The Jacques Cartier and Champlain Bridges Incorporated

# Contrat 62659 - Pont Jacques-Cartier, sections 1 à 9, services de consultant, études et applications pilotes pour l'entretien hivernal de la piste cyclable et du trottoir (2019-2021)

## Post-mortem report

271877-REP-POSTMORTEM-001

Final Report | July 3 2020



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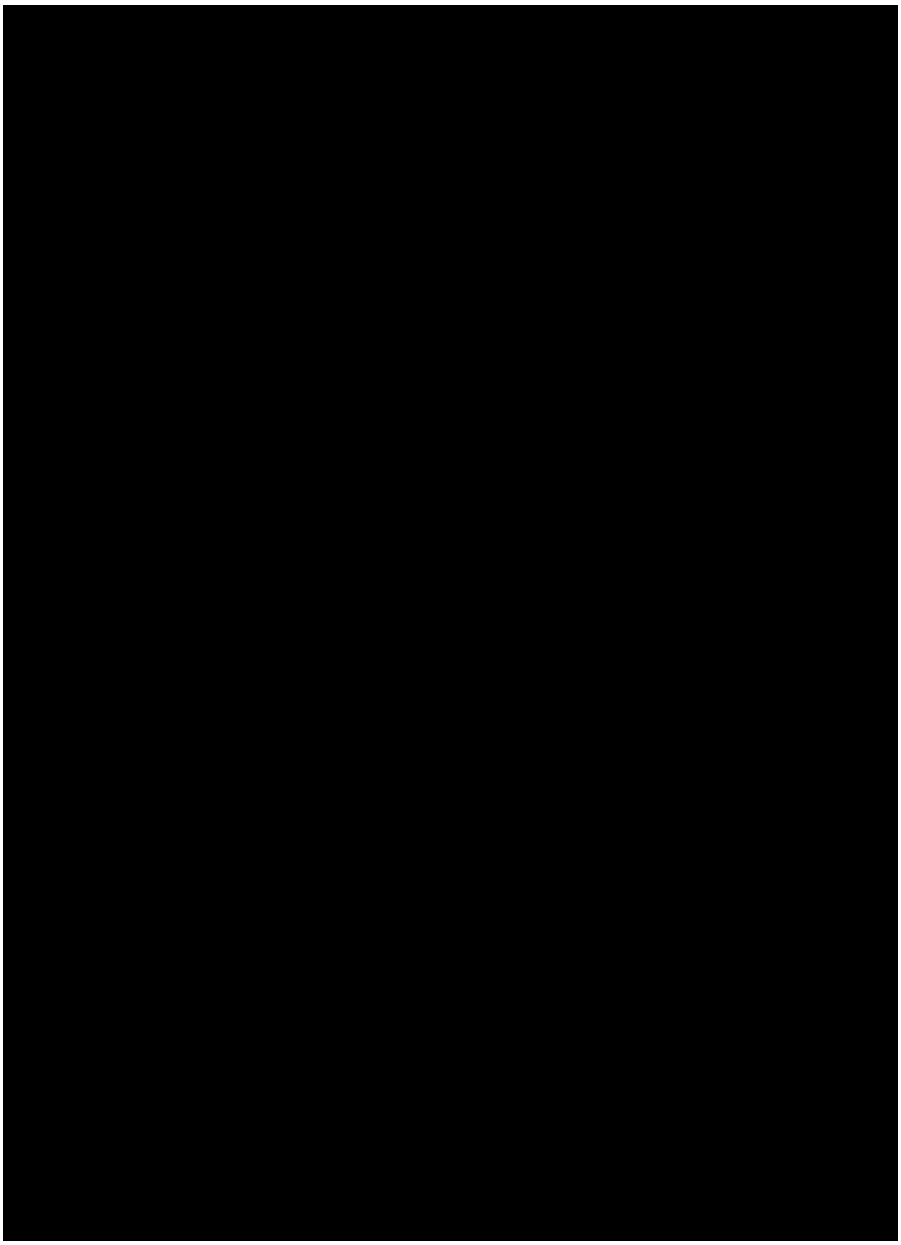
# Project Team



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# Executive Summary

In the context of an increasingly prosperous urban mobility sector, the Jacques Cartier Bridge multipurpose path is at the center of a debate revolving around the winter maintenance of cycling infrastructure. In fact, despite challenging winter conditions in Montreal, the demand for winter cycling continues to rise. The recent opening of the multipurpose path along the Samuel-De Champlain Bridge constitutes a prime example.

Over the past few years, The Jacques Cartier and Champlain Bridges Incorporated (JCCBI), advised by Arup as well as other consultants, has conducted several studies, including a winter maintenance pilot project to better understand issues and challenges related to winter maintenance of the multipurpose path and sidewalk. It has been observed that the reduced width and the length of the multipurpose path make the snow removal operations complex and unsuitable to be performed simultaneously with public access. As such, and due to adverse winter conditions, unforeseen closures became mandatory and unavoidable.

The objective of the previous winter maintenance pilot project, conducted in 2017-2018, was to evaluate various possible winter maintenance options and to identify their associated risks and costs. During pilot testing, no public access was granted, and only sporadic snow removal tests were carried out. At the end of the project, it was concluded that mechanical snow removal could be a feasible solution to obtain a sufficient path width and an adequate surface friction while ensuring safe two-way cyclist traffic on the bridge. A number of unknown variables and risks inherent to this option were however identified, such as the associated required communication burden and the complexity of managing operations in the event of unforeseen weather conditions. Therefore, it was deemed that adequate risk management and mitigation measures should be identified and implemented prior to the eventual opening of the multipurpose path in winter.

The pilot project made it possible to carry out a simulation of snow removal operations under “real” conditions with limited public access in a second phase, which occurred during the winter of 2019-2020. To ensure the success of the project and of the winter opening of the multipurpose path and sidewalk, Arup developed an integrated maintenance, monitoring and communication protocol to properly manage on-site operations by overseeing logistics, communication and data collection, all key issues to permit an eventual opening the multipurpose path and sidewalk to the public.

As such, on December 23rd 2019, the multipurpose path was closed to the public for the winter. Only 25 control cyclists, previously nominated by JCCBI to provide input to optimize the study, and three (3) partnering cyclists could access the multipurpose path during weekdays from 6:00 am to 8:00 pm. The multipurpose

path was then reopened to the public on March 12, 2020. During the simulation period, the multipurpose path was closed 5 times for snow removal operations (excluding daily night closures). As a result, the intended opening time window for the multipurpose path was achieved up to 93% of the weekdays, and conditions were deemed "very safe" (green) for 60% of the simulation period. Overall, the control cyclists' feedback was very encouraging with an average satisfaction rating of 2.87 on a scale of 3 (3 being a perfect score) with regards to the surface quality of the multipurpose path.

This simulation has allowed the identification of all broad issues related to a potential opening of the path to the public in winter, particularly in terms of user safety (speed, surface conditions and presence of "chicane" barriers on the multipurpose path), technical maintenance issues (durability of structures, environmental impact, equipment redundancy, drainage and supply of materials) and logistics (internal communication, communication to users and reliability of weather forecasts). In addition, the controlled tests allowed the various involved parties to learn about and become familiar with the winter maintenance and operation of the multipurpose path. The findings listed in this report are aimed at consolidating previous findings and at improving snow removal operations. The 2017-2018 studies on durability and environmental issues were also been updated with more details on the de-icing products selected. Additionally, the opening scenarios have been costed based on the procurement method recommended by JCCBI for the snow removal contract.

Upon concluding the various studies, a list of recommendations for additions and modifications was compiled to improve the multipurpose path's safety measures, make operations more efficient, and improve the communication flow path with the path's users. Lastly, a risk analysis was completed to evaluate the measures taken during the simulation of the 2019-2020 winter as well as the improvements proposed to upgrade the path for winter operation.

In conclusion to this study, it was determined that opening of the multipurpose path would be feasible under conditions similar to those of the simulation tests carried out during the 2019-2020 winter. However, a gradual and conservative approach, as advocated to date by JCCBI, will make it possible to progressively adjust the logistics and communication systems according to user needs. Knowing that winter conditions can vary considerably from one winter to the other, regular monitoring and inspections should be envisaged similar to those performed during the winter of 2019-2020. As such, any unfavorable or unsafe conditions must result in the early closure of the multipurpose path for a few hours or even a few days.

A gradual improvement in the level of service could be considered if the winter operation of the path is successful in the 2020-2021 winter. This strategy would include optimizing untimely closures, increasing daily operating hours or opening on some, if not all, weekends while maximizing the return on future investments

(cost/benefit ratio). In the event that the multipurpose path is officially opened, a re-evaluation of the level of service could be carried out after the first winter.

Despite various challenges, the JCCBI project team, supported by the Arup team and other external participants, succeeded in safely supervising and managing the opening of the multipurpose path in winter conditions. Should the multipurpose path open next winter, the Jacques Cartier Bridge, a signature landmark of the city, would undertake a new role in terms of active mobility between Longueuil and Montreal, during both summer and winter periods.

# 1 Introduction

## 1.1 Mandate description

In order to meet the growing demand for winter cycling, JCCBI carried out a series of closed snow removal tests on the Jacques Cartier Bridge multipurpose path during the winter of 2019-2020. The main objectives of the in-situ tests conducted under actual conditions were to improve maintenance, monitoring and communications protocols, to identify risks and issues, to assess the level of service that could be offered on the multipurpose path, and to keep the path open for as long as possible until weather conditions affect access and safety.

JCCBI's mission is to ensure user mobility, and the safety and longevity of its infrastructure by using a systemic management approach based on sustainable development. This will be achieved through the management, maintenance and repair of infrastructure that promotes seamless traffic flow while maintaining a commitment to the environment. This project aims to pursue JCCBI's strategic objectives through the development of maintenance, monitoring and communication protocols and, subsequently, through safe simulation [1]operation accompanied by an assessment of the potential opening of the multipurpose path to the public during the winter period. The results of the tests completed were used to conduct an analysis of the issues and risks related to the opening of the multipurpose path to the public, and to develop a mitigation plan.

Secondly, Arup updated the analyses carried out in 2017 - 2018. These included the durability assessment of the structure, the environmental impact analyses, and the cost estimates, in order to provide a framework for the operations. This report summarizes the aforementioned key aspects.

Arup will then analyze the winter maintenance specifications for future snow removal contracts and prepare a management guide for the multipurpose path and sidewalk in the event of a winter opening. At the end of the winter 2020-2021 operations, an analysis and follow-up report will be made available, as well as an update of the guide.

## 1.2 The Jacques Cartier Bridge

The Jacques Cartier Bridge features five vehicle lanes, a multipurpose path and a sidewalk for the exclusive use of pedestrians. It spans the St. Lawrence River and the Seaway over a distance of 2,725 meters, linking the Island of Montreal, Île Sainte-Hélène and the South Shore. It constitutes a key link between the city of

[1] simulation: a pilot project was carried out to simulate an opening to the public under controlled conditions. This project made it possible to collect the experiences of 25 "control" cyclists and three (3) partner cyclists and to ensure the implementation of safe conditions before a potential opening to the public.

Montreal and the city of Longueuil, as demonstrated by the thousands of users who use the bridge daily for utility and recreational trips. The bridge is composed of several sections, including :

- Sections 8 and 9 on the island of Montreal;
- Section 7, easily recognizable with its signature superstructure erected over the St. Lawrence River;
- Sections 5 and 6 on Île Sainte-Hélène;
- Section 4, which connects Île Sainte-Hélène with Île Notre-Dame;
- Section 3, over the St. Lawrence Seaway, and;
- Sections 1 and 2 in Longueuil.

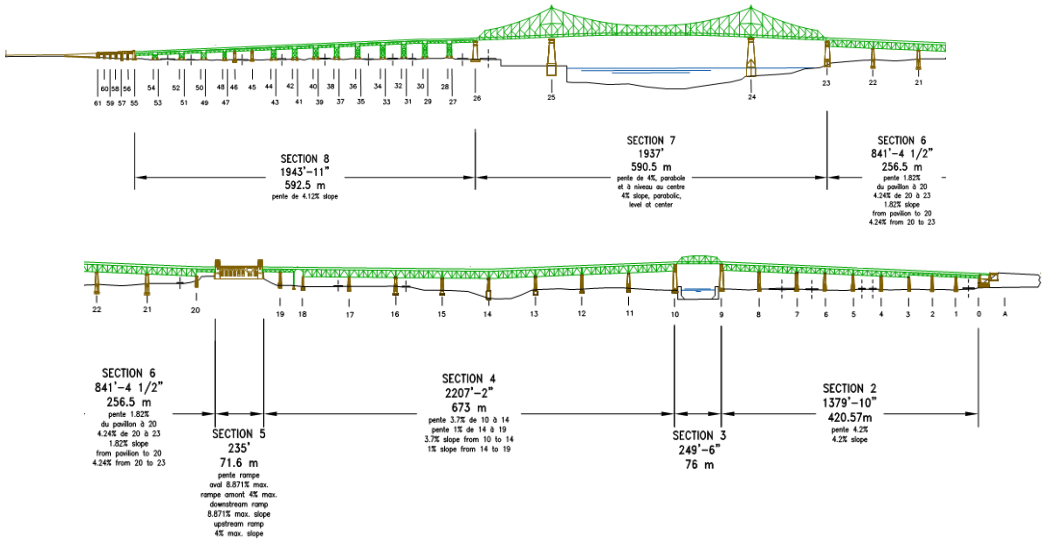



Figure 1 : Schematic representation of the bridge profile (not to scale)

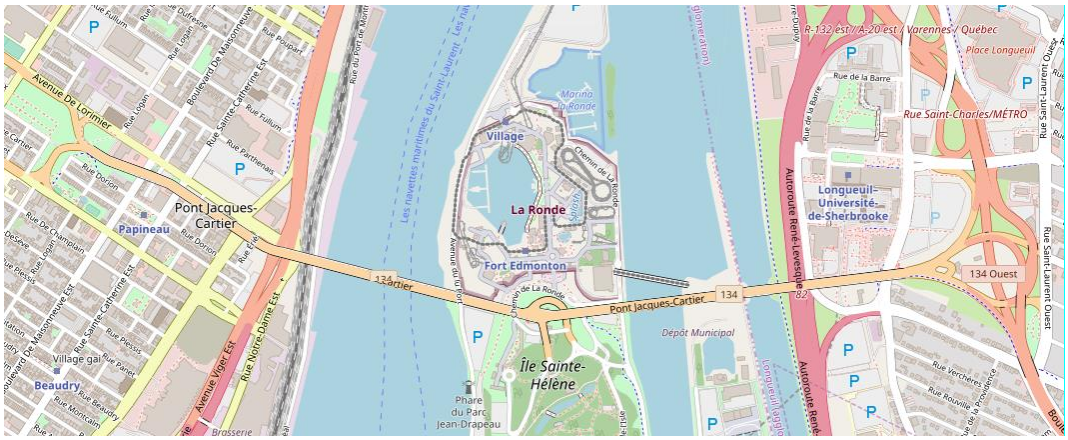



Figure 2 : OpenStreet Map of the Jacques Cartier Bridge [OpenStreet Map]

Figure 3 : General view of the multipurpose path and sidewalk

The multipurpose path located on the upstream side of the bridge is on average 2.5 meters wide and is open to pedestrians, joggers, cyclists and electric scooters. The path becomes narrower in some areas, particularly near the superstructure element and near the streetlights. On the Montreal side, the access point to the multipurpose path is at the intersection of Des Confiseurs St. and Dorion St. On the Longueuil side, access to the multipurpose path is at the intersection of La Fayette boulevard and Taschereau boulevard.

On the downstream side, the 1.25-meter-wide sidewalk is only accessible to pedestrians and joggers. In Longueuil, stairs at Saint-Charles St. West gives access to the Jacques Cartier Bridge and in Montreal the sidewalk joins the wider sidewalk network at de Lorimier Avenue.

## 1.3 Mandate objectives

The objective of this project is to establish an appropriate operational strategy for winter maintenance of the multipurpose path and to implement tangible measures that ensure safe management and operation of the bike path during the winter. The measures suggested are as follows:

- Developing a **management guide** including a maintenance manual, a communication protocol, and a procedure for monitoring and collecting data;
- Updating the **risk analysis** of the winter maintenance pilot project to identify residual risks and new risks related to snow removal operations and logistics, user safety, the existing structure or the environment;
- Following the results of the tests and studies carried out, a proposal for **necessary modifications and additions** to ensure safe and proper use of the multipurpose path.

## 1.4 Project considerations

To allow a successful opening the multipurpose path during winter, a number of key issues need to be considered:

- **User safety** is a critical consideration in all decisions made related to the width of the multipurpose path, the measures to reduce the speed of cyclists, ice falling from or onto the path, and the surface quality;
- To better manage **the safe use of the multipurpose path** for the public, special consideration is given to peak hour traffic management;
- The complexity of snow removal and maintenance operations, management of business hours and all inherent communications complexities are among the key aspects of the project;
- **Weather forecasts and associated precipitation amounts** define the planning and logistical decisions associated with snow removal and maintenance operations, and multipurpose path closures in winter;
- The use of de-icing products is linked to considerations for **durability** of the bridge's structural elements of the path, and to the **environmental issues** associated with discharges.

## 1.5 Literature review

The following documents have been reviewed under the new mandate. Some of the studies reviewed in 2017 - 2018 were also consulted on an as needed basis:

Table 1: Review of past studies/projects

| Document, Contract no., Author | Document Title | Summary/conclusion | Relevance |
|---|---|---|---|
| **62576, Arup** | Compte rendu du projet pilote d'entretien hivernal de la piste cyclable du pont Jacques-Cartier (daté du 9 mai 2018) | Summary of the winter maintenance pilot project for the Jacques Cartier Bridge multipurpose path and the conclusions and recommendations of the final report | The first phase of the pilot project for the winter maintenance of the Jacques Cartier Bridge multipurpose path, undertaken in 2017, serves as the basis for subsequent studies under the current mandate. |
| **Fiches techniques, Divers** | Fiches techniques et spécifications des équipements de déneigement disponibles au cours du projet | Dimensions and technical characteristics of the snow removal equipment used | These inputs were used to validate the clearance requirements and efficiency of snow removal vehicles according to the size, |

| | | | |
|---|---|---|---|
| | | | turning radius and type of vehicle. |
| **Fiches techniques, Divers** | Fiches techniques et spécifications des membranes d'étanchéité | Technical characteristics of the waterproofing membranes under study | These inputs were used to validate the performance and stress tests of the waterproofing membranes installed on the bridge. |
| **M03567A-621, 62065, CIMA+** | Évaluation de l'impact des chicanes sur la multipurpose path du pont Jacques-Cartier | Study aimed at qualifying and quantifying the impact of chicanes (barriers) on the speed and behaviour of cyclists in terms of a perceived insecurity, risk of injury and user comfort. | These inputs were consulted in order to learn about other studies carried out on chicanes (barriers), railings, dissuasive fences and guardrails in a security context. |
| **M04466A, 62517, CIMA+** | Réparation et améliorations aux garde-corps, aux clôtures dissuasives, aux glissières et à la dalle de béton du trottoir et de la piste cyclable du pont Jacques-Cartier | Results of the preliminary design study for the planning or repair and reinforcement work on guardrails, dissuasive fences and guardrail rails as well as repair work on the sidewalk and multipurpose path between Abutment A and Section 9 of the Jacques Cartier Bridge | |
| **M04466A, 62517, CIMA+** | Documentation de l'impact de l'installation des nouvelles chicanes sur la multipurpose path du pont Jacques-Cartier | Analysis of the impact of the implementation of the new chicanes (barriers) on the multipurpose path of the Jacques Cartier Bridge and improvement of the current situation through the development of temporary mitigation measures and identification of permanent measures, including the further testing | |
| **28874TT, 62408, Tetra Tech, Structura** | Rapport d'inspection annuelle | Detailed Inspection of Abutments A & 0, the Structural System and Section 1 Deck of the Jacques Cartier Bridge | The annual inspection program for Abutments A & 0, the structural system and Section 1 Deck of the Jacques Cartier Bridge was considered as part of this mandate. |

# 2 Winter maintenance operations

## 2.1 Winter 2019 – 2020 Simulation

The geometry of the multipurpose path requires closure of the path to the public to allow an efficient winter maintenance to be completed. The logistics surrounding daily operations in winter are relatively complex and are significantly different from the conventional operations that apply to other bike paths in the region.

To better understand the challenges faced by operators and users, a simulation of operations on the path was completed. During the simulation, the path remained closed to the public. The tests were completed to help support the decision-making linked to winter operation of the multipurpose path and to the path's potential future opening.

An integrated maintenance, monitoring and communication protocol was developed in advance to guide the on-site simulation and to ensure the success of the project. Twenty-five (25) control cyclists and three (3) partner cyclists were selected to participate in the winter simulation.

## 2.2 Integrated Protocol for the 2019 – 2020 Simulation

An integrated protocol was developed to coordinate three logistical components of the project for the winter 2019-2020 simulation:

- Communication and decision making;
- Operations (operations), and;
- Monitoring and approval.

Two additional components were added to the protocol to provide guidance for weather forecasting and data collection. The 5 steps are linked as follows:

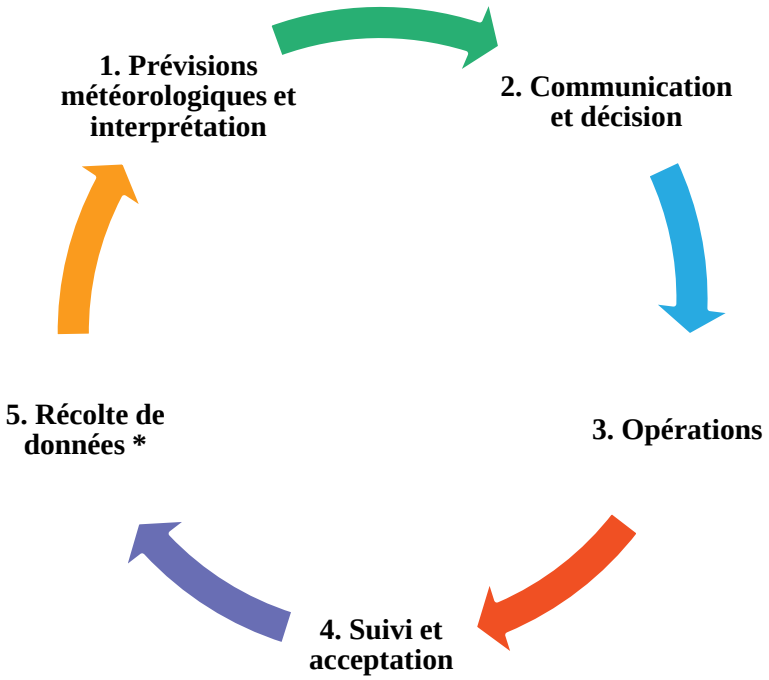



Figure 4 : General Steps of the Integrated Protocol

The protocol allows for internal coordination between the different teams (Management, Communication, Research and Applications Department (DRA), Operation / Maintenance (O/M), Arup, Contractor, etc.) and serves as a communication tool with the path users.

The integrated protocol is presented in detail in Appendix A.

### 2.2.1 Forecasts and Analysis

Regular weather monitoring is necessary to prepare for operations, to manage opening and closure of the multipurpose path, and to communicate with the path users. During the simulation, several sources for weather forecasts were used by the Operations and Maintenance teams and by the Contractor. Some are available online free of charge; others are adjusted to local conditions via weather stations installed on the bridge. While no one source is complete in terms of information on actual conditions or forecast reliability, the combined analysis of data from these sources provides good information on past, present and future weather conditions. Further details are provided in the appendix.

Interpretation of the forecast data has a significant impact on snow removal operations and, by extension, on closures of the multipurpose path. A flowchart was developed to detail the criteria for operations and for closure of the multipurpose path based on forecast data and on expected and actual weather conditions. The purpose of this flowchart was to standardize and guide decision making in daily

operations, and to optimize operations to avoid the unnecessary closure of the multipurpose path.

### 2.2.2 Communication and decision-making

Communication between various internal parties (namely Operations/Maintenance, Engineering and Communications) is essential to optimize the operations and the opening hours of the multipurpose path. Regular communication with users through one or more channels has reduced the impact of closures.

For the 2019-2020 simulations, the main communication tool for the control cyclists was a customized e-mail sent twice a day. A first communication was sent in the morning at 5:30 am and a second in the afternoon at 3 pm. However, when it was required due to weather conditions, an additional communication was sent to users to notify them of any status change regarding the multipurpose path.

The chart in Figure 5 below shows a typical communication protocol with several communication options and is intended to assist JCCBI in formulating its own communication protocol, both internally and externally.

