TORONTO TRANSIT COMISSION
PLATFORM EDGE DOOR STUDY
BUSINESS CASE

PREPARED BY

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Morteza Hagshenas
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March 28, 2025

TTC Contract # G85-362
AECOM Project # 60602481

PRIVILEGED AND CONFIDENTIAL

Dear Mr. Hagshenas:

Subject: **Toronto Transit Commission, Platform Edge Door Study**
Business Case Study

I am attaching the business case report for the platform Edge Door study for your review and comment. Please contact me if you have any questions.

Sincerely,
AECOM Canada ULC

Walter Gaudet, OAA, SAA, NSAA, MRAIC LEED AP BD+C
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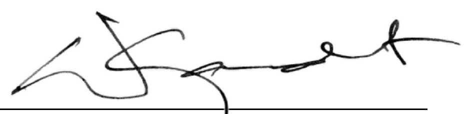

Walter Gaudet, OAA

Senior Vice-President

Executive Summary

The installation of Platform Edge Doors (PEDs) in the Toronto subway is recognized by the Toronto Transit Commission (TTC), the City of Toronto, and members of the public as a priority for improving the delivery of efficient and safe transit services. Unlawful track access, whether it is a suicide, a homicide, an accident, debris, or a simple track intrusion can incur significant costs to the community, not only in terms of safety, but also from an operational perspective (service delays, overtime, staff trauma, public image, etc.).

This Business Case represents the third and last piece of the "Platform Edge Door Study". Phase One resulted in a preliminary Investigation Report (May 2020), which reviewed previous studies and documented observed conditions at each station. Phase Two culminated in a Feasibility Report (September 2023), which developed a group of representative designs for PED installation and prepare Class 5 capital cost estimates. Phase Three, the Business Case Study, builds on the previous reports and findings to provide an evidence-based justification to allow the TTC to make an informed decision for proceeding with the installation of PEDs on Lines 1, 2 and 4 of the Toronto subway system.

The implementation of Platform Edge Doors throughout the subway network should mitigate unlawful track intrusion and improve the reliability and efficiency of subway services by reducing operational delays, protect passengers and transit operators from death and injuries, improve users' perception of the TTC network, and enhance the TTC's public image. Between 2017 and 2022, 2,689 recorded subway service interruptions could have been completely or partially avoided by PEDs, representing an annual cost to society of $120 million in delays, injuries, loss of life and operating costs that could be avoided with the installation of PEDs.[1]

The benefits of installing PEDs in the Toronto subway align with the values and beliefs of the TTC. The project specifically aligns with three of the six pillars of "the TTC Way"[2], namely: Stay Safe, Value Each Other's Time and Mind your Space.

To meet the TTC requirements, the consulting team developed a combination between full-height and half-height systems. The barrier design is envisioned to be "full-height" in terms of door size and the use of door headers above the barrier, but "half-height" in the sense that the doors do not reach fully to the ceiling. The TTC estimated the capital cost to retrofit the 74 subway station platform levels including interchange stations with PEDs at $4.1 billion in 2036 dollars, with an average cost per station of $55 million. The project costs are augmented with the anticipated incremental operations and maintenance costs and compared against the project benefits that can be quantified and included in a cost-benefit analysis framework.

The cost-benefit analysis considers the following four categories of benefits:

1. Avoided Passenger Injury and Loss of Life (annual savings of $92.2 million with PEDs)
2. Passenger Delays (annual additional travel times of $16.0 million with PEDs)
3. Employee Health Improvement (annual savings of $0.8 million)
4. Emergency Response Cost Savings (annual savings of $19.0 million with PEDs)

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[1] *AECOM compilation and analysis based on incident logs provided by the TTC. Section 4 provides the detailed Benefits Assessment.*

[2] *TTC (2020). The TTC Way, On line <https://ttc.ca/theTTCway/index.jsp>*

The results suggest that the full-height PEDs could create between $2.2 billion and $2.5 billion in socioeconomic benefits in present value terms. The lifecycle costs are estimated between $2.0 and $2.2 billion in present value terms (in real terms, using a social discount rate of 3.5%). The results are reported as ranges to reflect the results of sensitivity analyses performed on key variables. The lower bound assumes an annual ridership growth rate of 1.5% and a construction inflation rate of 3% per year while the higher bound assumes ridership will grow faster at 2% per year on average and inflation in the construction sector will increase 2.5% per year on average (in nominal terms)). The benefits are generally more than enough to offset lifecycle costs, resulting in a positive net present value of up to more than $500 million and a benefit-cost ratio of up to 1.24.

The improved service reliability resulting from avoided service interruptions and travel time penalties could attract 900,000 new riders to the subway system each year, resulting in incremental fare revenue of $60-70 million in present value. From an operational perspective, the TTC is also better off due to cost savings associated with avoided emergency services and shuttle bus deployment that offset the additional costs of operating the PEDs. The TTC could save approximately $90-100 million in operating costs over 60 years.

The Risk Analysis identified a total of 44 potential impacts, with 18 impacts (8 cost, 8 schedule, and 2 safety) were threats with a rating of -4 (Critical) and 2 impacts (both cost) were opportunities with a highest rating of 4 (Critical). The risk assessment modelled the 44 potential impacts in a Monte Carlo simulation and analyzed the distribution of outcomes. It results that the most undesirable outcomes could increase costs by $640 million and create schedule delays of 229 weeks.

The business case study concludes that the implementation of the PEDs system throughout the subway network can mitigate unlawful track intrusion and improve reliability and efficiency of subway services by reducing operational delays, protect passengers and transit operators, improve users' perception, and enhance TTC's public image. From a financial perspective, the capital intensive improvement results in net revenue loss for TTC.

The study recommends proceeding with implementation of the PEDs system at all the existing subway station platforms in phased and priority based approach. It also recommends that prior to the next stage of PEDs project (Planning), TTC implements a pilot installation at the stations representing a typical group of stations' structure. This would refine the design requirements, identify constraints, refine risks, cost, schedule, and lessons learned for each type of station's structure as well as obtain customer feedback, assess O&M impact, and generate public interest.

Table of Contents

Acronyms/Definitions

APM – Automated People Mover

ATC – Automatic Train Control

BAU – Business as Usual Scenario

C&L – Closed and Locked

ATCGHG – Greenhous Gas

I/O – Input / Output

NPV – Net Present Value

PED – Platform Edge Doors

PSD – Platform Screen Door

SES – Simulation Computer Program

TBTC – Transmission-based Train Control

UPS – Uninterruptible Power Supply

1. Introduction

1.1 Background

The installation of Platform Edge Doors (PEDs) in the Toronto subway is recognized by the Toronto Transit Commission (TTC), the City of Toronto, and members of the public as a priority for improving the delivery of efficient and safe transit services. Unlawful track access, whether it is a suicide, a homicide, an accident, debris, or a simple track intrusion can incur significant costs to the community, not only in terms of safety, but also from an operational perspective (service delays, overtime, staff trauma, public image, etc.).

Since 2004, the Toronto Transit Commission has recorded 20 suicide attempts in the subway on average each year, often resulting in fatalities or severe injuries. In recent years, the number of suicide attempts has risen steeply to 44 and 43 in 2021 and 2022, respectively.

Source: Historical data provided by the TTC.

The TTC has initiated several studies to assess the feasibility and long-term benefits of PEDs since 1992. Previous studies have found that potential solutions such as closed-circuit TV, intrusion detection and policy improvements would not, on their own, be sufficient to address safety and operational issues into the future[3]. Studies conducted to date[4] suggest that PEDs provide the highest level of safety as it prevents track level intrusion altogether. Although widely used in Asian and European metro systems, the use of PEDs in North America is limited only to specialized centres or airports whereby ventilation issues such as air conditioning and passenger safety is an issue.

In 2010, the TCC approved recommendations by the board to continue planning for PEDs installation and include required budget in the 2010–2015 Capital Budget. The same year, the TTC commissioned a Business Case assessment for the installation of PEDs to identify the socio-economic considerations that justify the capital expenditures of installing PEDs at existing stations as well as standard installation at new stations. The report concluded that the installation of PEDs "has the sustainability required to request funding to different levels of government."[5]

In 2014, Toronto Public Health published a report on suicide prevention in Toronto and identified jumping or lying before a moving object such as a subway/train/car as one of the most common mechanisms of suicide in Toronto. The report states that suicide attempts and deaths on the subway system can have serious impacts not only on terms of morbidity and mortality, but also in the economic cost to transit system operations and psychological impacts on the driver, passenger and witnesses.

In 2015, Toronto City Council adopted an amendment requesting TTC to consider improvements to passenger safety and suicide prevention in future budget submissions for the design of stations with PEDs or other means for restricting unauthorized access to the subway tracks by members of the public.

TTC now requires a more comprehensive feasibility study and business case to develop a project plan and prepare for a future capital budget submission.

[3] Arup, 2010. PED Constructability Review Report prepared for the TTC.

[4] Refer to the "Platform Edge Door Study – Investigation Report" (2020-05-25) for a compilation of the observed conditions at each subway station and a detailed summary of information presented in previous TTC studies & reports along with relevant information from other transit operations that may be instructive in addressing the TTC requirements.

[5] Systra Group, 2010. Platform Edge Doors Business Case Report (G85-282). 89 pages.

1.2 Purpose of This Study

The Business Case Report represents the third and last piece of the "Platform Edge Door Study." Phase one resulted in a preliminary Investigation Report (May 2020), which reviewed previous studies and documented observed conditions at each station. The Investigation Report refined the previously identified classifications of stations with greater specificity to facilitate the identification and grouping of installation solutions. Phase two culminated in a Feasibility Report (September 2023), which built on the knowledge gained from the investigation and assessment of each station to develop a group of representative designs for PED installation. The TTC provided Class 5 capital cost estimates for retrofitting each of the 74 station platform levels including interchange stations included in this study.

Phase three, the Business Case Study, builds on the previous reports and findings to provide an evidence-based justification to allow the TTC to make an informed decision for proceeding with the installation of PEDs throughout the Toronto subway system. The business case evaluates how the installation of PEDs would contribute towards meeting the TTC goals and mission with regard to the provision of safe and efficient transit services, the financial and economic performance of the investment project, and deliverability considerations that could impact the effectiveness of the project.

1.3 Organization of the Report

The business case report is divided into six sections. Section 2 sets out the rationale for proceeding with the investment in PEDs; it makes the case for change at a policy level. Section 3 provides an overview of the preferred design and cost estimates developed during Phase 2. Section 4 provides the economic justification for proceeding with the investment from a societal perspective using a cost-benefit analysis approach. Section 5 summarizes the financial impacts of the project by comparing the project costs against increased farebox revenue to the TTC and Section 6 identifies project assumptions, constraints, interdependencies, risks and construction and operational implications.

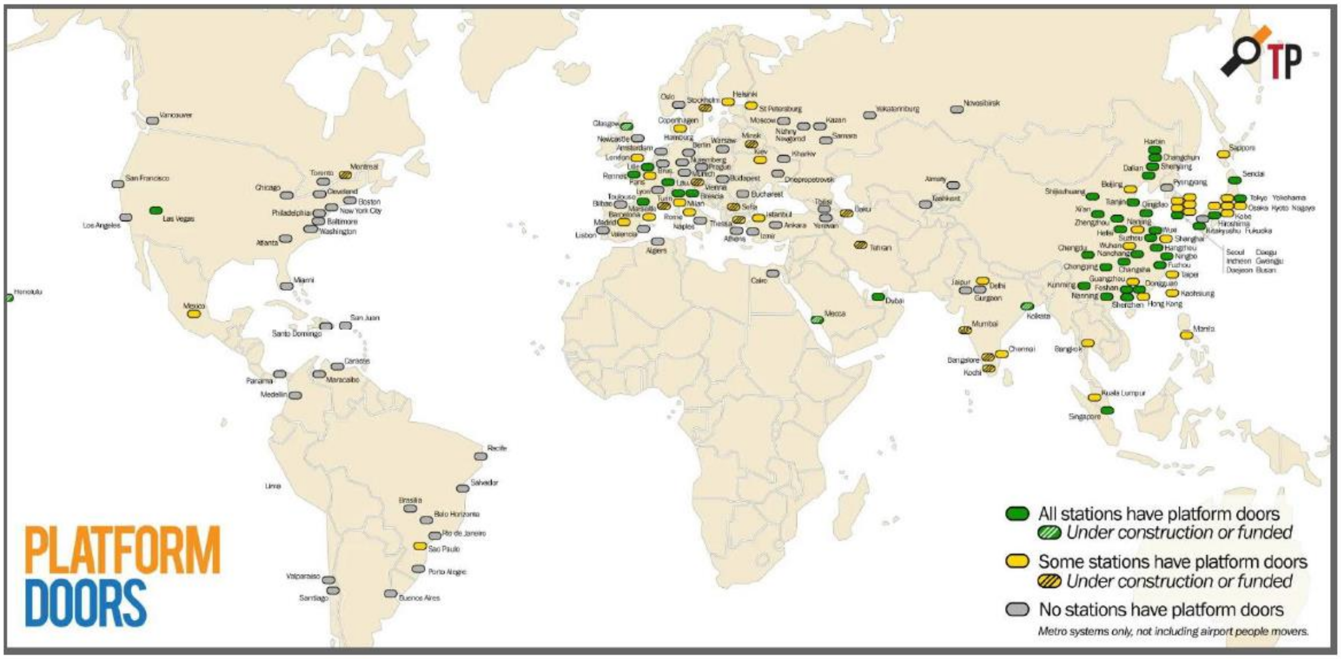

Figure 1: Transit Systems using Platform Edge Doors Around the World

While most subway systems operate with an open platform design, increases in ridership in recent years have raised several concerns, specifically in regard to safety. With increased platform congestion comes an elevated risk of someone accidentally being pushed or falling onto the tracks. Platform congestion can also cause trains to remain in the station longer due to passengers delaying door closure. Many new systems, particularly in Asia, are being constructed with PEDs; and many existing systems, particularly in Europe, are having PEDs retroactively installed, as illustrated in Figure 1. Retrofitting existing subway systems is far more complex, which explains why there are less PED-equipped stations in Europe and almost none in America.

2. Drivers for Change

This chapter sets out the rationale for proceeding with the implementation of PEDs in the TTC subway. It explains the objectives to be achieved, the strategic policy context and the fit with TTC's public policy objectives.

2.1 Problem/Opportunity Definition

The TTC plays a significant role in providing reliable, comfortable and safe travel experience in Toronto. In 2019, the TTC subway carried closed to 230 million people, representing a 3.6% growth relative to the previous year. In 2022, subway ridership was close to 130 million, achieving a 55% recovery rate relative to prepandemic levels.[6] The demand keeps growing. In May 2023, subway demand was at 63% of pre-COVID levels for the period.[7] Increasing ridership raises several concerns, specifically with regard to safety. Increased platform congestion leads to an elevated risk of someone accidentally being pushed or falling onto the tracks. Incidents caused by track intrusions can lead to material damages, injuries, and death as well as emotional trauma for subway workers and operators. The pandemic resulted in a rise in subway incidents, with the number of injuries increasing 8.7% per year on average between 2017 and 2022. In addition, service disruptions cause travel time penalties for many subway users who are in the network when interruptions occur. Longer service interruptions require emergency shuttle services to carry stranded subway users, causing additional operational costs to the TTC and to society as a whole.

The implementation of Platform Edge Doors throughout the subway network should mitigate unlawful track intrusion and improve the reliability and efficiency of subway services by reducing operational delays, protect passengers and transit operators from death and injuries, improve users' perception of the TTC network, and enhance the TTC's public image. Between 2017 and 2022, 3,362 subway service interruptions could have been completely or partially avoided by PEDs representing an annual cost to society of $108 million in delays, injuries, loss of life and operating costs that could be avoided with the installation of PEDs.[8]

Table 1: Advantages and Disadvantages of PEDs

Advantages	Disadvantages

• Increased passenger safety
• Increased Security
• Prevent debris and trash buildup on tracks
    • Reduced fire risk
    • Prevent train damage or obstruction
• Potential for higher speed codes when entering a station
    • Enhanced headway
• Potential to reduce dwell times
• Increased platform capacity
• Potential for increased advertising revenue
	• Addition of a possible point of failure which may result in delays, but high reliability with proper maintenance
	• Another system to maintain
	• May add to dwell time though calibrations can be performed to minimize this
	• Prevents direct trackside access for maintenance personnel along the full trackway in stations. Maintenance personnel may need to access the track only from certain specified areas
	• Potential legal claims if not all platforms are equipped with PEDs

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[6] *TTC (2023). Operating Statistics. Online. < Operating Statistics (ttc.ca) >*

[7] *TTC (2023). CEO's Report: August 2023. Online. < Microsoft Word - August 2023 CEO's Report Cover (azureedge.net)>*

[8] *AECOM compilation and analysis based on incident logs provided by the TTC. Section 4 provides the detailed Benefits Assessment.*

2.1.1 Economic

Numerous European and Asian systems have retrofitted their platforms with PEDs because the benefits of platform door systems were deemed to outweigh the required investment. Similarly, in Toronto, the cost of retrofitting existing subway station with PEDs is prohibitive, in part because aging stations require significant rehabilitation or structural modifications to support the additional weight of a PED structure. In the case of the Toronto Subway, the variation in Station structure and organization requires different design solutions to accommodate all stations in the system, incurring additional costs compared to a uniform system. Section 4 shows that the social and economic benefits of installing PEDs in the Toronto Subway far exceed the capital and operating costs over a 60-year horizon. However, from a strictly financial perspective, the additional revenue associated with the additional ridership in the subway resulting from greater accessibility do not outweigh the costs of PEDs, as shown in Section 5 below. In other words, the installation of PEDs will require significant government subsidy, estimated at $4 billion over 20 years.

2.1.2 Organizational

These benefits of installing PEDs in the Toronto subway align with the TTC's corporate objectives for 2024-2028:

- Build a Future-Ready Workforce.
- Attract New Riders, Retain Customer Loyalty.
- Place Transit at the Centre of Toronto's Future Mobility.
- Transform and Modernize for a Changing Environment.
- Address the Structural Fiscal Imbalance.

PEDS will increase passenger safety and reduce injuries and fatalities, thereby reducing staff trauma. Ensuring the safety and security of customers and employees is one of the six pillars that compose "the TTC Way." For several years, the TTC has made the effort of taking actions to intervene and prevent such incidents by developing the Suicide Prevention Program that helps reduce the incidence of suicide such as providing Crisis Link phones on subway platforms, organizing Suicide Prevention Working Groups, and other initiatives. In addition to the effort of minimizing suicides, the TTC has been focused on helping TTC employees such as subway operators that involved in these accidents with mental health supports. Meanwhile, the TTC is looking into the platform edge door system that is more effective on suicide prevention.

PEDS are expected to reduce the number and duration of service interruptions, thereby reducing delays for passengers, which addresses the second pillar, which states that the TTC will do all it can to keep people moving quickly, efficiently and reliably by working to minimize the impact of closures, detours and other disruptions in the community. The reduced number of service disruptions should help keep day-to-day operations more consistent and help train adhere to a more regular service schedule. Systems like TTC that utilize train operators have noted that the barriers allow for faster train speeds when entering a platform area.

As the PEDs provide a vital assurance of trackside integrity, the transit authority can allow the ATC to permit higher train speeds while approaching platforms, and the operators can follow this trend. Although inconclusive, findings seem to indicate a positive impact on operation times of around 2 secs. As platform doors prevent people from entering the trackside, so too do they prevent objects or debris from being tossed on the trackside. This reduces the delays caused from removing/retrieving such objects and preventing fire hazards. Unfortunately, no conclusive data can be provided, but anecdotal evidence, of course, points to a net positive impact on operations.

PEDs would contribute to TTC's effort to provide a cleaner, quieter, and more comfortable platform environment for passengers. This aligns with the fifth pillar, providing a clean, clear and easy to use environment. PEDS allow passengers to safely utilize the 600 tactile warning strip along the platform right up to the barrier itself without major cause for concern. This allows congested stations to offer more passenger room, and thus slightly increase station capacity. Consequently upon installation of PEDs, the usable platform space is increased by 30 square metres, which roughly translates to 18 passengers based on the TTC space planning standard for Level of Service "C", (1.39 to 2.33 m^2/p).

PEDS could also have a positive impact on the air quality within the system as well as act as a noise barrier. The extent and magnitude of the change will depend on a number of factors including station configuration, wall finishes, service frequency, etc. Table 2 below summarized the expected directional impacts of PEDs on air quality. A detailed literature review of the impacts of PEDs system on the reduction of air pollution is provided in Section 5.2 of the Feasibility Report. Regardless of which type of PED systems will be installed, a strategic ventilation plan shall be developed for the stations to control underground environments in a subway station to achieve the most desirable conditions related to air quality at the passenger accessible areas.

Lastly, train noise in stations has always been an issue that affects the hearing of passengers, transit workers, operators, and may cause noise-induced hearing loss under the long-term exposure. PEDs could act as physical barriers and block the transmission of noise generated by trains. The acoustic room response to the PEDS would likely vary between stations, depending on the overall room volume proportions and surface finishes.

Table 2: PED Configurations Compared to Air Quality in Different Areas of the Subway System

PED Configurations	¾ Height or Partial Segregation	Full Height or Full Segregation
Platform Air Quality Impact	Minimal change	Will improve
Tunnel Air Quality Impact	Minimal to no change	Will degrade
Train Car Air Quality Impact	Minimal change	Will degrade (depending on current train cars filtration system)
Ventilation System change	Minimal change (study suggested forced ventilation will help reduce PM_{10} accumulations)	Will require change or upgrades to work with PSD

Source: AECOM, 2023. Platform Edge Door Study – Feasibility Report.

2.1.3 Safety and Environment

The primary purpose of PEDs is to separate the trainway from the passenger platform and in so doing provide a safer platform environment protecting both passengers and transit employees on the platform from the tracks and train. The severity of platform level passenger accidents is greatly reduced with the elimination of slips and falls or pushing incidents that result in a track level incursion, in addition suicide attempts could be dramatically reduced. PEDs also reduce debris blown onto the tracks that may cause track fires. Evidence from elsewhere suggest that many systems equipped with platform doors have also noted a distinct reduction in suicide attempts, which approaches zero on platforms equipped with barrier doors.[9]

The space created between the train car doors and the PED system doors may present a hazard should a passenger become trapped between closed doors. To minimize risk, a minimum distance of 145 mm from the edge of the platform to the face of the PED door has been calculated.

Evidence from Abroad:

Paris Metro Network reports an average of 150 suicide attempts per year. Line 14, the only line with PEDs, has had zero attempts since its installation in 1998; and

MTRC in Hong Kong reported an average of 20 suicide attempts per year. Following the installation of PEDs on all new lines, the number of attempts dropped to zero.

Between 2017 and 2022, the TTC recorded 75 fatalities and 197 injuries resulting from unauthorized at track level or contact with trains, representing 13 fatalities and 32 injuries per year on average.[10] The number of events resulting in injuries or fatalities and subway ridership levels are negatively correlated, as shown in Figure 2. The number of events tends to decrease in years of high ridership as was the case in 2018 and increase in years of lower demand as was the case in 2020.

