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ASSESSMENT OF THE SOCIO-ECONOMIC COSTS OF DAMAGES TO UNDERGROUND INFRASTRUCTURE IN CANADA

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Assessment of the Socio-Economic Costs of Damages to Underground Infrastructure in Canada

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Abstract

This article presents the complete overhaul of the tool for estimating the socio-economic costs of damage to underground infrastructure in Canada, originally developed by CIRANO in 2015. The 2026 version expands the geographic coverage to include all Canadian provinces, enriches the estimation framework with four new cost categories (additional avoided road accidents, evacuation, water service interruption, material damage from water main breaks), updates existing methodologies, and, most importantly, refines all calculations at the census subdivision level (approximately 4,000 local areas). The tool processes data from the DIRT database, a repository of third-party infrastructure damages voluntarily reported by infrastructure owners. It estimates eight categories of indirect costs based on the type of damaged infrastructure, geographic location, and severity of the damage.

Applied to Canadian data from 2024, the tool estimates annual indirect costs of 160 million Canadian dollars. These estimates remain conservative due to certain inherent limitations of the damage database. Nonetheless, they provide robust orders of magnitude to inform prevention strategies and support data-driven decision-making.

Résumé

Cet article présente la refonte complète de l'outil d'estimation des coûts socio-économiques des dommages aux infrastructures souterraines au Canada, développé initialement par le CIRANO en 2015. La version 2026 élargit la couverture géographique à l'ensemble des provinces canadiennes, enrichit le cadre d'estimation avec quatre nouvelles catégories de coûts (accidents routiers supplémentaires évités, évacuation, interruption du service d'eau, dommages matériels liés aux bris de conduites d'aqueduc), actualise les méthodologies existantes et surtout affine l'ensemble des calculs à l'échelle de la subdivision de recensement (environ 4 000 zones locales).

L'outil traite les données de la base DIRT, une base de données des dommages aux infrastructures causés par des tiers remplie par les propriétaires d'infrastructures sur une base volontaire. L'outil estime huit catégories de coûts indirects en fonction du type d'infrastructure endommagée, de la localisation géographique et de la magnitude du bris.

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Appliqué aux données canadiennes de 2024, l'outil estime des coûts indirects annuels de plus de 160 millions de dollars. Ces estimations demeurent toutefois conservatrices en raison de certaines limites inhérentes à la base de données sur les dommages. Elles fournissent néanmoins des ordres de grandeur solides pour éclairer les stratégies de prévention et soutenir une prise de décision fondée sur les données.

Mots-clés/Keywords : Coûts indirects, infrastructures souterraines, dommages, prévention, analyse coûts-avantages, coûts socio-économiques / Indirect costs, Underground infrastructure, Damages, Prevention, Cost-benefit analysis, Socio-economic costs.

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1 Introduction and Background

Damage to underground infrastructure—natural gas lines, electrical cables, telecommunications networks, water and sewer lines—generates costs that go far beyond the simple repair bill. These so-called hidden or indirect costs encompass all the economic and social disruptions experienced by households, businesses, and the community following a damage: power outages, Internet disruptions, evacuations, traffic congestion, emergency service responses, and damage to water infrastructure. Despite significant progress made in Canada in terms of prevention, damage caused by third parties remains frequent and continues to have considerable impacts on society. However, these impacts are still largely underestimated: available assessments focus primarily on direct repair costs, without considering the much broader socio-economic consequences.

It was in this context that CIRANO developed, in 2015, an initial tool for estimating the indirect costs of underground infrastructure damage, originally designed for Quebec. Ten years later, changes in the economic landscape, the availability of new, high-resolution data, and the identification of new relevant cost categories have led to a complete overhaul of the tool.

It is important to note that direct costs—i.e., repair expenses such as materials and technician mobilization—are not covered by this tool. The tool focuses exclusively on **indirect costs**, defined as the economic assessment of all disruptions associated with damage to underground infrastructure, according to the following formula:

Total Cost (TC) = Direct Costs (DC) + Indirect Costs (IC)

The fundamental objective of the project is to make these hidden costs visible and measurable, so that damage prevention efforts can be based on solid, evidence-based data rather than on a partial view that reflects only a fraction of the actual impact of breakages.

This report is organized as follows. Section 2 presents the four major improvements that distinguish the 2026 version from the original version. Section 3 describes the general methodology that guided the redesign, including the literature review and stakeholder interviews. Section 4 details the tool's input data and parameters, including the handling of geolocation and missing data. Section 5 constitutes the methodological core of the report: it presents in detail the eight categories of indirect costs estimated by the tool, their respective scopes of application, and the calculation formulas used. Section 6 illustrates the tool's capabilities through an application to 2024 Canada data. Finally, Section 7 discusses the scope and limitations of the tool, particularly the central role of data quality in the Underground Infrastructure Damage Reporting Tool (DIRT), before concluding with the strategic value of the tool for stakeholders and decision makers.

2 Four Key Improvements in the 2026 Version

The 2026 overhaul of the tool is based on four major improvements. These features fundamentally distinguish it from the original version developed ten years earlier.