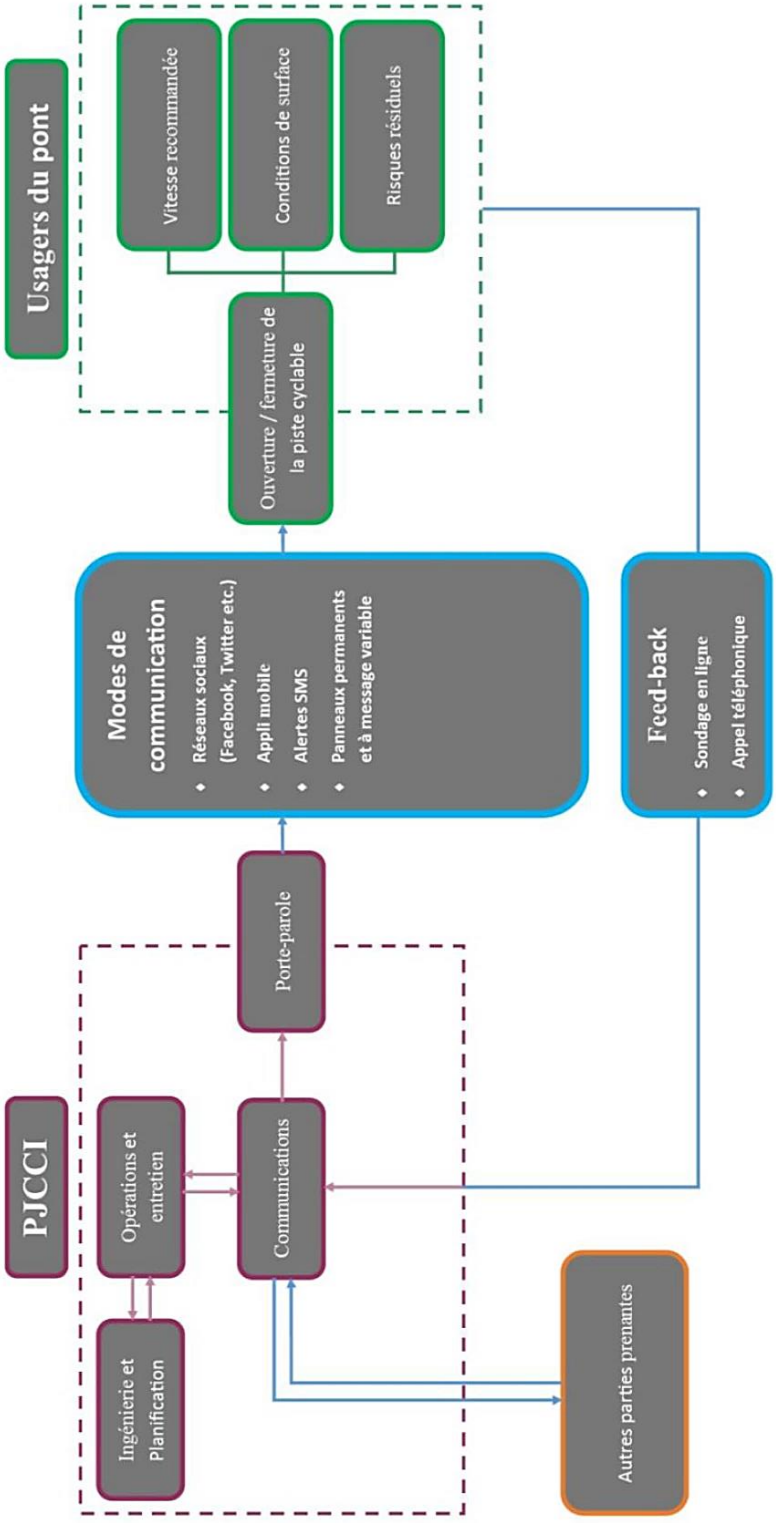



Figure 5 : Typical Communication Protocol

### 2.2.3 Contractor Operations

Using the flowchart for operations and the criteria developed, the Contractor was able to complete snow removal and maintenance of the multipurpose path and open it in time for the control cyclists. Regular monitoring of the multipurpose path surface conditions was essential to maintain real-time operations. Sidewalk maintenance was carried out by JCCBI's in-house Operations and Maintenance team.

For the 2019-2020 simulation, the following equipment was available (duplicates were available except for the items marked with an asterisk*):

- Benco snowplow with blade, for the multipurpose path;
- Dump truck (for solid de-icing products);
- Trailer for liquid de-icing products*;
- Blower (snow removal);
- Rotary brush*;
- Sidewalk snowplow (blade, snowblower, brush, liquid product, solid product).

Figure 6: Benco snowplow for multipurpose path (model 2345D)

Appendix A provides more details on available equipment and operating criteria.

### 2.2.4 Monitoring and Acceptance by Operations and Maintenance

In addition to the Contractor's monitoring and operations, JCCBI's Operations and Maintenance personnel were also on site to validate, plan and direct operations, and to manage opening and closure of the multipurpose path. In addition, protocols were updated and communication with control cyclists were facilitated to allow a proper management of physical opening and closing of the multipurpose path.

### 2.2.5 Data Collection

Various monitoring forms were used to improve operations and continuous communication including :

- An exit form to track the Contractor's day-to-day operations;
- A look-out form to inspect the multipurpose path and its surface condition; and
- An online form to collect daily feedback from the control cyclists.


Figure 7 : Monitoring forms used

Other data such as weather information, traffic statistics and meeting minutes was compiled for the same purpose.

## 2.3 Results of the 2019-2020 Simulation

The experience documented and the data collected during the simulation project was reviewed and consolidated. An analysis and interpretation of the results is presented in sections that follow. These results will allow, among other things, an informed decision to be made regarding the potential opening of the multipurpose path to the public.

### 2.3.1 Opening the path

The multipurpose path remained open for 93% of weekdays during the 2019-2020 simulation. For 60% of the simulation period, the conditions on the path were considered very safe (green). Figure 9 demonstrates that precipitation has a direct causal link with the opening status of the multipurpose path. During periods of snow accumulation, rain, or freezing rain, the status of the multipurpose path was most often classified as yellow (open in non-ideal conditions). The multipurpose path was closed on only five (5) occasions due to snow and freezing rain.

These results are considered very satisfactory and demonstrate that the multipurpose path can be maintained while providing an adequate level of service to users during the winter. However, the opening timeframes could vary depending on weather conditions and the mildness or harshness of the winter. A theoretical estimate of the opening period for different scenarios is presented in the following section.

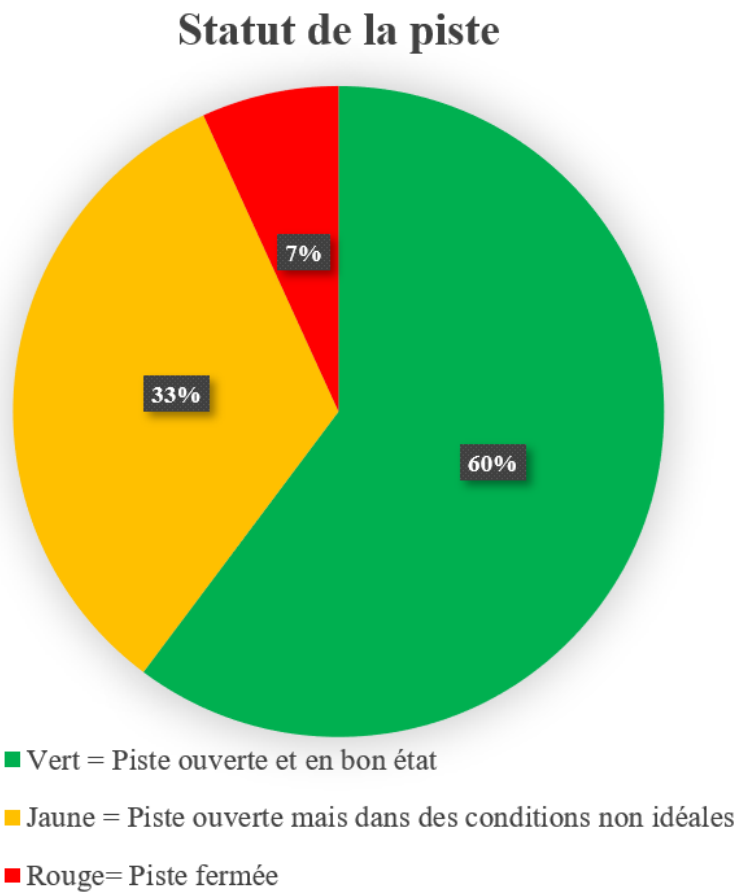



Figure 8 : Average multipurpose path condition in winter 2019-2020

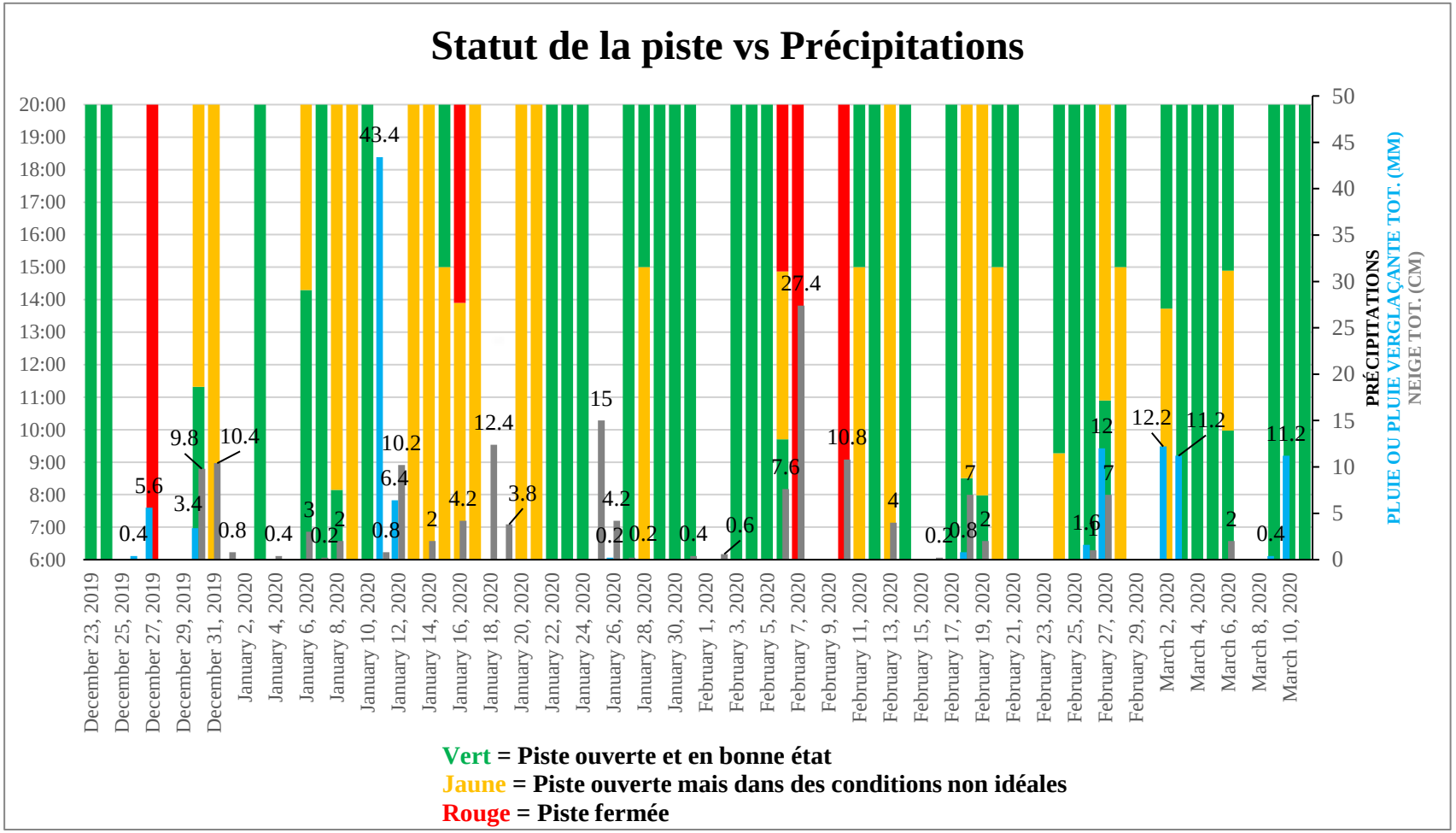



Figure 9 : Multipurpose path condition in winter 2019-2020

### 2.3.2 Maintenance Operations

During the 2019-2020 simulation, 40 snow clearing operations were completed between December 18 and March 10, representing a period of 83 days. The majority of these operations involved different types of interventions, i.e., clearing with a tractor equipped with a blade, a snowblower, a rotary broom or a dump truck designed to spread de-icing products. Some operations were aimed at restoring the quality of the surface; in such cases, only the rotary broom or the spreading of de-icing products was required. The number of operations and the average number of round trips for each type of intervention completed during the winter of 2019-2020 is presented in Table 2 below:

Table 2 : Number of operations and average number of round trips

| Winter maintenance operation type | | Number of winter maintenance operations | Average number of back-and-forth sweeps |
|---|---|---|---|
| **Blade sweep** | | 12 | 1,1 |
| **Snow blower trip** | | 14 | 1,3 |
| **Rotating sweeper trip** | | 10 | 1,5 |
| **Liquid de-icing application** | Road salt | 20 | 1,0 |
| | Product A[2] | 13 | |
| **Liquid de-icing application** Product B[2]) | | 1 | 1,0 |

In light of what was noted, the Contractor generally favored the application of de-icing products to ensure an adherent surface. This is discussed in more detail in subsection 2.3.2.1.

The total duration of snow removal operations varied as it depended on the type of operation, the number of different operations and the number of passes completed. On average, the duration of snow-clearing operations during the winter 2019-2020 season was 2 hours 15 minutes. Figure 10 depicts the duration of the snow clearing/maintenance operations and the precipitation quantities recorded during the winter.

The longest operation lasted 5 hours and included one round trip with a snowblower, two round trips with a rotary broom and one round trip to spread de-icing products. The shortest operation took 15 minutes for a round trip to spread de-icing products over a small, localized area.

[2] Refer to section 3.1 for more information on the products

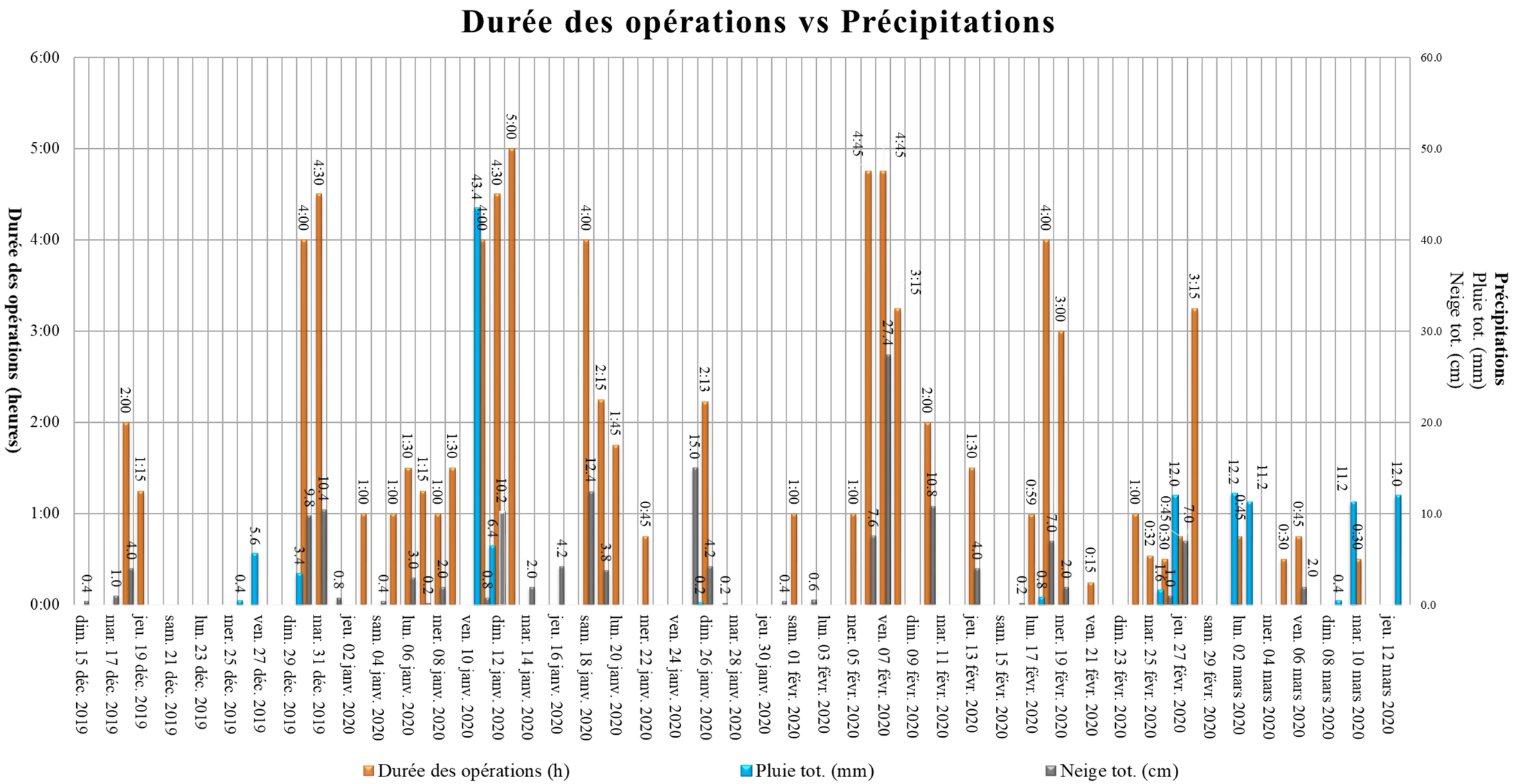



Figure 10 : Duration of operations and precipitation in winter 2019-2020

#### 2.3.2.1 Spreading De-icing Products

Although the integrated protocol does not recommend its use, the Contractor frequently opted for the use of road salt during snow removal operations in December and January. It was also noted that a large quantity of de-icing products was applied on all occasions where de-icing product application was favored. Figure 11 demonstrates that a majority of the de-icing operations were completed with an application rate that was higher than the rates recommended in the integrated protocol (green and red line); on two occasions, more than 2 tons of road salt was applied.

Under certain severe weather conditions or when preventative spraying is necessary, it may be justifiable, as indicated in Section 3.4 of Appendix A, to apply a special rate of de-icing product that is higher than the high rate. Otherwise, in such scenarios, the amounts applied should remain reasonable to avoid compromising the durability of the structure and the user's ride experience.

Following an awareness meeting with the Contractor on January 26, road salt was only applied to the path three times. The rotary broom was the preferred method for surface finishing during the period from January 26 to February 13. During this period, the cyclists seemed satisfied with the surface quality and provided an average rating of 2.95 on a scale of 3. This rating was obtained despite the absence of de-icing products, and despite the numerous precipitations that were recorded during the period. Based on this result, it can be concluded that the rotary broom provides an acceptable surface quality and that the application of de-icing products is not imperative when the rotary broom can provide surface conditions deemed safe.

Beginning February 13, the Contractor started using De-icing Product A. The Contractor applied the product at a rate well above the 390 kg rate recommended in the integrated protocol. Several occurrences of 800 kg of product application were noted.

The chart below demonstrates the rate at which de-icing products were applied along with the amount of precipitation recorded during the winter.

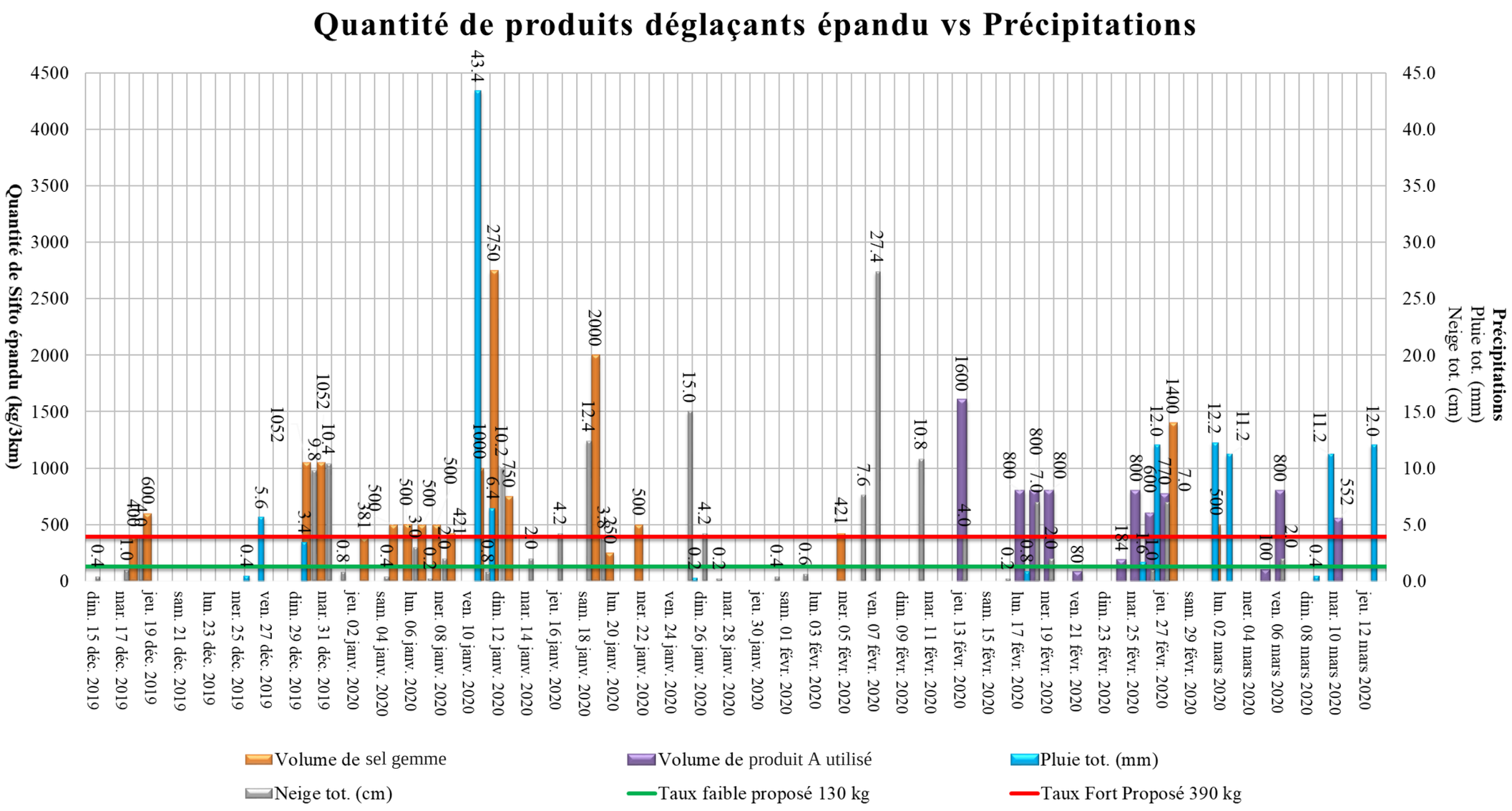



Figure 11 : De-icing application rates and precipitation during the winter of 2019-2020

### 2.3.3 Participation of Cyclists

In November 2019, JCCBI issued a call for applications to encourage volunteer cyclists to participate in the 2019-2020 winter simulation project. More than 150 cyclists applied and a total of 25 control cyclists and three (3) partner cyclists were selected. To collaborate in the project, participants agreed to respect the conditions of use enacted by JCCBI, to participate in an information meeting, and to cross the bridge several times a week when path conditions permitted. The control cyclists were asked to fill out an electronic form after each crossing and assign a grade for surface quality, provide observations, and raise any other relevant comments.

The surface quality rating scale was established as follows:

**3** = The riding surface is adherent along the length of the bridge

**2** = The riding surface is generally adherent, but slippery in some places

**1** = Riding surface is slippery in several places along the length of the bridge

In the period from 23 December 2019 to 11 March 2020, details of 1,095 user trips were collected using the form; this represents an average of 23 trips per day[3]. It is possible that some cyclists did not fill out the form at each trip and that these numbers were underestimated. In general, the control cyclists appreciated the path riding conditions and the overall experience crossing the bridge's multipurpose path. The average rating of surface quality by the control cyclists was 2.87 on a scale of 3. It can be concluded that the cyclists were generally satisfied with the quality of the snow removal operations. Figure 12 shows the average assessment of surface quality for the multipurpose path during the 2019-2020 winter period. In general, the control cyclists gave a rating of 3.00 almost every day. As expected, the average rating drops below 3.00 when precipitation occurs during the day or on the previous day. The average score is close to the 3.00 mark; this demonstrates the effectiveness of snow removal operations in providing a safe and adherent surface quality that meets the user expectations. It is important to consider that the assessment of surface quality is a subjective criterion and it is likely to vary from one cyclist to another.

During the winter tests, the control cyclists reported several findings related to conditions and to their experience riding on the bridge. The following sections discuss the findings that are considered relevant. Weekly reports on the return of the cyclists were prepared and shared with the JCCBI team to allow the observations to be actioned.