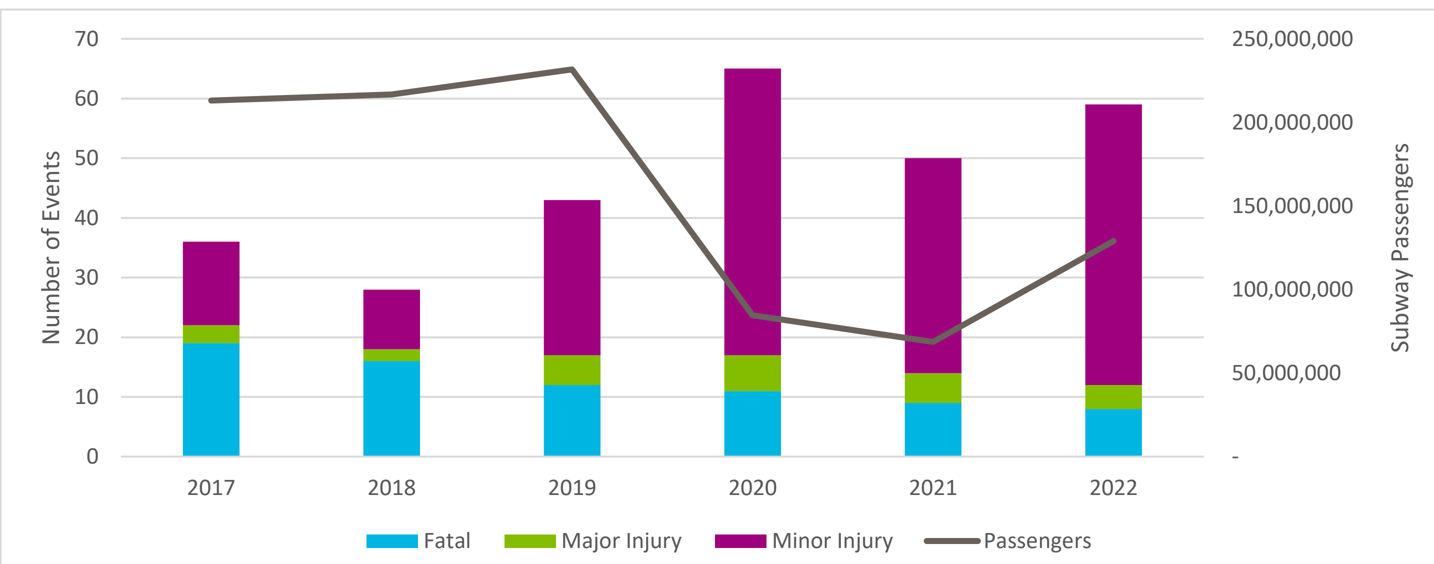


Figure 2: Relation between the Number of Injuries and Fatalities and Subway Passenger Demand

[9] *Systra Group, 2010. Platform Edge Doors Business Case Report (G85-282). 89 pages.*
[10] *Historical data provided by TTC.*

Historically, the TTC has recorded 28 suicide incidents per year on average between 2004 and 2021. However, there has been a significant growing trend since 2013. With the upward trend in recent years, the total number of suicide fatalities and attempts reached 49 in 2020 and reduced only marginally to 44 and 43 in 2021 and 2022 respectively, as shown in Figure 3.

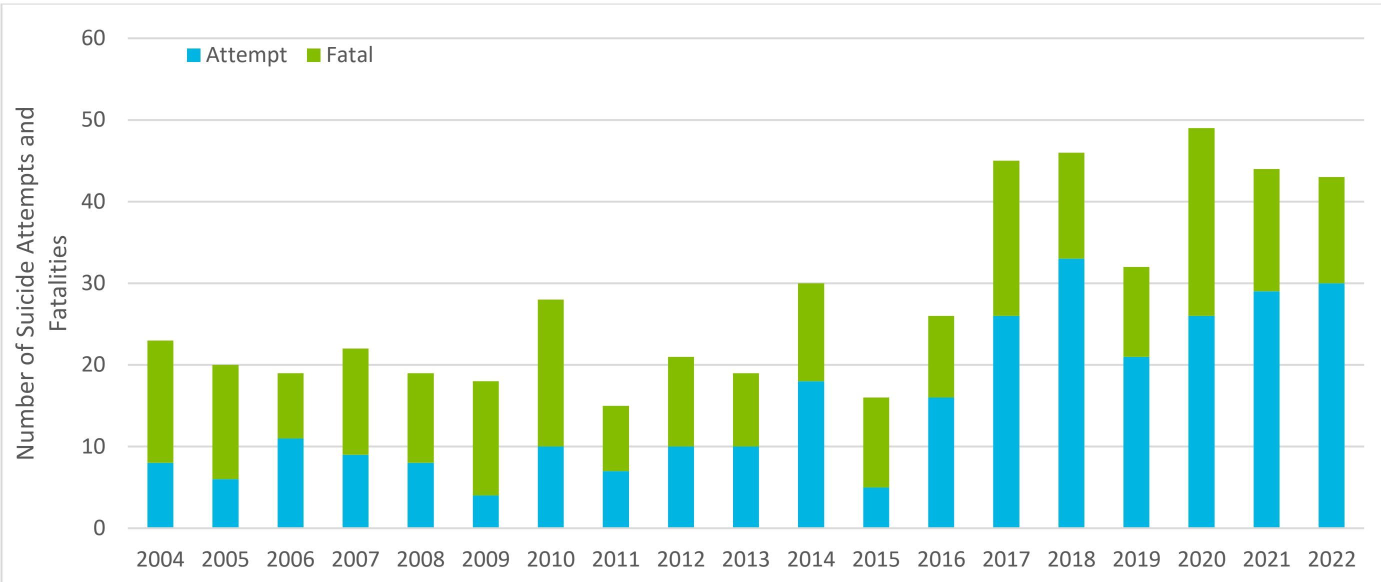


Figure 3: Suicide Attempts and Fatalities in the Toronto Subway, 2004–2022

Evidence from abroad suggests that although reducing the accessibility to subway tracks does not completely eliminate suicide attempts, it can greatly reduce the rate. Several studies have investigated the effectiveness of PEDs in preventing suicides in Japan, South Korea, Mexico, and China.

- One study in Japan suggest that half-height PEDs could reduce the number of suicides by 76% but it could not eliminate suicide completely as passengers could still climb over the barriers.
- A South Korean study indicated that the installation of PEDs had led to an 89% decrease in the number of fatal suicide cases, noting that half-height PEDs had a reduced barrier effect due to the space between the ceiling and the PEDs.
- In Mexico City, an agent-based simulation model assessed the effectiveness of physical barriers in suicide prevention and found that PEDs can effectively reduce 76% of passenger suicides.
- A study in Shanghai investigated the effects of from 2008 to 2017 for 94 metro stations. The results indicated that all types of PEDs are effective on suicide prevention. Specifically, 1.2 m and 1.5 m half-height PEDs could reduce the number of suicides by 60.2% and 79.2% respectively, while full-height PEDs could eliminate metro suicides completely by fully separating the platform from the track area.

Error! Reference source not found. provides a summary of a literature review conducted to identify and assess the p otential benefits of PEDs.

Figure 4 compares the total number of fatalities for a sample of subway systems Worldwide. The arrow identifies Toronto, which ranks amongst the systems with the highest recorded number of fatalities, with results very similar to those observed in Montreal, New York, and Vancouver.

Table 3: Key Findings from the Literature Review on the Economic Benefits of PEDs

Title	Year	Source	Abstract	Key Findings
Evaluating the Effectiveness of Platform Screen Doors for Preventing Metro Suicides in China	2019	Journal of Affective Disorders	This study examines and compares the effectiveness of different types of platform screen doors (PSDs) (e.g. full-height and half-height) in contributing to the decrease in metro suicides, including fatal and nonfatal cases. The analysis uses a Poisson regression model and monthly suicide data provided by the Shanghai metro operator for 94 subway stations from 2008 to 2017.	The analysis shows that the number of metro suicides declined by 90.9% after the installation of PSDs (all types combined) at subway stations. Full-height PSDs can eliminate metro suicides by completely preventing passengers from entering the track area, while half-height PSDs of 1.5 m and 1.2 m high reduce the number of suicides by 79.2% and 60.2%, respectively. Moreover, the study did not find any significant indication that the installation of PSDs at subway stations displaced suicides to stations without PSDs. The authors also found safety risks associated with the use of PSDs. For example, in 2014, someone was caught between the PSDs and the doors of the train and was crushed to death. The authors recommend that PSDs be equipped with effective detecting systems that automatically open the doors if an object is caught between them.
The Combined Effect of Platform Edge Doors and Level Access on Boarding and Alighting Process in London Underground	2016	Transport for London	This study aims to bridge the gap in research on the effect of PEDs on boarding and alighting time (BAT) and passenger behaviour patterns. The analysis of the boarding and alighting processes is based on observations made on video footage recorded under actual operating conditions at two London Underground platforms. The BAT were corrected to eliminate the effect of "late runners", i.e. passengers boarding the train after the main group has already boarded. This helps to remove the impact of longer dwells which are to do with the train being held at the platform rather than with passenger movements, which are the focus of this analysis.	The study found that BAT was generally 16% lower at without PEDs compared to those at a station with PEDs. However, when the impact of changes in demand is taken into account, the additional BAT with PEDs is approximately 1% higher when the total number of boarders and alighters is between 0–25 and 7% higher when the total number of boarders and alighters exceeds 25. The results also show that PEDs seem to have an important effect in encouraging passengers to wait beside the doors when demand is low (0 to 15 boarders) and when it is high (>25 boarders), but not when demand is at medium level. Conversely, when demand is low, PEDs have a positive impact on deterring passengers from waiting in front of and beside the doors and therefore could be useful in controlling crowded situations.

Title	Year	Source	Abstract	Key Findings
Operational Impacts of Platform Doors in Metros	2018	Journal article prepared for the Transportation Research Board Record 2018, Vol. 2672(8)	This study investigates and quantifies the impact of platform doors on station dwell times as well as other operational impacts on subways. The study uses data from a large database of survey results collected on a rolling basis over the past 15 years, and questionnaire responses from a detailed case study conducted in 2013 about dwell time management.	Overall, platform doors have a net negative impact on dwell times, leading to between 4 and 15 seconds of extra time per station stop. This is due to: 1. The additional time required for the larger doors to open and close, 2. Slower passenger movements due to the additional distance between platforms and trains; and 3. Extended departure delays after both sets of doors are closed caused by the need to ensure safety (that no one is trapped in the gap between the two sets of doors). The authors also found that the impact of additional dwell time is offset by the many benefits of PEDs, consisting of: 1. Removes the risk of an incoming train striking a passenger that reduce delays and improve service performance; 2. Reduces delays associated with retrieving or removing objects, as well as the prevalence of track fires. 3. Full-height PEDs limit airflow from tunnels into stations, which helps control heating, ventilation, and air conditioning, thereby reducing energy use. If subways have manual driving, then platform doors can enable faster train speeds when entering stations. Anecdotal evidence from surveys suggests that this could potentially save 2 seconds per station.
Installation of Platform Screen Doors and Their Impact on Indoor Air Quality: Seoul Subway Trains	2014	Journal of the Air & Waste Management Association	This study investigates the change in particulate matter (PM_{10}) at indoor subway stations before and after the installation of PEDs in Seoul, South Korea. Specifically, the authors seek to confirm the following hypothesis: particulate matter concentrations on the platform decreases after installing PEDs by preventing particles suspended by the train-induced wind in the tunnels from flowing into the	This study revealed that air quality at subway stations improved following the installation of PEDs. However, the air quality in trains was negatively impacted by PSDs with PM_{10} concentrations increasing by 29.9%. The increase in PM_{10} levels inside the trains is influenced by tunnel depth and the length of the underground segments. Moreover, concentrations further increased after all stations along a line were equipped with PEDs. The authors recommend the installation of appropriate ventilation systems inside the subway trains and tunnels to reduce passengers' exposure and to protect public health.

Title	Year	Source	Abstract	Key Findings
			platforms. The authors measured PM10 and PM2.5 concentrations using mini-volume air samplers with cellulose filters. Each sample was collected for 11 hr (from 7 a.m. to 8 p.m.) at a flow rate of 5 L/min.	
Change of Acoustic Characteristics Caused by Platform Screen Doors in Train Stations	2012	Journal of Applied Acoustics	The aim of this study is to clarify the effects of PSDs on acoustic characteristics. Train noises were recorded in ground and underground train stations with mobile full-height (MFH) PEDs, mobile half-height (MHH) PEDs and without PEDs.	The study found that MFH and MHH reduced the train noise level by approximately 2 dB and 1 dB at aboveground stations. In underground stations, MFH reduced the train noise level by approximately 5 dB in come intervals and 3 dB in go intervals. MHH reduced the train noise level by approximately 6 dB in come intervals and 5 dB in go intervals. The authors also noted that PSDs made train noises more diffused and blocked the lower frequency components of train noises.
Assessment of various critical incident management and support protocols for railway employees after a serious incident	2018	Institut de recherche Robert-Sauvé en santé et en sécurité du travail	This study assesses various critical incident (CI) management and employee support protocols in the railway industry.	Locomotive engineers and train conductors will face an average of four critical incidents resulting in fatalities or serious injuries during the span of their careers. The effects experienced may range from slight, temporary discomfort to serious symptoms, and may even evolve into mental health disorders. These effects are major and affect cognition (concentration, rumination, distraction), energy (fatigue, insomnia) and emotions (guilt, grief) of the personnel involved in a CI. They may also interfere with their ability to perform their work optimally. More than 15% of these employees will experience more severe problems, including depression, acute stress or post-traumatic stress disorder, or anxiety disorders.

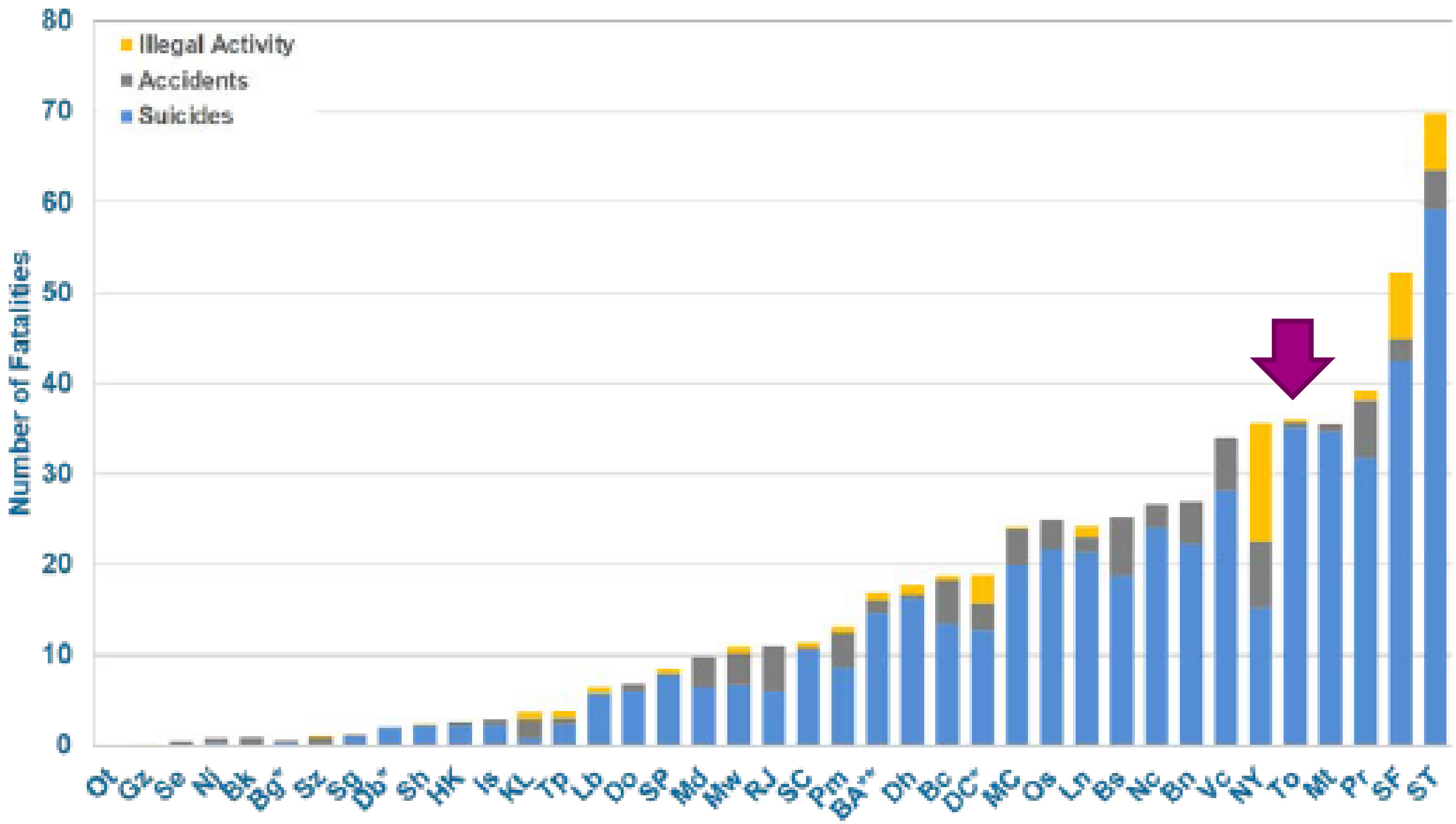


Figure 4: Total Fatalities per Billion Passenger Journeys (Average 2010-2019)

Source: The Community of Metros (comet and Nova). 2020 Final KPI Report.

2.1.4 Accessibility

PEDs are expected to generate travel time savings for subway users by reducing the frequency and duration of service interruptions. The increased reliability should attract new users to the network, thereby reducing reliance on the automobile. However, the extent of the shift towards subway is relatively low, as detailed in Section 6.

The installation of PEDs also aligns with the goals and objectives pursued in the 2019–2023 TTC Multi-Year Accessibility Plan.[11] More specifically, the installation of PEDs reduces the horizontal gap between the platform and the train, which reduces risks of tripping and inconveniences for mobility-challenged passengers. PEDs also provide a physical barrier which can assist blind or visually impaired passengers.

2.1.5 Processes and Technology

The investment scenario recommended in the Feasibility Report consists of retrofitting 74 existing subway station platform levels with automatically operated door panels fixed to the platform edge and aligned at the train berthing locations, to provide a physical barrier between passengers on the platform and the trackside. Sections 3 and 7 provide more details on the new technology considered for PEDs, as well the Feasibility Report contains the detailed assessment by station.

The next section summarizes the alternative PED designs and implementation strategies assessed in the Feasibility Report and defines the recommended solution.

[11] *TTC (2019). 2019–2023 TTC Multi-Year Accessibility Plan. https://www.ttc.ca/About_the_TTC/Commission_reports_and_information/Commission_meetings/2019/May_8/Reports/2019-2023_TTC_Mulit-Year_Accessibility_Plan_Presentation_upd.pdf*

3. Proposed Solution

This section summarizes the alternative PED designs and implementation strategies assessed in the Feasibility Report and identifies the recommended solution.

3.1 Proposed Design

The consulting team developed a combination between full-height and half-height systems. The barrier design is envisioned to be “full-height” in terms of door size and the use of door headers above the barrier, but “half-height” in the sense that the industry definition states that half-height doors do not reach fully to the ceiling. Instead of extending the top portion of the PED to the ceiling (which would be a problem in some of the TTC platform types. This solution has been named “full height, partially segregated” PEDs.

The 74 station platform levels including interchange stations under investigation were grouped into seven categories based on similar characteristics and issues so as to limit the number of PED solutions to be developed for the entire system. Refer to the Feasibility Report for further details on the proposed solution.

3.1.1 Station Retrofits

During Phase 1 on this Study, a number of significant issues were observed that are common to varying numbers of stations. The resolution of some of these issues will require station upgrades to rectify the problem as part of the PED implementation.

Deteriorated Platforms: A number of platforms are in poor condition and will require significant rehabilitation which may include reconstruction of the cantilever portion or complete replacement of the platform slab. The nature of this work in an operating station will require a lengthy schedule or may necessitate alternative construction solutions such as replacement with precast units. Kennedy Station is a good example of a station with deteriorated platform.

Rock Swelling: A couple of early stations on Line 1 (e.g., King Station, St. Patrick Station) were constructed with platforms directly upon bed rock (no base slab), subsequent rock swelling has led to the platforms shifting and cracking, while it is contemplated these platforms will be restored any future swelling could impact PED function.

High Ceilings/ Roof Structure: The vertical structure incorporated in PED systems are generally small in cross section to minimize obstructions to platform passengers or emergency breakaway panels, tall ceilings/ roof structure such as those found at Sheppard West Station may preclude lateral bracing at the top and necessitate a cantilever design.

Insufficient Electrical Isolation Zone: A number of stations such as Davisville have less than the 2.3m clear dimension from the platform edge to the nearest station element as per the current TTC approach for electrically isolating and alighting (and potentially charged) passenger sufficiently from the station ground.

Stations Without Base Slabs: Stations constructed with grade beams or other systems do not offer a base slab that may serve as bearing/ anchorage for PED system columns. Rosedale Station is an example of a station built without a base slab.

3.1.2 Required Platform Modifications

The installation of PEDs will require platform modifications. The Feasibility Report includes replacement of a portion of platform floor finish in front of each sliding door unit with new tiles designed to provide guidance to passengers on where to stand while waiting for the train, along with directional arrows to allow for improved passenger flow while entering and exiting the train. The indicative PEDs design is nominally 400 mm deep, leaving 200 mm on the platform side that will be refinished with new granite or terrazzo tile. At stations where the platforms are too low relative to the train door threshold, the difference in height can be adjusted by installing the adjacent floor finish (the proposed demarcation zone in front of the sliding doors) at a slope to provide level boarding for customers using mobility devices.

3.1.3 PED Control Room Modifications

PED implementation will require a PED control room at every station. The design shall take advantage of the existing emergency response rooms (which are made redundant with PEDs) or another suitable vacant or underutilized room near the ends of the platform. One room will serve both platforms and house all the control equipment to run the PED system. The PED control system will also require a Local Control Panel (LCP), which provides the ability for an authorized TTC employee to control and monitor the PEDs directly from the platform (as may be required for maintenance activities or to support in degraded modes of operation). LCPs are typically placed at each end of a platform to control and monitor the corresponding PEDs. While it is possible to install these LCPs in the station equipment rooms with the rest of the PED hardware, it would be far more practical if they were to be installed right on the platform beside the PED structure. A TTC employee would have a clear view of the PEDs while manipulating the control functionality of the LCP since they are designed with line-of-sight considerations in mind.

3.1.4 PED Grounding Approach

The installation of PEDs will introduce two distinct scenarios for potential shock hazard. First, a passenger or maintenance person may touch a PED and the train at the same time. Second, a passenger or maintenance person may touch a PED and a metallic station element at the same time. Both of these scenarios could result in the risk of shock due to voltage difference, and they will need to be considered in the design. Several options for PED grounding schemes are available that take these two hazard scenarios into account. The Feasibility Report recommends applying insulation/dielectric coatingto the entire PED.

3.2 Cost Estimates

The section summarizes the anticipated lifecycle costs include the capital investment, ongoing operations and maintenance and workforce changes.

3.2.1 Project Costs

The TTC estimated the capital cost to retrofit the 74 subway station platform levels including interchange stations with PEDs at $4.1 billion in 2036 dollars, including taxes and assuming a construction sector-specific annual inflation rate of 2.50%.

The TTC prepared cost estimate by pairing each of the 74 station platform levels including interchange stations with one of four structural solutions and a standardized PED system along with minimum but necessary station modifications. A PED system controller and associated room and services have been identified for each station and similarly included in the costing exercise. No specific LEED designation is targeted but the project will meet all applicable codes and standards. A class 5 Cost Estimate typically has a project maturity level of 0%-2% and a low expected accuracy range of -20%-50% and high range of +30%-100%. In other words, bid results might vary by this amount if the construction budget were set at this milestone estimate. The costs include the following: construction costs plus 20% for engineering and management costs, 15% for contract change allowance, 25% contingency allowance and 1.76% non-refundable HST rebate. The costs are then projected to approximate mid-point of construction (2036).

For the purposes of the Business Case Study, the capital cost estimates are converted to 2023 dollars by removing the inflation and the taxes, which reduces the estimate to $2,924 million. Table 4 presents the proposed phasing and the annual and cumulative capital expenditure over the construction period which is assumed to extend between 2026 and 2042, with the retrofit of 4.4 stations on average per year.

