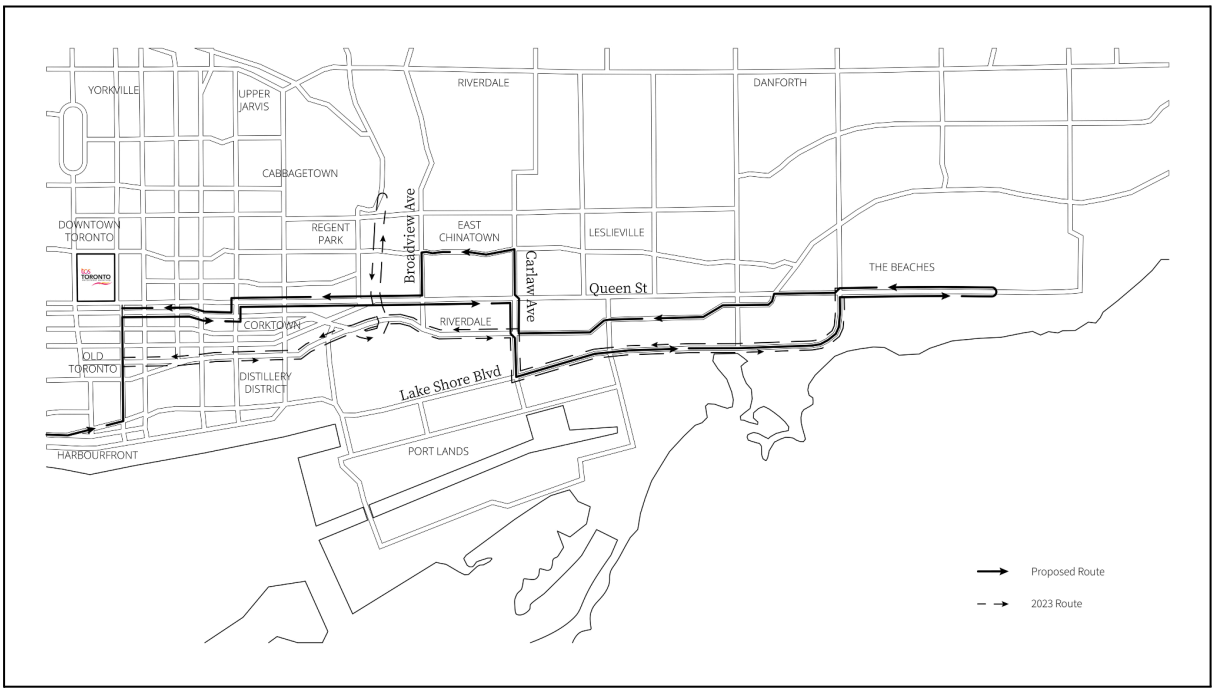


Figure 11: Route 2.3, the chosen prototype overlayed with the baseline

Future Work

As designed, the route evaluation framework and program is encouraged to be adapted and evolved to capture dynamic and changing considerations. For example, arising in discussion, a change in preference by relevant stakeholders to include Greektown and Danforth in the route can be internalized by adjusting weights and/or adding additional metrics. Additionally, future developments such as the revitalization of the Port Lands, the Ontario Line, and the Waterfront East LRT present potential expansions and restrictions to eligible routing areas for which this framework and program can remain a useful tool to navigate.

As new ideas and data become available, the framework and program benefit from additional metrics which add depth and comprehension enhancing its measurement of performance. This framework and program also applies to any routing analysis and is not restricted to marathon routes. Pending approval, this framework and program can be used to evaluate and select potential routes for a new 5k route.

Further traffic modelling stands out as an opportunity for future work to enhance the measurement of road closures' effect on traffic congestion and emissions. Access and expertise with the full version of PTV VISSIM would allow for complete modelling of the route area. A calibrated model and dynamic traffic assignment would provide comprehensive simulation and measurement of routes' effect on traffic congestion and emissions across the whole city in addition to specific intersections.

Conclusion

This project aimed to reroute the TCS Toronto Waterfront Marathon to make it the most sustainable race in Canada. A result of comprehensive research, consultation with community partners and stakeholders, and a robust evaluative framework and program, the proposed new route improves performance in the three objective categories: sustainability, community engagement and participant experience.

This report and route recommendation completes the scope of this MUCP project. However, it is not intended to close the process. Throughout the research, design, and implementation phases of this project, flexibility and evolution has been a guiding theme to ensure delivery of a product which will remain useful beyond the scope of this project. This report captures a static optimization of the considerations at the time of writing and presents the best route recommendation. Acknowledging the dynamic nature of this process, it is hoped and intended this recommendation may change to best reflect changing contexts and deliver the most sustainable TCS Toronto Waterfront Marathon route.

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