[3] Data for the period of December 24 to January 2 and the days on which the path was closed have been removed as they are not representative of the average daily flow

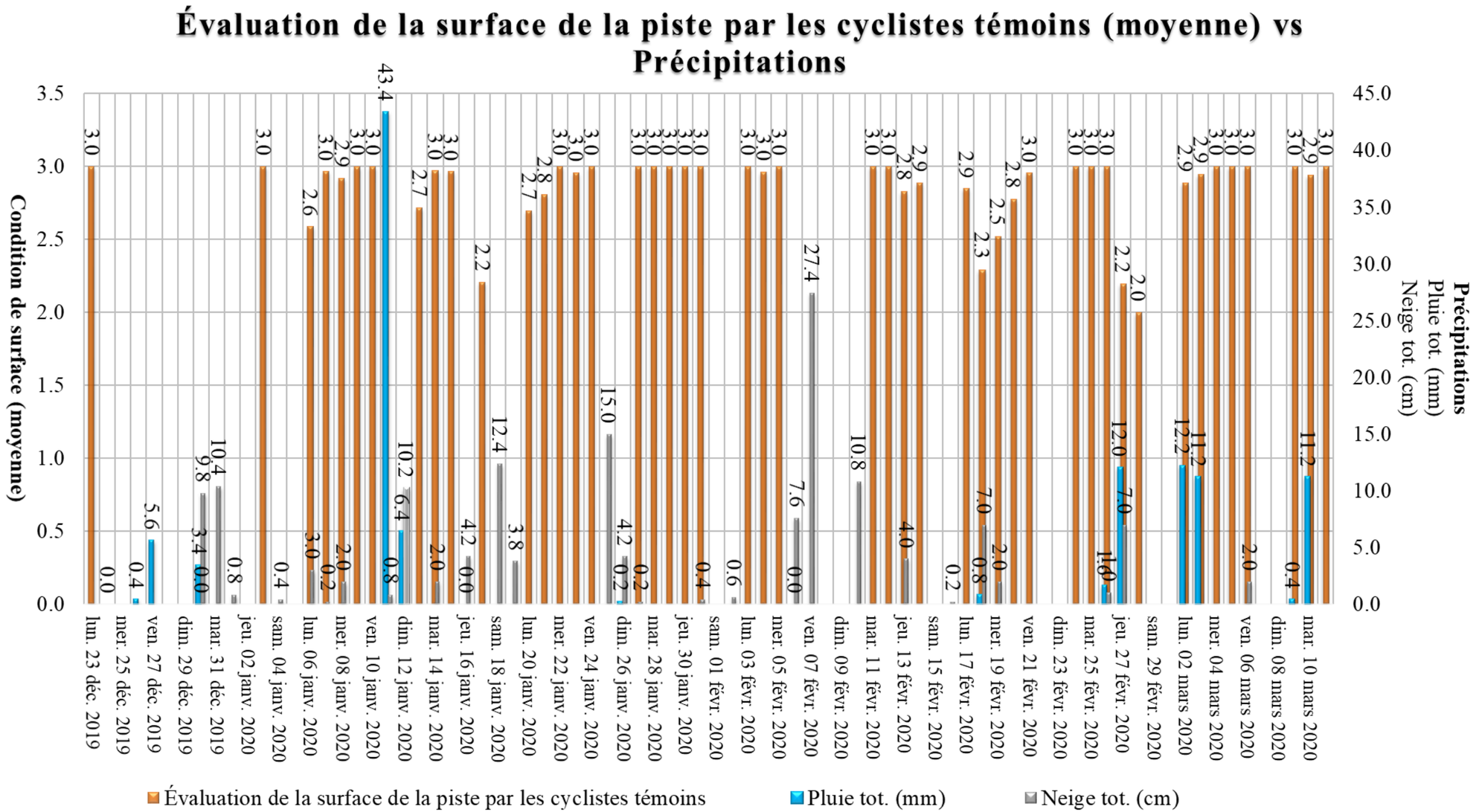



Figure 12 : Surface conditions (average) and precipitation during winter 2019-2020

#### 2.3.3.1 Surface Quality on the Deck versus Surrounding paths

Several cyclists commented that the quality of snow removal operations on the bridge path were superior to those encountered elsewhere on their daily route. On several occasions, when snowfall was affecting Montreal, control cyclists observed that the surface quality of the multipurpose path on the Jacques Cartier Bridge was superior to that of the adjacent bicycle networks.

#### 2.3.3.2 Surface Quality on the Approaches to the Bridge

In general, surface quality seemed to be appreciated by all participants with the exception on the two approaches that were problematic. The surface on the approaches to Sections 1 and 9 does not appear to be drained optimally and remains wet, creating the potential for ice formation (see Figure 13).

Figure 13 : Wet and undrained surface at Section 2 of the Jacques Cartier Bridge

#### 2.3.3.3 « chicane » barriers

Cyclists commented on the presence of certain barriers, particularly the barrier belonging to the City of Longueuil, near the entrance to the multipurpose path at La Fayette Boulevard, which restricts the available width of the multipurpose path. Snow removal does not seem to provide adequate space to avoid the barrier. Figure 14 shows that cyclists must leave the snow-cleared area and ride on a snow-covered surface to maneuver around the barrier. Figure 15 shows a traffic area small enough to get around the barrier.

Based on this observation, one of the barriers of the City of Longueuil was opened to improve the trips for cyclists.

Figure 14 : Barrier on the territory of the City of Longueuil near La Fayette Boulevard

Figure 15 : Width available to bypass the barrier on the territory of the City of Longueuil

Figure 16 : One of the barriers on the territory of the City of Longueuil has been shifted to improve flow

#### 2.3.3.4 Road Splashes

Following precipitation, snow melts and turns into water on the roadside of the Jacques Cartier Bridge. The road drains are located near the median that separates the road from the multipurpose path; the result is an accumulation of water on the path. Some control cyclists reported splashes of dirty water from the road onto the multipurpose path when vehicles travelled at high speed. This is a risk associated with any network that has a bike path juxtaposed to the road.

Figure 17 : Splashes of dirty water from the road on the multipurpose path

#### 2.3.3.5 Quantity of De-Icing Materials Applied

On several occasions, cyclists noted that a large quantity of de-icing products had been applied. In their opinion, a smaller amount would have been equally effective and would have enhanced their riding experience. Some cyclists suggested that overuse of de-icing products could adversely affect the durability of their bicycles.

Cyclists noted a more pleasant riding experience on the path when the finer grains, including those of Product A, were used rather than when the coarser grains (road salt) were applied. The use of too much salt reduces the contact surface between bicycle tires and the concrete surface, which can lead to risky riding.

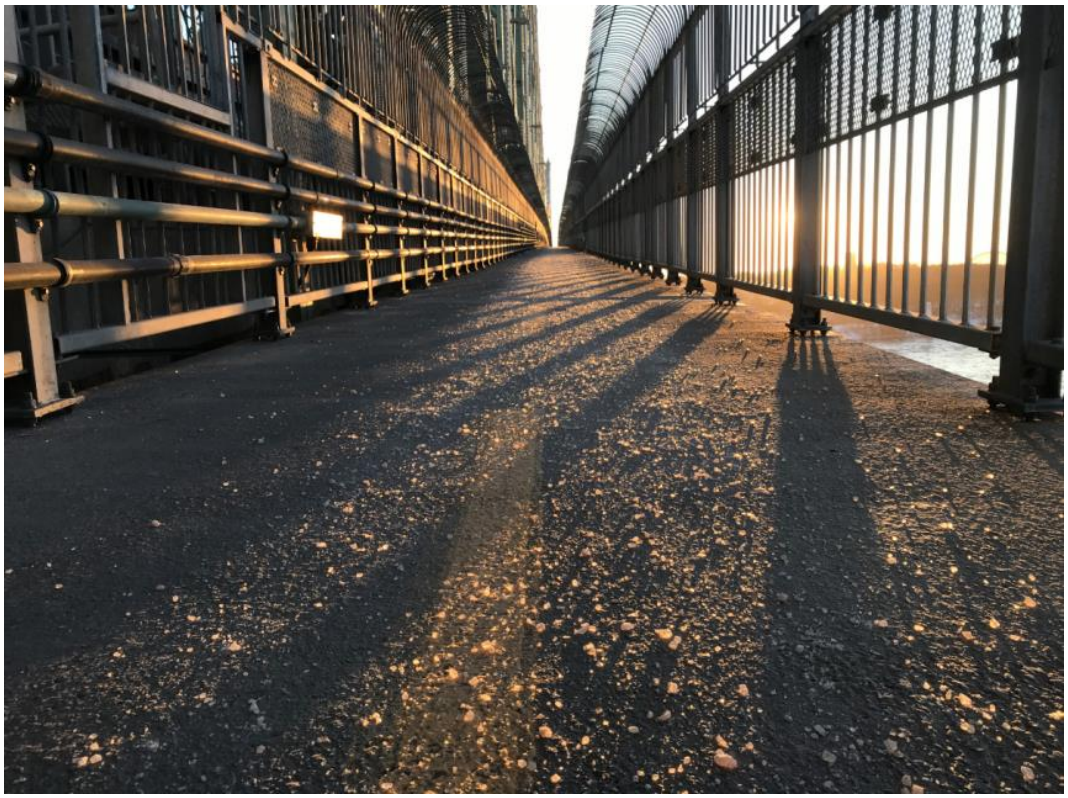


Figure 18 : A large amount of de-icing products spread on the multipurpose path

### 2.3.3.6 Ice Formation by Melt Water

Some cyclists have observed that patches of ice formed after the snow walls on the multipurpose path melted. Warmer temperatures above 0°C followed by a cooling episode lead to this situation. This ice patch formation was not widespread and affected only a portion of the usable section of the multipurpose path.

Figure 19 : Slush edge leaving water puddles on the multipurpose path that are conducive to freezing

#### 2.3.3.7 Puddle Formation in Section 1

It was observed that drainage of the multipurpose path was inadequate on the Longueuil side, just past the abutment of the A-axis. Cyclists noted on many occasions that a puddle formed near the historical sign at the bridge entrance. The geometry at this location favors this type of phenomenon, particularly in an overhanging situation.

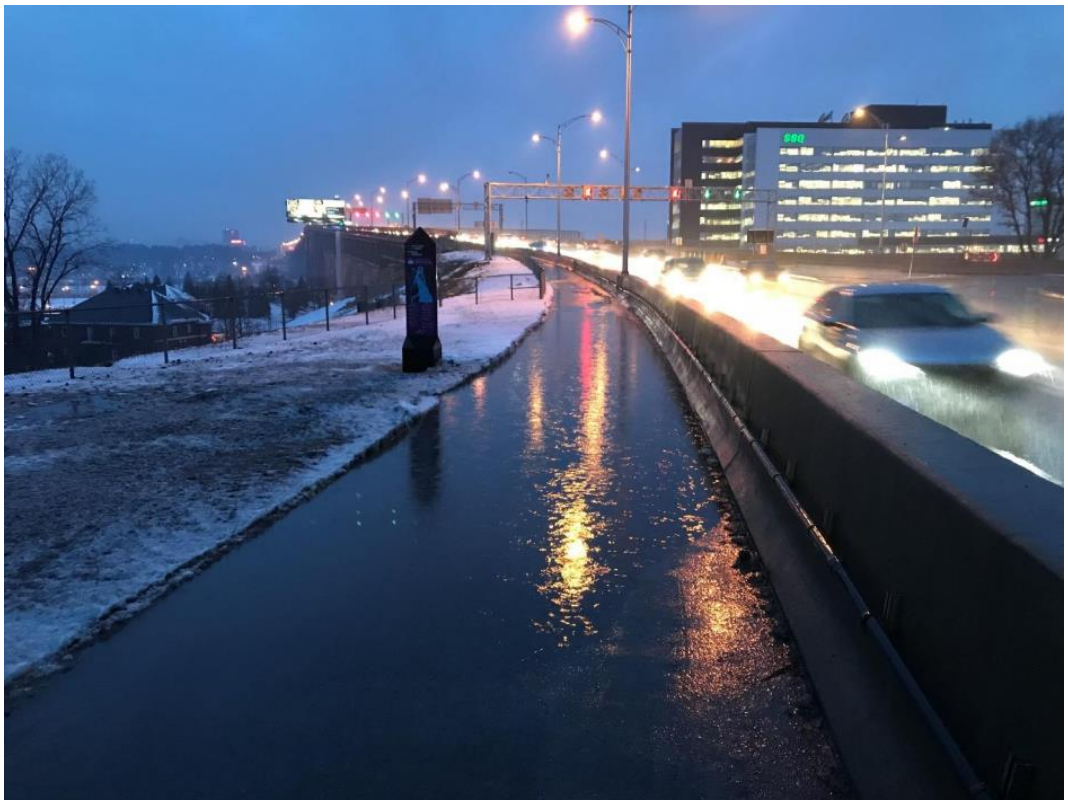


Figure 20 : Puddle in Section 1 of the bridge

Figure 21 : A worker creates a path to evacuate water from the path

### 2.3.4 Analysis of cyclist movement

A total of 25 control cyclists and three (3) partner cyclists participated in the winter simulation and travelled on the bridge in the winter of 2019-2020. Although this number represents a limited population for statistical analysis of the data collected,

the sample of 28 cyclists is considered acceptable, considering that the potential traffic on the multipurpose path is expected to be 330 daily trips [4]. As indicated in Section 2.3.3, the average number of daily trips was 23 during the 2019-2020 winter simulation. This number represents a sample of approximately 7% of all anticipated traffic. It is possible to draw conclusions on the general behaviour of cyclists from the data collected, while considering the specific profile of a winter cyclist.

### 2.3.4.1 Time of trip for cyclists

During the winter simulation, opening hours of the multipurpose path were 6:00 am to 8:00 pm. Figure 22 shows that the control cyclists used the multipurpose path during peak hours, mainly to get to and from work on either side of the bridge. Very few cyclists used the bridge between 10:00 a.m. and 2:00 p.m.; this period could represent an opportunity to close the lane to complete snow removal or to apply essential or preventive de-icing products, while minimizing the impact on users.

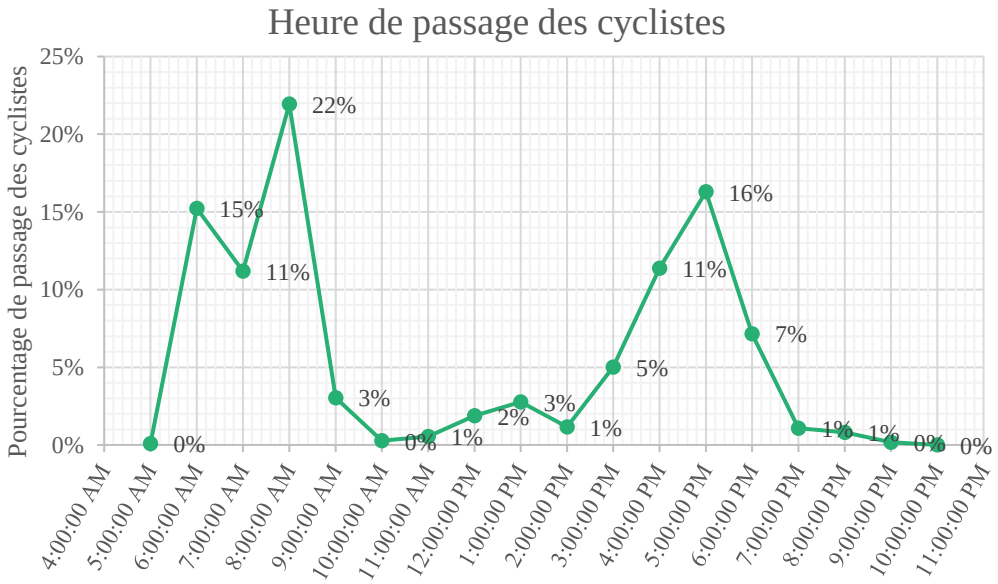



Figure 22 : Time of trip of control cyclists

### 2.3.4.2 Number of Cyclists in Relation to Weather Conditions

Figure 23 and Figure 24 illustrate the number of cyclist trips as well as the ambient temperatures and precipitation observed during the simulation completed during the winter of 2019-2020.

[4] Page 24 - Post-mortem report on the winter maintenance pilot project for the multipurpose path of the Jacques Cartier Bridge - Arup - October 09, 2018

Figure 25 and Figure 26 present graphs comparing the number of cyclist trips to the ambient temperature and wind speed as a scatterplot. These figures show a lack of correlation between the number of cyclists using the bridge on a daily basis and the outside temperature or wind speed. This could be explained by the observation that winter cyclists are generally more seasoned and fearless in the face of weather conditions. Based on this result, it has been concluded that the multipurpose path should remain open, regardless of the outside temperature or wind factors, unless conditions are deemed unsafe.

Figure 27, however, presents a scatter plot comparing the number of cyclist trips against recorded precipitation; it appears to show a slight correlation between the two. Fewer cyclists appear to use the multipurpose path when precipitation in the form of snow or rain reaches 4 cm and 4 mm respectively.

This data[5] characterizing the behaviour of control cyclists corresponds closely to the data presented in Figure 28 by Vélo Québec on the behaviour of winter cyclists in relation to weather conditions.

To confirm this data and the conclusions drawn from the data, it is suggested that data collection continues at an opening to the general public to allow an informed decision to be made on the opening of the multipurpose path in the face of weather forecasts. If decisions are taken to frequently close the multipurpose path, this could result in a perception of unpredictability of the path's opening status among users. It is argued that cyclists could choose not to use the bridge when precipitations are forecast, for fear of not being able to use the bridge on their return trip due to a potential closure during the day. Therefore, it is recommended that the number of closures be kept to a minimum, while ensuring safe status.

[5] Data for the period of December 24 to January 2 and the days on which the path was closed have been removed as they are not representative of the average daily flow

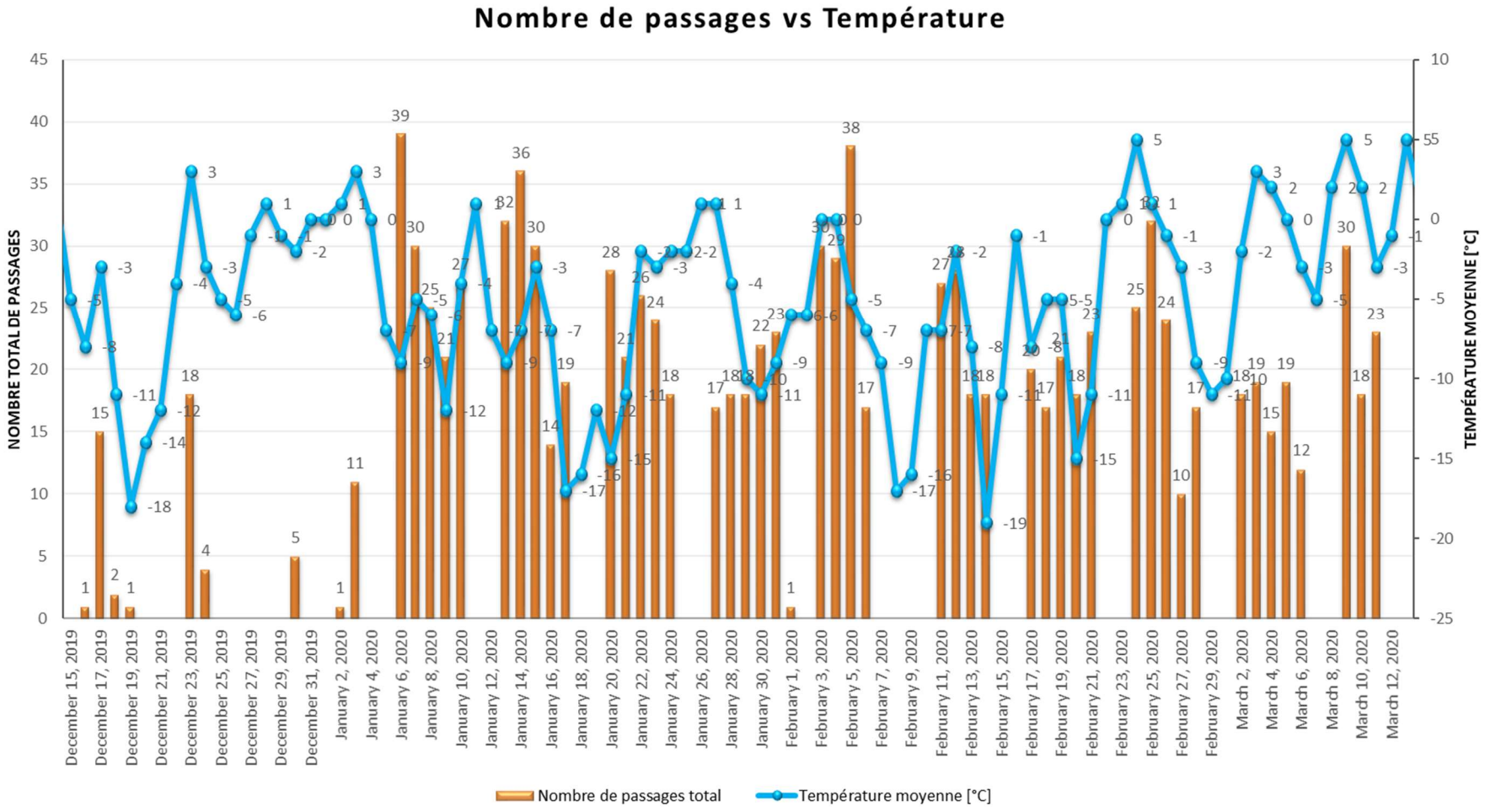



Figure 23 : Number of passes vs. outdoor temperature in the 2019-2020 winter simulation

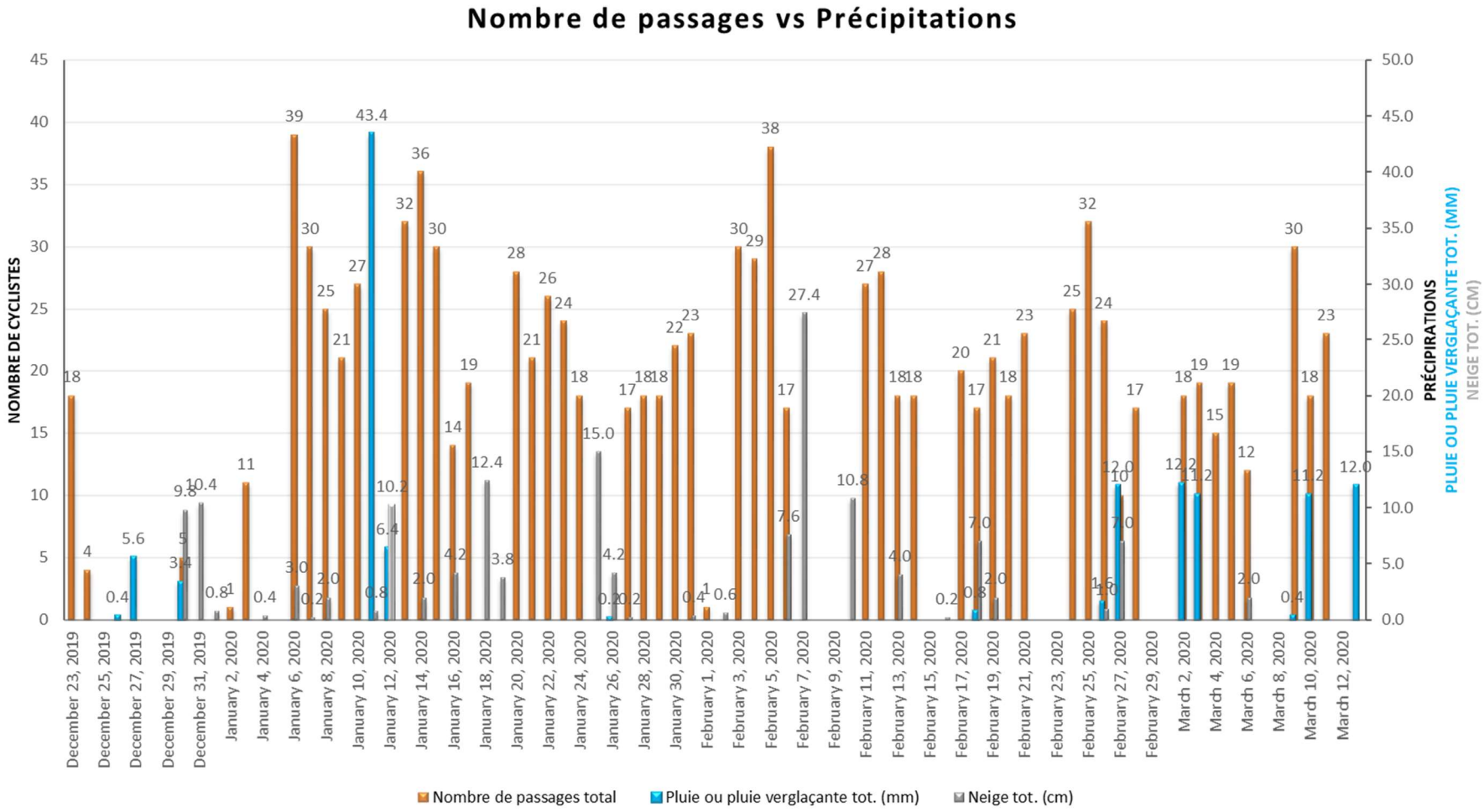



Figure 24 : Number of passes vs. precipitation in the 2019-2020 winter simulation