Table 4: Capital Cost Estimates for Retrofitting all 74 Ex. Station Platform levels with PEDs (in millions of 2020 $)

Year	No. of stations	Stations Cumulative	Construction Start Date	Capital Cost ($M)	Capital Cost Cumulative ($M)
Pilot Project	4.0		2026	$158	$0
1	3.7	8	2027	$146	$304
2	3.7	11	2028	$146	$449
3	3.7	15	2029	$146	$595
4	3.7	19	2030	$146	$740
5	3.7	22	2031	$146	$886
6	3.7	26	2032	$146	$1,032
7	3.7	30	2033	$146	$1,177
8	3.7	33	2034	$146	$1,323
9	3.7	37	2035	$146	$1,468
10	3.7	41	2036	$146	$1,614
11	3.7	45	2037	$146	$1,759
12	3.7	48	2038	$146	$1,905
13	3.7	52	2039	$146	$2,051
14	3.7	56	2040	$146	$2,196
15	3.7	59	2041	$146	$2,342
16	3.7	63	2042	$146	$2,487
17	3.7	67	2043	$146	$2,633
18	3.7	70	2044	$146	$2,778
19	3.7	74	2045	$146	$2,924

3.2.2 Life Cycle Costs

Once PEDs have been installed and commissioned in the TTC system, it will be imperative for the system to be properly maintained to ensure correct and reliable operation. Since the PEDs will require several new maintenance activities at each station in which they are installed, TTC will likely need to expand their existing maintenance capabilities through the hiring of additional staff. The exact staffing needs will be dependent on the current TTC workforce (at the time PED commissioning), the number of stations in which PEDs are installed, and the manufacturer recommended maintenance items of the product that TTC ultimately selects. The specific maintenance items and prescribed maintenance schedule for a PED product will be recommended by the selected PED supplier and defined during the actual PED design project.

However, for the purpose for the Business Case Report, it is assumed that that the annual operation and regular maintenance will require one additional full-time employee for every three stations. Assuming an annual salary of $75,000 results in additional costs of $25,000 per station per year. An additional provision of $15,000 is included for additional material and electricity costs, for a total annual spending of approximately $40,000 per station or $3.0 million per year for the entire system.

Major rehabilitation of the PED should be necessary after 30 years of operation, with costs estimated at 10% of the capital costs. This rehabilitation program would begin in 2056 and extend to 2075 at a cost of $18 million per year in 2023 dollars.

The next section identifies and quantifies the economic benefits that can be compared against the project costs to determine the net benefit of the project for society.

4. Economic Benefits Assessment

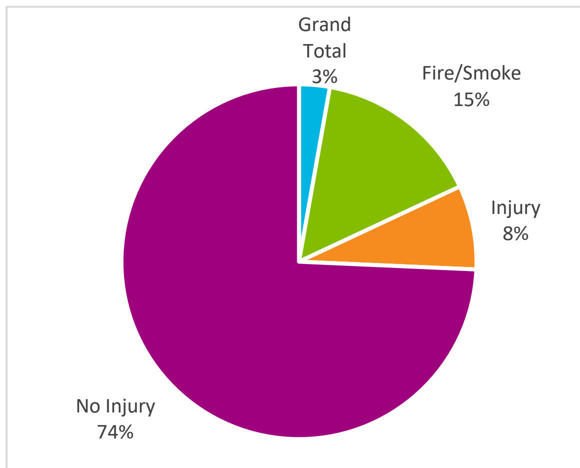
This section assesses the overall economic value generated by the installation of PEDS in the Toronto subway using a cost-benefit analysis framework.

The cost-benefit analysis considers the following four categories of benefits:

1. Avoided Passenger Injury and Loss of Life
2. Passenger Delay Reductions
3. Emergency Response Cost Savings
4. Employee Health Improvement

Once quantified and monetized, the benefits are projected over 60 years and discounted back to a single value, which is compared against the discounted project costs to determine the net value creation for society stemming from the investment in PEDs. Appendix A summarizes the baseline assumptions and data sources.

Benefits are evaluated relative to a Business as Usual (BAU) Scenario. The BAU represents a continuation of the current conditions in the future with increasing number of service interruptions, passenger delays, staff and passenger injuries and fatalities, and their associated cost to society. The benefits thus represent the avoided cost of these impacts for society. The benefits assessment is based on a compilation of 2,689 events recorded and provided by the TTC between 2017 and 2022. The records include the date and time of incident, type of incident (code), corresponding delay, the service line and station where the incident occurred for the majority of events. Events involving smoke and fire represented 15% of the total, 74% of events resulted in no injury, 8% of events resulted in minor or major injury, and 3% of events resulted in fatality.



For analysis purposes, the reported incident types were restricted to the incidents that could be partially or fully prevented by the implementation of PEDs. The analysis relied on the following prevention rates established in collaboration with the TTC to denote the effectiveness of PEDs in preventing each type of incident:

- Fire/smoke Plan B: 25% prevention rate (i.e., 1 in 4 events can be prevented with PEDs)
- Door problems caused by passengers: 50% prevention rate
- Passenger-related incidents: 100% (with the exception of fatal suicide attempts)

4.1 Avoided Passenger Injury and Loss of Life

The introduction of a complete barrier between the tracks and the platform will eliminate accidental and voluntary passenger track intrusions and thus reduce, or even completely eliminate injuries and fatalities resulting from track intrusion. Between 2017 and 2022, the TTC recorded 75 fatalities and 206 injuries resulting from fall to the track level, an average of 13 fatalities and 34 injuries per year. Table 5 summarizes the number of fatalities and injuries recorded by the TTC between 2017 and 2022.

Table 5: TTC Subway Service Interruptions Resulting in Injury and Fatality, 2017–2022

	Fatal	Major Injury	Minor Injury	Total
2017	19	3	14	36
2018	16	2	10	28
2019	12	5	26	43
2020	11	6	48	65
2021	9	5	36	50
2022	8	4	47	59
Total	**75**	**25**	**181**	**281**
Annual Average	**13**	**4**	**30**	**47**
Share of total	**26.7%**	**8.9%**	**64.4%**	**100%**

Source: AECOM analysis based on historical data provided by TTC.

Injuries and fatalities not only cause physical and emotional burden to the victims, their families and friends but also have economic costs for individuals, employers, and the society. The total cost to society is thus comprised of both direct costs and indirect costs such as medical costs and human capital costs. The Treasury Board of Canada's Cost-Benefit Analysis Guide uses the following values (adjusted to 2023$)[12,13]

- Fatality: $9.7 million
- Major Injury: $1.2 million
- Minor Injury: $44,500

Applying these values to the number of events that could have been prevented with PEDs indicates that between 2017 and 2022, **fatalities and injuries in the subway have cost society $120 million on average each year.** Under the BAU scenario, this cost is expected to grow at 1.5% per year on average, following subway ridership growth. It is assumed that PEDs will prevent 100% of accidental and unlawful track intrusions. However, in cases of suicide attempts, the analysis considers that a quarter (25%) of suicide attempts resulting in fatalities cannot be prevented. In total, if PEDS were installed today, they could result in cost **savings of $92 million** and save more than ten lives per year. These figures are considered conservative as they do not include the potential trauma and stress endured by passengers who may witness incidents.

[12] *Transport Canada (2020). 2020 statistics on the social costs of collisions in Canada. On line. https://tc.canada.ca/en/road-transportation/statistics-data/statistics-data-road-safety/2020-statistics-social-costs-collisions-canada*

[13] *Based on Canadian Consumer Price Index from Statistics Canada, Table 18-10-0004-01 Consumer Price Index, monthly, not seasonally adjusted.*

4.2 Passenger Delay Savings

By preventing unlawful track intrusion and falls to track levels, PEDs will result in fewer service interruptions in the subway network. The 2,689 events recorded between 2017 and 2022 are estimated to have caused 864 hours of service interruptions, averaging 144 hours per year. Recorded service interruptions vary between 2 minutes and 382 minutes, with an average of 19 minutes per event. Together, passengers impacted by these service interruptions lost 204,900 hours per year on average. Without any intervention, passenger delays are likely to continue increasing in the future as the number of incidents and the number of passengers using the subway continues to grow. However, the installation of PEDs could have saved up to 174,200 hours (or 85% of total passenger delays) per year. By avoiding these delays, passengers could have used their time for more productive use, representing **savings of $16 million per year in passenger delay**.[14] The approach used to estimate passenger delay savings is summarized below.

In addition to passengers on the train, the interruption will affect those waiting at the platform to board and those arriving during the shutdown at the affected station as well as at all stations between the impacted station and the next train turnback station in the network. Events involving a fatality or smoke and fire will typically impact both directions, whilst injuries or material falling to the track will impact only one bound.

Average Service Interruption Duration per Event Category:

- Fatal: 111 minutes
- Fire/Smoke: 22 minutes
- Major Injury: 54 minutes
- Minor Injury: 29 minutes
- No Injury: 14 minutes

During shutdowns, impacted passengers can either walk to their destination, wait at the station or take a shuttle bus service to the next station in service, when service interruptions last more than 25 minutes, with the exception of the station located in the "U". As per discussions with TTC staff, if there is a delay where half of the "U" is affected (Bloor to Union, St. George to Union) and the delay is expected to be under two hours in duration, shuttle bus service will not be provided. As per TTC staff, if the delay affects the whole "U", or is expected to be over two hours in length, then shuttle bus service may be implemented, however, no such events were found in the records. Therefore, the analysis assumes that shuttle buses are not deployed in the "U". Refer to Appendix A for more details on the methodology.

The analysis considers the additional travel times associated with the lag for PEDs to open and close. Generally, platform doors are wider than the train doors by approximately 22% to 48%, they are both heavier and slower to close. The larger size of platform doors cause delays of 1 to 2 seconds.[15] Given that the median length of suway trips in Toronto is 6.5km and the average distance between stations is approximately 0.95km, subway passengers travel 6.9 stations on average per trip, the PED are estimated to add 2 seconds at every station. The additional dwell time leads to **travel time penalties of more than $60 million** per year once PEDs are fully deployed. It should be noted that PEDs also impact passenger behaviour, particularly when queuing up to board on the platform. Since many passengers view PEDs as "automatic" rather than being controlled by a human operator, the passengers may avoid trying to trip a door recycle. Additionally, PEDs may tend to make dwell times more consistent, which could improve regularity when extrapolated across the system.

[14] *Total passenger delays are multiplied by a value of time of $18.42 per hour in 2019$ based on Metrolinx, 2019. Business Case Manual Volume 2 : Guidance. Table 5.1 Economic Parameters, page 86. Online. <http://www.metrolinx.com/en/regionalplanning/projectevaluation/benefitscases/Metrolinx-Business-Case-Guidance-Volume-2.pdf>.*

[15] *Barron et al., Operational Impacts of Platform Doors in Metros, Transportation Research Record 2018, Vol. 2672(8) 266–274.*

4.3 Emergency Response Cost Savings

Each year, service interruptions incur additional operating cost for the TTC. This section assesses the additional operating cost specifically associated with events that entailed emergency shuttle bus deployment. Of the 2,689 events recorded between 2017 and 2022, 379 events (14%) required emergency shuttle buses, which caused an additional 2,239 vehicle kilometres travelled on average each year.

The TTC provided closures and diversions costs for past events which average $400,000 per event, or $25.3 million annually.[16] The total cost associated with the shuttle bus deployment With the installation of PEDS, the number of events could have been significantly reduced resulting in **annual savings of $19 million**. The balance represents the cost of events that could not be prevented by the installation of PEDs.

The assessment assumes that shuttle buses are deployed after 25 minutes (i.e. the first riders step onto the bus 25 minutes after the shutdown at the subject station) and run until the subway is back into service or until all riders have been transported to the next station in operation (whichever comes first assuming a bus capacity of 45 riders, the maximum for accessible 12-metre buses[17]). Shuttle buses are assumed to complete round trips between the impacted stations and the next station in service to minimize the number of shuttle buses required, however, the minimum number of buses allows for a dwell time to fill up the bus and leave with another bus waiting right behind and so on until the first bus comes back to the subject station. The number of buses varies depending on the number of stations impacted and the time it takes a bus to do the round trip and come back to the subject station to pick up riders again. The reduction in annual bus VKTs could alleviate 2.2 tonnes of Greenhouse Gas Emissions each year. However, given that the ongoing transition towards an electric fleet will be almost complete before the end of the PEDS installation, future cost savings associated with GHG emissions reductions are not considered in this analysis.

4.4 Employee Health and Safety Prevention

Subway incidents resulting in injuries and fatalities not only affect the victims and their families but also affect subway workers and operators who have witnessed the incidents. They have been reported to have a higher chance of developing Post-Traumatic Stress Disorder (PTSD) and it is difficult for them to return to work due to the long-lasting psychological trauma. The TTC records lost-time injuries rate (LTIR) on a continued basis. The indicator represents the number of lost-time due to injuries reported per 100 employees. According to the past TTC CEO's Report the LTIR has grown 12% per year on average between 2017 and 2023, culminating with 932 injured employees in 2022. Of course these include all TTC employees and all types of events. According to the TTC, acute emotional injuries caused by sudden and expected traumatic events account for 16% to 17 % of all lost-time injuries since 2014. Assuming that trauma events occurring in the subway represent 43% of all events and an average leave of 40 days per employee results in more than 2,300 days of work missed by employees due to traumas. Removing the impacts of events that could not be prevented by the installation of PEDS results in an average of 1,446 days of leave that could be avoided each year, representing a **cost saving of close to $800,000** in insurance claims and losses to the TTC each year.

Figure 5 shows the evolution of the annual Lost-Time Injuries recorded by the TTC since 2015.

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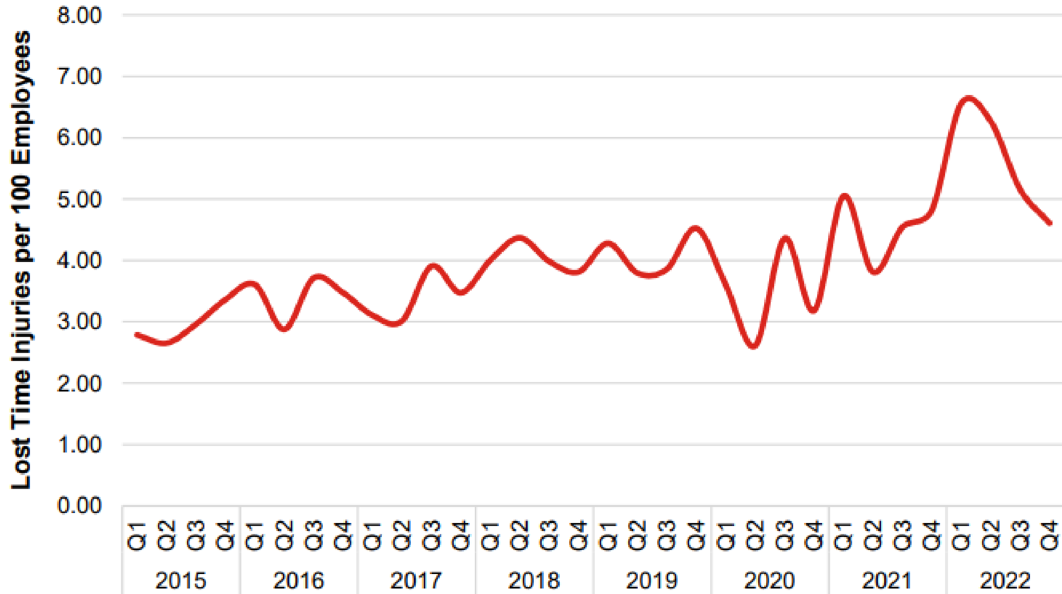
[16] *TTC, 2023. RFI 2_Subway Closure Cost Estimates.*
[17] *TTC, 2023. Operating Statistics. Online < Operating Statistics (ttc.ca)>*

Figure 5: Lost-Time Injuries Rate in 2014 – 2022



Source: TTC, CEO's Report - July 2023.

4.5 Benefit-Cost Analysis Results

The cost-benefit analysis compares the project benefits against the project costs to derive the net value creation for society over a 60-year evaluation period. The benefits described and quantified above are considered to represent the baseline year conditions (i.e., the benefits to society if PEDs were installed in 2023) using the average annual results for the 2017 to 2022 period. Table 6 recapitulates the annual cost to society of not having PEDs under the BAU and the estimated annual savings associated with PEDs for the baseline year. In total, PEDs could save up to $128 million in cost to society during the baseline year.

Table 6. Economic Benefits of PEDs for the Baseline Year

Benefit Category	Cost under BAU	Cost With PEDs	Annual Saving with PEDs relative to BAU
Public Health and Safety	$119.2M	$27.0M	$92.2M
Passenger Delays*	$10.3M	-$5.7M	$15.9M
Emergency Response	$1.2M	$0.5M	$0.8M
Employee Health	$25.3M	$6.2M	$19.0M
Total	**$156.0M**	**$28.1M**	**$127.9M**

*Excludes impact of additional train dwell time.

These results are then projected over the horizon time to determine total annual benefits. For simplicity, the analysis assumes that ridership, number of events and savings will grow steadily at a rate of 1.5% per year for the first 30 years of operations and remain constant thereafter. Benefits are also assumed to ramp up to maturity over the 20-year construction period, increasing proportionally to the cumulative number of PED-equipped stations until all 74 station platform levels including interchange stations have been retrofitted. The benefits are then summed and discounted to a single present value figure using a 3.5% discount rate.

Table 7 below presents the results of the economic cost-benefit analysis. The results are reported as ranges to reflect the results of sensitivity analyses performed on key variables. The lower bound assumes an annual ridership growth rate of 1.5% and a construction inflation rate of 3.0% per year while the higher bound assumes ridership will grow faster at 2% per year on average and inflation in the construction sector will increase 2.5% per year on average (in nominal terms)). These sensitivity tests show that the economic cost-benefit analysis results are highly sensitive to small changes in baseline assumptions.

In total, over the 60-year evaluation period, benefits amount to between $2.3 billion and $2.7 billion in present value terms. The lifecycle costs are estimated between $2.1 and $2.4 billion in present value terms (in real terms, using a social discount rate of 3.5%).

Over the evaluation period, the installation of PEDs will result in a net benefit for society with a positive net present value exceeding $500 million for society with a benefit-cost ratio (BCR) that could reach 1.24, which indicates that every dollar invested in the project will create $0.24 in added value to society. Appendix B presents the detailed results on an annual basis throughout the evaluation period.

Table 7: Benefit-Cost Analysis Results

Category	2023 $Million, Present Value
Benefits	
Public Health and Safety	2,097 – 2,486
Passenger Delays	-273 – -339
Employee Health	26 – 26
Emergency Response	433 – 513
Total Benefits	**2,283 – 2,686**
Project Costs	
Capital Costs	2,077 – 1,943
Major Maintenance and Refurbishment	234 – 187
Operations and Maintenance	41 – 41
Total Costs	**2,353 – 2,172**
Net Present Value	**-70 – 514**
Benefit Cost Ratio	**0.97 – 1.24**

5. Financial Viability Assessment

In addition to the cost-benefit analysis, which provides an indication of the project's performance in terms of value creation for society, the analysis also assesses the financial impacts of the project in terms of net revenue for the organization. The Financial Assessment compares the incremental capital expenditures, operating and maintenance costs and fare revenues relative to the BAU scenario. The dollar figures for the 60-year evaluation period are in nominal dollars (i.e., the dollar figure expected to be paid or received expressed in the year of the payment). Nominal dollars are calculated assuming an annual inflation rate of 2%. The annual costs and revenues are discounted back to a single value using a nominal discount rate of 5.5%. Once discounted, the total costs are compared against the incremental revenues to derive the net present value for the financial case as well as the life cycle revenue to cost ratio and the operating cost recovery ratio. Appendix A summarizes all the financial baseline assumptions and data sources.

5.1 Incremental Revenue

The improved service reliability associated with avoided interruptions are expected to attract new riders to the subway network. The extent of the shift depends on the sensitivity of users to changes in travel times. The incremental ridership is estimated by applying an elasticity measure of -0.705[18] (i.e. the responsiveness of users to changes in travel costs) to the average travel time saving per passenger (for the entire system) to determine the additional demand resulting from the installation of PEDs. The results suggest that PEDs could attract more than 900,000 new passengers per year once all stations have been retrofitted. It should be noted that these numbers are indicative, and that further analysis should be conducted to refine the assumptions. The analysis assumes that additional passengers will contribute $3 each to the TTC's farebox revenue (average concession fare per trip).

Other transit agencies have considered ways to increase revenue through advertising methods that incorporate the PED structure itself. Some systems that do not currently have PEDs installed use the back wall of subway stations behind the tracks as advertising space that can target passengers waiting on the platform. However, this results in a need for trackside access every time the advertisements are due to be changed. If PEDs were to be installed, these advertisements can instead be moved closer to the waiting passengers on the platform-facing side of the PED structure. This provides a much easier way to change advertisements since trackside access would no longer be required. Since the PED structures are closer to passengers than the back wall of the station, this also allows for smaller and more compact ads, which results in the ability to accommodate more ads into the passengers' visual field (and therefore can create additional revenue). The non-operating glass panels on PEDs can also accept changeable electronic advertising screens, which provides an even easier method of swapping out advertisements. A side benefit of using electronic screens for advertising is that the screens can also be used to display important system-related information when necessary (special service announcements, special events, subway closures, etc.).

[18] *Based on findings from the Fares Market Research Report prepared by AECOM for Metrolinx in May 2017.*

5.2 Net Revenue

The total incremental fare revenue of close to $60-$70 in present value terms over the evaluation period is not enough to outweigh the project costs over the 60-year evaluation period. In addition to the additional farebox revenue, the TTC will save $80 million in operating cost savings from avoided emergency services and shuttle bus deployment, which are enough to offset the additional staff and energy costs for operating the PEDs.

The results are reported as ranges to reflect the results of sensitivity analyses performed on key variables. The lower bound assumes an annual ridership growth rate of 1.5% and a construction inflation rate of 3% per year while the higher bound assumes ridership will grow faster at 2% per year on average and inflation in the construction sector will increase 2.5% per year on average). All figures are discounted at a rate of 5.5% (i.e., nominal discount rate).

Table 8: Financial Viability Assessment Results

Category	Millions of dollars, Present Value
Revenue	**57 – 67**
Costs	
Capital Costs	2,091 – 1,958
Refurbishment	98 – 78
Operating and Maintenance Costs	43 – 43
Emergency Response Cost Savings	-75 – -88
Employee Health Savings	-13 – -13
Total cost	**2,143 – 1,978**
Net revenue	**-2,200 – -2,045**
Operating Cost Recovery Ratio	**124% – 115%**

6. Deliverability and Operations

6.1 Project Scope

The scope of work for the installation of PEDs at each of the 74 existing station platform levels including interchange stations along Lines 1, 2 and 4 includes but is not limited to installing the PED system with support frame work and nonconductive cladding, modifying existing emergency response room into PED Control Room, required mechanical and electrical systems modifications, and/or new implementations. No specific LEED designation is targeted but the project should meet all applicable codes and standards.

6.1.1 In Scope

The major components included in the scope of work for this project include the following:

- PED system installation with support frame work and nonconductive cladding;
- Existing emergency response room (ERR) modification into PED control room. At stations not currently equipped with an ERR, the PED control room can be installed in any vacant room on platform level, or on the concourse.
- Other required mechanical, electrical, and communication systems modifications; and
- New implementations;
- PEDs testing and roll out; and
- PEDs maintenance and operations.

6.2 Project Assumptions

This section discusses the main assumptions (i.e., unverified or unknown aspects) identified at this stage.

6.2.1 Applicable Standards

A number of reference documents and design manuals were reviewed as part of the Platform Edge Doors Study. However, the research did not find any Canadian standards containing design requirements specific to a PED system. CENELEC, the European Committee for Electrotechnical Standardization, is currently revising a PED systems-specific standard (EN17168). For projects in the American market and some Chinese and European projects, it is typical for an American Automated People Mover (APM) standard known as ASCE21-13 to be used for the design of PED systems. Although ASCE21-13 is specifically an APM standard, it contains measurable criteria for PED systems and was adopted for systems similar to TTC. ASCE21-13 was used to define criteria used in the Feasibility Report.