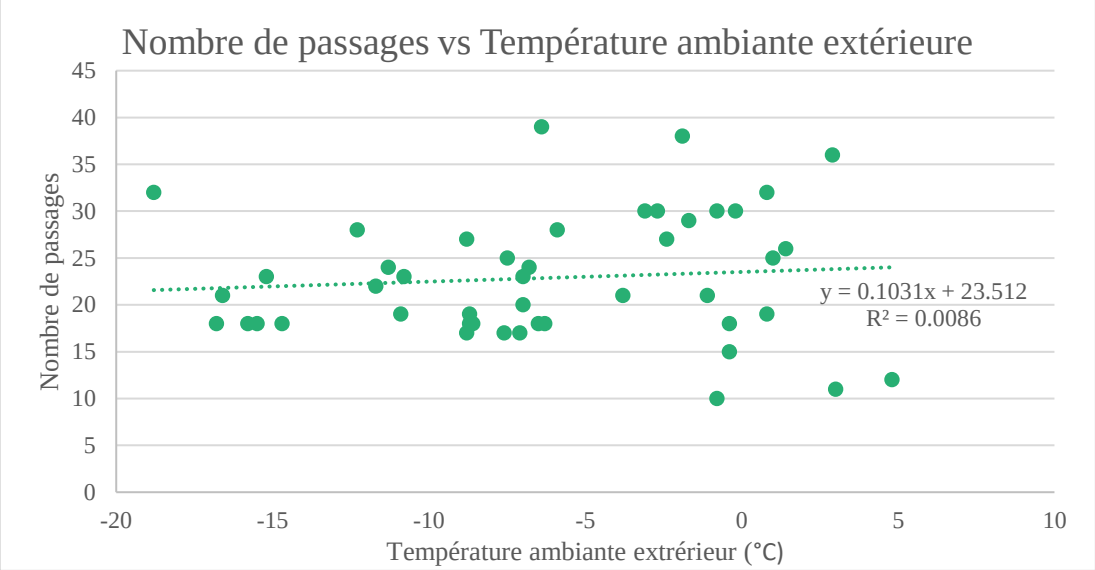



Figure 25 : Number of passes vs. outdoor temperature

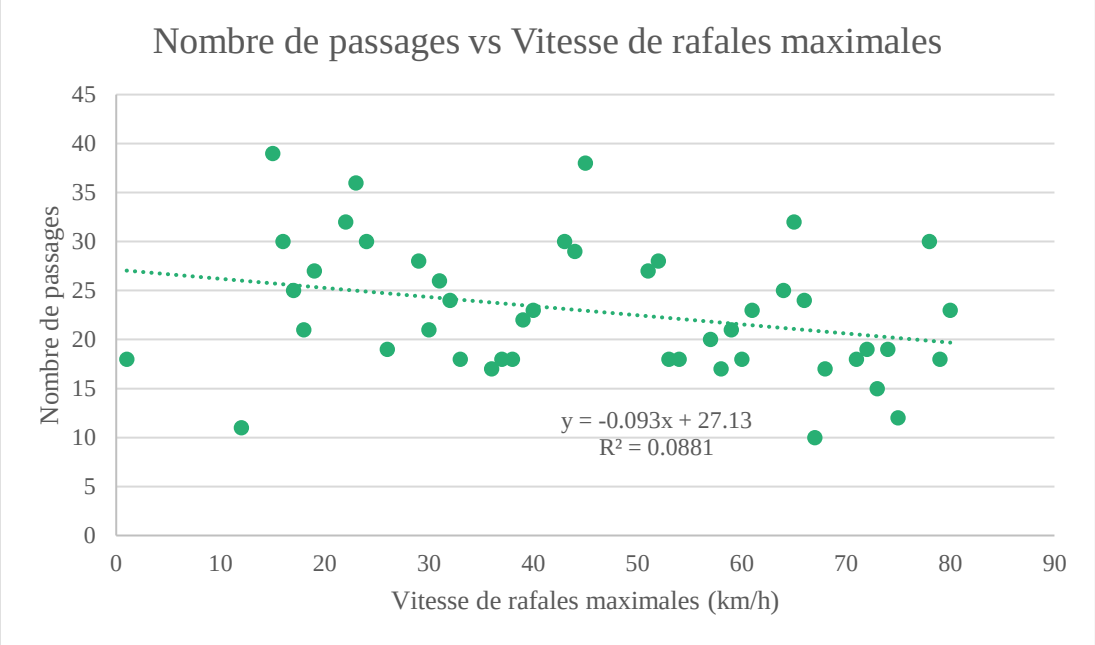



Figure 26 : Number of passes vs. maximum gust speed

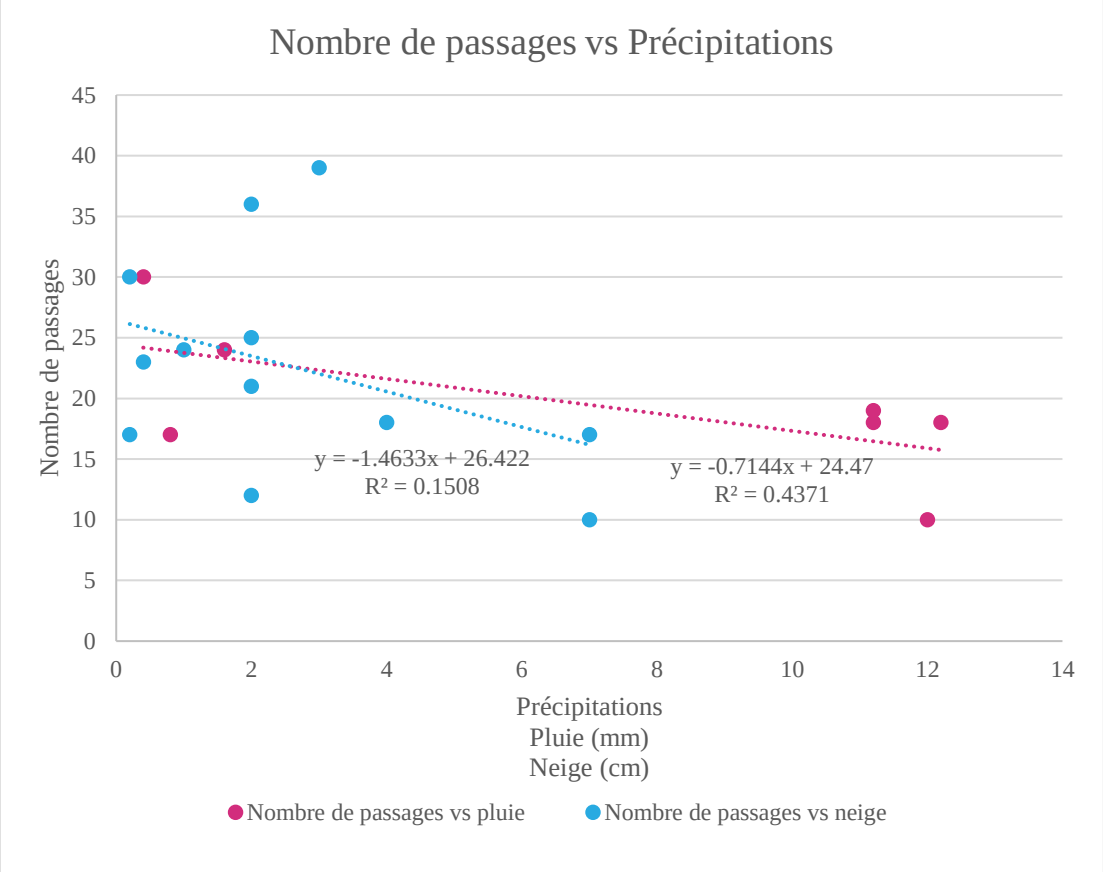



Figure 27 : Number of passes vs. Precipitation

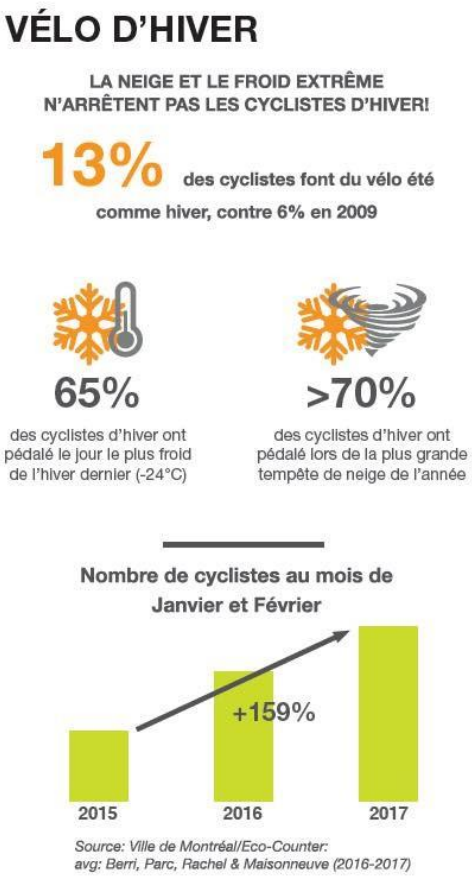



Figure 28 : Eco-counter data for the City of Montreal, 2017

## 2.4 Modelling of Theoretical Opening Hours

A second snow removal operations modelling exercise was completed as part of this mandate. The objective was to determine the theoretical number of opening and closing hours according to the winter maintenance protocol, assuming it had been applied during the previous winters, i.e., the winters from 2016 to 2019. As with the model used in the previous study, meteorological data and statistics (snow and ice accumulation, duration of precipitation, etc.) were processed to generate a winter profile specific to each year and serve as input for subsequent analyses.

### 2.4.1 Methodology

Building on the modelling of snow removal operations conducted during contract 62576, a new, more detailed modelling approach was adopted. This approach considered that the rate of snow removal varied in relation to snow accumulation and to the intensity of the event. The reference period modelled runs from November 1 to April 30, with the exception of the analysis conducted for the 2019-2020 winter season, which ends in early February due to the availability of data at the time of the study. The reference period extends over a semi-annual period (November to April) due to the probability of snow based on Canadian climate normals (Montreal/Pierre Elliott Trudeau Intl A weather station) as shown in the following table:

Table 3 : Days with snow according to climate norms at the Montreal/Pierre Elliott Trudeau Intl A weather station from 1981 to 2010

| acc. (cm) | jan. | feb. | mar | apr. | may | jun | jul. | aug | sep | oct. | nov. | dec. | year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| >= 1 | 28.7 | 26.4 | 20 | 2.6 | 0 | 0 | 0 | 0 | 0 | 0.1 | 5 | 21.2 | 104.1 |
| >=5 | 23.6 | 20.9 | 15 | 1.3 | 0 | 0 | 0 | 0 | 0 | 0 | 2.2 | 16.5 | 79.6 |
| >=10 | 15.5 | 14.1 | 11.2 | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 10.3 | 52.5 |
| >=20 | 5.2 | 7.4 | 6 | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 2.4 | 21.3 |

The model was also optimized to reduce the number of openings of 3 hours or less. This new approach produced more representative results than those obtained in contract 62576. The model considers a variable snow removal rate based on the snow removal protocol used, the equipment deployed and the total accumulation of snow on the multipurpose path. The goal of this was to calibrate the model to better calculate the total duration of operations. The snow removal rates are approximate and are based on the average durations of the various operations and protocols

observed during site visits. Calibration of snow removal rate parameters is shown in the following table.

Table 4 : Calibration of snow removal rate parameters

| Accumulation | 0 – 3 cm | 3 – 6 cm | 6 – 8 cm | 8 – 10 cm | 10+ cm |
|---|---|---|---|---|---|
| **Snow removal rate** | 0 (night-time snow removal only) | 0.5 cm/h | 2.0 cm/h | 3.0 cm/h | 4.0 cm/h |
| **Corresponding performance** | 0 (night-time snow removal only) | 2.0 h/cm | 0.5 h/cm | 0.33 h/cm | 0.25 h/cm |

Furthermore, a second scenario with an acceptability threshold of 5 cm or less was considered to assess the level of resources required and to compare the gain in hours of operation between the two levels of service potentially offered. As an example, Figure 29 and Figure 30 show a one-time comparison of the two scenarios over a 72-hour period from January 7 to 9, 2018. The opening criteria of 3 and 5 cm of snow were reduced by 0.5 cm in the following model and graphs to simulate a proactive approach to weather forecasting.

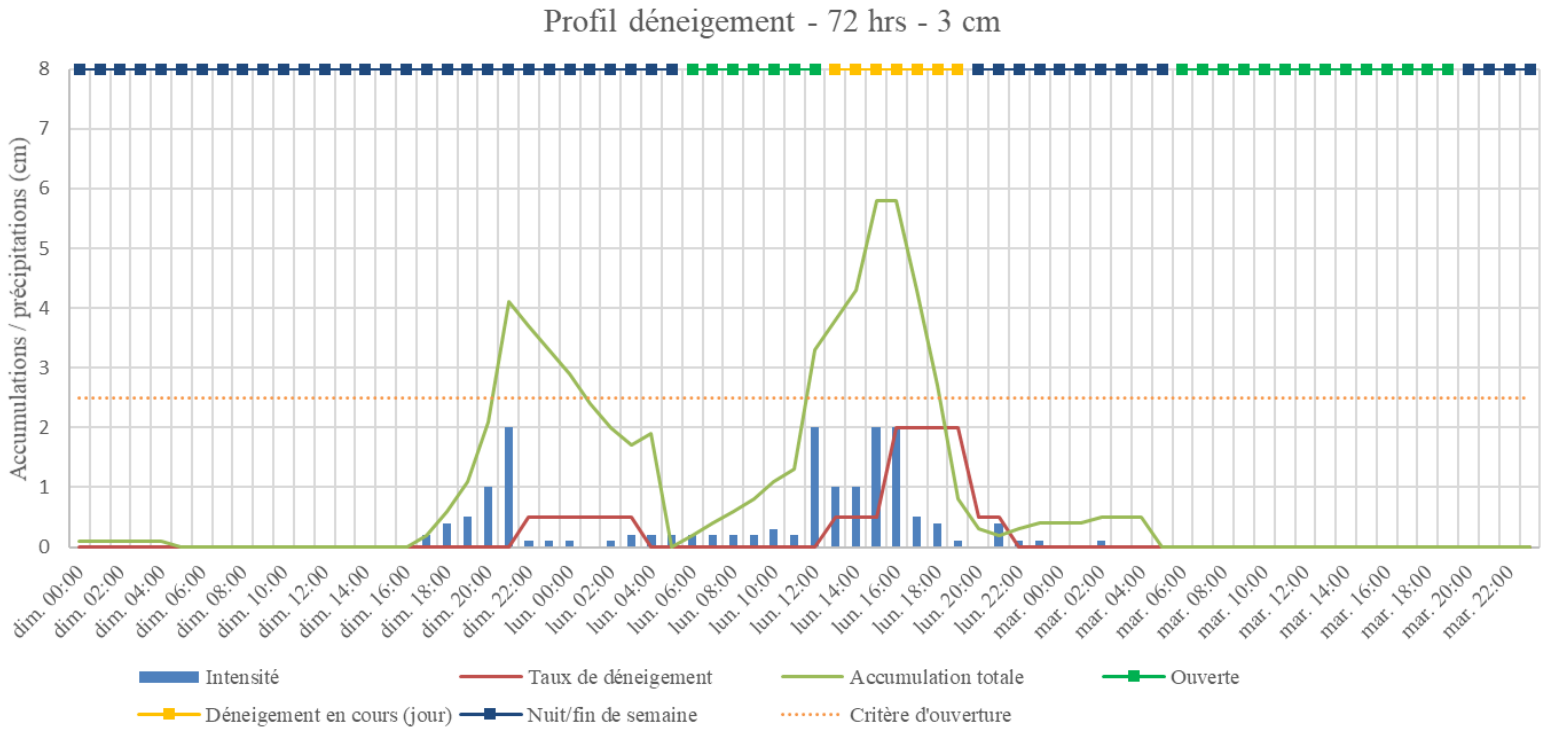



Figure 29 : Profile of snow removal operations over a 72-hour period (between 7 and 9 January 2018, acceptability criterion of 3 cm)

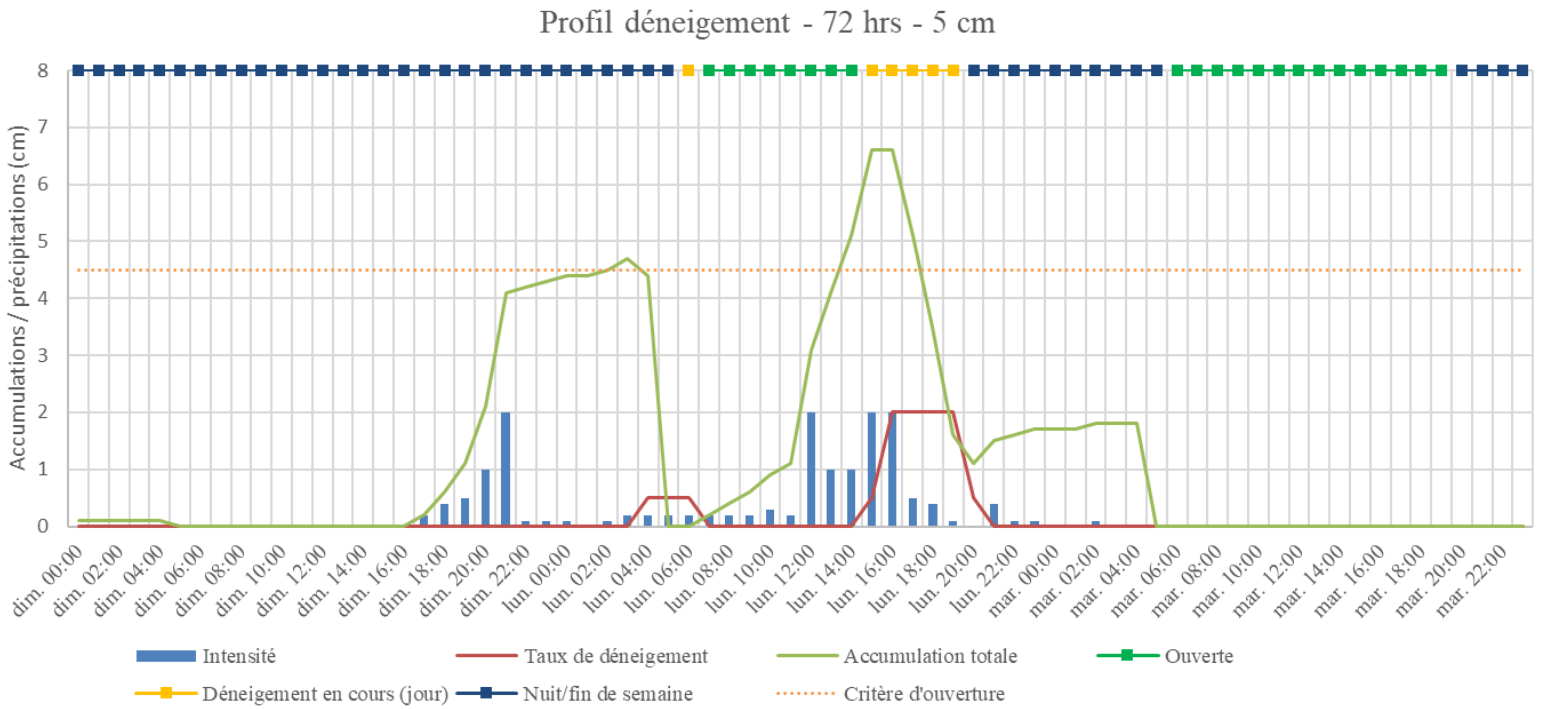



Figure 30 : Profile of snow removal operations over a 72-hour period (between 7 and 9 January 2018, 5 cm acceptability criterion)

## 2.4.2 Results

### 2.4.2.1 Profile of Previous Winters (criterion: 3 cm)

Based on the results of the models using a 3 cm acceptability criterion, and using the graphs in Figure 31 and Figure 32, the following conclusions were observed:

- The multipurpose path is open on average 110 days out of 129 days, i.e. 85% of the potential opening time, excluding weekends, which constitutes 61% of the 181 days of the reference period as shown in the following graphs;
- The multipurpose path is open on average 1 170 of the 1 286 hours, i.e. 91% of the potential opening time (excluding weekend and night hours), which constitutes 27% of the 4 344 hours of the reference period;
- Snow removal operations took place on 11 of the 52 weekend days, i.e. 21% of the time or 44 of the 1,248 hours (5.9% of the time) of the weekend;
- Snow removal operations took place during 125 of the 1,810 hours (6.9% of the time) at night.

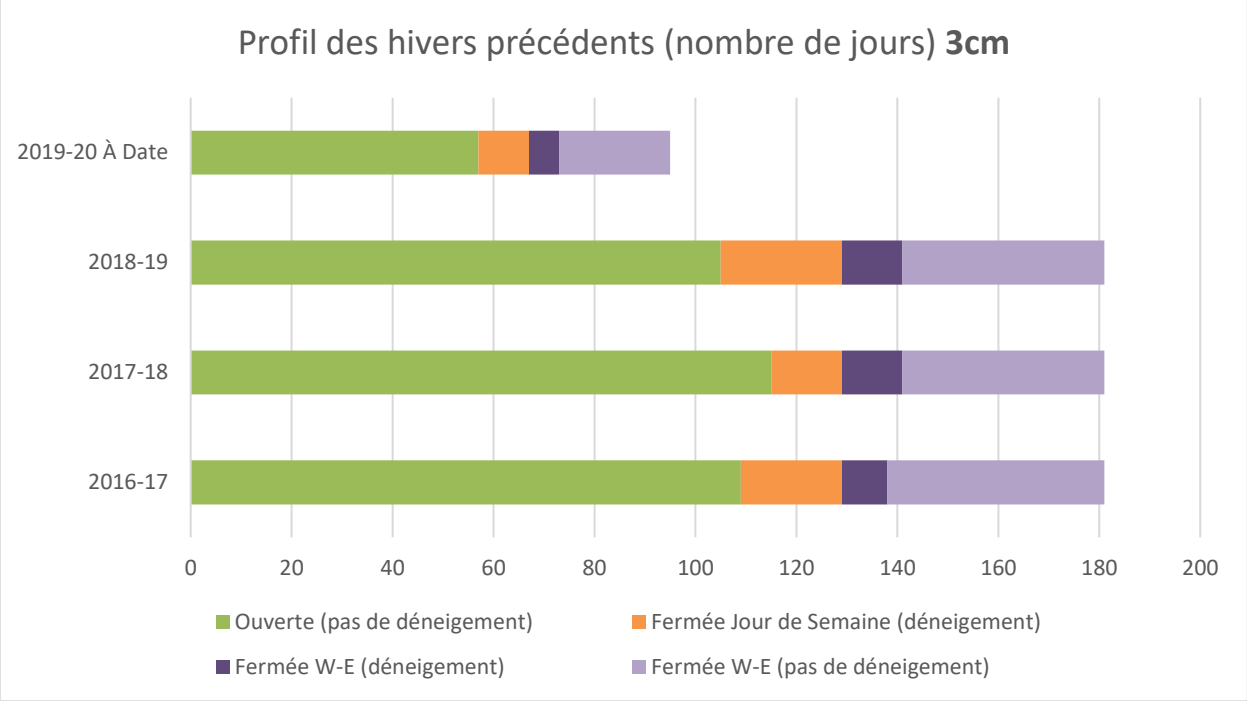



Figure 31: Profile of previous winters in number of days (acceptability criterion of 3 cm)

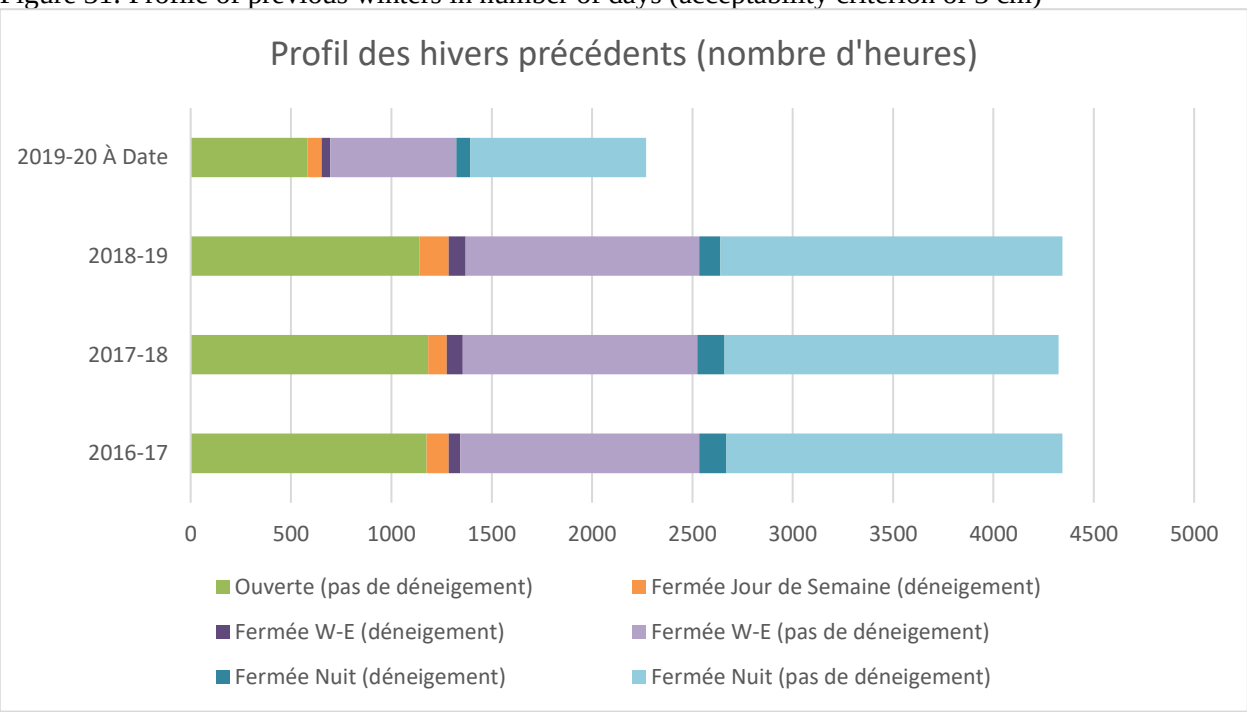



Figure 32: Profile of previous winters in number of hours (acceptability criterion of 3 cm)

### 2.4.2.2 Profile of previous winters (criterion: 5 cm)

From the results of the models using an acceptability criterion of 5 cm, and using the graphs in Figure 33 and Figure 34, it can be noted that:

- The multipurpose path could remain open an average of 114 days out of 129 days, i.e. 88% of the opening time, excluding weekends, which constitutes 63% of the 181 days of the reference period;
- The multipurpose path could remain open for an average of 1,214 hours out of 1,286 hours, i.e. 94% of the potential opening time, excluding weekend and night hours, which constitutes 28% of the 4,344 hours of the reference period;
- Snow removal operations took place on 8 of the 52 weekend days, i.e. 15% of the time, or on 44 of the 1,248 hours (3.5% of the time) of the weekend;
- Snow removal operations took place during 78 of the 1,810 hours (4.3% of the time) at night.

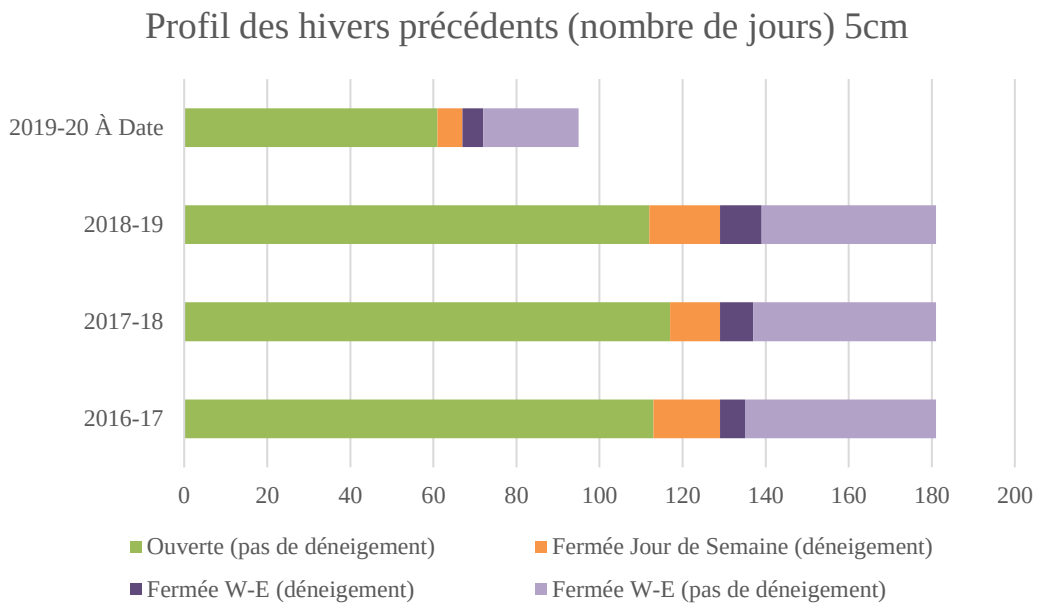



Figure 33: Profile of previous winters in number of days (acceptability criterion of 5 cm)

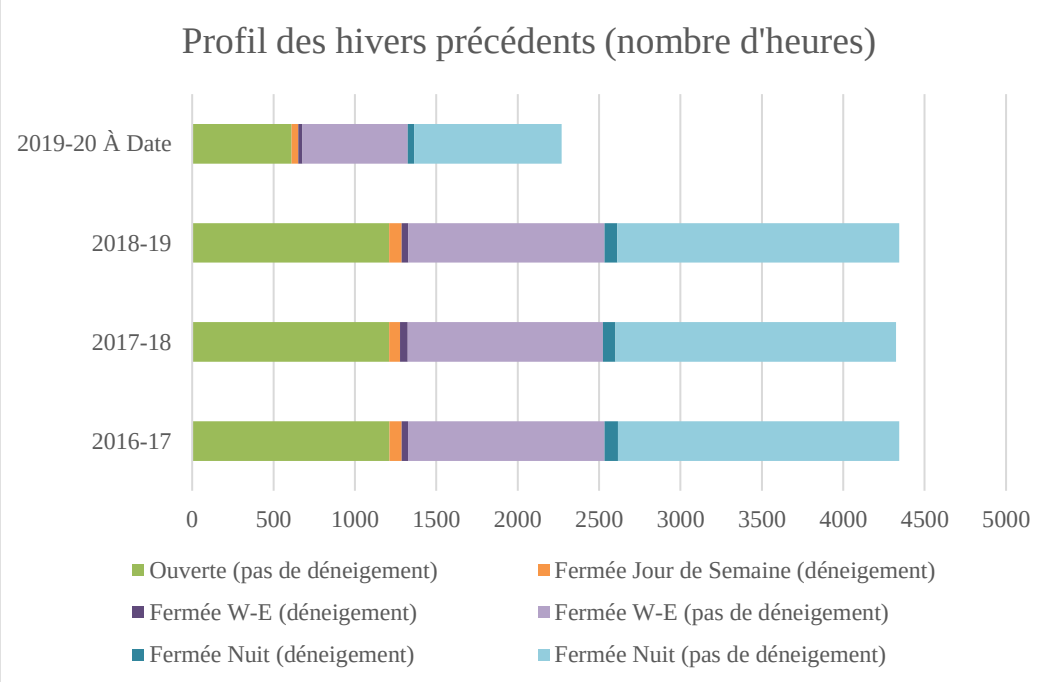



Figure 34: Profile of previous winters in number of hours (acceptability criterion of 5 cm)

#### 2.4.2.3 Comparison of a Typical Winter (3 cm to 5 cm criterion)

A comparison of a typical winter was made by changing the criterion from 3 cm to 5 cm. From the graphs in Figure 35 and Figure 36, the following can be concluded:

- A gain of 4 days, on average, from 3 cm to 5 cm, i.e. a gain of 3.6% on potential opening days, excluding weekends;
- A gain of 44 hours, on average, or a gain of 3.8% on potential business days, excluding weekends;
- A negligible increase in the opening time of the multipurpose path by increasing the opening criterion.

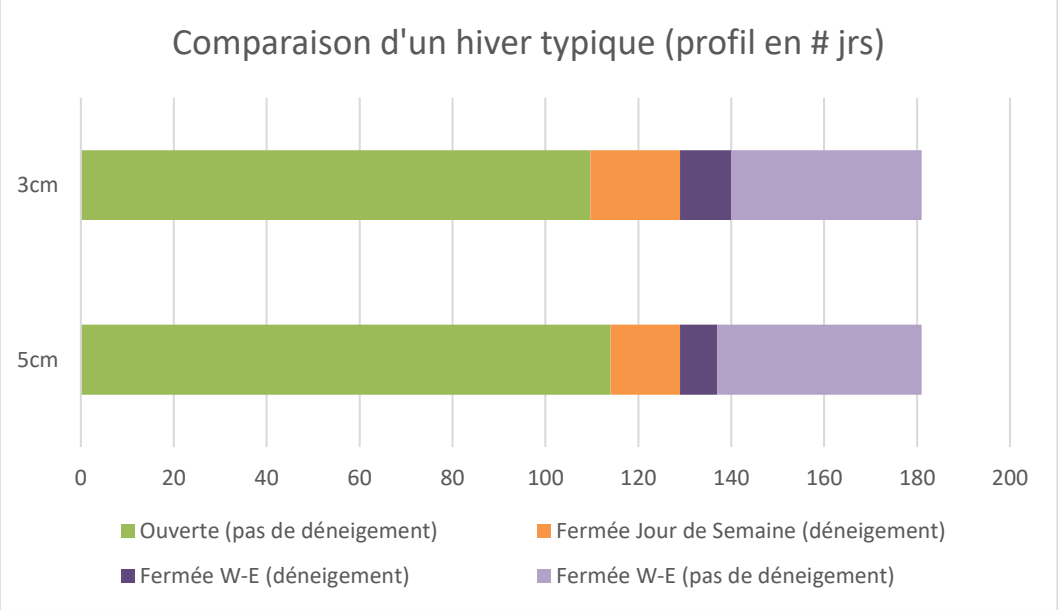



Figure 35 : Comparison of a typical winter (number of days) by changing the acceptability criterion from 3 to 5 cm

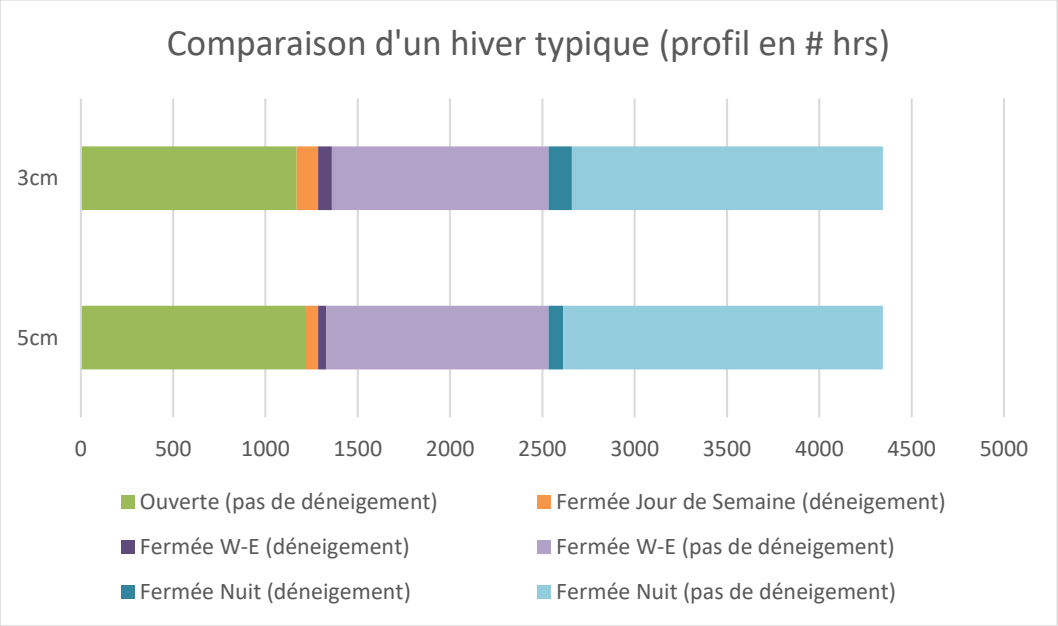



Figure 36 : Comparison of a typical winter (number of hours) by modifying the acceptability criterion from 3 to 5 cm.

# 3 Durability of the Concrete Slab

## 3.1 Qualitative Analysis - Evaluation of De-icing Products

Based on the preliminary analysis conducted during the 2017 – 2018 [6] pilot project, the choice of de-icing products was reduced to the four products that received the highest scores for the snow removal simulation undertaken this winter. This study also includes additional information obtained on the products that were the subject of this analysis.

The current list of selected products, including road salt as a reference product, is as follows:

- Product A

  **Main components:** sodium chloride, beets and other agricultural by-products

  **Description:** This product is derived mainly from beets and other organic components, mixed with conventional salt. According to the manufacturer, it is also effective down to -30°C.

- Product B

  **Main components:** proprietary blend of polyols, sodium chloride

  **Description:** This liquid de-icing product is an agricultural product derived from renewable resources, a proprietary blend of polyols and sodium chloride brine, offering superior performance to traditional brines, but with less corrosion.

- Product C

  **Main components:** glycerol (glycerine) and other agricultural by-products

  **Description:** According to the manufacturer, this product does not contain chloride, sulphate or nitrite and therefore will not harm concrete surfaces or metals. It is marked as non-toxic and remains effective down to -30°C. It can be used in an anti-icing frame as well as a de-icing product.

- Road salt (reference product)

  **Main components:** Sodium chloride

  **Description:** Conventional road salt is relatively inexpensive and remains widely available in Quebec. However, its great corrosive potential is a major

[6] Report on the winter maintenance pilot project for the Jacques Cartier Bridge bike path (dated May 9, 2018)

drawback and its use is not adapted to Montreal conditions given the drop in efficiency below -15°C.

Table 5 : Product Comparison Table

| Product name | Primary component | Risk factor | | |
|---|---|---|---|---|
| | | **Accelerated ASR** | **Chemical Attack** | **Corrosion** |
| **Product A** | Sodium chloride, NaCl + beet juice and agricultural by-products | 1 | 0 | 3 |
| **Product B** | Exclusive polyol blend + sodium chloride, NaCl | 1 | 0 | 2 |
| **Product C** | Glycerin (glycerol) + glycol + polyether | 0 | 0 | 1 |
| **Road salt** | Sodium chloride, NaCl | 2 | 1 | 4 |

***for comparison only***
Legend

| Result | **Accelerated ASR** | **Chemical Attack** | **Corrosion** |
|---|---|---|---|
| **0** | None | None | None |
| **1** | Reduced | Reduced attack and expansion | Reduced penetration rate |
| **2** | Moderate | Moderate cracking and expansion | Moderate penetration rate |
| **3** | High | High cracking and expansion | High penetration rate |
| **4** | Extreme | Extreme cracking and expansion in dolomite | High corrosion and penetration rate |

Note the following considerations, notably related to the use of glycerol/glycerine products:

- Although glycerine (glycerol) based products can corrode certain metals / alloys, its low impact on the oxidation of materials remains the main advantage of glycerine (glycerol). The risk of corrosion for steel reinforcing bars in reinforced concrete remains very low as they are not in direct contact with the product;
- Glycerine (glycerol) based products carry a potential risk of (slow) disintegration for concrete surfaces. This substance, compared to ethylene glycol (glycol), appears to be less harmful from a durability point of view. To date, there are no specific references that comment on this subject;

- Glycerine (glycerol) based products generally have a lower melting capacity than other liquid products. Typically, additional components will need to be added to improve performance (e.g. 20% salt brine + glycol); and,
- Ethylene and propylene glycol have no negative effect on the durability of concrete surfaces. However, at higher temperatures they can potentially become corrosive to metals and harmful to concrete (due to chemical decomposition and subsequent formation of oxalic and formic acids).

## 3.2 Quantitative Analysis - Sustainability Analysis

To validate the durability analysis carried out during contract 62576, various tests could be carried out on the slab of the multipurpose path of the Jacques Cartier Bridge. The durability analysis of the bridge's multipurpose path was completed using a tool developed in-house by Arup. This probabilistic sustainability modelling tool is based on Fib Bulletin No. 34 Model Code for Service life Design. The analysis is based on the parameters, variables and distributions shown in table 7 below.

The tests that could be carried out are as follows:

Table 6: Potential Durability Tests

| | Test | Test details | Test objective |
|---|---|---|---|
| **1** | Confirmation of concrete coating | - Pachometer<br>- Non-destructive testing | - Confirm the data used in the sustainability analysis<br>- See point 1 below for the entry in the sustainability analysis that will be impacted |
| **2** | Corrosion state of the reinforcement | - Half-cell potential mapping (ASTM C876-15)<br>- 1-inch holes are drilled in the slab | - Confirm the state of corrosion of the reinforcing bars<br>- Identify the area most at risk of corrosion to perform tests 3 and 4. |
| **3** | Hydrochloric profile | - Water-soluble chloride content in concrete (ASTM C 1218)<br>- 3 to 5 concrete cores over 3 km of the bridge (50mm diameter x 100mm length)<br>- Possibility to take the cores from the slide and interpret the concentration in the track slab | - Confirm the concentration of chloride ions to refine the durability analysis.<br>- See point 2 below for the entry in the sustainability analysis that will be impacted |
| **4** | Permeability of concrete | - "Rapid Chloride Permeability" (ASTM C 1202)<br>- 3 to 5 concrete cores over 3 km of the bridge (100mm diameter x 50mm length) | - Confirm the porosity of the concrete and the rate at which chloride ions could enter the slab.<br>- See point 3 for the entry in the sustainability analysis that will be impacted. |

Table 7: Parameters, Variables and Distributions Used to Conduct Probabilistic Sustainability Analysis

| Parameter | | Variable | Dist. | Values | Unit | Ref. | |
|---|---|---|---|---|---|---|---|
| Non steady state chloride diffusion coefficient design values: | | | | | | | |
| **Chloride migration coefficient** | Initial assumption for w/c=0.40 at t0=28 days | $D_{rcm,0}$ | Normal | μ=4.0; σ=0.2·μ | x $10^{-12}$ $m^2/s$ | [2] | 4 |
| | Assumption for w/c=0.40 at t=15 years | | | μ=0.4; σ=0.2·μ | | [-] | |
| **Reference point of time** | time for first exposure (initial chloride load) | $t_0$ | Constant | 28 | days | [1] | |
| | time for exposure (salt spread event) | $t_0$ | Constant | 15 | years | [-] | |
| Ageing factor | | | | | | | |
| **Ageing factor** | | a | Beta | μ=0.40; σ=0.16·μ; a=0; b=1 | - | [2] | |
| Temperature effects | | | | | | | |
| **Reference temperature for laboratory tests** | | $T_{ref}$ | Constant | 293.15 | K | [1] | |
| **Real temperature of the structural element** | | $T_{real}$ | Normal | μ=278.4; σ=10.9 | K | [-] | |
| **Environmental variable** | | $b_e$ | Normal | μ=4800; σ=700 | - | [1] | |
| Concrete cover | | | | | | | |
| **Concrete cover to reinforcement** | | a | Normal | μ=50.0; σ=15.0/1.64 (horizontal) μ=50.0; σ=10.0/1.64 (vertical) | mm | [-] | 1 |
| Initial chloride content of concrete | | | | | | | |
| **Initial chloride content** | | $C_0$ | Normal | μ=0.055; σ=0.028 | wt.-%/cem. | [3] | 3 |
| Chloride content | | | | | | | |
| **Convection depth** | Spray or surface runoff | Δx | Constant | 0 | mm | [1] | |
| | Splash / wetting-drying effects | | Beta | μ=8.9; σ=5.6; a=0; b=50.0 | mm | [1] | |
| **Surface chloride concentrations** | | $C_{s\Delta x}$ | Lognormal | (C-1.2) t<15 years, spray μ=2.0, σ=0.75·μ (C-1.2) t>15 yr, deck μ=4.0, σ=0.75·μ (C-1.3) t>15 yr, glissière μ=3.0, σ=0.75·μ | wt.-%/cem. | [2] | |
| Critical chloride concentration | | | | | | | |
| **Conventional steel reinforcement** | | $C_{crit}$ | Beta | μ=1.2; σ=0.30; a=0.6; b=3.0 | wt.-%/cem. | [4] | |
| Design life | | | | | | | |
| **Time** | | $t_{SL}$ | Constant | 5-year increments until 75 years | years | [-] | |

It is proposed that the tests be conducted in the sequence presented below with the objective of identifying the optimal position to conduct tests #3 and #4, i.e., the position with the highest probability of having a large concentration of chloride ions.

- Test #1 (confirmation of concrete embedding) at one location (Section 8);

- Test #2 (potential mapping) at 4 different locations (Sections 2, 7, 8 and 9). These sections have been selected to test the different configurations of the multipurpose path and thus identify the location where the risk of corrosion is the highest;
- Drill three cores for each of tests #3 and #4 at the location identified as the most at risk of corrosion.

The sustainability analysis could be updated based on the results of these tests.

# 4 Environment

The study below is intended to provide additional information regarding the Environment section of the post-mortem report from the previous project, Ct. 62576. The context and methodology are not repeated, and the results are only discussed briefly. Since the last revision dated October 9, 2018, both new regulations and new products have been introduced. These are reviewed in the following sections.

## 4.1 Regulatory Review following Recent Legislative Changes

In 2019, Bill C-68 "An Act to amend the Fisheries Act and to make consequential amendments to other Acts" received Royal Assent. The modernization of the Fisheries Act provided a framework for the conservation and protection of fish and fish habitats. The new provisions ensure that the Act applies to all fish and fish habitats across Canada. Also noteworthy is the return of prohibitions that were in place prior to the 2012 amendments to the Act, namely the prohibitions against causing the death of fish and the harmful alteration, disruption or destruction of fish habitats (HADD). As a result, section 35(1) has been amended for this text:

"No person shall carry on any work or undertaking or carry on any activity that results in the harmful alteration, disruption or destruction of fish habitat. »

However, the definition of deleterious substance in sections 34(1a) and 34(2) is unchanged, as is the prohibition on depositing these substances in waters frequented by fish (section 36(3)).

With the introduction of sections 34.2 and 35.1, the government is empowering itself to issue standards and codes of practice to guide the protection of fish and fish habitats, and to identify projects that are likely to result in the death of fish or HADD. The Department of Fisheries and Oceans Canada's (DFO) website contains the standards and codes of practice as well as a list of avoidance, mitigation and compensation measures. When consulting the DFO website, no information was noted concerning snow removal activities, snow dumping in a watercourse, or the use of de-icing products.

On the provincial side, it was important to verify whether the above-mentioned activities were included in the MELCC[7]'s instruction note (April 2019) "Negligible Risk Activities - Lists of Administrative Exemptions from the Application of Sections 22 and 30 of the Environment Quality Act", pending the enactment of the Regulation respecting Ministerial Authorization and Statement of Environmental Compliance. After verification, the only reference found in relation to snow and de-icing products concerns the transportation and disposal of snow in large parking

[7] Ministère de l'Environnement et de la Lutte contre les changements climatiques

lots. Instruction Note 09-02 accompanying this activity does not specifically prohibit the discharge of snow into a watercourse, but does require the following:

"Snow that falls on a parking lot of a business or institution and that is removed, transported and permanently deposited in another location in the same parking lot, located more than 15 metres from any lake, pond, watercourse, wetland, outside the 0-20 year flood zone and more than 100 metres from a drinking water supply well, and this, without passing through a public thoroughfare, constitutes an exception to Section 1 of the Regulation respecting snow disposal sites. Thus, this snow disposal site does not constitute a disposal site within the meaning of the Regulation and does not require a certificate of authorization under section 22".

In summary, this review did not identify any new requirements specific to the winter maintenance project of the Jacques Cartier Bridge bike path. Therefore, it is still relevant that, according to Quebec regulations, snow will be treated as a contaminant (residual material) only if it is part of a removal and transportation operation. Quebec and Canadian legislation are more focused on the discharge of used snow containing de-icing products but does not formally prohibit the activity of discharging snow removal (without transportation) into a watercourse or lake. Thus, the conclusions and recommendations made in the Environment section of the 2018 postmortem report remain valid.

## 4.2 Analysis of New De-icing Products

The table below presents the new de-icing products considered by Arup and JCCBI. Note that road salt is selected as the reference product. The three products tested are quite different in terms of their composition and usefulness.

Table 8 : De-icing products considered

| Name | Primary component | Comment |
|---|---|---|
| **Road salt** | Sodium chloride | Reference product |
| **Product A** | Sodium chloride and sugars | Road salt (95 to 97% by weight) sieved with an alkaline degraded beet sugar extract (3 to 5% by weight). More effective as a de-icing agent. |
| **Product B** | Biological components from cultured products, an exclusive polyol | Beets, corn and soybeans. Ideally diluted with brine (30:70 ratio) but remains effective down to -30°C. Product designed for pre-wetting or use as an anti-icing or de-icing agent. |
| **Product C** | Glycerin (glycerol) + glycol + polyether | Marked as non-toxic and remains effective down to -30°C. It can be used both in an anti-icing frame and as a de-icing product. |
| **Dust control product (not tested)** | Glycerine and other components (85%) | Contains a low proportion of sodium chloride and metals. Dust control product to be diluted with at least 50% or ideally 100% water. |

### 4.2.1 More Explicit Justification of Analysis Criteria

The criteria used for each of the deleterious effects on the aquatic environment were only partially described in the initial methodology section. The table below provides a more explicit and quantitative description of this exercise. The scale of ratings ranges from 1 to 5 (worst to best substance, respectively), with each selected substance being compared to the others. As such, a high rating does not imply that there are no effects, but that they are less severe than those of the others. This exercise does not take into account the very high dilution of the river (see discussion in Section 2.5).

Table 9 : Environmental Criteria Considered in Evaluating De-Icing Products

| Effect | Description | Rating between products |
|---|---|---|
| **Salt buildup** | Accumulation of salts in water, usually sodium chloride (NaCl). Its main consequences are an increase in osmotic pressure in aquatic organisms (fauna and flora). | 1 for road salt (100% NaCl)<br>2 for the product containing 61 to 99% NaCl<br>3 for the product containing 31 to 60% NaCl<br>4 for the product containing 1 to 30% NaCl<br>5 for the salt-free product (0% NaCl) |
| **Oxygen demand (DO)** | Decomposition of organic or oxidizable materials that require a certain amount of oxygen. The process will deplete the aquatic environment of oxygen. | 1 for the product likely to have the highest BOD5[1].<br>2 for the product likely to have a BOD5 that falls between the intermediate and strongest position<br>3 for the product likely to have a BOD5 which is classified in an intermediate position<br>4 for the product likely to have a BOD5 that falls between the lowest and intermediate position<br>5 for the product likely to have the lowest BOD5 |
| **Toxicity** | Capacity of the substance to cause adverse health or survival effects in any form of life | 1 for the product with the highest rat oral LD50[2].<br>2 for the product with an oral LD50 in the rat that falls between the intermediate and strongest position<br>3 for the product with an oral LD50 in the rat that is intermediate in position<br>4 for the product with an oral LD50 in the rat that falls between the lowest and intermediate position.<br>5 for the product with the lowest oral LD50 in rats |

| Effect | Description | Rating between products |
|---|---|---|
| **Bioaccumulation, persistence and biodegradation** | Ability of certain organisms to absorb and concentrate the substance/product in all or part of their organism; resistance of the product to natural biological degradation | 1 for the product with the longest half-life<br>2 for the product with the half-life between the intermediate and the longest position<br>3 for the product with the half-life in an intermediate position<br>4 for the product with the half-life between the shortest and the intermediate position<br>5 for the product with the shortest half-life |
| **Eutrophication** | Enrichment of water with nutrients. The increase of macrophyte and phytoplankton populations can completely change the composition of the aquatic fauna present. Hypoxia or anoxia is also a corollary of this effect | 1 for the product containing the highest amount of the nutrient (N, P, K)[3].<br>2 for the product containing an amount of nutrient (N, P, K) which falls between the intermediate and the highest position<br>3 for the product containing a quantity of nutrient (N, P, K) which is in an intermediate position<br>4 for the product containing a quantity of nutrient (N, P, K) which falls between the lowest and intermediate position<br>5 for the product containing the lowest amount of nutrient (N, P, K) |

[1] Biochemical oxygen demand measured after 5 days

[2] Median lethal dose

[3] Chemical symbol for nitrogen, phosphorus and potassium, respectively

### 4.2.2 Re-evaluation of New Products

The following table shows the results of the evaluation of de-icing products based on the multi-criteria matrix described in the 2018 report. The best choice for the environment is the product that yields the highest total. This choice does not consider the quantity applied; such an analysis is conducted in a second step and presented in the following section.

The total score favors road salt. The disadvantaged product combines being the sweetest, which could lead to higher biological oxygen demand, and the richest in nutrients, which could lead to eutrophication.