6.2.2 Safe and Proper Grounding of the PEDs

When designing a PED system for retrofitting on an existing railway, thorough consideration needs to be given to the grounding scheme. The steel wheeled TTC trains operate on 600VDC and use running rails, which are insulated from earth ground, as the return path for traction power current. The platform elements such as the elevators, electronic signage, and metallic structure elements are grounded to the local earth at the passenger station. This means that the voltage on the running rails (and therefore the body of the railcars) is at a different potential to that of the grounded equipment in the stations. If a passenger were to simultaneously touch an active train and a metallic platform element, a mild shock could occur which would be alarming and discomforting, and a risk exists for serious shock causing ventricular fibrillation, pacemaker malfunction, medical device implant malfunction, or in extreme cases even death due to voltage potential difference between the train and platform. The system is currently designed so that a passenger cannot simultaneously touch a train and a platform metallic element (thus minimizing this risk), but PEDs introduce a new station element that will be positioned much closer to trains and will also extend out further into the platform area. It would be much easier for a passenger to make intentional or accidental contact with a PED and a train at the same time. The grounding system for the PEDs required to mitigate the electrical shock hazard was selected in consultation with TTC stakeholders with the objective to avoid active systems with maintenance requirements and minimize station rework and associated costs. It consists of a durable non-conductive finish material applied to all potential contact surfaces.

6.2.3 Vehicle Retrofitting

It is noted in the TTC PED Concept of Operations that the train operator will be responsible for opening the train doors and the PEDs. This implies that the existing Toronto Rockets either already have the capacity to perform this function, or they will need to be retrofitted to accommodate it.

6.3 Project Interdependencies

Currently, the TTC has the following ongoing programs that will have an impact on PEDs implementation; these programs are at various stages of execution.

- Easier Access Program;
- Stations Modernization;
- Subway Ventilation;
- Lines 2 and 4 Automatic Train Control (ATC) Project;
- Second Exit/Entrance Projects;
- Bloor-Yonge Capacity Improvement Project;
- Rail Projects;
- Train Door Monitoring (TDM);
- Subway Radio Antenna System (SRAS); and
- Ongoing state of good repair projects.

6.4 Project Schedule and Stage Gate Deliverables

6.4.1 Construction Sequencing

Complexity should not be taken for granted when it comes to a project that aims to integrate a new system like platform edge doors with an intricate existing system such as a railway (including automatic train control). If unforeseen issues or “growing pains” are going to occur during the installation and integration of the platform edge doors, it is best to work through those bugs at a station that does not have a high ridership. Therefore, PEDs should first be installed as a test bed on one platform, preferably the platform that sees the least amount of passenger ridership in the system. This would greatly lessen the system impact of any issues since less passengers would be affected. A test bed project at a single platform would also help to better understand retrofit constraints, obtain customer feedback, assess the O&M impact, measure results, and generate public interest and support through a comparatively small up-front investment.

In prior PED projects, proper staging of the installation is key to delivering the system as efficiently as possible. In many Asian brownfield PED projects, the entire station is shut down completely for one or two weeks (depending on supplier estimates). Work can then take place around the clock with the largest components being transported in via the tunnel from the yards during the night, and small equipment and personnel using the main station entrance during the day. This shutdown period also allows for longer testing windows to verify the installation before opening them to the public. Finally, this also prevents passengers from interacting with unfinished installation, which mitigates some hazards present before the PED can be tested and enter operation. While this does cause a severe disruption to service that is difficult to implement across multiple station successively (or at the same time, depending on available manpower) the alternative of only working within limited windows during night and/or weekend shifts often prolong the project considerably. In addition to labour costs, smaller installation windows are generally much less efficient due to the time it takes to properly setup and remove installation equipment, particularly regarding civil reconstruction.

However, if service must be continued with minimal disruption during the installation process, it is recommended that weekend shutdowns are utilized to reinforce the platform and implement components that will not adversely affect passengers (e.g. cable and conduit runs, ERR retrofits). Once this prep work is completed, then the actual barrier installation can begin. During this time, TTC and the supplier must decide if they are able to shut down the platforms (i.e. lock installed doors closed) or keep them operating (i.e. lock installed doors open) one at a time. This introduces some risk of passengers and trains interacting with the barriers before they have been tested, such as during a train misalignment, so it is crucial train operators are trained prior to any installation work.

Finally, to better understand resource loading, construction times, and potential hazards, it is strongly recommended that TTC initiate a pilot project on a low traffic station before any other work on the system takes place (preferably one pilot PED installation on each of the six platform types defined in this study). A pilot program for low-traffic stations would provide valuable lessons learned that can be carried forward to other higher-traffic stations.

PED implementation at all stations will require a sequential approach with staged installation of structural elements followed by door units with minimal hoarding to maintain platform capacities and access to egress facilities. The PED system sliding door units will remain open for the entire installation process to permit normal platform operation. The anticipated sequence for platform edge reconstruction is as follows:

- During nightly work windows, install temporary supports beneath the platform (either anchored to the wall or supported on the base slab where required), for Union station they were anchored on the wall.
- During nightly work closures, remove the tactile edge tile and install a temporary edge finish.
- During nightly work closures, raise the edge finish to cut column notches in the existing cantilever and beam holes through lower support wall.
- During nightly work closures install the support beams under the platform and PED support columns.
- Remove the temporary supports as appropriate.
- During nightly closures door head supports will be installed.
- Once the PED framing system has been installed, and modifications made to the platform to accommodate the PEDs as described previously, the PEDs can be delivered by work car and installed during non-operating hours. It is anticipated that it will take several working windows to install all the PEDs, unless weekend closures can be accommodated to install the PEDs at once. The PEDs would remain in the open position until completely installed and tested.
- During temporary night closures, remove and replace floor finish at door locations.

6.5 Project Risks

Table 9 lists the critical threats identified that may impact the delivery of the project. These threats were identified from the risk assessment detailed in Appendix C. The assessment included a series of workshops with subject matter experts and stakeholders to identify and define threats and opportunities, followed by quantitative modelling and analysis.

Table 9 includes only *threats* (potential undesirable outcomes). The risk assessment also identified two critical *opportunities* (potential desirable outcomes), both relating to cost. They were as follows, both rated with a probability of Almost Certain (5): > 90% and impact of 5 (>$20M savings):

- 6 (Pilot project lessons) – Pilot project could yield valuable lessons learned. Could result in cost savings (vs. current estimate which assumes separate contracts); and
- 7 (Contract bundles) – Number of and extent of contract bundles is still to be determined. Could result in cost savings from economies of scale (vs. current estimate which assumes separate contracts).

The probability ratings are the same as those defined in Appendix C.

Table 9 includes only *critical* threats, that is, threats where:

- The combination of the rated probability and most likely impact corresponded to the most undesirable (Critical) rating of overall risk as defined in Appendix C; or
- The threat ranked in the top 5 by one or more of the quantitative measures considered in Appendix C.

See the risk register in Appendix C for details on the threats included in Table 9, and on the other threats and opportunities identified.

For each threat, Table 9 calculates a risk score as the product of the probability rating and impact rating. The risk score is a qualitative rating of the magnitude of each threat.

For each type of impact (cost, schedule, etc.), Table 9 calculates the total risk score. The total risk score is a qualitative rating of the magnitude of the total threat for each type of impact.

Table 9 also calculates the total risk score over all risks. The total risk score is a qualitative rating of the magnitude of the total threat for the project. The total risk score should be interpreted with caution, since it assumes that impacts of different types are weighted equally, which might not accurately reflect TTC's risk attitudes.

The capital cost estimate and schedule described in Section 3.3.1 do not specifically include the risks identified in Table 9 or detailed in Appendix C. However, the capital cost estimate does include gross allowances for design and pricing unknowns (20%) and construction unknowns (22%). These allowances are top-down estimates of cost risk. Appendix C includes preliminary estimates of the distribution of cost risk (and schedule risk) based on a bottom-up approach (of identifying individual risks and estimating their probability, impact, and combined risk). There is likely some overlap between the top-down and bottom-up estimates of cost risk. However, at this stage of the project there are still many significant unknowns, so a conservative approach that adds some or all of the distribution from Appendix C (depending on TTC's risk tolerance) to the capital cost estimate is likely warranted.

Table 9: Project Risks: Impact, Probability, and Response Strategy

Impact to…	Risk Description	Impact (1-min, 5-max)	Probability (1-min, 5-max)	Risk Score (Impact x Probability)	Risk Response Strategy
Cost	8 (Grounding (Design)) – Remaining viable grounding alternative is not known to be service-proven and likely requires special fabrication work by a supplier. Could result in delays or increased costs for suppliers to develop grounding solution, for TTC to review safety of grounding solutions developed, or due to reduced competition.	4	5	20	Mitigate
Cost	11 (Communication system hardware) – Impacts of PEDs on communication system hardware (radio systems, train door monitoring system, public address system, etc.) are partly unknown. Radio surveys are recommended (during the design of each station) to measure impacts. Could result in delays or increased costs to identify and/or mitigate impacts.	4	4	16	Mitigate
Cost	12 (Platform width) – At stations with narrow platforms, pivoting emergency egress panels between PED sliding door units (to allow egress from a significantly misaligned train) could reduce the clear width for egress to less than the minimum required by the OBC and NFPA 101. Could result in increased costs or delays to obtain variance or mitigate non-compliance. Platforms might need to be replaced.	5	5	25	Mitigate

Impact to...	Risk Description	Impact (1-min, 5-max)	Probability (1-min, 5-max)	Risk Score (Impact x Probability)	Risk Response Strategy
Cost	35 (Unforeseen site conditions) – Conditions at stations (e.g., platform and under-platform condition) might be different than anticipated. Could result in delays or increased costs beyond those allowed for in current estimates.	5	5	25	Mitigate
Cost	38 (Limited work windows) – Typical working windows are limited to 2:00 am to 5:00 am daily. More closures than originally planned might be needed to complete work on schedule.	5	3	15	Mitigate
Cost	39 (Safety during installation) – Installation work will temporarily create hazards or obstacles on the platform (e.g., holes, support columns, uneven floor surfaces, hoardings). Could result in injury to workers or passengers or in increased costs or schedule to mitigate safety risks.	4	5	20	Mitigate
Cost	48 (Lack of competition among construction contractors) – There might be a lack of qualified and interested construction contractors to bid for the project, resulting a less competitive process. Could result in increased costs.	5	2	10	Mitigate
Cost	51 (Scope changes during construction) – Scope changes during construction are not priced under competitive tension. Could result in delays or increased or higher-than-market costs.	4	4	16	Mitigate
Cost	57 (Platform condition) – Platform edges at Davisville and Rosedale need to be replaced, but the cost for this is not included in the current cost estimate. Further study during the Design phase could show that these platforms (or other platforms) need to be upgraded further or replaced entirely. Could result in increased costs delays to upgrade or replace platforms.	5	5	25	Mitigate
			Cost Subtotal:	**172**	
Operations Disruption	37 (Unplanned disruptions to service) – Construction work at stations could interfere with service functions in unplanned ways (e.g., unexpected electrical, safety, or structural problems could be encountered). Could result in unplanned reductions to platform capacity, station closures, and disruptions to service.	3	2	6	Mitigate
			Operations Disruption Subtotal:	**6**	

Impact to…	Risk Description	Impact (1-min, 5-max)	Probability (1-min, 5-max)	Risk Score (Impact x Probability)	Risk Response Strategy
Safety	39 (Safety during installation) – Installation work will temporarily create hazards or obstacles on the platform (e.g., holes, support columns, uneven floor surfaces, hoardings). Could result in injury to workers or passengers or in increased costs or schedule to mitigate safety risks.	4	5	20	Mitigate
Safety	40 (Construction safety at platform edge) – Installation requires work at the platform edge. Could result in injury to workers at platform level and in increased costs or schedule to mitigate safety risks.	4	5	20	Mitigate
			Safety Subtotal:	**40**	
Schedule	8 (Grounding (Design)) – Remaining viable grounding alternative is not known to be service-proven and likely requires special fabrication work by a supplier. Could result in delays or increased costs for suppliers to develop grounding solution, for TTC to review safety of grounding solutions developed, or due to reduced competition.	5	5	25	Mitigate
Schedule	11 (Communication system hardware) – Impacts of PEDs on communication system hardware (radio systems, train door monitoring system, public address system, etc.) are partly unknown. Radio surveys are recommended (during the design of each station) to measure impacts. Could result in delays or increased costs to identify and/or mitigate impacts.	5	4	20	Mitigate
Schedule	12 (Platform width) – At stations with narrow platforms, pivoting emergency egress panels between PED sliding door units (to allow egress from a significantly misaligned train) could reduce the clear width for egress to less than the minimum required by the OBC and NFPA 101. Could result in increased costs or delays to obtain variance or mitigate non-compliance. Platforms might need to be replaced.	5	5	25	Mitigate
Schedule	14 (Lack of ATC on Line 2) – Line 2 does not yet have ATC and ATC plans for Line 2 are uncertain. Could result in delays or increased costs to adapt PED control system (possibly with a different type of ATC system), make PEDs ATC-ready, or integrate with ATC upgrades.	5	3	15	Mitigate
Schedule	32 (Unanticipated challenges in obtaining TTC approvals) – Obtaining TTC approvals might not work out as planned (due to staff workload, internal disputes, etc.). Could result in delays.	5	3	15	Mitigate

Impact to…	Risk Description	Impact (1-min, 5-max)	Probability (1-min, 5-max)	Risk Score (Impact x Probability)	Risk Response Strategy
Schedule	35 (Unforeseen site conditions) – Conditions at stations (e.g., platform and under-platform condition) might be different than anticipated. Could result in delays or increased costs beyond those allowed for in current estimates.	5	5	25	Mitigate
Schedule	51 (Scope changes during construction) – Scope changes during construction are not priced under competitive tension. Could result in delays or increased or higher-than-market costs.	5	4	20	Mitigate
Schedule	57 (Platform condition) – Platform edges at Davisville and Rosedale need to be replaced, but the cost for this is not included in the current cost estimate. Further study during the Design phase could show that these platforms (or other platforms) need to be upgraded further or replaced entirely. Could result in increased costs delays to upgrade or replace platforms.	5	5	25	Mitigate
			Schedule Subtotal:	**170**	
			Grand Total:	**388**	

6.6 Operations and Maintenance Plan

Once PEDs have been installed and commissioned in the TTC system, it will be imperative for the system to be properly maintained to ensure correct and reliable operation. Since the PEDs will require several new maintenance activities at each station in which they are installed, TTC will likely need to expand their existing maintenance capabilities through the hiring of additional staff.

The exact staffing needs will be dependent on the current TTC workforce (at the time PED commissioning), the number of stations in which PEDs are installed, and the manufacturer recommended maintenance items of the product that TTC ultimately selects. While the specific maintenance items and prescribed maintenance schedule for a PED product will be recommended by the selected PED supplier and defined during the actual PED design project, the consulting team has compiled a list of several items that should be considered so TTC knows what to expect in terms of PED maintenance.

Table 10: PEDs Indicative Maintenance Plan

Item	Description	Recommended Schedule	Procedure
1	Make sure that all doors are fully closed and locked.	Weekly	Visual and manual check. Perform full close and recycle of doors to check that C&L signal is being received by ATC.
2	Make sure that glass is clean and unbroken.	Weekly	Visual check and cleaning.
3	Make sure that wiring is properly connected and secured from sharp edges and moving parts.	Monthly	Visual and manual check. Manually move wiring to clear sharp edges and moving parts.
4	Make sure that all fasteners are present and tight.	Monthly	Visual and manual check. Re-tighten any loose fasteners.
5	Make sure that the platform area is free of debris.	Monthly	Visual check. Regularly clean the platform area.
6	Inspect and clean load wheels and bottom guide track.	Monthly	Visual check and cleaning.
7	Inspect and clean interior and exterior of fixed panel.	Monthly	Visual check and cleaning.
8	Inspect and adjust PED bottom clearance.	Trimonthly	Visual and manual check.
9	Inspect and adjust drive belt tension.	Yearly	Visual and manual check.
10	Inspect, adjust, and lubricate solenoid lock assembly.	Trimonthly	Visual check, manual check, and cleaning.
11	Inspect, adjust, and lubricate PED manual release linkage.	Trimonthly	Visual check, manual check, and cleaning.

Item	Description	Recommended Schedule	Procedure
12	Inspect and clean PED manual release handle.	Trimonthly	Visual check and cleaning.
13	Manually test PED release handle fully opens and closes the door(s).	Monthly	Visual and manual check.
14	Inspect and adjust EED bottom clearance.	Yearly	Visual and manual check.
15	Inspect and adjust EED upper pivot.	Yearly	Visual and manual check.
16	Inspect and adjust EED latch/crashbar.	Yearly	Visual and manual check.
17	Inspect and adjust EED Closed & Locked monitor switches.	Yearly	Visual and manual check.
18	Check unlocking and opening force is equal to or less than 35 lbs.	Monthly	Measurement.
19	Check key locking function is working properly.	Monthly	Manual check.
20	Check locking zone is equal to or less than 0.25".	Monthly	Measurement.
21	Check that there is no gap greater than 1".	Monthly	Measurement.
22	Check keyswitch manual open function is working properly.	Trimonthly	Manual check.
23	Check keyswitch cutout function is working properly.	Trimonthly	Manual check.
24	Check that door opening time is less than 4secs.	Trimonthly	Measurement.
25	Check that door closing time is less than 6secs.	Monthly	Measurement.
26	Check that closing force of doors is equal to or less than 30lbs.	Monthly	Measurement.
27	Check that obstruction detection/door recycle detects 1" obstruction.	Monthly	Measurement.
28	Check that EED manually open with a force equal to or less than 35 lbs.	Monthly	Measurement.
29	Check sensors detect train alignment equal to or less than 36".	Monthly	Measurement and check logs at PED Controller terminal.
30	Check sensor detect train door opening.	Monthly	Visual check and check logs at PED Controller terminal.
31	Check sensor detect train door being forced open and recycles platform door.	Monthly	Visual check and check logs at PED Controller terminal.

Item	Description	Recommended Schedule	Procedure
32	Check sensor detects train door closing.	Monthly	Visual check and check logs at PED Controller terminal.
33	Check that when Closed & Locked signal is lost a zero speed is applied on the platform within 2sec.	Monthly	Measurement and check logs at PED Controller terminal.
34	Check that the dielectric PED covering provides sufficient insulation against shock hazards at each platform.	Monthly	Measurement.

7. Conclusion

This Business Case Study represents the third and last piece of the "Platform Edge Door Study". The evaluation builds on the previous reports prepared by the AECOM team to provide evidence-based justification to support the TTC's decision-making process for proceeding with the investment.

The business case study concludes that the implementation of the PEDs system throughout the subway network can mitigate unlawful track intrusion and improve reliability and efficiency of subway services by reducing operational delays, protect passengers and transit operators, improve users' perception, and enhance TTC's public image. In total, over the 60-year evaluation period, PEDs could create between $2.2 billion and $2.5 billion in socioeconomic benefits in present value terms. The lifecycle costs are estimated between $2.0 and $2.2 billion in present value terms (in real terms, using a social discount rate of 3.5%). The benefits are generally more than enough to offset lifecycle costs, resulting in a positive net present value of up to $500 million and a benefit-cost ratio of up to 1.24.From a financial perspective, the capital intensive improvement results in net revenue loss for TTC when considering additional farebox revenue. However, the net revenue loss does not consider any grants or subsidies from the Province or the Federal government. Strictly from an operational perspective, the TTC is better off financially due to the cost savings associated with avoided emergency services and shuttle bus deployment that offset the additional costs of operating the PEDs.

The study recommends proceeding with implementation of the PEDs system at all the existing subway station platforms in phased and priority based approach. It also recommends that prior to the next stage of PEDs project (Planning), TTC implements a pilot installation at the stations representing a typical group of stations' structure. This would refine the design requirements, identify constraints, refine risks, cost, schedule, and lessons learned for each type of station's structure as well as obtain customer feedback, assess O&M impact, and generate public interest.

Appendix A Baseline Assumptions

Baseline Assumptions

The table below presents the baseline assumptions used in the Economic and Financial Analyses.

Parameter Description	Value	Source
Year of Cost Estimates	2023	AECOM Assumption
Construction Period Start	2026	AECOM Assumption
Operation start	2027	AECOM Assumption
Annual Subway Ridership Growth Rate	1.5%	Provided by TTC Service Planning
Average subway fare ($ per trip)	3	AECOM assumption based on TTC fare schedule
Project Evaluation Period (Years)	60	Metrolinx Business Case Manual Volume 2 (April 2019)
Growth Cap Year	2076	
Discount Rate, Real (%)	3.5%	
Discount Rate, Nominal (%)	5.5%	
Annual Inflation Rate (%)	2%	
Construction Annual Growth Rate (Real)	0.5%	
Value of Time ($ per hour)	21.24	
Walk Time Weight (multiplier)	2.00	
Wait Time Weight (multiplier)	2.50	
Social value of a fatality	$9.0 million	Transport Canada, 2020 statistics on the social costs of collisions in Canada.
Social value of a major injury	$1.1 million	
Social value of a minor injury	$42,000	

The delay experienced by each reaction type is estimated based on the following assumptions and methodologies.

<u>Walk Reaction</u>

At the time of an incident, passengers might experience an increased wait time; consequently, extra travel time in their commutes. As per the Ontario Ministry of Transportation's Transit Supportive Land Use and Planning Guidelines, most people are willing to walk approximately 400 to 800 metres to a transit stop. Considering a walking speed of 1.2 m/s, passengers affected by an incident are likely to walk for approximately 8 minutes to get to either their end destination or other alternative transit connections. It was assumed that 50% of the impacted passengers at a given subject station (i.e., in-vehicle line load excluding alighting passengers) have a destination or an alternative faster transit option within an 8-minute walk. Hence, for incidents that cause a delay of 8 minutes or more, 50% of the impacted passengers are expected to experience an average delay of 8 minutes.

Wait Reaction

Passengers will wait when an incident causes a delay of less than 25 minutes (i.e., shuttle buses not deployed). When this is the case, all passengers except those with a walk reaction are deemed to wait on the platform for the next available service. The following assumptions were made to calculate the delay time for the wait reaction:

- Stations impacted by the interruption include the subject station, where the incident occurs at time t_{inc} as well as set of stations, or stations block, impacted by the incident at the subject station. The extent of the impacted block stations was determined based on the descriptions of the incidents from the records. The stations blocks were considered for the incidents with the indication of the train turnaround operations at downstream or upstream stations of the subject station. The turnaround stations are expected to remain in service. It should be noted that for incidents with incomplete descriptions the stations block were estimated based on stations with similar incidents.
- TTC subway delay records indicate the delay in minutes to subway service. It was assumed that the incident will increase the travel time of the passengers who arrive at the subject station within $(t_{inc}, t_{inc} + d)$, where *d* denotes the delay time.
- All passengers at the subject station and the downstream stations within the block will experience the same average delay caused by the incidents.

Shuttle Bus Reaction

Shuttle bus services are expected to be used for an incident record with a delay time of 25 minutes or more[19] in the network excluding the "U". The impacted passengers are deemed to be delayed for $\delta = TT_{shuttle} - TT_{Sub}$, where $TT_{shuttle}$ and TT_{sub} indicate travel times between first and last stations in the block by shuttle buses and subways, respectively. TT_{sub} is estimated using Google Maps subway travel times. Designated shuttle bus services are primarily intended to shuttle passengers within a block. $TT_{shuttle}$ is hence estimated using Google Maps by auto-driving mode with an adjustment to account for bus travel speeds and dwell times.