# Table 10: De-icing Product Evaluation Results

| Nom du produit | Critères | | | | | Total |
|---|---|---|---|---|---|---|
| | Salinisation | Consommation d'oxygène | Toxicité | Bioaccumulation, persistance et biodégradation | Eutrophisation | |
| *Pondération* | *2* | *3* | *5* | *3* | *4* | |
| Sel gemme | 1 | 5 | 4 | 5 | 5 | 72 |
| Produit A | 2 | 2 | 3* | 4 | 3 | 49 |
| Produit B | 3 | 2 | 5 | 3 | 2 | 54 |
| Produit abat-poussière | 4 | 2 | 5 | 4 | 4 | 67 |

* en l'absence d'information, une cote neutre a été donnée

**Échelle**

| Pondération | Critère |
|---|---|
| *5* | Forte pondération – Importance majeure du critère par rapport aux autres critères |
| *4* | Pondération moyenne à forte – Importance notable du critère par rapport aux autres |
| *3* | Pondération moyenne – Importance équivalente du critère par rapport aux autres |
| *2* | Pondération faible à moyenne – Importance moindre du critère par rapport aux autres |
| *1* | Pondération faible – Importance mineure du critère par rapport aux autres critères |

**Résultat**

| Total | Description |
|---|---|
| 85 | Meilleur choix |
| 68 | |
| 51 | |
| 34 | |
| 17 | Choix le moins privilégié |

| Cote | Critère |
|---|---|
| 5 | C'est le meilleur produit. Ceci n'implique pas qu'il n'y a aucun effet, mais qu'ils sont moins sévères que ceux des autres produits. |
| 4 | Les effets de ce produit sont légèrement plus sévs que ceux du meilleur produit |
| 3 | Entre 2 et 4 |
| 2 | Les effets sont considérablement plus sévères que ceux du meilleur produit |
| 1 | Les effets négatifs sont majeurs par rapport à ceux du meilleur produit |

### 4.2.3 Effect of quantities used

The final comparison criterion is the quantity spread for winter multipurpose path maintenance. The smaller the quantity required for de-icing, the less significant the impact of the overall effects on the aquatic environment.

The calculation was developed based on the quantity suggested by the manufacturer or the quantity currently being considered. Where a range of values was proposed, the median value was used. For liquid products, the application rate for de-icing takes into account a 1:1 dilution with water. The correction factor was calculated according to the following equation:

$K = T\_max / T\_appl$

*T_max = Maximum application rate of the selected products*

*T_appl = Application rate of the evaluated product*

The following table shows the total offset based on the application rate.

Table 11: Results adjusted for application rate

| Nom du produit | Taux d'application (source) | Taux d'application (kg/km) | Facteur de correction** | Total*** |
|---|---|---|---|---|
| Sel gemme | Littérature | 85 | 1,000 | 72 |
| Produit A | Arup | 60 | 1,417 | 69 |
| Produit B | Arup* | 53 | 1,615 | 87 |
| Produit abat-poussière | Arup* | 53 | 1,619 | 108 |

* en tenant compte d'une dilution de 1:1 avec de l'eau

** qui tient compte du taux d'application minimum et maximum

*** résultat du facteur de correction appliqué au total de la matrice multicritère

This exercise shows that the result offset by application rates favor products that were not previously offset with the multi-criteria matrix.

### 4.2.4 Effect of using the Rotary Broom

The evolution of the project suggests that the use of the rotary broom would reduce the amount of de-icing required. In the present environmental analysis, which looks at a comparison of products, this factor would not change the ranking results shown previously. The net consequence would be that the overall and subsequent analyses would give even less weight to the environmental component.

### 4.2.5 Recommendations according to the Receiving Environment

In recent years, the various levels of government have focused on the sound management of road salts through the development of codes and guides for good

practice and environmental management plans. Recently, there has been a trend to identify sensitive areas for the application of road salts. These areas correspond to water bodies that include lakes and ponds. These areas have a high ecological value and a long turnover time. Because of its high flow volume, the St. Lawrence River does not fall under this definition. Thus, it is suggested that the overall and subsequent analyses for the selection of de-icing products should give only a low weight to the environmental component in relation to the very high dilution caused by the receiving environment, i.e. the St. Lawrence River.

# 5 Improvements proposed for a Winter Opening

To improve safety and to improve the level of communication with users in winter on the multipurpose path, several modifications or additions are proposed in the subsections that follow.

## 5.1 Installation of Kick-back Plates

To reduce the issues related to snow and ice fall at the bottom of the bridge, “kick-back" plates are planned to be installed in the lower part of the guardrails. Installation in certain areas was completed in 2018. Since then, new areas that present a concern, particularly above inhabited or busy areas, have been identified.

The installation of snow fencing over the roads and residential areas underlying the bridge remains a potential additional solution to reduce the risk of projections off the bridge.

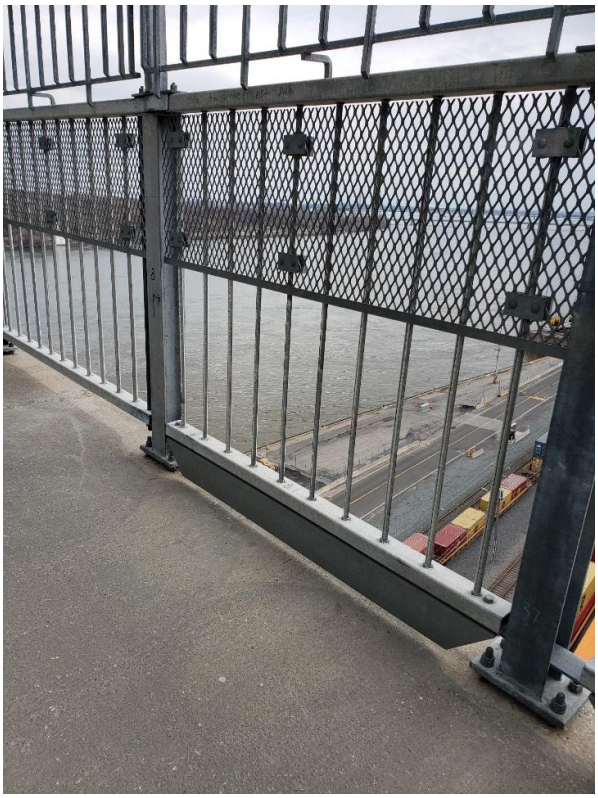


Figure 37 : Kick-back plate in the lower part of the guardrails

## 5.2 Presence of "Chicane" Barriers on the Multipurpose Path

### 5.2.1 Atypical Characteristics of the Multipurpose Path

The multipurpose path of the Jacques Cartier Bridge is a bicycle link with an atypical geometry that is exposed to very specific weather conditions.

The path has several slopes:

- 4.2% over 768 m (Sections 1 and 2 of the bridge)
- 3.7% over 673 m (Section 4 of the bridge)
- 4.24% over 260 m (Section 6 of the bridge)
- 4.12% over 655 m (Sections 8 and 9 of the bridge)

The multipurpose path of the Jacques Cartier Bridge is variable in width from 2.5 to 2.16 meters at the super-signal structures. As a comparison, and considering the slopes of the Jacques Cartier Bridge, the MTQ's bike path design guide suggests a total width of 3.6 meters for two-way bike paths and 4.6 meters for two-way multipurpose paths[8].

Considering the reduced width of the Jacques Cartier Bridge multipurpose path, and the potential speed of cyclists that can reach up to 45km/h for slopes of 3% over 150m or more, according to this guide[9], speed moderation devices (chicane barriers) have been installed. The location and geometry of these devices are shown in Figure 38 below.

[8] MTQ – Tome 1 – Conception routière – Chapitre 15, Tableau 15.4-2 et 15.4-5 – 15 juin 2016
[9] MTQ – Tome 1 – Conception routière – Chapitre 15, Tableau 15.4-3 – 15 juin 2016

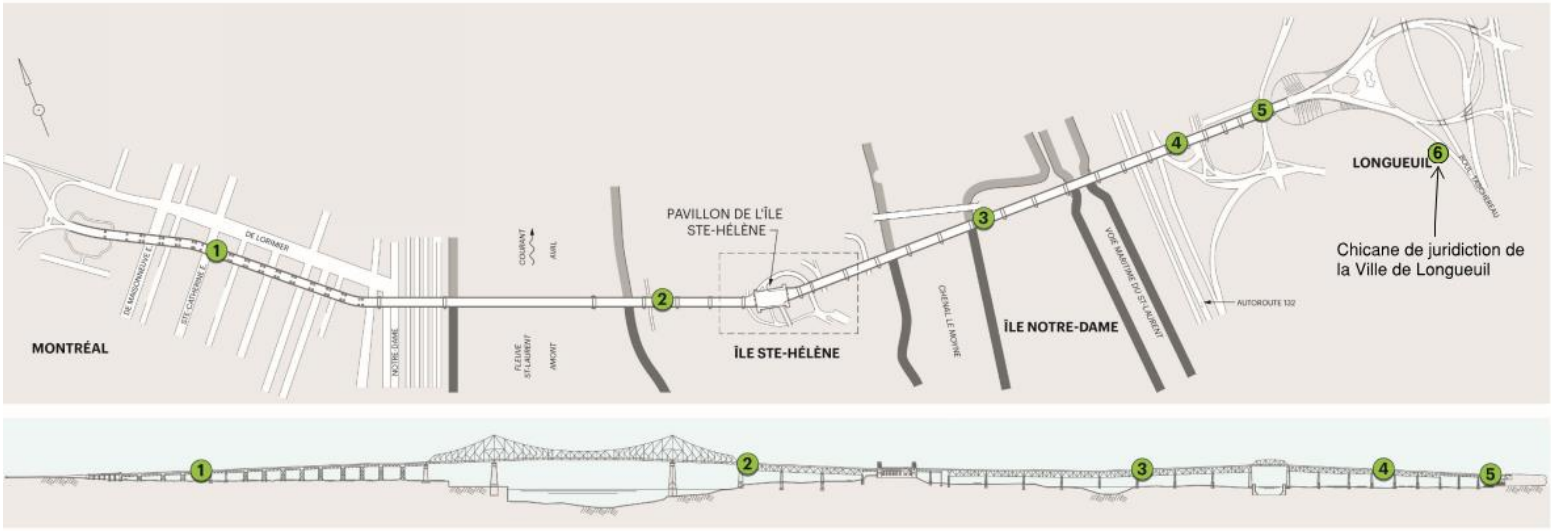



Figure 38 : Geometric survey of the Jacques Cartier Bridge barriers

### 5.2.2 Winter Context

While considering the atypical nature of the multipurpose path, an overall analysis of the presence of barriers and their impact on snow removal operations and cyclists' behaviour in a winter service context was conducted. The observations and conclusions described below emerged from this analysis.

From an operational point of view, to allow machinery to pass through, the barriers must be opened and closed at the beginning and end of each maintenance operation. The presence of barriers therefore has the effect of slowing down slightly maintenance operations.

In addition, the barriers can limit the useful width of the multipurpose path locally since snow accumulates along the slide that separates the path from the road in the bicycle corridor that allows them to be crossed. Consequently, less than one meter may be available to cross them, which has the effect of hindering the user-friendliness of the path and increasing the risk of collision. To remedy these problems, manual clearance must therefore be carried out in their vicinity when the situation requires it.

In addition, since the barriers represent an obstacle to cyclists' trips, it is important to consider the inherent characteristics of winter cycling, such as reduced visibility and grip. Consequently, improvements and complementary measures are necessary to reinforce the message to track users regarding speed limits and the behaviour to adopt in the presence of barriers. These awareness-raising measures, including the addition of signage such as speed signs, signs warning users of the presence of barriers, signs indicating right-of-way and speed feedback radars upstream of the barriers, are presented in the following sections.

Finally, it is suggested that a follow-up be carried out during subsequent winters when the multipurpose will be open to the general public to ensure that the barriers adequately fulfill their purpose.

## 5.3 Signage

Following an analysis of the existing signage on the multipurpose path, and given the safety concerns associated with the path, it was determined that some modifications and additions are required. The following proposals were put forward:

1. The addition of a downhill speed sign to encourage cyclists to respect the 20 km/h limit is suggested;


Figure 39 : Addition of a 20 km/h traffic sign

2. The addition of advanced warnings to warn of the presence of barriers for downhill cyclists is advisable;

Figure 40 : Adding advanced warnings to barriers

3. A review of the signage at the intersection at the Île Sainte-Hélène pavilion is recommended with consideration for the requirements of the road safety standard and code.


Figure 41 : Clarification required at the intersection

At the sidewalk level, the current signage appears to be adequate. Cyclists' speed issues do not apply there.

The analysis of existing signage and the detailed proposals are available in Appendix B.

## 5.4 Speed feedback radars

In addition to changes to the signage on the path, speed feedback radars are also proposed to improve user safety.

Installation of the speed feedback radar is suggested where the slope is steepest in the direction of descent, and far enough away from any barriers that are present. These radars should be installed in the cyclists' field of vision and should be small enough to avoid being confused with vehicle radars. The radars should display a predetermined maximum speed to avoid the "challenge" effect of users.


Figure 42: Different models of speed feedback radar

## 5.5 Variable Message Signs

To improve communication with users, variable message signs can be installed. These provide real-time information on the multipurpose path, surface and weather conditions, and safety tips. The dynamic aspect will potentially attract more attention. Ideally, these signs should be located at key points to inform users in advance of their journey, especially if the multipurpose path is closed.


Figure 43 : Different models of variable message signs Ref: Google Maps / Arup

## 5.6 Automated Doors

To secure the multipurpose path without having to send maintenance crews on site, it is possible to install remote-controlled automated doors at the entrances to the multipurpose path or sidewalk.

Sustainability issues for this type of mechanism need to be considered. Repeated snow clearing of the multipurpose path and traffic lanes will significantly reduce the service life of the equipment. Protection against vandalism will also be required.

Finally, for logistical reasons, camera coverage of the automated barrier should be considered to ensure that no obstructions are blocking the closure, that no users are present on the bridge at the time of closure, etc.

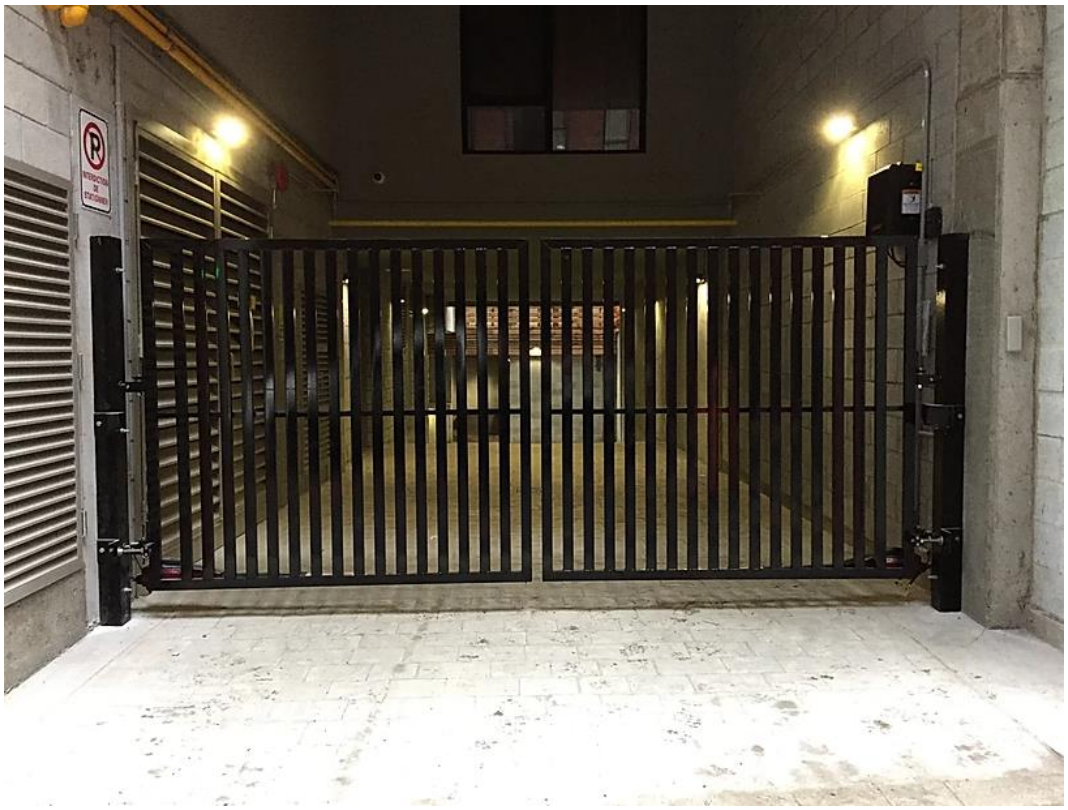


Figure 44 : Example of an automated barrier [MastergatePlus]

## 5.7 System Integration

All of the electronic systems installed on the bridge or suggested here can be integrated into a single platform to maximize their potential. It details the main advantages associated with system integration for the management of the following items:

- systems and how they work;
- the people in charge;
- interfaces between the different systems (e.g. display of messages once the automatic door is closed);
- recording, use and analysis of data;
- the need for IT and electrical infrastructure.

The current systems that can be integrated are the two weather stations, the cyclist counter installed on the Montreal side and the external communication system (website, emails, etc.) designed to inform users of the condition of the path. Access to these systems will be required for data integration and centralization purposes.

New systems that could be integrated into the system include variable message signs, automatic doors, speed cameras, bridge cameras, etc.

# 6 Cost Estimates

## 6.1 General

This section analyzes the costs associated with snow removal operations on the multipurpose path and sidewalk using mechanical equipment and de-icing products.

Initial capital costs (CAPEX) and operating costs (OPEX) were estimated for the operating scenario where a competitive multi-year snow removal contract would be awarded to a contractor.

Based on the scope of the present mandate, a class II estimate (-10%, +30%) was completed. In addition, [redacted] was added to the total estimates for CAPEX and OPEX.

The costs presented are non-exhaustive and are presented only for the purpose of informing decision making in the winter simulation project.

## 6.2 Initial Investment Costs - CAPEX

### 6.2.1 Upgrading of the Multipurpose Path

Based on the observations and analyses presented in this report, it is acknowledged that certain modifications can be made to the Jacques Cartier Bridge multipurpose path to improve its safety. Such modifications would make it possible to open the multipurpose path during the winter seasons, increase its safety, and improve communication with users. The work presented below will be carried out under separate contracts.

CAPEX costs associated with the upgrade of the multipurpose path include the following:

- Addition of a galvanized rail at the foot of the deterrent barrier to prevent ice from being projected from the multipurpose path onto road, pedestrian and bicycle crossings under the bridge;
- Addition and removal of signage to make users aware of safety measures and identify risk areas;
- Addition of automatic doors at the bridge entrances;
- Addition of variable message signs at the various bridge access points; and,
- Addition of speed feedback radar to sensitize users who exceed the maximum speed limit;

The following table shows the initial investment costs for opening the multipurpose path in winter.

Table 12: Initial investment costs - CAPEX

| Description of Works - Jacques Cartier Bridge Multipurpose path | Cost Estimate $ 2020 |
|---|---|
| **CAPEX - Multipurpose path upgrades** | |
| Addition of a 150 mm x 3-4 mm thick galvanized steel rail to prevent ice from falling on the lanes below the bridge | [redacted] |
| Installation and dismantling of fixed signs listing the risks shared between users and JCCBI | |
| Automatic doors | |
| Variable message signs | |
| Speed feedback radars | |
| General mobilization and demobilization, traffic organization and control | |
| **Upgrades for the path - Total** | |
| [redacted] | |
| **CAPEX - Upgrades - Total** | |
| **CAPEX – Upgrades - Total (-10 %)** | |
| **CAPEX – Upgrades - Total (+30 %)** | |

These costs are based on the following assumptions :

- The work is carried out during periods that are favorable for construction work (fall, spring and summer);
- The work is carried out on a regular basis during the week (without overtime);
- Labour costs are based on the most recent collective agreement; and,
- The amount presented for the variable message signs includes three panels in a horizontal configuration and two panels in a vertical configuration.

The estimate of the initial capital costs to upgrade the multipurpose path excludes the costs of the relevant work that requires in-depth analysis and is therefore deemed to be outside the scope of this mandate. This work includes:

- Structural integrity assessment and reinforcement work on the bridge structure or secondary elements (deterrent barriers, guardrails, streetlights, etc.) and other ancillary work required to support the additional weight of the signage, automatic gates and its components;
- The installation of a waterproofing membrane. If the option of an addition is chosen, an approximate amount between [redacted] would be added to the direct costs (before contingencies);
- Protection of the existing C-section electrical conduit along the slide; and

- Costs associated with repainting the markings on the multipurpose path that could deteriorate over time and with the use of snow removal equipment.

### 6.2.2 Mechanical Snow Removal

Based on the options recommended and adopted for the Jacques Cartier Bridge traffic lanes, and on the 2019-2020 winter simulation, it is envisaged that the snow removal of the multipurpose path will be carried out by a specialized contractor whose services will be awarded through a snow removal contract.

However, if JCCBI plans to carry out snow removal operations in-house, i.e., by its own operations and maintenance teams, Table 13 below shows the costs of purchasing the new equipment required to accomplish this task. If JCCBI wishes to award a contract spread over several years through a competitive and well-supervised tendering process, the costs presented will still be applicable in the estimate of the contractor who wishes to bid on such a tendering process.

Table 13: Additional CAPEX - Purchase of snow removal equipment

| Snow removal equipment | Quantity | Purchase price $ 2020 |
|---|---|---|
| **CAPEX - Multipurpose path** **Purchase of snow removal equipment** | | |
| Tractor | [redacted] | [redacted] |
| 54" Snow Blade | | |
| 54" Blade Accessory | | |
| Rotary Broom - 60" Width | | |
| Towable spreader for solid or liquid de-icing products | | |
| Towable spreader for solid or liquid de-icing products | | |
| 48" Snowblower | | |
| **Total** | | |
| [redacted] | | |
| **CAPEX – Equipment purchase - Total** | | |
| **CAPEX – Equipment purchase - Total (-10 %)** | | |
| **CAPEX – Equipment purchase - Total (+30 %)** | | |

## 6.3 Operation and Maintenance Costs - OPEX

### 6.3.1 Multipurpose Path

This estimate explores the option of JCCBI issuing a call for tenders for a competitive service offer from a contractor mandated to clear the multipurpose path for several years. The purchase of the snow removal equipment and all necessary accessories are included in the operating costs presented below and have been amortized over a period of 7 years. A [redacted] as been added to the total. This is presented in the following table.

Based on data from the previous three winters presented in Section 2.4, an average of about 30 snow-clearing operations are required to maintain the multipurpose path. During the winter simulations, 70% of the outings resulted in the use of de-icing products. Based on this, it can be assumed that 21 de-icing product application operations would be required in an average winter. Road salt is not recommended as the main de-icing product for the multipurpose path because of its corrosive potential and its harmful effects on the environment. De-icing Product A was chosen as the preferred product for the cost analysis. According to the supplier and as discussed in Section 2.2, a spreading rate of 390 kg/3 km would be sufficient to ensure good snow and ice melting.

Moreover, when blowing is required from the multipurpose path, additional manpower is required to close the adjacent roadway. During the winter simulation, 33% of the exits resulted in snow blowing. An average winter should require in average 10 blowing operations.

Table 14 : OPEX - Operating costs associated with the maintenance of the multipurpose path through a competitive multi-year contract

| Multipurpose path (multi-year contract) | |
|---|---|
| **Snow removal** | |
| Purchase of equipment (amortized cost over 7 years) | [redacted] |
| Equipment maintenance | |
| Snow removal<br>(two operators) | |
| Blowing<br>(an operator) | |
| Supervision of the work<br>White collar (JCCBI) | |
| **Admin** | |
| Planning and coordination of staff scheduling<br>Contractor | [redacted] |
| Planning of snow removal work<br>White collar (JCCBI) | |
| Daily assessment of pathway conditions<br>White collar (JCCBI) | |
| **De-icing products** | |
| De-icing Product A | [redacted] |
| [redacted] | |
| **OPEX - Multipurpose path - Total** | |
| **OPEX - Multipurpose path - Total (-10%)**<br>**OPEX - Multipurpose path - Total (+30%)** | |

### 6.3.2 Sidewalk

During the 2019-2020 winter simulation, the sidewalk was plowed by the JCCBI operations and maintenance team. To carry out the snow removal operations on the

sidewalk, JCCBI rented the necessary equipment from a supplier. The assumptions made in the previous section regarding the number of snow removal, spreading and blowing operations were used to establish the following estimate.

Table 15 below presents the operating costs associated with sidewalk maintenance for a scenario where JCCBI is responsible for snow removal.

Table 15 : OPEX - Operating Costs Associated with Sidewalk Maintenance

| **Sidewalk** | |
|---|---|
| **Snow removal** | |
| Rental of snow removal equipment | [redacted] |
| Snow removal<br>Blue collar (JCCBI) | |
| Snow Blowing<br>Blue collar (JCCBI) | |
| **Administrative** | |
| Planning of snow removal work<br>White collar (JCCBI) | [redacted] |
| Daily assessment of multipurpose path conditions<br>White collar (JCCBI) | |
| **De-icing Products** | |
| Product A | [redacted] |
| **Sub-total** | |
| [redacted] | |
| **OPEX - Sidewalk – Total** | |
| **OPEX - Sidewalk - Total (-10 %)**<br>**OPEX - Sidewalk - Total (+30 %)** | |

## 6.4 Summary

The following table summarizes the CAPEX and OPEX costs required to upgrade the multipurpose path and to maintain the sidewalk and multipurpose path during the winter.

Table 16 : CAPEX and OPEX Costs Required for Winter Multipurpose path and Sidewalk Maintenance

| CAPEX – Initial investments | [redacted] |
|---|---|
| Path upgrades | |
| [redacted] | |
| **Total CAPEX** | |
| **Total CAPEX (-10%)** | |
| **Total CAPEX (+30%)** | |
| **OPEX – Operational costs each winter** | |
| Annual operating costs for the bike path | |
| Annual operating costs for the sidewalk | |
| [redacted] | |
| **Total OPEX** | |
| **Total OPEX (-10%)** | |
| **Total OPEX (+30%)** | |

### 6.4.1 Assumptions, Inclusions and Exclusions

To establish the operating cost estimates presented in the previous subsections, the following assumptions were considered:

- Shift duration during snow removal operations was estimated at 5 hours;
- [redacted] in maintenance costs for the equipment needed to clear snow from the multipurpose path;
- Costs associated with equipment maintenance are excluded from the sidewalk operation costs presented in Section 6.3.2, since these are included in the rental of snow removal equipment; and,
- Labour rates are based on the collective agreement.

### 6.4.2 Reference Documents

The following documents were used for estimation purposes:

- E-mail dated 31 March 2020 - Emmanuel D., JCCBI - [External] RE: JCAP0015 / 62659: Snow removal equipment;
- E-mail dated April 19, 2018 - [redacted] Arup - JCCBI bikepath - Sharefile updated;
- E-mail dated March 10, 2020 - [redacted], MI8 Innovation - RE: Variable message sign in town
- Email dated March 10, 2020 - [redacted], MasterGate+ - Re: [External] Automatic doors on a bike path of a bridge
- Installation contract for the instep beam (2018) - Contract 62583

# 7 Risk Analysis

A risk analysis was developed as part of this mandate to prioritize the decisions and actions to be taken in the event that the multipurpose path is opened. This analysis presents a non-exhaustive list of risks, issues and opportunities associated with the opening of the multipurpose path in winter.

The content of this list is specific to this mandate. It represents the result of the knowledge acquired as well as the conclusions of various analyses and studies carried out as part of this project. It is a decision-making tool the main purpose of which is to mitigate, or eliminate, the risks associated with multipurpose path operations.

## 7.1 Event Categories

The events (risks or issues) identified within the framework of this mandate are grouped into 5 categories:

- Structure and sustainability;
- Security;
- Socio-political issues and level of service;
- Winter maintenance; and,
- Environment.

It should be noted, however, that the categorization of events can sometimes be challenging, since events may include causes or consequences that link to or depend on other categories.

## 7.2 Action Plan

For each event identified, measures were taken to reduce or eliminate the causes or consequences associated with the risk. This includes, but is not limited to, the following actions:

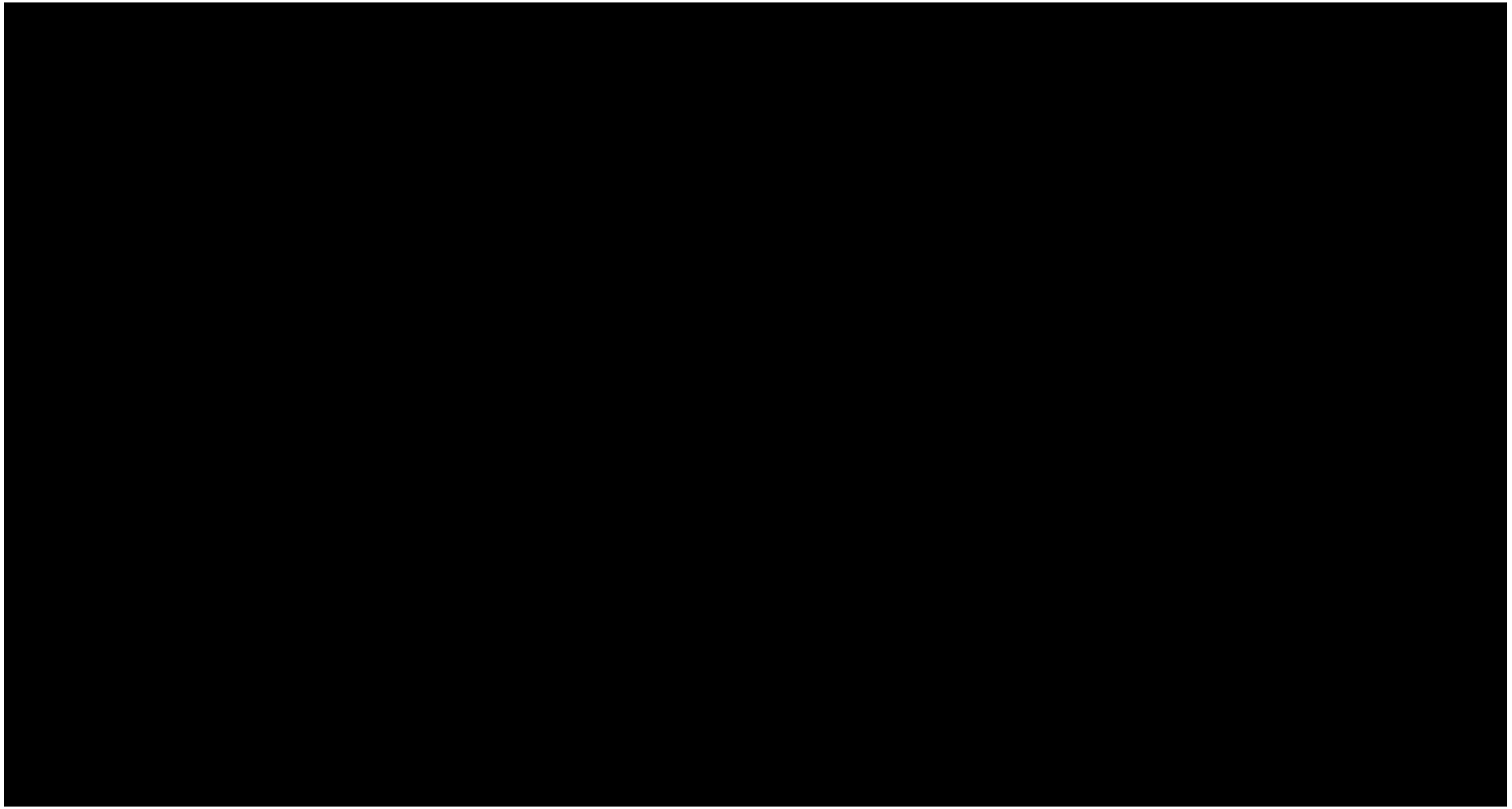
- Implementation of a clear mechanism for decision-making (operating protocol and decision-making scheme);
- Implementation of a clear communications protocol that allows better management of the path and cyclists' expectations;
- Proposal of new signage and speed feedback radar to make users aware of their speed and the presence of barriers on the bridge;
- Installation of automatic gates and variable message signs at the entrance to the multipurpose path to allow rapid closure of the multipurpose path, if required, and to indicate the multipurpose path's open status;

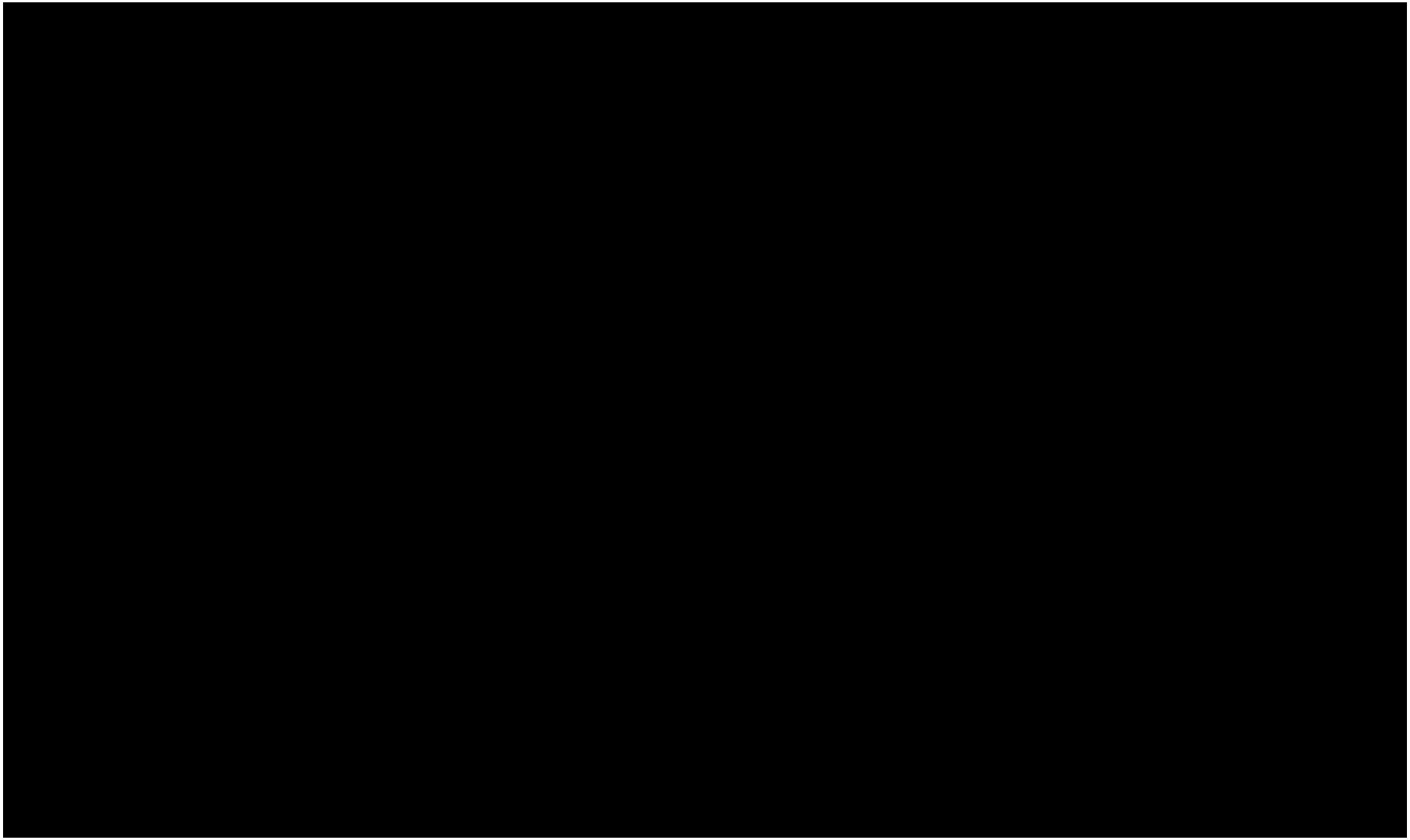
- Installation of kick-back plates in places where there is a risk of splashing off the multipurpose path; and,
- Integration of all existing and proposed intelligent transportation systems on the bridge.

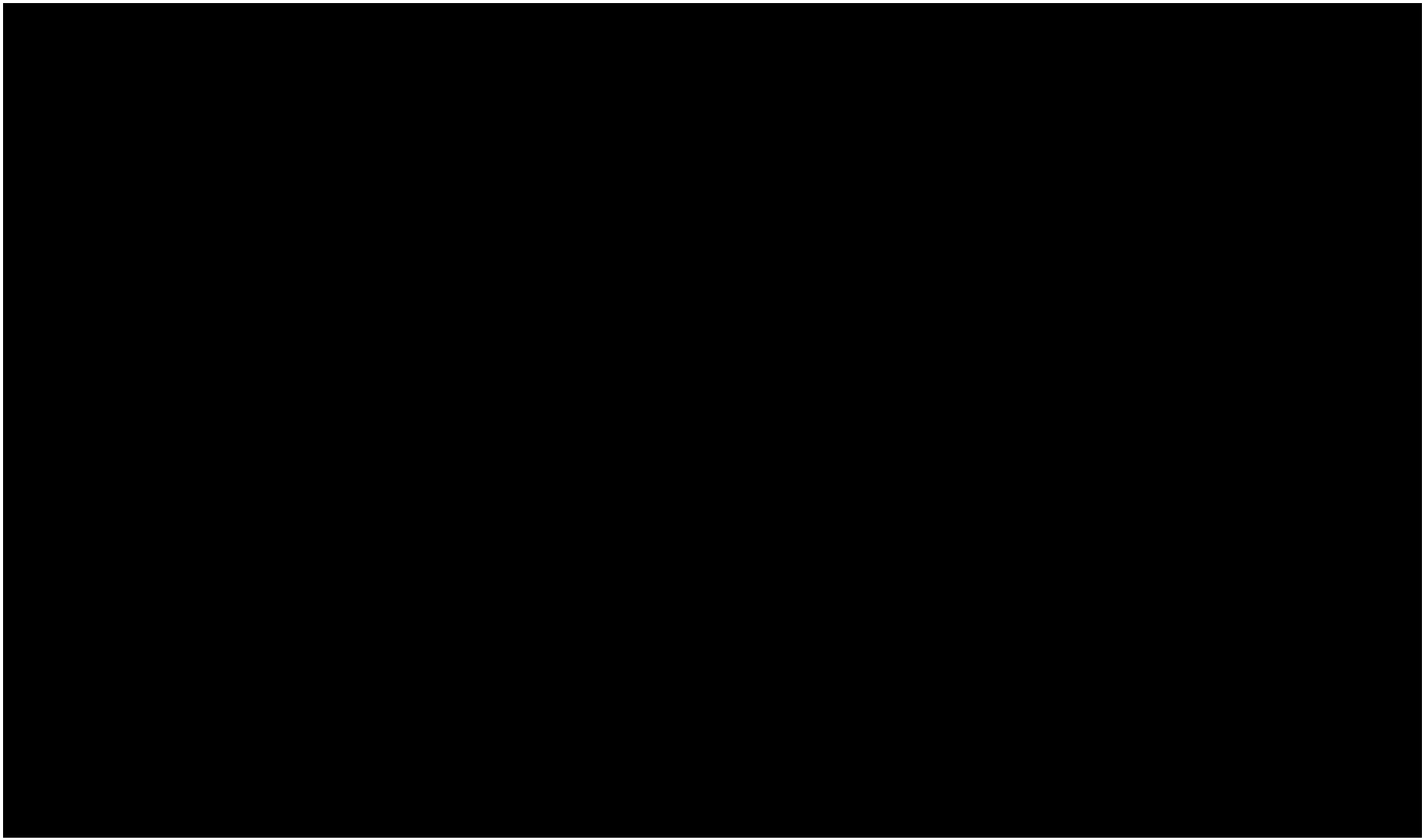
A list of additional actions is also proposed in order to further reduce these risks, if deemed necessary.

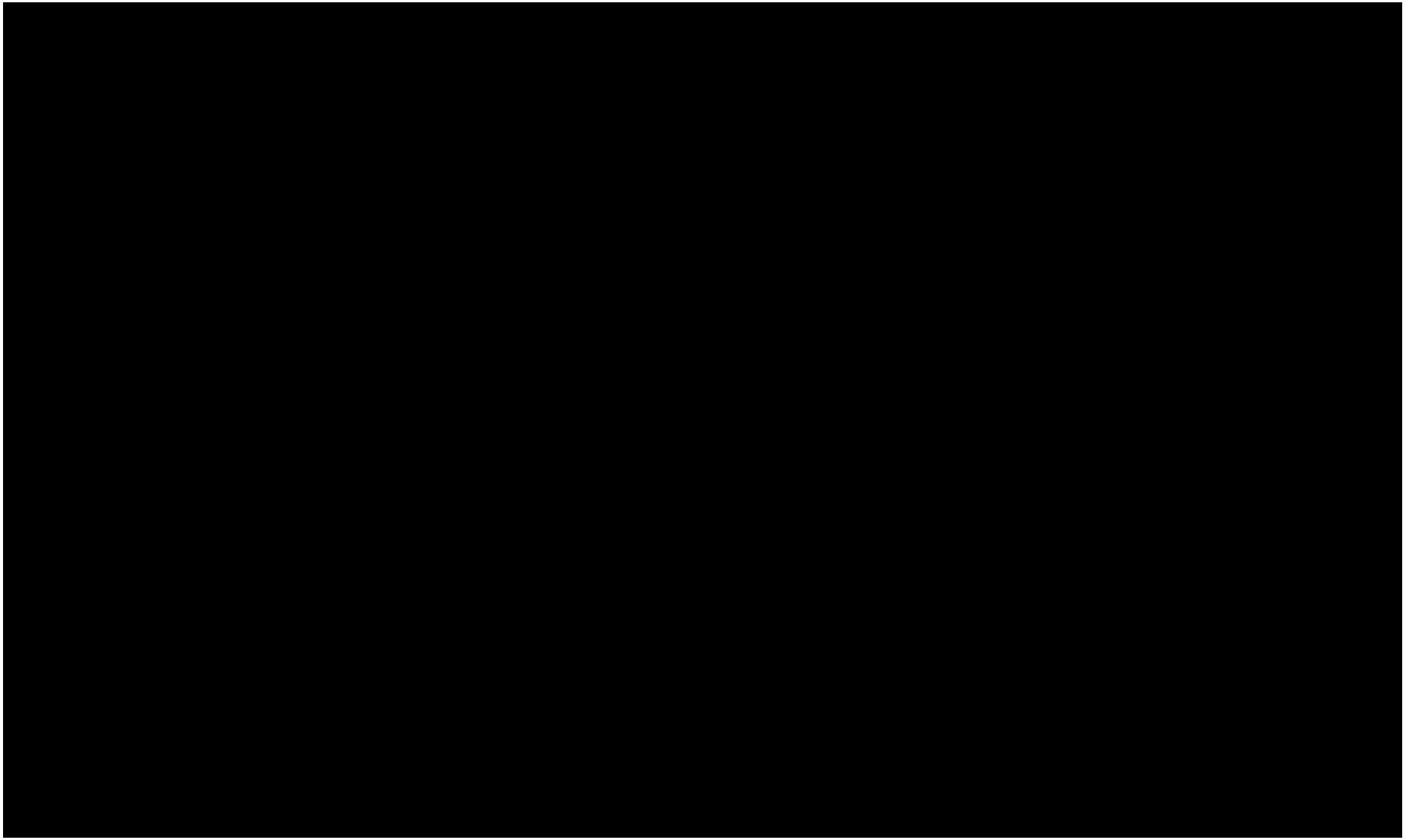
## 7.3 Results

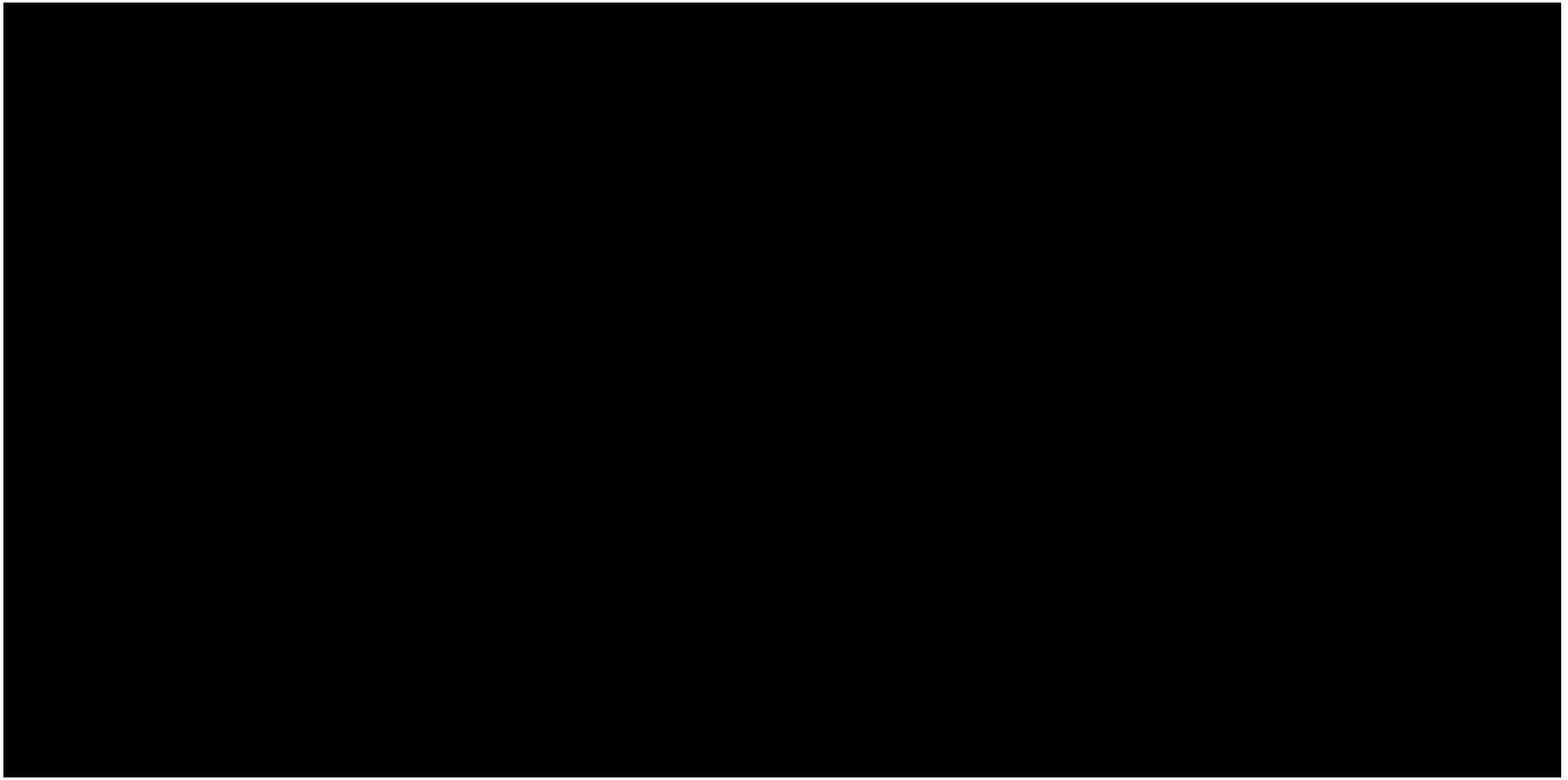
The following table provides a complete list of the events considered, their consequences and the proposed action plan.











# 8 Enhanced Operating Scenarios

## 8.1 Description of scenarios

During the winter simulation, the targeted opening timeframes of the multipurpose path was from 6:00 a.m. to 8:00 p.m., Monday to Friday. In the event that JCCBI wishes to provide a higher level of service to users, three enhanced operating scenarios with extended opening timeframes were analyzed. The following three enhanced operating scenarios were studied:

- 5 days / week (6h to 22h)
- 7 days / week (6h to 22h)
- 7 days / week (24 hours a day)

To better identify the potential increase in traffic that these increased levels of service would allow, the following section presents the overall picture of cyclist traffic trends on the Jacques Cartier Bridge. Section 8.3 then presents the benefits and drawbacks associated with these different scenarios.

## 8.2 Multipurpose path Traffic Trend

### 8.2.1 Daily profile during the week

Since the end of April 2015, JCCBI has installed a pedestrian and cyclist counter on the multipurpose path. The data collected[10], mainly during the summer, allows the distribution of traffic by day, week and month to be evaluated.

The profile of bicycle traffic on the multipurpose path is pendulum-type (see Figure 45). A majority (50% to 70%) of cyclists use the bridge during the morning and evening rush hours to get to work. Traffic is mostly unidirectional: between 65% and 70% of traffic goes to Montreal in the morning (between 6:00 a.m. and 9:30 a.m.) and to Longueuil in the evening (between 4:00 p.m. and 6:30 p.m.).

In Figure 45, the blue line represents the number of relative trips of cyclists heading towards Montreal (morning peak). The orange line represents the number of relative trips of cyclists heading towards Longueuil (evening peak).

[10] Source: https://www.eco-visio.net

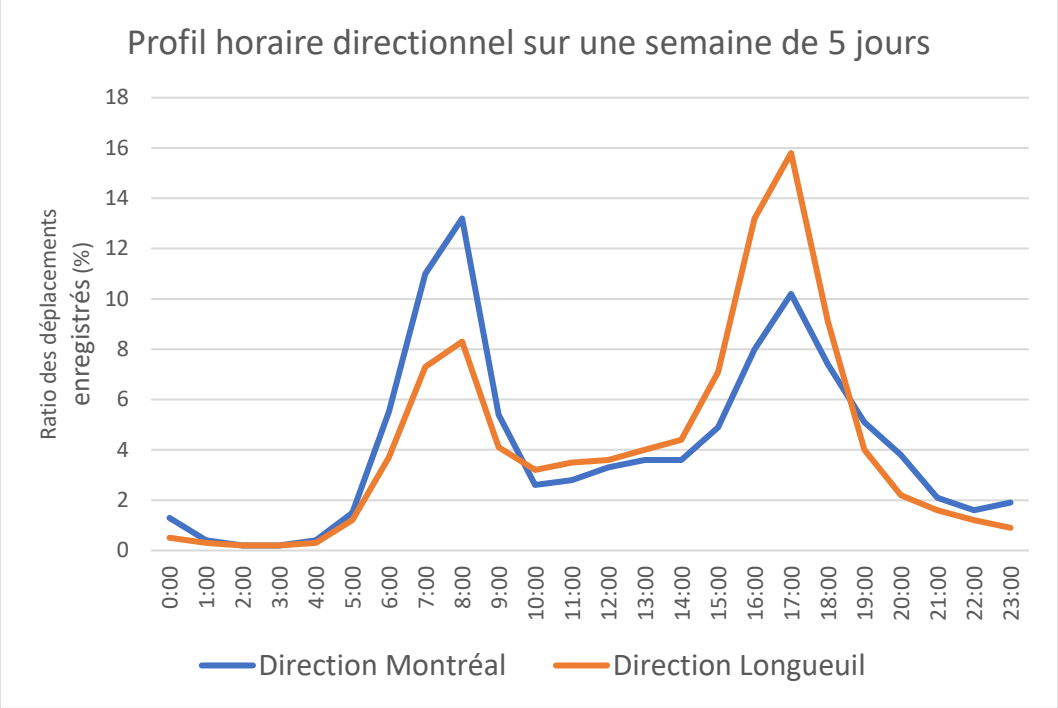



Figure 45 : Directional time profile over a 5-day week (April 1, 2019 to October 31, 2019)

### 8.2.2 Weekend Daily Profile

Despite the commuting nature of weekday traffic, a certain proportion of cyclists (between 20% and 25%) use the multipurpose path on weekends, as shown in Figure 46. These trips, mostly for recreation, cycling training, walking, shopping and other leisure activities, are generally spread out over the entire day in both directions, and are mostly between Montreal and Île Sainte-Hélène.