The ridership data used to estimate total travel time losses to users was retrieved from the Ultimate Demand Scenario provided by the TTC. The data includes the number of boarding and alighting passengers as well as arrival loads at each station for both directions during the AM and PM peak hours. Using the Metrolinx Annualization Calculator, a conversion factor with a range of 0.1 to 0.3 was applied to convert the peak hour ridership to a 1-hour off-peak ridership. The hourly ridership were further adjusted, considering uniform arrivals, to account for the impacted passengers associated with a reaction type (i.e., walk, wait, etc.) in a given reaction group. The total travel time saving for each incident was estimated using the average delay times weighted by their corresponding adjusted ridership in each reaction group. A PED prevention factor depending on the type of the incident was then applied to the estimated travel time saving to reflect the effectiveness of PEDs to the type of the incident. As suggested in the Metrolinx Business Case Guidance[20], weight factors of 2 and 2.5 were also considered to reflect the inconvenience associated with the rider's mode perception of additional walk and wait time, respectively. The total number of passenger hours was further estimated by summing the travel time savings over the PED-related incidents in a year.

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[19] *Based on TTC Priority One Procedure: Contact with a subway vehicle (Procedure N0. STT P7-S5T).*
[20] *Metrolinx, 2019. Business Case Manual Volume 2 : Guidance. Table 5.5 Inconveneience Factors, by Trip Purpose, page 98. Online. <http://www.metrolinx.com/en/regionalplanning/projectevaluation/benefitscases/Metrolinx-Business-Case-Guidance-Volume-2.pdf>.*

Appendix B Quantification of Benefits

Quantification of Benefits

The table below summarizes all the economic costs and benefits expected to result from the installation and operations of PEDs over a 60-year evaluation period, which begins in 2027 at the start of PEDs operations. The costs and revenues are presented in 2023 dollars, unless noted otherwise. All benefits are capped after 30 years of operations and remain constant thereafter to reduce the uncertainty associated with projecting ridership growth and benefits in the distant future.

Year	Capital Costs	Refurbishment	Operating and Maintenance Costs	Total Costs	Public Health and Safety	Passenger Delays	Employee Health	Emergency Response	Total Benefits	Net Benefits
2026	(53,480,248)	-		(53,480,248)	-		-	-	-	**(53,480,248)**
2027	(53,747,649)	-		(53,747,649)	-	-	-	-	-	**(53,747,649)**
2028	(54,016,388)	-		(54,016,388)	5,092,330	(956,742)	45,047	1,050,766	5,231,401	**(48,784,987)**
2029	(150,002,358)	-		(150,002,358)	5,168,715	(971,093)	46,218	1,066,528	5,310,368	**(144,691,990)**
2030	(150,752,370)	-		(150,752,370)	5,246,245	(842,105)	47,420	1,082,526	5,534,085	**(145,218,284)**
2031	(151,506,131)	-		(151,506,131)	10,649,878	(2,000,888)	97,305	2,197,527	10,943,822	**(140,562,309)**
2032	(152,263,662)	-	(480,000)	(152,743,662)	16,214,439	(3,046,352)	149,753	3,345,735	16,663,575	**(136,080,087)**
2033	(153,024,980)	-	(640,000)	(153,664,980)	21,943,541	(4,122,729)	204,862	4,527,895	22,553,569	**(131,111,412)**
2034	(153,790,105)	-	(800,000)	(154,590,105)	27,840,868	(5,230,713)	262,736	5,744,766	28,617,658	**(125,972,448)**
2035	(154,559,056)	-	(960,000)	(155,519,056)	33,910,177	(6,371,008)	323,481	6,997,125	34,859,776	**(120,659,280)**
2036	(155,331,851)	-	(1,080,000)	(156,411,851)	38,721,184	(7,274,895)	373,379	7,989,843	39,809,510	**(116,602,341)**
2037	(156,108,510)	-	(1,240,000)	(157,348,510)	45,124,520	(8,477,947)	439,841	9,311,126	46,397,540	**(110,950,971)**
2038	(156,889,053)	-	(1,440,000)	(158,329,053)	53,188,708	(9,993,038)	524,064	10,975,114	54,694,849	**(103,634,204)**
2039	(157,673,498)	-	(1,520,000)	(159,193,498)	56,985,791	(10,706,430)	567,563	11,758,615	58,605,539	**(100,587,959)**
2040	(158,461,866)	-	(1,600,000)	(160,061,866)	60,884,819	(11,438,975)	612,969	12,563,152	62,621,964	**(97,439,901)**
2041	(159,254,175)	-	(1,720,000)	(160,974,175)	66,432,948	(12,481,352)	676,075	13,707,969	68,335,640	**(92,638,535)**
2042	(160,050,446)	-	(1,840,000)	(161,890,446)	72,133,822	(13,552,426)	742,048	14,884,304	74,207,749	**(87,682,697)**
2043	(160,850,698)	-	(2,120,000)	(162,970,698)	84,357,369	(15,848,973)	877,199	17,406,547	86,792,142	**(76,178,556)**
2044	(161,654,952)	-	(2,280,000)	(163,934,952)	92,084,822	(17,300,799)	967,933	19,001,052	94,753,008	**(69,181,943)**
2045	(162,463,226)	-	(2,440,000)	(164,903,226)	100,025,118	(18,792,613)	1,062,792	20,639,476	102,934,774	**(61,968,453)**
2046	(163,275,543)	-	(2,640,000)	(165,915,543)	109,847,257	(20,637,986)	1,179,806	22,666,205	113,055,282	**(52,860,261)**
2047	(164,091,920)	-	(2,800,000)	(166,891,920)	118,252,237	(22,217,105)	1,283,845	24,400,513	121,719,490	**(45,172,430)**
2048	-	-	(2,960,000)	(2,960,000)	126,884,650	(23,838,954)	1,392,497	26,181,751	130,619,945	**127,659,945**
2049	-	-	(2,960,000)	(2,960,000)	135,749,429	(25,504,459)	1,505,932	28,010,935	139,761,837	**136,801,837**
2050	-	-	(2,960,000)	(2,960,000)	137,785,670	(25,887,026)	1,545,088	28,431,099	141,874,832	**138,914,832**
2051	-	-	(2,960,000)	(2,960,000)	139,852,455	(26,275,331)	1,585,263	28,857,566	144,019,953	**141,059,953**
2052	-	-	(2,960,000)	(2,960,000)	141,950,242	(26,669,461)	1,626,483	29,290,429	146,197,693	**143,237,693**
2053	-	-	(2,960,000)	(2,960,000)	144,079,496	(27,069,503)	1,668,774	29,729,786	148,408,553	**145,448,553**
2054	-	-	(2,960,000)	(2,960,000)	146,240,688	(27,475,545)	1,712,165	30,175,733	150,653,040	**147,693,040**
2055	-	-	(2,960,000)	(2,960,000)	148,434,299	(27,887,679)	1,756,684	30,628,369	152,931,672	**149,971,672**
2056	-	-	(2,960,000)	(2,960,000)	150,660,813	(28,305,994)	1,802,361	31,087,794	155,244,974	**152,284,974**
2057	-	-	(2,960,000)	(2,960,000)	152,920,725	(28,730,584)	1,849,225	31,554,111	157,593,477	**154,633,477**
2058	-	(37,510,407)	(2,960,000)	(40,470,407)	155,214,536	(29,161,542)	1,897,308	32,027,423	159,977,724	**119,507,317**
2059	-	-	(2,960,000)	(2,960,000)	157,542,754	(29,598,966)	1,946,641	32,507,834	162,398,263	**159,438,263**
2060	-	-	(2,960,000)	(2,960,000)	159,905,895	(30,042,950)	1,997,257	32,995,452	164,855,653	**161,895,653**
2061	-	(40,394,605)	(2,960,000)	(43,354,605)	162,304,484	(30,493,594)	2,049,189	33,490,383	167,350,461	**123,995,856**
2062	-	(41,404,470)	(2,960,000)	(44,364,470)	164,739,051	(30,950,998)	2,102,471	33,992,739	169,883,263	**125,518,792**
2063	-	(42,439,582)	(2,960,000)	(45,399,582)	167,210,137	(31,415,263)	2,157,139	34,502,630	172,454,642	**127,055,060**
2064	-	(43,500,572)	(2,960,000)	(46,460,572)	169,718,289	(31,886,492)	2,213,228	35,020,170	175,065,194	**128,604,622**
2065	-	(44,588,086)	(2,960,000)	(47,548,086)	172,264,063	(32,364,790)	2,270,775	35,545,472	177,715,521	**130,167,435**
2066	-	(34,277,236)	(2,960,000)	(37,237,236)	174,848,024	(32,850,261)	2,329,819	36,078,654	180,406,236	**143,169,000**
2067	-	(46,845,358)	(2,960,000)	(49,805,358)	177,470,745	(33,343,015)	2,390,398	36,619,834	183,137,961	**133,332,604**
2068	-	(60,020,766)	(2,960,000)	(62,980,766)	180,132,806	(33,843,161)	2,452,552	37,169,132	185,911,329	**122,930,563**
2069	-	(24,608,763)	(2,960,000)	(27,568,763)	182,834,798	(34,350,808)	2,516,323	37,726,669	188,726,981	**161,158,218**
2070	-	(25,223,982)	(2,960,000)	(28,183,982)	185,577,320	(34,866,070)	2,581,751	38,292,569	191,585,570	**163,401,587**
2071	-	(38,781,546)	(2,960,000)	(41,741,546)	188,360,980	(35,389,061)	2,648,881	38,866,957	194,487,757	**152,746,211**
2072	-	(39,751,084)	(2,960,000)	(42,711,084)	191,186,394	(35,919,897)	2,717,756	39,449,961	197,434,215	**154,723,130**
2073	-	(95,071,115)	(2,960,000)	(98,031,115)	194,054,190	(36,458,696)	2,788,422	40,041,711	200,425,628	**102,394,513**
2074	-	(55,684,409)	(2,960,000)	(58,644,409)	196,965,003	(37,005,576)	2,860,926	40,642,337	203,462,690	**144,818,280**
2075	-	(57,076,520)	(2,960,000)	(60,036,520)	196,965,003	89,128,842	2,860,926	40,642,337	329,597,108	**269,560,588**
2076	-	(73,129,476)	(2,960,000)	(76,089,476)	196,965,003	(37,005,576)	2,860,926	40,642,337	203,462,690	**127,373,214**
2077	-	(59,966,018)	(2,960,000)	(62,926,018)	196,965,003	89,128,842	2,860,926	40,642,337	329,597,108	**266,671,090**
2078	-	(61,465,169)	(2,960,000)	(64,425,169)	196,965,003	(37,005,576)	2,860,926	40,642,337	203,462,690	**139,037,521**
2079	-	-	(2,960,000)	(2,960,000)	196,965,003	89,128,842	2,860,926	40,642,337	329,597,108	**326,637,108**
2080	-	-	(2,960,000)	(2,960,000)	196,965,003	(37,005,576)	2,860,926	40,642,337	203,462,690	**200,502,690**
2081	-	-	(2,960,000)	(2,960,000)	196,965,003	89,128,842	2,860,926	40,642,337	329,597,108	**326,637,108**
2082	-	-	(2,960,000)	(2,960,000)	196,965,003	(37,005,576)	2,860,926	40,642,337	203,462,690	**200,502,690**
2083	-	-	(2,960,000)	(2,960,000)	196,965,003	89,128,842	2,860,926	40,642,337	329,597,108	**326,637,108**
2084	-	-	(2,960,000)	(2,960,000)	196,965,003	(37,005,576)	2,860,926	40,642,337	203,462,690	**200,502,690**
2085	-	-	(2,960,000)	(2,960,000)	196,965,003	89,128,842	2,860,926	40,642,337	329,597,108	**326,637,108**
2086	-	-	(2,960,000)	(2,960,000)	196,965,003	(37,005,576)	2,860,926	40,642,337	203,462,690	**200,502,690**

Appendix C Detailed Risk Analysis Results

This appendix describes the methodology and results of the risk assessment completed as part of the Business Case Study.

The primary steps making up the risk and opportunities assessment were to:

1. Identify and define risks;
2. Model risks; and
3. Analyze risks.

Sections C1 through C3 describe each step. Sections C4 and C5 summarize the conclusions and recommendations of the risk assessment.

The risk assessment considers only risks up to but excluding operations. It excludes risks that occur at stations where PEDs are in normal operation, even if work to implement PEDs at other stations is not yet complete.

Table 13 defines risk assessment terms used in this appendix.

Table 11: Definition of risk assessment terms used

Term	Definition
impact	Unplanned effect of the types considered by this risk assessment. Impacts may be represented by a numeric rating or a quantitative value. Negative ratings and values represent undesirable effects (threats), and positive ratings and values represent desirable effects (opportunities).
Monte Carlo simulation	A simulation technique for forecasting a range of outcomes from a model by generating random numbers for the input variables and recording the distribution of the output variables over a large number of trials.
opportunity	An event or situation that, if encountered, can have a desirable effect. The opposite of a threat.
probability	The likelihood of encountering a risk factor over the lifetime of the project, expressed on a scale for 0% to 100%.
risk	The combination of the probability of encountering a risk factor over the lifetime of the project and the impact of the risk factor if it is encountered.
risk factor	A threat or opportunity.
risk register	A formalized list of risks that have been identified.
simulation	An analytical method that is meant to imitate a real-life system.
threat	An event or situation that, if encountered, can have an undesirable effect. The opposite of an opportunity.
trial	One iteration of a Monte Carlo simulation, for which each input variable is assigned a single value according to its distribution, and each output variable receives a unique value based on its relationship with the input variables.

C.1 Identify and Define Risks

AECOM held a series of workshops with subject matter experts and stakeholders to identify and define known threats and opportunities. Table 14 details the dates and participants of the workshops.

The primary objective of the workshops was to answer the following questions:

- **What could go better or worse than planned?** Using their collective knowledge and experience, participants identified threats and opportunities, i.e., events or situations that could have desirable or undesirable effects;
- **How likely is it?** For each threat or opportunity identified, the participants, as a group, rated the likelihood that the threat or opportunity would impact the project cost or schedule. Participants assigned either a quantitative probability value or a qualitative probability rating using the scale shown in Table 15;
- **What are the potential impacts?** For each threat or opportunity identified, the participants, as a group, identified the types of potential impact (from the types considered as shown in Table 16) and rated the best case, most likely, and/or worst case impact. Participants assigned either quantitative impact values or qualitative impact ratings using the scale shown in Table 17; and
- **How should the TTC respond to the risks?** For each threat or opportunity, the participants, as a group, outlined where possible how TTC should respond to the risk.

The output of the risk workshops is captured in the risk register shown in Table 19. Each row in the risk register represents a potential impact of a risk factor. Some risk factors have more than one type of potential impact, so have more than one row in the risk register. The columns in the risk register as follows:

4. **Risk ID** – A sequential number that uniquely identifies the risk factor, assigned in the order that the risk factor was identified;
5. **Phase** – The project phase in which the risk factor would occur, either Design, Pilot, Construction Contracts, or Operations;
6. **Threat or Opportunity** – A short name for the threat or opportunity;
7. **Cause** – A description of the possible cause of the threat or opportunity;
8. **Effect** – A description of the possible effects of the threat or opportunity;
9. **Probability** – The rated probability that the threat or opportunity will occur, which may be either quantitative probability value or a qualitative probability rating using the scale shown in Table 15;
10. **Impact Type** – The type of potential impact of the risk threat or opportunity (from the types considered as shown in Table 17);
11. **Best Case Impact** – The rated best case impact, which may be either a quantitative impact value or qualitative impact rating per the scale shown in Table 17;
12. **Most Likely Impact** – Same for most likely impact;
13. **Worst Case Impact** – Same for worst case impact;

14. **Risk Rating** – The qualitative rating of the risk per Table 18**Error! Reference source not found.** given the rated p robability and most likely impact;
15. **Notes** – Discussion of the threat or opportunity, or of the assumptions behind the rated probability or impact;
16. **Risk Response** – An outline of the risk response;
17. **Feasibility Study Sections** – A list of the sections in the Feasibility Study Report from which the threat or opportunity was identified, where applicable; and
18. **Date Identified** – The date the threat or opportunity was identified.

Table 19 lists the risks in order of Phase and Risk ID.

For completeness, Table 19 includes all 56 risk factors that were identified. Of these, 23 were eventually excluded from the assessment because:

- The risk factor duplicated another risk factor;
- The risk factor would occur during operations (since the risk assessment considers only risks up to but excluding operations);
- The risk no longer exists; or
- It was assumed the cost or schedule estimates included sufficient scope or contingency to capture the risk.

Table 19 shows these 23 risk factors in gray text with a probability of 0%. For risk factors that would occur during operations, the 0% probability must be interpreted with caution. It does not mean that the risk factor will never occur. Instead, it means that the risk factor will not occur during the phases considered by this assessment (up to but excluding operations).

Of the remaining 33 risk factors, there were 5 for which the risk workshop participants could not rate or quantify the probability. The effect of these 5 risk factors is excluded from the assessment.

For the remaining 28 risk factors, 46 potential impacts were identified (since impacts of more than type were identified for some risk factors).

Of the 46 potential impacts, there were 2 for which the workshop participants could not rate or quantify an impact. The effect of these 2 impacts is excluded from the assessment.

For the remaining 44 potential impacts, the distribution by impact type and risk rating was as shown in Table 20.

Table 21 lists the threats and opportunities identified with a Critical risk rating in ascending order of impact type, descending order of risk ranking (per the rankings defined in Table 18), and ascending order of Risk ID. Higher risk rankings represent higher risks.

Table 12: Risk workshop participants

Workshop Date	Participants
May 27, 2020	Bryan Shaw (AECOM), David Leblanc (AECOM), Brian Camiré (AECOM)
May 29, 2020	Jeff Mastinsek (AECOM), Sean Williams (Lea+Elliot), Brian Camiré (AECOM)
May 29, 2020	Bryan Shaw (AECOM), David Leblanc (AECOM), Ali Osgouei (AECOM), Jeff Mastinsek (AECOM), Brian Camiré (AECOM)
September 24, 2020	Morteza Hagshenas (TTC), Trisha Neilson (TTC), Yesika Beer (TTC), Andrew Brown (TTC), Ali Osgouei (AECOM), Jeff Mastinsek (AECOM), Brian Camiré (AECOM)
September 25, 2020	Bryan Shaw (AECOM), Ali Osgouei (AECOM), Jeff Mastinsek (AECOM), Brian Camiré (AECOM)
October 13, 2020	Morteza Hagshenas (TTC), Trisha Neilson (TTC), Yesika Beer (TTC), Andrew Brown (TTC), Ali Osgouei (AECOM), Jeff Mastinsek (AECOM), Brian Camiré (AECOM)
November 2, 2020	Morteza Hagshenas (TTC), Trisha Neilson (TTC), Andrew McKinnon (TTC), Daniel Mackinnon (TTC), Milan Vignjevic (TTC), Gary Yip (TTC), Shari Wills (TTC), Kirpal Parhar (TTC), Matt Hagg (TTC), Christine Triggs (TTC), Andrew Brown (TTC), Richard Gentry (TTC), Syed Shere (TTC), Mary Bertoli (TTC), Ellen Stassen (TTC), Lynn Middleton (TTC), Ali Osgouei (AECOM), Jeff Mastinsek (AECOM), Brian Camiré (AECOM)
November 6, 2020	Morteza Hagshenas (TTC), Trisha Neilson (TTC), Andrew Brown (TTC), Ali Osgouei (AECOM), Jeff Mastinsek (AECOM), Brian Camiré (AECOM)

Table 13: Probability ratings

Probability Rating[21]	Qualitative Description
Almost Certain (5): > 90%	The event is expected to occur during the life of the project.
Very Likely (4): 66% - 90%	The event could easily occur during the life of the project.
Possible (3): 36% - 65%	The event is plausible to occur during the life of the project.
Unlikely (2): 10% - 35%	The event could occur in certain circumstances during the life of the project.
Very Unlikely (1): < 10%	The event could occur in exceptional circumstances during the life of the project.

21 The probability ratings are as defined in the TTC Major Projects Risk Scale provided to AECOM on July 15, 2020.

Table 14: Types of impacts considered

Impact Type[22]	**Definition**
Schedule	Unplanned effects to on-time completion of PED implementation (excluding operation).
Cost	Unplanned effect to cost of PED implementation (up to but excluding operation).
Reputation	Unplanned effects to reputation/media caused during PED implementation (up to but excluding operation).
Safety	Unplanned effects to health & safety caused during PED implementation (up to but excluding operation).
Public Disruption	Unplanned public disruption caused during PED implementation (up to but excluding operation).
Operations Disruption	Unplanned operations disruption caused during PED implementation (up to but excluding operation).

[22] *The impact types are as identified in the TTC Major Projects Risk Scale provided to AECOM on July 15, 2020, except some names are abbreviated. Specifically, the Cost, Schedule, Safety, and Reputation impact types in **Error! Reference source not found.** correspond to the Project Cost, Project S chedule (Critical Path Impact), Health & Safety, and Reputation/Media impact types in the TTC Major Projects Risk Scale.*

Table 15: Impact ratings

Impact Type	Impact Rating[23]										
	Threats						Opportunities				
	-5 (Significant Negative)	-4 (Very High Negative)	-3 (High Negative)	-2 (Medium Negative)	-1 (Low Negative)	0 (None)	1 (Low Positive)	2 (Medium Positive)	3 (High Positive)	4 (Very High Positive)	5 (Significant Positive)
Schedule	>4 months delay	2–4months delay	4–8weeks delay	1–4weeks delay	<1 week delay	None	<1 week savings	1–4weeks savings	4–8weeks savings	2–4months savings	>4 months savings
Cost	>$20M cost	$10M - $20M cost	$5M - $10M cost	$1M - $5M cost	<$1M cost	None	<$1M savings	$1M - $5M savings	$5M - $10M savings	$10M - $20M savings	>$20M savings
Reputation	Extensive stakeholder concerns/organized community reaction. National media reporting.	Significant concerns raised by numerous stakeholders. Widespread media reporting.	Significant concern raised by individual stakeholder. Local media reporting for a prolonged period.	Localized public and/or stakeholder concern. Adverse local media reporting over a period.	Minor individual stakeholder concerns. Adverse local media reporting.	None	Positive local media report.	Positive local media reporting over a period. Localized public and/or stakeholder support.	Substantial positive media interest creating public support. Positive stakeholder statements.	Significant stakeholder support. Major positive local media campaign.	Prolonged and widespread positive reactions from key stakeholders and/or media.
Safety	Fatality/fatalities	Critical injury/permanent long term disabilities	Critical injury/multiple lost time injuries	Medical attention/lost time minor injury	Medical attention/no lost time injury	None	Prevention of medical attention/no lost time injury	Prevention of medical attention/lost time minor injury	Prevention of critical injury/multiple lost time injuries	Prevention of critical injury/permanent long term disabilities	Prevention of fatality/fatalities
Public Disruption	Extended disruption(s) to traffic, business, residences, services, etc.	Disruption to traffic, business, residences, services, etc.	Moderate impact on traffic, business, residences, services, etc.	Minor impact on traffic, residences, business, services, etc.	Insignificant impact on traffic, business, residences, services, etc.	None	Prevention of insignificant impact on traffic, business, residences, services, etc.	Prevention of minor impact on traffic, residences, business, services, etc.	Prevention of moderate impact on traffic, business, residences, services, etc.	Prevention of disruption to traffic, business, residences, services, etc.	Prevention of extended disruption(s) to traffic, business, residences, services, etc.
Operations Disruption	Extended disruption(s) to operations. 1 day plus.	Disruption to operations. Full AM/PM peak period.	Moderate impact on operations. Multiple headway delays (20–60 min.) with turn backs & bus bridge.	Minor impact on operations. Multiple headway delays (less than 20 min.) with short turns.	Insignificant impact on operations. Headway delay.	None	Prevention of insignificant impact on operations. Headway delay.	Prevention of minor impact on operations. Multiple headway delays (less than 20 min.) with short turns.	Prevention of moderate impact on operations. Multiple headway delays (20–60 min.) with turn backs & bus bridge.	Prevention of disruption to operations. Full AM/PM peak period.	Prevention of extended disruption(s) to operations. 1 day plus.