It is expected that this type of traffic will be reduced considerably in winter, considering that Parc Jean-Drapeau, La Ronde amusement park and Circuit Gilles Villeneuve (training track for cyclists) are closed during this season. In addition, the Jacques Cartier Bridge is not a "proximity" multipurpose path that accommodates short bike trips (grocery shopping, evening entertainment, etc.). Thus, weekend cycling traffic should be extremely reduced and limited to users who work during this period or who use it when the weather is particularly favorable. As early as March, depending on the weather outside, it is possible that pedestrian/cyclist traffic may be heavy on weekends, suggesting a total reopening (for summer) as soon as the fine weather arrives.

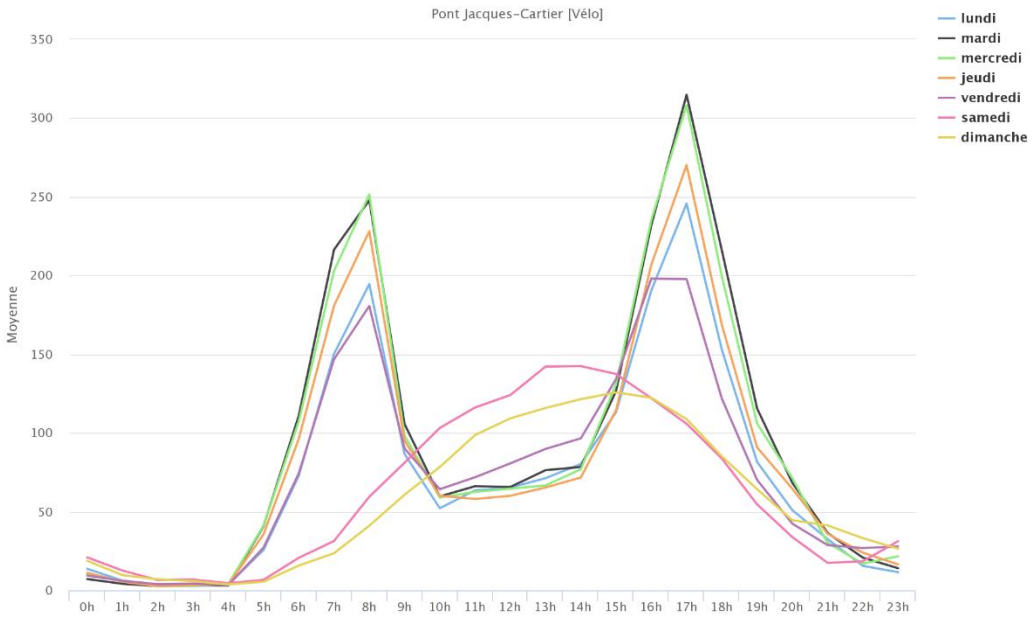



Figure 46 : Hourly profile over the 7 days of the week - number of cumulative trips in both directions, per hour - average over the analysis period (April 1, 2016 to October 31, 2016)

### 8.2.3 Daily profile during winter simulation

During the 2019-2020 winter simulation, the opening hours of the multipurpose path were from 6:00 a.m. to 8:00 p.m., Monday to Friday. The daily traffic profile of the control cyclists is shown in Figure 22. The following points emerge from the analysis of this figure:

- 48% of trips were made between 6:00 and 9:00 am while 39% of trips were made between 3:00 and 7:00 pm. Consequently, a total of 87% of trips were made during peak hours, which reaffirms the utilitarian and pendulum nature of the advanced multipurpose path in section 8.2.1.
- In contrast to the daily profile shown in Figure 45, only 10% of the trips took place between 9:00 am and 3:00 pm, which seems to indicate that very few cyclists used the bridge for recreational purposes.
- Only 2% of trips were made after 7:00 p.m., which seems to indicate that few cyclists use the bridge in the evening.

## 8.3 Scenario analysis

The following sections present the advantages and disadvantages of the following three enhanced operating scenarios:

- 5 days / week (6h to 22h)
- 7 days / week (6h to 22h)
- 7 days / week (24 hours a day)

The opening timeframes in these scenarios represent target levels of service and any widening of these timeframes due to inclement weather is not considered in these analyses. JCCBI has the option of allowing an extended multipurpose path opening if weather conditions permit. Such a decision would not affect the level of effort by the operations and maintenance team but would affect the effort for communication management, as the multipurpose path opening times would become variable. This could make it more difficult to manage users expectations.

### 8.3.1 5 weekdays (6 am to 10 pm)

The operating scenario from Monday to Friday from 6:00 a.m. to 10:00 p.m., would be very close to the opening timeframes adopted during winter simulation (2019-2020). The opening hours would be extended by an additional two hours in the evening, an option that would benefit only a small percentage of cyclists. This was discussed in section 8.2. This option could offer the possibility for some night workers to use the bridge to commute to work.

Snow removal operations lasted an average of 2 hours 15 minutes and a maximum of 5 hours during the winter simulation. The closing timeframe between 10:00 p.m. and 6:00 a.m. would provide sufficient time to carry out snow removal operations for the vast majority of events. Extending the time period to 10:00 p.m. would not represent an operational issue.

Compared to the opening timeframes adopted in the winter simulation (2019-2020), this operating scenario does not involve considerable additional effort on the part of the operations and maintenance team. The operational operating costs would be very similar to those presented in section 6.

Nevertheless, one of the consequences of extending the time slot until 10pm would be an increase in the evening opening period. The night period generally poses more risks for cyclists, considering the more difficult riding conditions associated with ice formation caused by the cold as well as reduced visibility due to darkness.

### 8.3.2 7 weekdays (6 am to 10 pm)

The second scenario envisaged would be the opening of the multipurpose path 7 days a week, from 6 am to 10 pm. This would improve the multipurpose path's opening hours by making it accessible at all times except at night.

As discussed in section 8.2, weekend traffic on the Jacques Cartier Bridge consists of trips mostly devoted to recreation, cycling, walking, shopping and other leisure activities. It is expected that these types of trips will be considerably reduced during the winter period. This scenario would allow seasoned cyclists and weekend workers to use an active mode of transportation to get to either side of the bridge. It could also represent an opportunity for all cyclists when weather conditions are particularly favorable during the weekend.

In addition to the issues associated with night traffic identified in the previous sub-section, the opening of the multipurpose path on the weekend means that additional operations and maintenance staff will be required to ensure regular monitoring of multipurpose path status and weather and, in this case, to close the multipurpose path if circumstances require it. The implementation of this scenario would necessitate higher operating costs in the order of 19%, as compared to the 5-day weekday scenario (6 a.m. to 10 p.m.).

During the winter simulation, a quarter of the snow removal operations took place on weekends. If the multipurpose path becomes accessible to the public on Saturdays and Sundays, the operations and maintenance team will no longer have the ability to perform a daytime upgrade during this weekly window. Sun and daytime heating contribute significantly to the achievement of the targeted levels of service. In addition, these weekend operations allow for less inconvenience to cyclists due to the lower traffic potential. A weekend opening would imply a risk of a decrease in the quality of the road surface. This issue could be partly addressed by planning for snow removal operations during the night, although this is less ideal.

### 8.3.3 7 weekdays (24 hours a day)

This scenario provides a maximum level of service, i.e. a full opening of the multipurpose path at all times, except on occasions when multipurpose path closure is essential for snow removal operations.

Compared to the improved operating scenario described in the previous sub-section, a 24-hour opening would benefit only a few additional users. As shown in Figure 45, the number of cyclists using the multipurpose path between 10:00 p.m. and 6:00 a.m. represents only about 2% of all users. Furthermore, this percentage is expected to be considerably reduced during the winter season due to the significant drop in night-time temperatures and the reduced frequency of recreational cycling during this season.

The risk of accidents for users increases in the evenings in winter as night-time cooling creates a risk of ice formation and there is a reduction in visibility.

Each closure of the multipurpose path for snow removal operations will represent a service stoppage for users and will increase the unpredictability of access to the multipurpose path. It is possible users will perceive each multipurpose path closure as a nuisance and an inconvenience.

The continuous opening of the multipurpose path means that additional manpower will be required 24 hours/day from the operation and maintenance team to ensure regular monitoring of the multipurpose path status and of the weather. When circumstances require it, they will need to close the path. This option also involves more complex internal and external operations and communication logistics, since each snow removal operation may result in a multipurpose path closure, which will invariably have to be reported to users. The implementation of this scenario therefore means additional operating costs of approximately 43% compared to the 5-day weekday scenario (6 a.m. to 10 p.m.).

Finally, similar to the scenario with a weekend opening from 6 a.m. to 10 p.m., a weekend opening means that the O&M team will no longer have the opportunity to upgrade the surface quality during the day on the weekend.

The following should therefore be considered: are the benefits associated with this improved operating scenario justified considering the little additional traffic, the risks to cyclists' safety and the investment required to ensure the operation of the multipurpose path?

## 8.4 Summary

Table 18 below provides a summary of the advantages and disadvantages for the three enhanced operating scenarios. This summary consists of a qualitative assessment with reference to the opening timeframe used in the 2019-2020 winter simulation, i.e., Monday to Friday, from 6 a.m. to 8 p.m.

Table 18 : Qualitative assessment of various enhanced operating scenarios

| | 5 days / week 6am - 10 pm | 7 days / week 6am - 10 am | 7 days / week 24/7 |
|---|---|---|---|
| **Increase in traffic** | [redacted] | | |
| **Safety issue for users** | | | |
| **Additional staff** | | | |
| **Range of operating costs (Difference with operating scenario 2019 - 2020)** | | | |
| **Complexity of operational logistics and internal communication** | | | |
| **Time slot available to perfor path maintenance outside of business hours** | | | |
| **Complexity of communicatio with users** | | | |
| **Additional level of effort to achieve this level of service** | | | |
| **Snow removal quality (maintain same quality)** | | | |

**Legend**

| | |
|---|---|
| ≈ | No appreciable benefit or disadvantage in relation to the benchmark |
| + | Slight profit compared to the reference |
| + + | Significant profit compared to the reference |
| - | Slight disadvantage or disadvantage in relation to the reference |
| - - | Significant disadvantage or disadvantage in relation to the reference |

# 9 Conclusion

As part of this project, Arup developed maintenance, monitoring and communication protocols and provided assistance to JCCBI during the 2019-2020 winter operation simulation of the multipurpose path. The results of this simulation have allowed for an analysis of the issues and risks related to the opening of the path to the wider public and the elaboration of a mitigation plan.

During the winter simulation, the multipurpose path remained open for 93% of the target opening hours. The established operational protocol and the snow removal methods adopted were a success and allowed the implementation of a safe cycling link on the Jacques Cartier Bridge. A total of 40 snow removal operations were completed during the winter months, each lasting on average just less than 3 hours.

The participating control cyclists provided daily feedback after each ride to assign a surface quality rating, provide observations and to raise any other relevant issues. This feedback was instrumental in the identification of areas of potential risk and concern. To this end, several actions were implemented to improve the quality of snow removal operations and to address the problems raised.

Furthermore, Arup updated previous analyses carried out in 2017-2018. These included studies on the durability of the bridge structure, the environmental impact of using de-icing products, and the project cost estimates in order to provide a framework for future snow removal operations. Should the multipurpose path open in winter, the following actions are recommended:

- The multipurpose path can be opened under conditions comparable to those of the 2019-2020 controlled simulation tests; that is, by continuing to adopt a gradual and conservative approach that will account for a few logistical adjustments and ensure the safety of all users;
- Continuous monitoring of weather forecasts is essential. Operational and communication adjustments may be required on an ad-hoc basis depending, on actual weather conditions and user behaviour;
- Install new traffic signs, speed radars, and other systems to increase user awareness and to improve the safety of users. The integration of these systems into a single platform would be preferable to maximize its potential;
- Regular coordination among stakeholders is required, both internally (e.g. with the contractor, and among the various departments within JCCBI) and externally (e.g. with the cities of Montreal and Longueuil);
- Drainage improvements on a few sections is advisable, specifically at section 1 on the Longueuil side and at the northern extremity of the multipurpose path;
- Development of an integrated communication protocol to ensure adequate communication with users on the condition of the multipurpose path and sidewalk;

- Regular maintenance of snow removal equipment and any systems essential to the operation of the multipurpose path is recommended to ensure redundancy;
- Monitoring the durability of the concrete slab is required. If de-icing products are to be used on the multipurpose path, controlled application is necessary to prevent premature corrosion, reduce environmental impacts and prevent a decrease in friction caused by an excessive accumulation of de-icing products on the multipurpose path;
- Based on available data, it is recommended that traffic data on the bridge be compiled to better understand user behaviour and to appropriately respond to their needs. If deemed necessary, an extension of the opening hours could be considered in the medium term; and,
- Finally, medium and long-term planning for the future of the multipurpose path and sidewalk is essential within JCCBI's strategic asset management plan. Such planning includes an assessment of active mobility needs over the next few decades as well as a long-term durability assessment of the structural elements of the multipurpose path and sidewalk. Considering improvement options, particularly those related to the guardrails and the configuration of the multipurpose path, will ensure sustainable management of resources and user needs for the future, and also showcase this iconic bridge of which all Montrealers are proud.

# Appendices

# Appendix B – Note on the Signage on the Multipurpose Path

ARUP

Subject **Appendix B – Note on the signage of the multipurpose path**

Date May 4, 2020 **Project number** JCAP0015 / 62659

# 1 Review of existing path signage

Considering the characteristics of the multipurpose path on the Jacques Cartier Bridge, the current signage regarding pedestrian and cyclist traffic is deemed insufficient, regardless of whether the chicanes/barriers are maintained or not. This analysis is based on information obtained from JCCBI (previous reports) and on current signage according to a site visit conducted on Wednesday, February 5, 2020 by the Arup team.

The signage currently in place for the multipurpose path as well as certain signs deemed relevant to this analysis are presented in the form of photos taken during the site visit. At the end of the text reference, the signs are also numbered N-1, N-2, etc. northbound from Longueuil to Montreal and S-1, S-2, etc. southbound from Montreal to Longueuil.

The following section deals with the observations and deficiencies observed during the field visit.

Regarding prescriptive signage:

- The 20 km/h speed limit on the path (which by default is intended for cyclists) is indicated in only four (4) places, namely:
    - A sign installed at the beginning of the junction of the path with the bridge structure on the Montreal side towards the South Shore (S-1);
    - A sign north of the junction on the Longueuil side towards Montreal (N-2);
    - Two other signs located downstream in each direction on either side of the intersection with the access ramp to Île Sainte-Hélène (S-24 and N-14).
- The standard prescribed for vehicles[1] (which applies in this specific case since there is no specific section for cyclists) stipulates that signs repeating the speed limit must be posted downstream of all intersections or entrance ramps (according to standard drawing 002A) as well as at each change of speed zone enacted by law or regulation and at intervals of no more than 15 km.
- Although the standard dealing with bicycle lanes does not indicate a minimum distance between two speed limit signs on a bike path, it can be logically interpreted that the maximum distance of 15 km between two speed limit signs on a section with no intersections, entrances or exits that is indicated in the road standard applies to highways with a maximum speed limit of 100 km/hr. Thus, in the case of a multipurpose 20 km/h path whose geometric conditions vary significantly both in plan and in profile along the route over the bridge, it is reasonable to consider that a reduced maximum distance adapted to local conditions between two speed limit signs directed at users of the path should be applied. For safety reasons, the signage currently present on the site is deficient.

[1] By default, the standard dealing with Road Signage (Volume V of the MTQ's Road Structures standard) is applied. when a particular case is not covered in the section dealing with signage on bicycle lanes (Chapter 7 of the Volume V).

> The existing 50 km/h vehicle speed limit signs for the South Shore direction on the bridge are in direct conflict with the path due to its overlapping positioning on the side of the path. This situation occurs five (5) times. Although the larger size of the signs and their placement on the left side of the path (towards the South Shore) should in principle indicate that this signage applies to vehicles, the fact that no sign for the speed limit of the multipurpose path is present on the right side of the path can lead to confusion in the interpretation of the sign for motorists. However, 50 km/h signs for the South Shore are present five (5) times (S-8, S-16, S-26, S-29 and S-34) between Montréal and Longueuil (including 3 south of Île Sainte-Hélène) and are never accompanied by a 20 km/h sign for the path path. The figure below shows the locations where this problem is encountered.


S-8


S-16


S-26

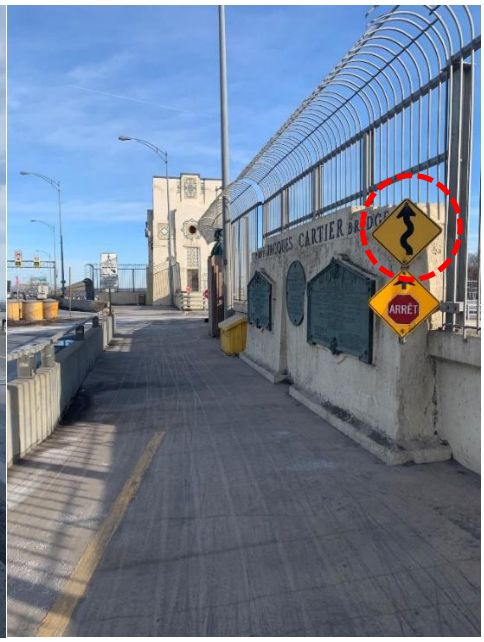

S-29


S-34

Figure 1 maximum vehicle speed signs (Source: Arup, 2020-02-05)

> The hazard signs warning in advance of the chicanes (removable plastic barriers) installed at the approaches to the intersection of the access ramp to Île Sainte-Hélène (N-12 and S-20) do not comply with current winter conditions. In addition, the sign used (D-110-5-G) indicating 3 curves is not representative of the conditions of the chicanes used in the summer period. This sign is also not in continuity with the signage used upstream of the other chicanes on the bridge (see example of marking and sign S-15).


N-12




S-20

S-15

Figure 2 advanced chicane danger signs (Source: Arup, 2020-01-05)

> There are no danger signs warning in advance of the presence of the chicanes (sign D-30 - Yield to oncoming traffic). Only the ground markings are indicated upstream of the chicanes/barriers. This marking becomes very little visible when the road becomes dirty or snowy (N-10, N-30, S-15, S-35 and S-39). It is normally customary to accompany all danger and prescription markings with a sign containing the same message.

N-10

N-30

S-15

S-35

S-39

Figure 3 : advance signage marking for yielding caution (Source: Arup, 2020-01-05)

> Missing steep slope hazard sign (D-230-7 modified) - "Slow Down / Ralentir / Slow Down" at the top of the path at Section 7 (see photos N-18 and S-12). This sign is currently used only at the top of the path at Section 3 (see photos N-7 and S-30).

N-18 S-12

Figure 4 : absence of steep slope danger signs at the top of the path at the superstructure on the Montréal side (Source: Arup, 2020-01-05)

N-7 S-30

Figure 5 steep slope danger signs at the top of the path at the superstructure on the Longueuil side (Source: Arup, 2020-01-05)

- Conflicting messages about vehicle and pedestrian priority when approaching the Île Sainte-Hélène access ramp intersection. The "Vehicle have priority" signs installed below the stop signs conflict with the ground markings on the crossing, which are yellow and which, according to the regulations, require vehicles to stop when pedestrians or cyclists enter the crossing (see photos N-13 and S-21 below).


N-13 S-21

Figure 6 Vehicle have priority" signs at the approaches to the Île Sainte-Hélène access ramp intersection (Source: Arup, 2020-01-05)

# 2 Potential improvements/solutions

Some of the measures recommended in this section could be considered regardless of whether the chicanes/barriers are retained in whole or in part in order to raise awareness to path users about the speed limit and the presence of chicanes/barriers. It should be noted that the locations proposed in the following sections are approximate and in most cases based on existing lighting or signage barrels. The exact location in terms of chainage is available on the plans detailed in Contract No. 62679.

The recommended measures are as follows:

- In the southbound direction, install "Maximum 20" km/h speed limit signs (P-70-2, 450x600) slightly downstream of the 50 km/h signs for vehicles currently in place for the South Shore. It should be noted that the particular conditions of the path in this direction do not allow the installation of signs on the outside-most side of the path due to the presence of the curved jump barriers at the top that do not allow for the minimum vertical clearance of 2.5 m or the maximum height of 3 m between the bottom of the signs and the path surface, as prescribed in the MTQ standard. It is therefore recommended that the panels be installed overhead in the centre and above the path when jump barriers are present on both sides of the path. When the sign must be installed on the road side of the path, it is recommended to add a sign with the bicycle pictogram (P-1-P) below the speed limit sign. In addition, signs located on the road side of the path should be installed at a 25 degree angle towards the inside of the path. These two

additional measures ensure that the message is directed to the path users and not to the road users. In order to avoid visual clutter with excessive use of signs and to limit them to areas deemed problematic in terms of speed, it is recommended that an additional 20 km/h limit sign be installed when on a downhill slope approaching the exit ramp to Île Sainte-Hélène, at the following location :

- Approximately. 20 m downstream of lighting shaft no. 68 on the signal structure shaft (see mounting on picture S-17 below).


S-17

Figure 7 Suggested locations for the installation of 20 km/h speed limit signs (Source: Arup, 2020-01-05)

- Repeat the "Maximum 20" km/h speed limit signs (P-70-2, 450x600) accompanied by a "Bicycle" sign (P-1-P, 450x300) below approximately one third (1/3) of the distance from the top of the structures to the chicanes when descending a slope. It should be noted that the standard does not prescribe a maximum distance between two speed limit signs for multipurpose paths, whereas it is 15 km for maximum speed road links. Considering the 20 km/h speed limit on the path and the particular geometric conditions, it is recommended to install speed limit reminder signs on downhill slopes at the following locations :
    - Northbound approximately one third (1/3) between the beginning of the downslope of Section 4 and the chicane plate. Install the panel on a new washer anchored in the concrete chute about 50 m downstream of lighting shaft no. 34;

- Northbound approximately one third (1/3) between the beginning of the downslope at section 8 and the chicane plate. Install the sign above the path between the two jump barriers approximately 10 m upstream of lighting shaft No. 100;
- Southbound approximately one third (1/3) between the beginning of the downslope at section 6 and the chicane plate. Install the sign on a new shaft anchored in the concrete barrier about 20 m downstream of lighting shaft no. 68;
- Southbound approximately one third (1/3) between the beginning of the downslope at section 2 and the chicane plate. Install the sign above the path between the concrete chute and the jump barrier approximately 20 m downstream of lighting shaft no. 28..

> Replace the two (2) hazard warning signs warning in advance of the chicane (3 curves - D-110-5-G) currently installed at the approaches to the Île Sainte-Hélène access ramp intersection (see photos N-12 and S-20 above) with a sign similar to those currently installed at the chicanes on the descending slope (Yield to cyclists engaged in the chicane - D-30, 450x450). Note that if these chicanes are removed during the winter period, the danger signs should also be removed.

> Install "Yield to Cyclists" signs for cyclists travelling in the opposite direction (P-30, 450x600 or smaller if required by the space available on the chicanes (first barrier) at the intersection of the access ramp to Île Sainte-Hélène (see locations on photos N-13 and S-21 below). Please note that the removable plastic chicanes/barriers were not in place during the site visit and therefore do not appear on the photos - see proposed locations in the photo below. See example of the recommended sign in photo N-31 above.


N-13 S-21

Chicanes installed in summer (source: Google Streetview, June 2019)

Figure 8 Suggested locations for the installation of Yield to Cyclists prescription signs (Source: Arup, 2020-01-05)

- Install "Yield to Cyclists" hazard signs in the baffle plate (D-30, 450x600) and a sign indicating the distance before reaching the baffle plate (D-245-P-1, 450x425) upstream of all downhill baffles (see photos N-10, N-30, S-15, S-35 and S-39 above) located to the right of the hazard markings of the same type.

In addition, certain improvements and/or measures could be considered to improve the signage and communication of messages around the P.I.S.H. intersection.. :

- Install "Advance Stop Signal" danger signs (D-10-1, 600x600) warning of the presence of a stop approximately 50 m upstream of the stop lines on the approaches to the two ramps coming from Île Sainte-Hélène, i.e. on lighting shaft no. A1 on the west side of the bridge and on lighting shaft no. T-4 on the east side of the bridge.
- Remove the signs indicating "Priorité aux véhicules / Vehicules have priority" installed under the stop signs on the approaches to the Île Sainte-Hélène access ramp intersection. See photos N-13 and S-21 above.
- Install advance warning signs for pedestrian and cyclist crossings in a diversion island (D-270-30, 600x600) for northbound and southbound vehicular traffic on the approaches to the Île Sainte-Hélène access ramp intersections. The signs should be installed approximately 50 m upstream of the pedestrian crossings on lighting shaft no. 62 (see photo S-19) in the southbound direction and on lighting shaft no. 51 in the northbound direction.


S-19

Figure 9 Suggested locations for the installation of advance warning signs for pedestrian and bicycle crossings in a divider island for southbound traffic (Source: Arup, 2020-01-05)