[23] *The impact ratings are as defined in the TTC Major Projects Risk Scale provided to AECOM on July 15, 2020, except that* ***Error! Reference source not found.*** *uses negative ratings for threats and adds opportunities for Safety, Public Disruption, and Operations Disruption. The TTC Major Projects Risk Scale defines only threats f or these impact types.* ***Error! Reference source not found.*** *adds opportunities that are the opposite of the corresponding threat rating.*

Table 16: Risk ratings and rankings

Probability Rating	Impact Rating[24]										
	Threats						Opportunities				
	-5 (Significant Negative)	-4 (Very High Negative)	-3 (High Negative)	-2 (Medium Negative)	-1 (Low Negative)	0 (None)	1 (Low Positive)	2 (Medium Positive)	3 (High Positive)	4 (Very High Positive)	5 (Significant Positive)
Almost Certain (5): > 90%	Critical 25	Critical 23	High 20	High 16	Medium 11	None 0	Medium 11	High 16	High 20	Critical 23	Critical 25
Very Likely (4): 66% - 90%	Critical 24	Critical 21	High 17	High 12	Medium 7	None 0	Medium 7	High 12	High 17	Critical 21	Critical 24
Possible (3): 36% - 65%	Critical 22	High 18	High 13	Medium 8	Medium 4	None 0	Medium 4	Medium 8	High 13	High 18	Critical 22
Unlikely (2): 10% - 35%	High 19	High 14	Medium 9	Medium 5	Low 2	None 0	Low 2	Medium 5	Medium 9	High 14	High 19
Very Unlikely (1): < 10%	High 15	Medium 10	Medium 6	Low 3	Low 1	None 0	Low 1	Low 3	Medium 6	Medium 10	High 15

Table 17: Risk register

Risk ID	Phase	Threat or Opportunity	Cause	Effect	Probability	Impact Type	Best Case Impact	Most Likely Impact	Worst Case Impact	Risk Rating	Notes	Risk Response	Feasibility Study Sections	Date Identified
1	Design	Design for gap between platform doors and train doors	There will be a gap between the platform doors and train doors. Design will need to mitigate the risk of a passenger becoming trapped between closed doors.	Mitigation could result in increased costs.	0%	Cost		$0 million		0 (None)	Platforms vary horizontally and vertically in relation to the train. 2020-09-25: To be addressed in design. Assume cost estimate already has sufficient scope and contingency. Gap will continue to be a slight risk during operations, but that is a separate risk.		1.4, 3.6.1.2	5/27/2020
2	Design	Emergency egress	Emergency egress must be reviewed with the provision of PEDs.	Analysis could lead to unanticipated changes in design, resulting in increased costs.	0%	Cost		$0 million		0 (None)	2020-10-14: Duplicate of Risk 12.		1.4	5/27/2020
3	Design	Feasibility of structural solutions	The feasibility of structural solutions will vary by station.	It could cost more than anticipated to determine feasibility and/or adapt solutions for each station.	0%	Cost		$0 million		0 (None)	2020-09-25: Assume cost estimate already has sufficient scope and contingency.		2.1	5/27/2020
4	Design	Design for outdoor stations	Outdoor stations are subject to precipitation and greater fluctuations in temperature and humidity.	Design will need to assess operating conditions and could adjust specifications for water tightness and supplemental heating. This could result in increased costs.	0%	Cost		$0 million		0 (None)	2020-09-25: Assume cost estimate already has sufficient scope and contingency.		2.5	5/27/2020

[24] *The risk ratings and rankings are as defined in the TTC Major Projects Risk Scale provided to AECOM on July 15, 2020, except that **Error! Reference source not found.** uses negative ratings for threats.*

Risk ID	Phase	Threat or Opportunity	Cause	Effect	Probability	Impact Type	Best Case Impact	Most Likely Impact	Worst Case Impact	Risk Rating	Notes	Risk Response	Feasibility Study Sections	Date Identified
8	Design	Grounding (Design)	Remaining viable grounding alternative is not known to be service-proven and likely requires special fabrication work by a supplier.	Could result in delays or increased costs for suppliers to develop grounding solution, for TTC to review safety of grounding solutions developed, or due to reduced competition.	90%	Cost	-$5 million		-$25 million	-4 (Critical)	2020-09-25: Assume cost estimate already has sufficient scope and contingency. 2021-01-08: Reverse this assumption per TTC guidance of January 8, 2021.		2.7, 3.2.5, 3.2.6, 3.4.5	5/27/2020
						Schedule	-20 weeks	-52 weeks	-104 weeks	-4 (Critical)	2020-09-25: Assume schedule already has sufficient scope and contingency. 2021-01-08: Reverse this assumption per TTC guidance of January 8, 2021.			5/27/2020
9	Design	Power capacity	Any station with less than 30kVA of excess power capacity should be identified and upgraded in terms of power.	Could result in delays (if many stations are affected) or increased costs.	0%	Cost		$0 million		0 (None)	2020-09-29: Assume cost estimate already has sufficient scope and contingency.		2.7	5/27/2020
						Schedule		0 weeks		0 (None)	2020-09-29: Assume schedule estimate already has sufficient scope and contingency.			5/27/2020
10	Design	Communication system interfaces	Impacts of PEDs on communication systems are partly unknown, at least until a supplier and product are chosen. A PED testbed installation at one station is recommended to test impacts.	Could result in delays or increased costs to identify and/or mitigate impacts.	Possible (3): 36% - 65%	Cost	$0 million		-$5 million	-2 (Medium)			2.7	5/27/2020
						Schedule	-3 weeks		-12 weeks	-3 (High)				5/27/2020
11	Design	Communication system hardware	Impacts of PEDs on communication system hardware (radio systems, train door monitoring system, public address system, etc.) are partly unknown. Radio surveys are recommended (during the design of each station) to measure impacts.	Could result in delays or increased costs to identify and/or mitigate impacts.	Very Likely (4): 66% - 90%	Cost	-$5 million		-$25 million	-4 (Critical)		Schedule and budget should consider impacts on existing systems (e.g., train door monitoring system).	2.7	5/27/2020
						Schedule	-12 weeks		-20 weeks	-4 (Critical)		Schedule and budget should consider impacts on existing systems (e.g., train door monitoring system).		5/27/2020
12	Design	Platform width	At stations with narrow platforms, pivoting emergency egress panels between PED sliding door units (to allow egress from a significantly misaligned train) could reduce the clear width for egress to less than the minimum required by the OBC and NFPA 101.	Could result in increased costs or delays to obtain variance or mitigate non-compliance. Platforms might need to be replaced.	100%	Cost	$0 million		-$60 million	-4 (Critical)	2020-11-02: Davisville and Union are the only stations with platforms narrower than 1.8 m, which is the current estimate of the minimum width needed to meet egress requirements. However, this estimate might change as PED designs evolve and/or if the egress requirements change. Impacts are unknown but could range from obtaining a variance to replacing the entire platform. Assume cost impacts range between 0 stations affected (i.e., impacts are covered by the scope and contingency already in the cost estimate) and 3 stations affected, with platforms needing to be replaced at an average cost of $20 million per station. There is a potential overlap between this risk and Risk 57 (Platform condition), in that both could result in replacing platforms at the same station, but for different reasons.	Review details of engineering solution at next stage (Concept Engineering Design).	1.4, 2.7	5/27/2020

Risk ID	Phase	Threat or Opportunity	Cause	Effect	Probability	Impact Type	Best Case Impact	Most Likely Impact	Worst Case Impact	Risk Rating	Notes	Risk Response	Feasibility Study Sections	Date Identified
						Schedule	0 weeks		-104 weeks	-4 (Critical)	2020-09-29: Schedule impact ranges between no delay and a delay of 2 years. This assumes that, even in the worst case (where 3 stations are affected, with platforms needing to be replaced), the delay to the overall project is limited to the delay at only 1 station (up to 2 years to replace the platform).	Review details of engineering solution at next stage (Concept Engineering Design).		5/27/2020
13	Design	CBTC integration	Efficiency of integration of PED system with CBTC could depend on existing relationships between PEDs supplier and CBTC supplier.	Could result in different costs or schedule than anticipated.	0%	Cost		$0 million		0 (None)	2020-09-25: Cost savings are unlikely.		3.4.3, 3.8.2	5/27/2020
						Schedule		0 weeks		0 (None)	2020-09-25: Schedule savings are unlikely.			5/27/2020
14	Design	Lack of ATC on Line 2	Line 2 does not yet have ATC and ATC plans for Line 2 are uncertain.	Could result in delays or increased costs to adapt PED control system (possibly with a different type of ATC system), make PEDs ATC-ready, or integrate with ATC upgrades.	40%	Cost	-$5 million		-$25 million	-3 (High)	2020-09-25: Risk still exists. If Line 2 PEDs are installed before ATC, there might be costs to change PEDS to integrate with ATC.	Separate procurements for Lines 1 and 2.	3.4.4, 3.4.8, 3.8.2.3	5/27/2020
						Schedule	-20 weeks	-20 weeks	-104 weeks	-4 (Critical)	2020-09-25: Risk still exists. If Line 2 PEDs are installed before ATC, time might be needed to change PEDS to integrate with ATC.	Separate procurements for Lines 1 and 2.		5/27/2020
15	Design	Network considerations for vital signals	Consideration should be given to how signals are currently run across the network, particularly vital signals that may need discrete I/O satellite to SER, redundancy, and highly reliable protocols.	Could result in delays or increased costs to retrofit or add cabling between stations to accommodate new signals.	0%	Cost		$0 million		0 (None)	2020-09-25: Assume cost estimate already has sufficient scope and contingency.		3.4.6	5/27/2020
						Schedule		0 weeks		0 (None)	2020-09-25: Assume schedule estimate already has sufficient scope and contingency.			5/27/2020
21	Design	Impact on subway maintenance vehicles	PEDs will restrict the manner in which items are moved on and off platforms from workcars.	Restrictions could lead to changes in equipment, labour, or other requirements.		Cost					2021-01-08: The impact on subway maintenance vehicles will be realized once the PEDs are in operation. However, this impact needs to be minimized through design, as the TTC cannot afford to wait until operations to identify impacts and workarounds for maintenance purposes.		3.6.1.3	5/27/2020
22	Design	Uninterruptible power supply	Existing UPS system is not designed for the additional load of PEDs.	Existing cost and schedule estimate assumes installation of new UPS hardware at each stations. Existing systems might be able to handle additional load, so there could be an opportunity for cost savings.	0%	Cost		$0 million		0 (None)	2020-09-25: Significant cost savings are unlikely.		3.7.2.5	5/27/2020
23	Design	Location of new control equipment	Stations that do not have an emergency response room will need be analyzed to identify a suitable space to house the PED control equipment.	Could result in increased costs to create or modify space to accommodate PED control equipment.	0%	Cost		$0 million		0 (None)	2020-09-25: Assume cost estimate already has sufficient scope and contingency.		3.8.1	5/27/2020
25	Design	Tunnel ventilation system effectiveness	Studies to date considered the TVS impact of PEDs for only one type of station configuration. The TVS impact of PEDs in other underground station configurations warrant further study. CFD modelling could indicate reduced effectiveness.	Could result in increased costs for further study or to mitigate impacts by modifying PED design or adjusting the TVS fan sizes.	3%	Cost	$0 million		-$5 million	-1 (Low)	2020-11-03: Study to date found no negative impact of PEDs on TVS effectiveness but considered only one station configuration. PEDs could have a negative impact under other configurations. 2021-01-08: Ensure that platform based fires are also studied during the TVS analysis of the remaining station configurations.	Complete additional analyses in next stage.		5/27/2020

Risk ID	Phase	Threat or Opportunity	Cause	Effect	Probability	Impact Type	Best Case Impact	Most Likely Impact	Worst Case Impact	Risk Rating	Notes	Risk Response	Feasibility Study Sections	Date Identified
26	Design	Noise impacts	Noise impacts will depend on PED configuration and construction detail, platform area and configuration, acoustic finishes, and train operations.	Could result in increased costs for further study or to mitigate impacts.	0%	Cost		$0 million		0 (None)	2020-09-25: No longer a risk. Noise impacts are no longer expected to result in increased costs.			5/27/2020
27	Design	Air quality impacts	Air quality impacts are not fully known and will depend on various factors.	Could result in increased costs to mitigate impacts.	0%	Cost		$0 million		0 (None)	2020-09-25: No longer a risk. Study has now been completed on a representative station. Based on the study, assume impacts are minimal.			5/27/2020
28	Design	Design cost estimate accuracy	Estimated design cost is based on various assumptions.	Actual design cost might be different than estimate.	0%	Cost		$0 million		0 (None)	Duplicate risk captured in Risk 29 (Cost estimate accuracy)			5/27/2020
30	Design	Unknown project delivery method	The project delivery method might be other than design-bid-build (e.g., construction management).	Different methods will have different effects on cost, schedule, operations, division of responsibility, coordination, and other considerations.		Cost					2020-11-06: Probability and impacts unknown at this time. TTC M&P might be able to provide guidance or benchmarks based on past projects.			5/27/2020
						Schedule								5/27/2020
31	Design	Changes in legislation or regulations	There could be changes in legislation or regulations (OBC, accessibility, etc.) that result in a need to change the design.	Could change project requirements and result in delays or increased costs.	Very Unlikely (1): < 10%	Cost		-5 (>$20M cost)		-3 (High)	2020-11-06: Unlikely to occur but could impact many stations.			5/27/2020
						Schedule		-5 (>4 months delay)		-3 (High)				5/27/2020
32	Design	Unanticipated challenges in obtaining TTC approvals	Obtaining TTC approvals might not work out as planned (due to staff workload, internal disputes, etc.).	Could result in delays.	Possible (3): 36% - 65%	Schedule		-5 (>4 months delay)		-4 (Critical)	2020-11-06: Consider opportunity for including maintenance in the construction contract (or a maintenance contract similar to the sliding doors in stations).			5/27/2020
33	Design	Changes to TTC standards	Changes to TTC standards (as to use of platform space, finishes, etc.) might result in a need to change the design.	Could result in delays or increased costs.	Unlikely (2): 10% - 35%	Cost		-5 (>$20M cost)		-3 (High)	2020-11-03: Project underway to update platform tiles.			5/27/2020
						Schedule		-5 (>4 months delay)		-3 (High)				5/27/2020
34	Design	Changes in political/public priorities	Political or public priorities might change.	Could result in significant changes in project scope and consequently changes in schedule and cost.		Cost					2020-11-06: Probability and impacts unknown at this time. This is a higher-level enterprise risk beyond just this project.			5/27/2020
						Schedule					2020-11-06: Impacts unknown at this time.			5/27/2020
41	Design	Conflicts with concurrent work	Other work at stations could impact PED design.	Could result in increased costs to adapt design, coordinate work, etc.	Almost Certain (5): > 90%	Cost	0 (None)		-3 ($5M - $10M cost)	-3 (High)		Hold regular meetings to coordinate work at stations.		5/28/2020
42	Design	Project deferral	The project could be deferred for reasons not covered by other risks.	Could delay implementation of PEDs.	50%	Schedule	0 weeks	0 weeks	-104 weeks	-2 (Medium)		Include appropriate escalation in cost estimate.		5/28/2020
46	Design	Bankruptcy of design contractor	A design contractor might go bankrupt and fail to complete work.	Could result in delays.	10%	Schedule	-20 weeks		-52 weeks	-3 (High)				5/28/2020
47	Design	Lack of competition among PED suppliers	There might be a lack of qualified and interested PED suppliers to bid for the project, resulting a less competitive process.	Could result in increased costs.	5%	Cost		-$48.1 million		-3 (High)	Most likely assumes 10% increase of estimated $6.5 million per station for 74 station platform levels.		3.2.6, 3.4.3, 3.5	5/28/2020

Risk ID	Phase	Threat or Opportunity	Cause	Effect	Probability	Impact Type	Best Case Impact	Most Likely Impact	Worst Case Impact	Risk Rating	Notes	Risk Response	Feasibility Study Sections	Date Identified
49	Design	Lack of competition among design contractors	There might be a lack of qualified and interested design contractors to bid for the project, resulting a less competitive process.	Could result in increased costs.	0%	Cost		$0 million		0 (None)				5/28/2020
54	Design	Line 1 rolling stock	Rolling stock on Line 1 might change.	Could result in delays or increased costs need to redesign or reconfigure PEDs to accommodate new rolling stock.		Cost					2020-11-06: Probability and impacts unknown at this time.			11/2/2020
						Schedule					2020-11-06: Impacts unknown at this time.			11/2/2020
55	Design	Line 2 rolling stock	Rolling stock on Line 2 might change.	Could result in delays or increased costs need to redesign or reconfigure PEDs to accommodate new rolling stock.	Possible (3): 36% - 65%	Cost					2020-11-06: Toronto Rocket expected to be introduced on Line 2, possibly during lifetime of this project, although PEDs will likely be installed first on Line 1. If the rolling stock design is the same as on Line 1, PED design for both lines could be the same. Otherwise, the PED design will need to be different. Design, timing, and impacts are unknown at this time.			11/2/2020
						Schedule					2020-11-06: Impacts unknown at this time.			11/2/2020
56	Design	Hazard analysis	Site-specific hazard analyses might identify new concerns (or larger concerns than anticipated).	Could result in delays or increased costs to address concerns.		Cost					2020-11-06: Probability and impacts unknown at this time. Feasibility study has laid out framework for preliminary safety certification but analysis of each station will need to happen during design. Excludes risk related to insufficient platform width for egress (Risk 12).			11/2/2020
						Schedule								11/2/2020
57	Design	Platform condition	Platform edges at Davisville and Rosedale need to be replaced, but the cost for this is not included in the current cost estimate. Further study during the Design phase could show that these platforms (or other platforms) need to be upgraded further or replaced entirely.	Could result in increased costs delays to upgrade or replace platforms.	Almost Certain (5): > 90%	Cost	-$20 million		-$136 million	-4 (Critical)	2020-11-06: Assume cost impacts range between best case of 2 stations (Davisville and Rosedale) needing platform edges replaced at $10 million each, and worst case of 10% of non-TYSSE stations (74 total - 6 TYSSE) needing platforms replaced at an average cost of $20 million each. There is a potential overlap between this risk and Risk 12 (Platform width), in that both could result in replacing platforms at the same station, but for different reasons. Both relate to the Design phase, so are separate from and Risk 35 (Unforeseen site conditions), which relates conditions not known until construction.			11/2/2020
						Schedule	0 weeks		-104 weeks	-4 (Critical)	2020-11-06: Schedule impact ranges between no delay and a delay of 2 years. This assumes that, even in the worst case, the delay to the overall project is limited to the delay at only 1 station (up to 2 years to replace the platform).			11/2/2020
5	Pilot	Pilot project delay	Pilot projects could lead to design refinements.	Could result in delays.	25%	Schedule		-26 weeks		-3 (High)	Assume pilot program takes place. Risks associated with not doing a pilot program are significant but not captured here. Pilot project might highlight problems that need redesign and result in delays.		2.6, 3.4.2	5/27/2020

Risk ID	Phase	Threat or Opportunity	Cause	Effect	Probability	Impact Type	Best Case Impact	Most Likely Impact	Worst Case Impact	Risk Rating	Notes	Risk Response	Feasibility Study Sections	Date Identified
6	Pilot	Pilot project lessons	Pilot project could yield valuable lessons learned.	Could result in cost savings (vs. current estimate which assumes separate contracts).	100%	Cost	$178 million	$89 million	$0 million	4 (Critical)	2021-02-08: Assumes that pilot project will occur but that cost savings are unknown. Best case assumes 10% savings over 74 total - 4 in pilot = 70 stations at baseline cost of $31 million per station from February 8, 2021 cost estimate, discounting 22% escalation. Mostly likely assumes 5% savings over 70 stations at baseline cost of $31 million per station from February 8, 2021 cost estimate, discounting 22% escalation. Worst case assumes no savings.			5/27/2020
7	Construction Contracts	Contract bundles	Number of and extent of contract bundles is still to be determined.	Could result in cost savings from economies of scale (vs. current estimate which assumes separate contracts).	100%	Cost	$178 million	$89 million	$0 million	4 (Critical)	2021-02-08: Assumes that contracts will be bundled but that cost savings are unknown. Best case assumes 10% savings over 74 total - 4 in pilot = 70 stations at baseline cost of $31 million per station from February 8, 2021 cost estimate, discounting 22% escalation. Mostly likely assumes 5% savings over 70 stations at baseline cost of $31 million per station from February 8, 2021 cost estimate, discounting 22% escalation. Worst case assumes no savings.		2.6	5/27/2020
29	Construction Contracts	Cost estimate accuracy	Estimated cost is based on various assumptions.	Actual cost might be different than estimate.	0%	Cost		$0 million		0 (None)	2020-09-29: Assume this risk is covered by the 20% design and pricing allowance (for design and pricing unknowns) and (compounded) 10% construction allowance (for construction unknowns) already in the cost estimate.			5/27/2020
35	Construction Contracts	Unforeseen site conditions	Conditions at stations (e.g., platform and under-platform condition) might be different than anticipated.	Could result in delays or increased costs beyond those allowed for in current estimates.	Almost Certain (5): > 90%	Cost		-5 (>$20M cost)		-4 (Critical)				5/27/2020
						Schedule		-5 (>4 months delay)		-4 (Critical)				5/27/2020
37	Construction Contracts	Unplanned disruptions to service	Construction work at stations could interfere with service functions in unplanned ways (e.g., unexpected electrical, safety, or structural problems could be encountered).	Could result in unplanned reductions to platform capacity, station closures, and disruptions to service.	Unlikely (2): 10% - 35%	Cost	$0 million		-$0.03 million	-1 (Low)	2020-11-06: Best case assumes no impact. Worst case assumes cost of bussing at 5% of 74 station platform levels for 1 peak period, assuming unit costs from "2019 Closures and Diversion Cost" template provided by TTC and quantities as follows: 4 hours of Customer Service Staff at $20.84/hour, 4 hours of Supervisor at $112.00/hour, 24 hours of Paid Duty Officer at $216.00/hour, and 400 km of bus mileage at $1.98/km, plus 13% HST.	Develop and implement mitigation plans.	2.2	5/27/2020
						Operations Disruption	0 (None)		-5 (Significant Negative)	-2 (Medium)	2020-11-06: Best case assumes no impact. Worst case assumes cumulative impact of multiple peak service impacts (individual rating of -4).	Develop and implement mitigation plans.		5/29/2020
38	Construction Contracts	Limited work windows	Typical working windows are limited to 2 AM to 5 AM daily.	More closures than originally planned might be needed to complete work on schedule.	50%	Cost	-$37 million	-$100 million	-$250 million	-4 (Critical)	Best case assumes 1 shutdown per station for 74 station at $0.5 million each.		2.2.2	5/27/2020
39	Construction Contracts	Safety during installation	Installation work will temporarily create hazards or obstacles on the platform (e.g., holes, support columns, uneven floor surfaces, hoardings).	Could result in injury to workers or passengers or in increased costs or schedule to mitigate safety risks.	100%	Safety	0 (None)	-4 (Very High Negative)	-5 (Significant Negative)	-4 (Critical)	2020-10-14: Assumes that hazards or obstacles will be created, but that impacts are unknown. 2020-11-03: Impacts assume current procedures and mitigations are not in place (or that some risk remains even if they are in place).	Develop and include mitigations (e.g., bypass station, do higher hazard work in non-service hours and/or inside hoardings) in construction contracts.	2.2, 2.2.1	5/27/2020
						Schedule	0 (None)	-1.5 weeks	-12 weeks	-3 (High)		Develop and include mitigations in construction contracts.		5/29/2020

Risk ID	Phase	Threat or Opportunity	Cause	Effect	Probability	Impact Type	Best Case Impact	Most Likely Impact	Worst Case Impact	Risk Rating	Notes	Risk Response	Feasibility Study Sections	Date Identified
						Cost	0 (None)	-4 ($10M - $20M cost)	-$100 million	-4 (Critical)		Develop and include mitigations in construction contracts.		5/27/2020
40	Construction Contracts	Construction safety at platform edge	Installation requires work at the platform edge.	Could result in injury to workers at platform level and in increased costs or schedule to mitigate safety risks.	100%	Safety	0 (None)	-4 (Very High Negative)	-5 (Significant Negative)	-4 (Critical)	2020-10-14: 100% probability reflects that work will be required at the platform edge.			5/27/2020
						Schedule	0 (None)	-1.5 weeks	-12 weeks	-3 (High)				5/29/2020
						Cost	$0 million	-$2.5 million	-$50 million	-3 (High)				5/27/2020
44	Construction Contracts	Bankruptcy of PED supplier	The PED supplier might go bankrupt and fail to deliver PEDs.	Could result in delays.	10%	Schedule		-1 weeks		-2 (Medium)				5/28/2020
45	Construction Contracts	Bankruptcy of construction contractor	A construction contractor might go bankrupt and fail to complete work.	Could result in increased costs.	10%	Cost		-$51 million		-3 (High)	Most likely assumes 10 stations affected at a cost of 20% of estimated $31 million total cost each from February 8, 2021 cost estimate, discounting 22% escalation.			5/28/2020
						Schedule	-52 weeks		-104 weeks	-3 (High)				5/29/2020
48	Construction Contracts	Lack of competition among construction contractors	There might be a lack of qualified and interested construction contractors to bid for the project, resulting a less competitive process.	Could result in increased costs.	10%	Cost		-$188 million		-3 (High)	Most likely assumes 10% increase of estimated $31 million per station from February 8, 2021 cost estimate, discounting 22% escalation, for 74 stations.			5/28/2020
50	Construction Contracts	Contractor performance	Contractor performance (adherence to budget and schedule, quality of work, safety, etc.) may be different than anticipated.	Could result in delays or increased costs due to rework or to quality or safety issues.	Unlikely (2): 10% - 35%	Schedule		-5 (>4 months delay)		-3 (High)		Hold regular progress meetings, include mitigation measures in contracts.		5/28/2020
						Cost		-4 ($10M - $20M cost)		-3 (High)				11/6/2020
51	Construction Contracts	Scope changes during construction	Scope changes during construction are not priced under competitive tension.	Could result in delays or increased or higher-than-market costs.	Very Likely (4): 66% - 90%	Cost		-4 ($10M - $20M cost)		-4 (Critical)				5/28/2020
						Schedule		-5 (>4 months delay)		-4 (Critical)				11/6/2020
16	Operations	Dwell time	PEDs are slower to open and close than train doors, delay passenger flow slightly, and tend to increase departure delays.	PEDs could increase dwell time by 6 to 12 seconds.	0%	Operations Disruption		0 (None)		0 (None)	This risk would occur during operations so is excluded from this analysis and considered instead via sensitivity analysis of project costs and benefits as agreed in July 13, 2020 conference call with TTC.		3.6.1.1	5/27/2020
17	Operations	Reduction in injury and loss of life	PEDSs help reduce the risk of injury and loss of life from incidents like suicide attempts, falls to track level, non-suicidal contacts with trains, and trackside incursions. However, the frequency of these incidents varies.	Reductions could vary depending on the effectiveness of PEDs or the frequency of incidents.	0%	Safety		0 (None)		0 (None)	This risk would occur during operations so is excluded from this analysis and considered instead via sensitivity analysis of project costs and benefits as agreed in July 13, 2020 conference call with TTC.		3.6.1.2	5/27/2020

Risk ID	Phase	Threat or Opportunity	Cause	Effect	Probability	Impact Type	Best Case Impact	Most Likely Impact	Worst Case Impact	Risk Rating	Notes	Risk Response	Feasibility Study Sections	Date Identified
18	Operations	Reduction in passenger delays	By reducing the risk of injury and loss of life from incidents, PEDs help reduce the risk of passenger delays that can result. However, the frequency and extent of these delays varies.	Reductions could vary depending on the effectiveness of PEDs, the frequency of incidents, or the frequency or extent of delays.	0%	Operations Disruption		0 (None)		0 (None)	This risk would occur during operations so is excluded from this analysis and considered instead via sensitivity analysis of project costs and benefits as agreed in July 13, 2020 conference call with TTC.			5/27/2020
19	Operations	Reduction in employee lost time	By reducing the risk of injury and loss of life from incidents, PEDs help reduce the impact of lost time due to trauma. However, the frequency and impact of lost time varies.	Reductions could vary depending on the effectiveness of PEDs, the frequency of incidents, or the frequency or extent of lost time impacts.	0%	Safety		0 (None)		0 (None)	This risk would occur during operations so is excluded from this analysis and considered instead via sensitivity analysis of project costs and benefits as agreed in July 13, 2020 conference call with TTC.			5/27/2020
20	Operations	Reduction in emergency response	By reducing the risk of injury and loss of life from incidents, PEDs help reduce the cost of emergency response (e.g., TTC, fire, police, and ambulance). However, the frequency and extent of emergency response varies.	Reductions could vary depending on the effectiveness of PEDs, the frequency of incidents, or the frequency or extent of emergency response.	0%	Cost		0 (None)		0 (None)	This risk would occur during operations so is excluded from this analysis and considered instead via sensitivity analysis of project costs and benefits as agreed in July 13, 2020 conference call with TTC.			5/27/2020
24	Operations	Resources to operate and maintain	Resources will depend on the current TTC workforce (at the time PED commissioning), the number of stations in which PEDs are installed, and the manufacturer recommended maintenance items of the product that TTC ultimately selects.	Resources could be different than anticipated.	0%	Cost		0 (None)		0 (None)	This risk would occur during operations so is excluded from this analysis and considered instead via sensitivity analysis of project costs and benefits as agreed in July 13, 2020 conference call with TTC.		3.9	5/27/2020
36	Operations	Operation of outdoor stations	PEDs at outdoor stations are subject to the effects of weather.	Could result in higher failure rate and maintenance costs.	0%	Cost		0 (None)		0 (None)	This risk would occur during operations so is excluded from this analysis and considered instead via sensitivity analysis of project costs and benefits as agreed in July 13, 2020 conference call with TTC.			5/27/2020
52	Operations	Added point of failure	Introduction of PEDs adds another subsystem that could affect revenue operations if it fails.	Could affect operations and reputation.	0%	Cost		0 (None)		0 (None)	This risk would occur during operations so is excluded from this analysis and considered instead via sensitivity analysis of project costs and benefits as agreed in July 13, 2020 conference call with TTC.			5/29/2020
						Reputation		0 (None)		0 (None)	This risk would occur during operations so is excluded from this analysis and considered instead via sensitivity analysis of project costs and benefits as agreed in July 13, 2020 conference call with TTC.			5/29/2020
53	Operations	Grounding (Operations)	Grounding alternative is not service-proven.	Maintenance costs might be higher than anticipated because design is not service-proven.	0%	Cost		0 (None)		0 (None)	This risk would occur during operations so is excluded from this analysis and considered instead via sensitivity analysis of project costs and benefits as agreed in July 13, 2020 conference call with TTC.			5/29/2020

Table 18: Number of potential impacts assessed by impact type and risk rating

	Risk Rating								
	Threats				Opportunities				
Impact Type	-4 (Critical)	-3 (High)	-2 (Medium)	-1 (Low	1 (Low)	2 (Medium)	3 (High)	4 (Critical)	Total
Cost	8	9	1	2	0	0	0	2	**22**
Operations Disruption	0	0	1	0	0	0	0	0	**1**
Public Disruption	0	0	0	0	0	0	0	0	**0**
Reputation	0	0	0	0	0	0	0	0	**0**
Safety	2	0	0	0	0	0	0	0	**2**
Schedule	8	9	2	0	0	0	0	0	**19**
Grand Total	**18**	**18**	**4**	**2**	**0**	**0**	**0**	**2**	**44**

Table 19: Critical threats and opportunities by impact type

Impact Type	Risk Factor	Effective Probability Rating	Effective Impact Rating
Cost	6 (Pilot project lessons)	Almost Certain (5): > 90%	5 (>$20M savings)
Cost	7 (Contract bundles)	Almost Certain (5): > 90%	5 (>$20M savings)
Cost	12 (Platform width)	Almost Certain (5): > 90%	-5 (>$20M cost)
Cost	35 (Unforeseen site conditions)	Almost Certain (5): > 90%	-5 (>$20M cost)
Cost	57 (Platform condition)	Almost Certain (5): > 90%	-5 (>$20M cost)
Cost	8 (Grounding (Design))	Almost Certain (5): > 90%	-4 ($10M - $20M cost)
Cost	39 (Safety during installation)	Almost Certain (5): > 90%	-4 ($10M - $20M cost)
Cost	38 (Limited work windows)	Possible (3): 36% - 65%	-5 (>$20M cost)
Cost	11 (Communication system hardware)	Very Likely (4): 66% - 90%	-4 ($10M - $20M cost)
Cost	51 (Scope changes during construction)	Very Likely (4): 66% - 90%	-4 ($10M - $20M cost)
Safety	39 (Safety during installation)	Almost Certain (5): > 90%	-4 (Very High Negative)
Safety	40 (Construction safety at platform edge)	Almost Certain (5): > 90%	-4 (Very High Negative)
Schedule	8 (Grounding (Design))	Almost Certain (5): > 90%	-5 (>4 months delay)
Schedule	12 (Platform width)	Almost Certain (5): > 90%	-5 (>4 months delay)
Schedule	35 (Unforeseen site conditions)	Almost Certain (5): > 90%	-5 (>4 months delay)
Schedule	57 (Platform condition)	Almost Certain (5): > 90%	-5 (>4 months delay)
Schedule	11 (Communication system hardware)	Very Likely (4): 66% - 90%	-5 (>4 months delay)

Impact Type	Risk Factor	Effective Probability Rating	Effective Impact Rating
Schedule	51 (Scope changes during construction)	Very Likely (4): 66% - 90%	-5 (>4 months delay)
Schedule	14 (Lack of ATC on Line 2)	Possible (3): 36% - 65%	-5 (>4 months delay)
Schedule	32 (Unanticipated challenges in obtaining TTC approvals)	Possible (3): 36% - 65%	-5 (>4 months delay)

C.2 Model Risks

AECOM used Monte Carlo simulation to model the risks identified in the risk register as follows:

1. For each risk factor:
    a) If only a qualitative probability rating was assigned, simulate the probability of occurrence as a uniform random variable over the range defined in Table 15;
    b) Simulate the occurrence as a yes/no random variable with the quantitative probability value assigned, if any, or the probability simulated in Step a, otherwise;
    c) If the risk factor does not occur, assume the impacts are zero; and
    d) Otherwise, for each type of impact identified for the risk factor, simulate the impact as follows:
        i) Determine the minimum (least desirable) possible impact (if any) as the minimum of the following:
            1) The worst case impact value assigned, if any;
            2) The minimum bound of the quantitative range represented by the worst case impact rating assigned, if any. The quantitative range is defined as follows:
                a. For cost and schedule impacts, the quantitative range is defined as part of the impact rating. For example, perTable 17, a cost impact rating of -4 ($10M - $20M cost) represents an impact of between $10 million and $20 million in cost, and the minimum (that is, most undesirable) bound of this range is -$20 million. In cases where the quantitative range defined by the impact rating is unbounded on one side, such as for a cost impact rating of -5 (>$20M cost), assume a bound equal to twice the bounded side, such as $40 million in cost, or -$40 million; and
                b. For other types of impacts, use the quantitative range for the corresponding cost impact;
            3) The same as Items 1) and 2) above for each of the most likely and best case impacts;
        ii) Determine that maximum (most desirable) possible impact (if any) as the maximum of the same;
        iii) Determine the most likely impact (if any) as follows:
            1) The most likely impact value assigned, if any;

2) For impact types other than cost and schedule, the most likely impact rating assigned, if any; and

3) For cost and schedule, the midpoint of the quantitative range (in dollars or weeks) represented by the most likely impact rating assigned, if any;

iv) If the minimum and maximum impacts are undetermined, assume the impact is zero;

v) Otherwise, if the minimum and maximum possible impacts are equal, assume that is the impact;

vi) Otherwise, if the most likely impact is undetermined, simulate the impact as a uniform random variable between the minimum and maximum impacts; and

vii) Otherwise, simulate the impact as a triangular random variable using the minimum, most likely, and maximum impacts as the minimum, mode and maximum, respectively;

2. Calculate the total cost impact (excluding the cost of schedule impact) as the sum of the simulated cost impacts over all risk factors;

3. For each phase, calculate the schedule impact as the sum of the following:

   e) The maximum of the positive simulated schedule impacts (if any) over all risk factors that belong to the phase, and

   f) The minimum of the negative simulated schedule impacts (if any) over all risk factors that belong to the phase;

4. Calculate the total schedule impact as the sum, over all phases, of the schedule impacts calculated in Step 3; and

5. Repeat the above for a total of 5,000 trials.

The result will be a set of 5,000 simulated project outcomes.

Note that Steps 3 and 4 model total schedule impacts differently from how Step 2 models total cost impacts. This represents a first attempt to account for the fact that, unlike cost impacts, schedule impacts are not necessarily cumulative. Individual schedule impacts may not impact the project duration, or may only partly impact it, depending on how much (if any) slack there is in the schedule for the activities they affect. However, a detailed project schedule is not yet available, so it is unknown how much slack activities will have or how risk factors could affect them. As a result, Steps 3 and 4 make some simplifying assumptions. Step 3 effectively assumes that individual schedule impacts in the same phase occur entirely in parallel. This may be optimistic. Step 4 effectively assumes that the phases occur entirely in series. This may be pessimistic. The net effect of Steps 3 and 4 is likely more realistic than assuming that schedule impacts are entirely cumulative. Nonetheless, total schedule impact results should be interpreted with caution.

The cost of schedule impact was not modeled.

No correlations between the risk factors were identified.

C.3 Analyze Risks

AECOM analyzed the simulated project outcomes as described in the following sub-sections.

C.3.1 Total Cost Impact

Figure 10 shows the distribution of total cost impact (excluding the cost of schedule impact) of the simulated project outcomes. For example, it shows that:

- The outcomes ranged from a desirable (positive) impact of a cost savings of $126 million to an undesirable (negative) impact of a cost increase of $658 million;
- 50% of the outcomes had cost increases of $152 million or greater; and
- 10% of the outcomes had cost increases of $317 million or greater.

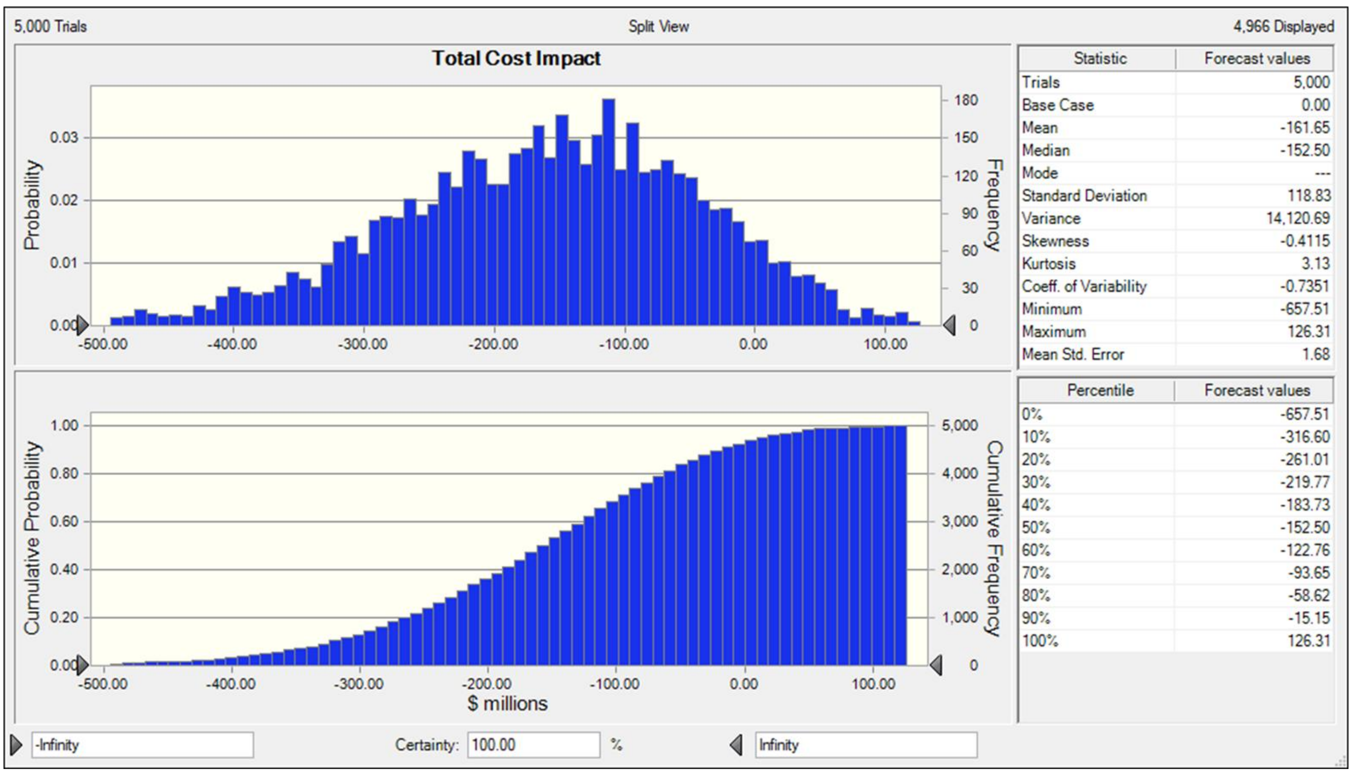

Figure 6: Distribution of total cost impact (excluding cost of schedule impact)

Figure 10 likely underestimates the magnitude of the cost risk. This is because of the following:

- There were 6 risk factors identified with potential cost impacts, but for which the risk workshop participants could not rate or quantify the probability or impact. Figure 10 excludes the effect of these risks;
- Figure 10 excludes the cost of schedule impact (for example, that could result from escalation or additional carrying costs due to delays);

- The design is at a relatively early stage, so there could be significant unidentified risks. It excludes the effect of unidentified risks; and
- The probability and impact ratings and values that were assigned by the risk workshop participants were mostly subjective. Subjective ratings can be appropriate as a first approximation, particularly for the purpose of identifying top risk factors. However, they may not accurately represent the cumulative risk.

Nonetheless, Figure 10 is potentially useful as an early indicator of the lower bound on the cost risk.

C.3.2 Total Schedule Impact

Figure 11 shows the distribution of the total schedule impact of the simulated project outcomes (as estimated according to the simplifying assumptions described in Section C2). For example, it shows:

- The outcomes ranged in undesirable (negative) impacts of (that is, delays) between 26 and 225 weeks;
- 50% of the outcomes had an undesirable a delay of 109 weeks or greater; and
- 10% of the outcomes had a delay of 146 weeks or greater.

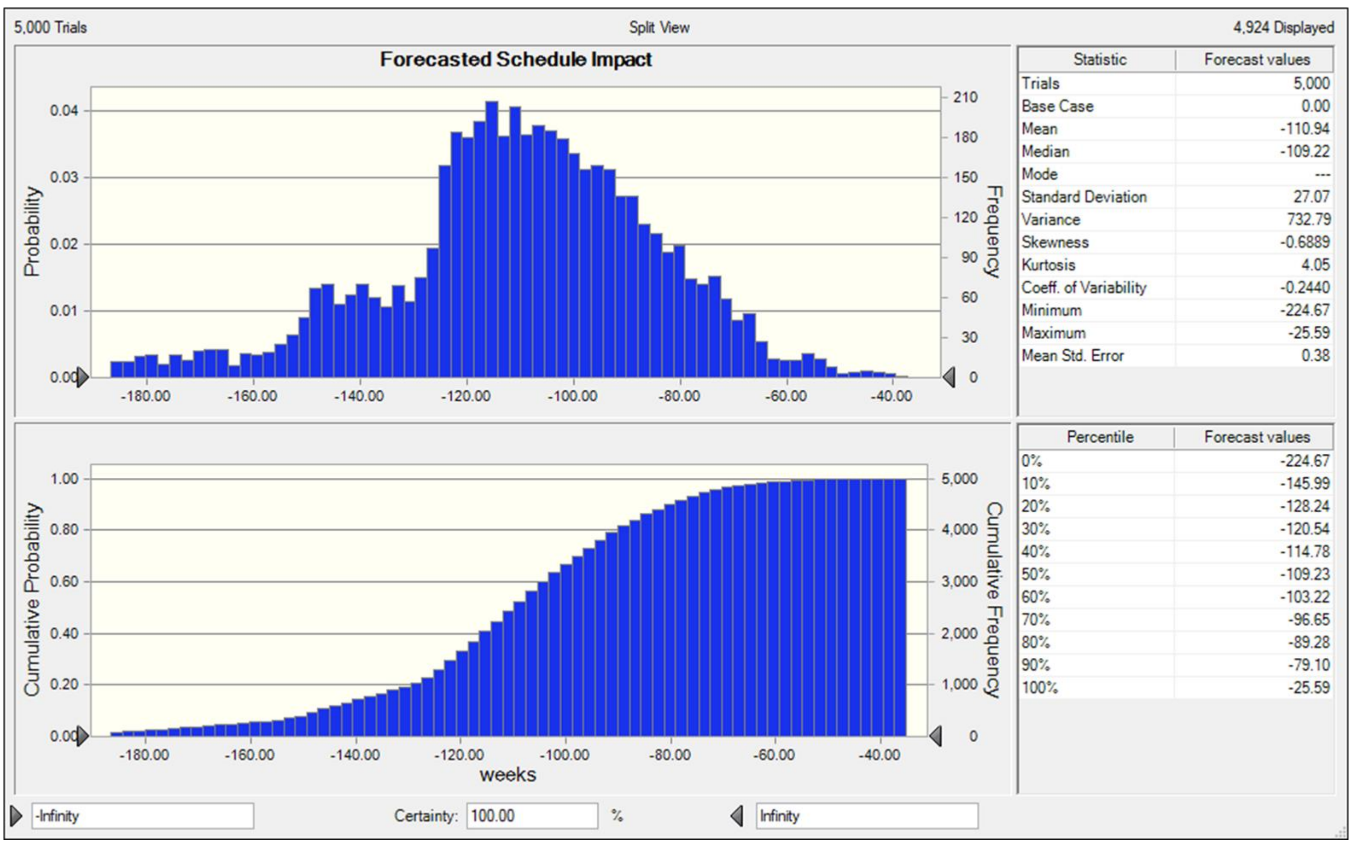

Figure 7: Distribution of total schedule impact

Figure 11 likely underestimates the magnitude of the schedule risk. This is because of the following:

- There were 5 risk factors identified with potential schedule impacts, but for which the risk workshop participants could not rate or quantify the probability or impact. It excludes the effect of these risks;

- It is based on simplifying assumptions, as described in Section C.2;
- The design is at a relatively early stage, so there could be significant unidentified risks. It excludes the effect of unidentified risks; and
- The probability and impact ratings and values that were assigned by the risk workshop participants were mostly subjective. Subjective ratings can be appropriate as a first approximation, particularly for the purpose of identifying top risk factors. However, they may not accurately represent the cumulative risk.

Nonetheless, Figure 11 is potentially useful as an early indicator of the lower bound on the schedule risk.

C.3.3 Top Risk Factors by Mean Cost Impact

Figure 12 shows the top 10 risk factors by mean cost impact (excluding the cost of schedule impact). These are the risk factors that, on average, have the largest (in absolute value) cost impact (excluding the cost of schedule impact).

Figure 12 shows that:

- The top 4 cost risk factors, with mean costs impacts ranging (in absolute value) from \$63 million to \$89 million stand out from the other risks. The next highest risk factor has a mean impact of \$39 million;
- 2 of the top 4 cost risk factors are threats, namely 57 (Platform condition), with a mean impact of a \$74 million cost increase, and 38 (Limited work windows), with a mean impact of a \$63 million cost increase. The total of the mean impacts of these 2 risk factors is approximately equal to total of the mean impacts of all other threats in the in the top 10; and
- 2 of the top 4 cost risk factors are opportunities, namely 6 (Pilot project lessons), with a mean impact of a \$89 million cost savings, and 7 (Contract bundles), with a mean impact of a \$88 million cost savings. No other risk factors in the top 10 are opportunities.

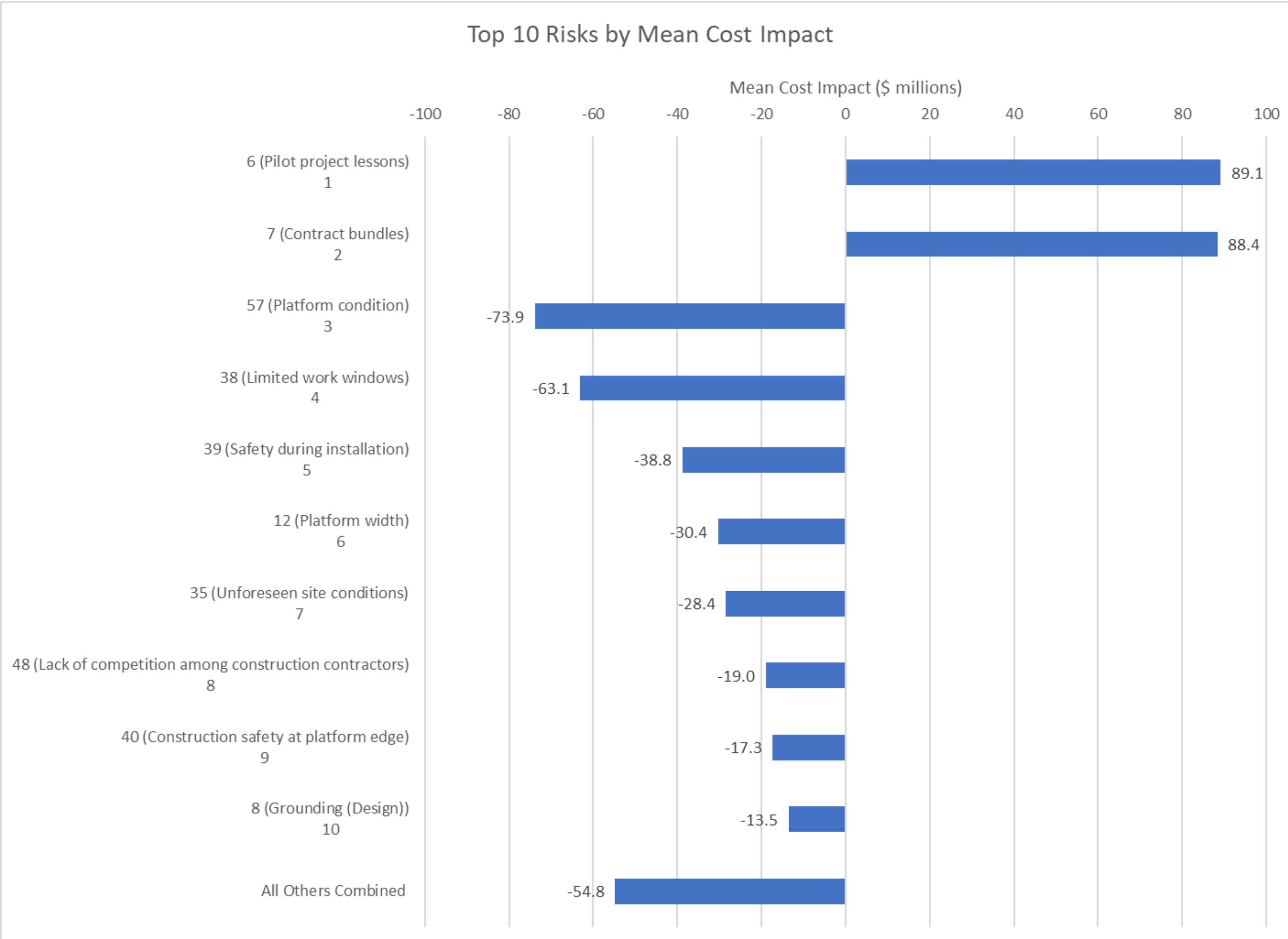

Figure 8: Top 10 risk factors by mean cost impact (excluding cost of schedule impact)

C.3.4 Top Risk Factors by Contribution to Variance in Total Cost Impact

Figure 13 shows the top 10 risk factors by contribution to variance in total cost impact (excluding the cost of schedule impact). These are the risk factors that cause the most variability in the total cost impact (excluding the cost of schedule impact). These can include low probability risk factors with large impacts, or risk factors with a wide range of potential impacts.

Figure 13 shows that:

- Risk factor 38 (Limited work windows) is the top risk factor by contribution to variance in total cost impact. It contributes an estimated 36% to the variance in the total cost impact;
- Together, the top 2 risk factors, 38 (Limited work windows) and 48 (Lack of competition among construction contractors), contribute more than half of the variance in the total cost impact.

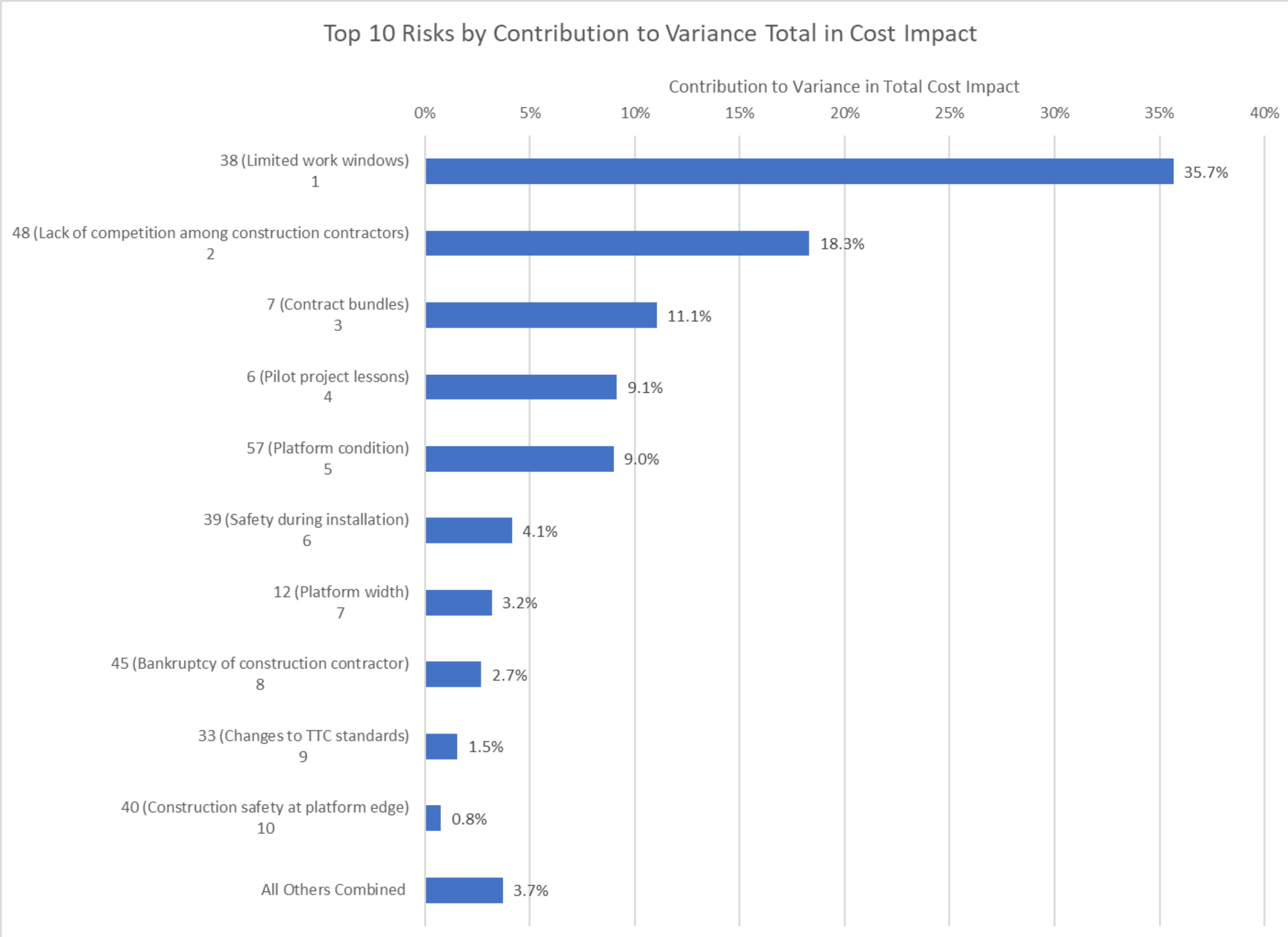

Figure 9: Top 10 risk factors by contribution to variance in total cost impact (excluding cost of schedule impact

C.3.5 Top Risk Factors by Mean Schedule Impact

Figure 14 shows the top 10 risk factors by mean schedule impact. These are the risk factors that, on average, have the largest schedule impact (in absolute value).

Figure 14**Error! Reference source not found.** shows that:

- The top 10 risk factors are all threats (that could delay the project);
- Risk factors 8 (Grounding (Design)), 12 (Platform width), and 57 (Platform condition) are the top risk factors by mean schedule impact, with mean impacts of 53 weeks delay, 52 weeks delay, and 49 weeks delay, respectively; and

The risk factors outside the top 10 have a combined mean impact of 33 weeks delay, although this should be interpreted with caution because schedule impacts are not necessarily cumulative, as explained in Section C.2.

Figure 14 considers each risk factor only in isolation.

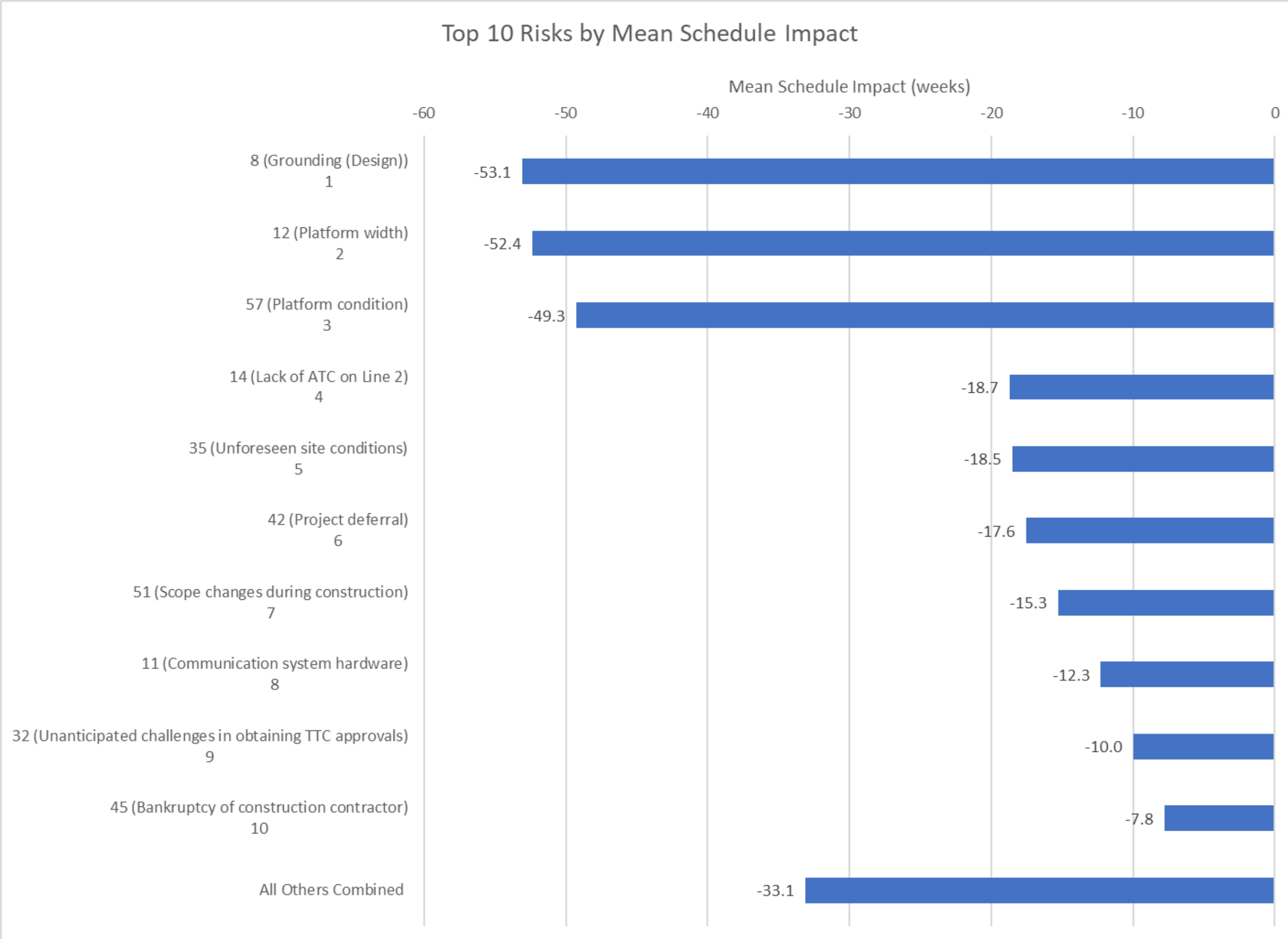

Figure 10: Top 10 risk factors by mean schedule impact

C.3.6 Top Risk Factors by Mean Reputation Impact

No risk factors with potential reputation impacts were identified.

C.3.7 Top Risk Factors by Mean Safety Impact

Only two risk factors with potential safety impacts were identified. Both risk factors had a mean impact equivalent to a rating of -4 (Very High Negative). These risk factors were:

- 39 (Safety during installation); and
- 40 (Construction safety at platform edge).

C.3.8 Top Risk Factors by Mean Public Disruption Impact

No risk factors with potential public disruption impacts were identified.

C.3.9 Top Risk Factors by Mean Operations Disruption Impact

Only one risk factor with potential operations disruption impacts was identified. This was risk factor 37 (Unplanned disruptions to service). It had a mean impact equivalent to a rating of -2 (Medium Negative).

C.4 Conclusions

Table 19 identified and defined in the risk assessment. In summary:

1. A total of 56 risk factors were identified;
2. Of the 56 risk factors, 23 were eventually excluded from the assessment (but retained for reference) because they were duplicates, were outside the scope of the assessment, no longer existed, or were assumed be included elsewhere;
3. For the remaining 33 risk factors, after excluding the cases where the risk workshop participants could not rate or quantify the probability or impact, there were 44 potential impacts identified (since impacts of more than type were identified for some risk factors);
4. Of those 44 potential impacts:
   a) 18 impacts (8 cost, 8 schedule, and 2 safety) were threats with the lowest (most undesirable) rating of -4 (Critical); and
   b) 2 impacts (both cost) were opportunities with a highest (most desirable) rating of 4 (Critical).

The risk assessment modelled the 44 potential impacts in a Monte Carlo simulation that generated 5,000 potential project outcomes. The assessment then analyzed the distribution of these outcomes to estimate total cost and schedule risks, and to identify top risk factors by different quantitative measures.

Table 22 summarizes the distribution of the total cost and schedule impacts of the simulated project outcomes, excluding the cost of schedule impact. Negative values represent undesirable outcomes, so the 0 percentile represents the most undesirable outcomes, which were a cost increase of $658 million and a schedule delay of 225 weeks.

Table 20: Distribution of total cost and schedule impacts (excluding cost of schedule impact)

Percentile	Total Cost Impact ($ millions)	Total Schedule Impact (weeks)
0%	-658	-225
5%	-371	-161
10%	-317	-146
20%	-261	-128
50%	-152	-109

Table 22 likely underestimates the magnitude of the cost and schedule risk. This is because of the following:

- There were risk factors identified with potential impacts, but for which the risk workshop participants could not rate or quantify the probability or impact. Table 22 excludes the effect of these risks;
- It excludes the cost of schedule impact (for example, that could result from escalation or additional carrying costs due to delays). This cost could be significant. For example, if a risk occurs early in the project and delays the project by one year, this could escalate almost all of the project's $2.3 billion total estimated cost. At the 4% annual escalation assumed by the cost estimate, this could amount to an increase of as much as $89 million;
- It is based on simplifying assumptions for estimating schedule impact, as described in Section C.2;
- The design is at a relatively early stage, so there could be significant unidentified risks. It excludes the effect of unidentified risks; and
- The probability and impact ratings and values that were assigned by the risk workshop participants were mostly subjective. Subjective ratings can be appropriate as a first approximation, particularly for the purpose of identifying top risk factors (discussed further below). However, they may not accurately represent the cumulative risk.

Nonetheless, it is potentially useful as an early indicator of the lower bound on the cost and schedule risk. For example, there is at least a 50% probability of cost increases (excluding the cost of schedule delay) of $152 million or greater, and of delays of 109 weeks or greater.

Table 23 summarizes the top risk factors by different quantitative measures. Results in Table 23 relating to total schedule impacts should be interpreted with caution due to the simplifying assumptions used to model total schedule impacts.

There were 8 cases where a risk factor had a combination of rated probability and most likely impact that resulted in a Critical risk rating, but did not rank as a top risk by the quantitative measures considered in Table 23. Table 24 lists these 8 cases.

Only two risk factors with potential safety impacts were identified.

Only one risk factor with potential operations disruption impacts was identified.

No risk factors with potential reputation or public disruption impacts were identified.

Table 21: Top risk factors by different quantitative measures

Impact Type	Measure	Rank	Risk Factor	Measure Value
Cost	Mean Cost Impact	1	6 (Pilot project lessons)	$89.1 million cost savings
		2	7 (Contract bundles)	$88.4 million cost savings
		3	57 (Platform condition)	$73.9 million cost increase

Impact Type	Measure	Rank	Risk Factor	Measure Value
		4	38 (Limited work windows)	$63.1 million cost increase
		5	39 (Safety during installation)	$38.8 million cost increase
	Contribution to Variance in Total Cost Impact	1	38 (Limited work windows)	35.7%
		2	48 (Lack of competition among construction contractors)	18.3%
		3	7 (Contract bundles)	11.1%
		4	6 (Pilot project lessons)	9.1%
		5	57 (Platform condition)	9.0%
Schedule	Mean Schedule Impact	1	8 (Grounding (Design))	53.1 weeks delay
		2	12 (Platform width)	52.4 weeks delay
		3	57 (Platform condition)	49.3 weeks delay
		4	14 (Lack of ATC on Line 2)	18.7 weeks delay
		5	35 (Unforeseen site conditions)	18.5 weeks delay
Safety	Mean Safety Impact	1	39 (Safety during installation)	-4 (Very High Negative)
		2	40 (Construction safety at platform edge)	-4 (Very High Negative)
Operations Disruption	Mean Operations Disruption Impact	1	37 (Unplanned disruptions to service)	-2 (Medium Negative)

Table 22: Critical risk factors not identified as top risks by quantitative measures considered

Impact Type	Risk Factor	Effective Probability Rating	Effective Impact Rating
Cost	12 (Platform width)	Almost Certain (5): > 90%	-5 (>$20M cost)
	35 (Unforeseen site conditions)	Almost Certain (5): > 90%	-5 (>$20M cost)
	8 (Grounding (Design))	Almost Certain (5): > 90%	-4 ($10M - $20M cost)
	11 (Communication system hardware)	Very Likely (4): 66% - 90%	-4 ($10M - $20M cost)
	51 (Scope changes during construction)	Very Likely (4): 66% - 90%	-4 ($10M - $20M cost)
Schedule	11 (Communication system hardware)	Very Likely (4): 66% - 90%	-5 (>4 months delay)
	51 (Scope changes during construction)	Very Likely (4): 66% - 90%	-5 (>4 months delay)
	32 (Unanticipated challenges in obtaining TTC approvals)	Possible (3): 36% - 65%	-5 (>4 months delay)

C.5 Recommendations

This report makes the following recommendations:

1. **Develop Response Strategies** – The risk register identifies response strategies, but only briefly, and only for some risks. TTC should further develop response strategies, ideally starting with the most important risks. These strategies could involve avoiding, transferring, or mitigating risks (or alternatively exploiting, sharing, or enhancing opportunities). Some residual risk could remain even after response. Responses might also introduce new risks;

2. **Rate or Quantify Undefined Probabilities and Impacts** – There are several risks for which probabilities or impacts remain to be rated or quantified. When feasible, TTC should rate or quantify these probabilities and impacts, update the risk register, and repeat the risk assessment;

3. **Refine Estimated Probabilities and Impacts** – The probability and impact ratings and values that were assigned by the risk workshop participants were mostly subjective. Subjective ratings can be useful and appropriate as a first approximation. However, as the project evolves, it will become more important to obtain better forecasts of the individual and overall risks. This will likely require developing more objective and quantitative estimates of probability and impact (and estimates of impact that consider the range and distribution of possible impacts in addition to the most likely impact).

   The risks identified in this assessment as critical risks or as top risks by quantitative measures should be early candidates to refine in this way.

   Other risks that were rated with the highest qualitative impact rating should also be early candidates. This is because the highest ratings are open-ended and compounded by narrowness of the rating scales relative to the size of the project. For example, the highest qualitative threat rating for cost represents a cost increase of greater than $20 million. Consider two risk factors with potential cost impacts of $30 million and $300 million, respectively, that have not been quantified, and so are assigned the same qualitative impact rating of greater than $20 million. Both might be possible given the current $3.5 billion cost estimate for the project. If the $300 million impact has a lower probability rating, it would be rated as a lower risk, even though it might be much a higher risk in quantitative terms. To avoid this, it will be important to quantify impacts for risks that were rated with the highest qualitative impact rating;

4. **Examine Types of Impacts with Few or No Risk Factors** – Cost and schedule impacts make up almost all the risk factors identified. For other types of impacts, the risk assessment identified few or no risk factors (specifically, 2 for safety, 1 for operations disruption, and 0 for each of reputation and public disruption). TTC should examine these types of impacts more closely to identify and define risk factors that might have been overlooked;

5. **Integrate Cost Estimates** – As more detailed cost estimates are developed, there may be opportunities to integrate them with the risk assessment, such as to:

   a) Use information from the cost estimate to better quantify the potential impact of risks already identified;

   b) Use information from the cost estimate (e.g., total construction cost, carrying costs, escalation, etc.) to quantify and include the cost of schedule impact; and

c) Add risks to capture key assumptions in the cost estimate (e.g., unit costs, productivity, escalation, etc.);

6. **Integrate Schedule Details** – As detailed project schedules are developed, there may be opportunities to integrate them with the risk assessment, such as to:

   a) Model schedule impacts in a more realistic way by associating risks with project activities and using the schedule to determine the effect of individual schedule impacts on the overall project; and

   b) Estimate the cost of schedule impacts based their impact on the overall project and parameters from the cost estimate (e.g., duration, escalation, etc.);

7. **Monitor and Control Risks** – The TTC should conduct regular risk review meetings to review risks that have already been identified, and to identify and quantify new risks that arise as the project progresses. The risk assessment should be repeated when there are significant changes in risks, and total cost and schedule impacts should be analyzed when more information becomes available;

8. **Use the Risk Register** – A risk register can be an effective tool for managing identified risks throughout the project. The TTC should update the risk register as designs, cost estimates, and schedules are further refined. Recommended uses of the risk register going forward include:

   a) Analyze risk allocation alternatives during planning and procurement;

   b) Provide project sponsors, stakeholders, and leadership/management with a documented framework from which risk status can be reported in the context of project controls;

   c) Communicate risk management issues; and

   d) Provide a mechanism for eliciting feedback and project control input; and

9. **Consider "Unknown Unknowns"** – The assessment considers only "known unknowns", that is, conditions that can be reasonably anticipated but not precisely quantified based on experience. However, threats and opportunities can also arise from "unknown unknowns", that is, conditions that cannot be foreseen based on experience. To control the associated risk, the TTC should:

   a) Regularly update the risk register to identify new risks as recommended in Item 8; and

   b) Consider planning to protect against unidentified risks.