2.1 A geographic scope expanded to cover all of Canada

The 2015 version of the tool covered only a limited number of provinces. The 2026 version now incorporates specific regional data for all Canadian provinces, from British Columbia to the Atlantic provinces. Each province has its own economic parameters, allowing for estimates tailored to local realities rather than relying on national averages.

2.2 Expansion of the cost spectrum and update of estimation methods

In terms of cost categories, the 2026 version includes two changes. First, four new cost categories have been added: avoided costs of additional traffic accidents, evacuation costs, cost of water service interruption, and property damage costs related to water main breaks. These categories, which were absent from the initial model, capture real socio-economic impacts that were previously overlooked. Second, the methodologies for four existing categories have been completely revised considering current best practices and the literature: traffic congestion, emergency services response, power outages, and Internet service interruption.

2.3 More granular calculation methods

The 2026 version introduces significantly greater geographic granularity. Cost calculations now incorporate the local context of each incident at the level of Statistics Canada's census subdivisions, covering approximately 4,000 local areas nationwide. This approach allows for the integration of precise economic and demographic data for each location—such as the composition of the local population, the industrial structure, or the number of households—rather than using data aggregated at the provincial level. The results are thus much more realistic and locally grounded.

2.4 A classification of damage into three severity levels

Finally, the 2026 version introduces a formal classification of damage into three severity levels, based on the type of infrastructure affected:

- minor incidents (affecting service/drop infrastructure): the impact is localized, for example, a residential connection
- moderate incidents (affecting distribution infrastructure): the impact is at the scale of a neighborhood or a local distribution network
- major incidents (transmission infrastructure): these affect critical networks, namely high-voltage transmission lines for electricity and large-diameter pipelines for natural gas or water, leading to potentially widespread impacts across the region.

This gradation allows for a more nuanced estimation of indirect costs, notably by adjusting the geographic impact radius used in evacuation calculations, for example, as well as the number of affected customers and response times, based on the actual severity of the incident.

Overall, the 2026 version of the tool has a broader scope, is methodologically more robust, and is better adapted to regional realities—thus providing a significantly more accurate picture of the indirect costs of damage to underground infrastructure across Canada. These improvements were not developed in isolation: they are the result of a methodological approach combining an in-depth literature review and field validation with more than twenty stakeholders across Canada, a description of which is provided in the following section.

3 General Methodology

The methodology is based on a multidimensional approach that combines academic rigor with field expertise.

3.1 Literature review

A comprehensive review of scientific and grey literature was conducted for each cost category.

The objective of this literature review was to explore recent advances in the methodology used to assess the indirect costs identified by De Marcellis-Warin et al. (2015) but not yet estimated. Consequently, this literature review closely follows the cost classification described in the original report, which draws on the work of Gilchrist and Allouche(2005) —a key reference still widely cited in recent literature on the socio-economic costs of construction.

The literature review identified best methodological practices, existing frameworks (notably the Lawrence Berkeley National Laboratory’s “Interruption Cost Estimate” calculator for electricity costs), and valuation parameters available in the Canadian context. This literature review was the subject of an internship report in 2025 by Maya Mansour as part of her bachelor's degree in economics from the University of Montreal, under the supervision of William Arbour.

3.2 Stakeholder interviews

The interviews were conducted following a rigorous four-step protocol: (1) development of a semi-structured questionnaire to systematically address the methodological assumptions specific to each cost category; (2) obtaining ethical approval from the University of Montreal (UdM) prior to any interview, in accordance with standards for research involving human participants; (3) conducting interviews with experts and practitioners across Canada; and finally (4) validating the results, with summaries of each interview submitted to participants for verification to ensure the accuracy of the collected information.

In total, more than twenty semi-structured interviews were conducted between January and September 2025 with, on the one hand, the seven regional partners of the CCGA and, on the other hand, sixteen infrastructure owners and other stakeholders across Canada: three municipalities, three gas companies, two telecommunications companies, four electric utilities, two fire safety organizations (national and provincial), a national energy organization, and a municipal underground utility organization.

These interviews helped validate methodological assumptions, collect field data that would otherwise be inaccessible (including actual data from a major national telecommunications service provider on incident duration and volumes), and ground the models in real-world operational practices.

4 Inputs and Parameters of the Tool

4.1 Input data: the DIRT database

The tool processes data from the DIRT (*Damage Information Reporting Tool*) database, which tracks damage to underground infrastructure reported by network operators in Canada.

The tool uses the following fields for its calculations:

- DATE_OF_DAMAGE: date of the incident, used to determine the season, day of the week, and the base year for inflation.

- STATE_PROV: province where the incident occurred, a key element in many geographically differentiated calculations.
- CITY and ADDRESS: used for geolocation.
- LATITUDE/LONGITUDE: GPS coordinates, used directly if available.
- FAC_DAMAGED: type of infrastructure damaged (electricity, natural gas, water, sewer, telecommunications, etc.).
- FAC_AFFECTED: type of operation affected (service/drop, distribution, transmission), used to determine the extent of the outage.
- RIGHTOFWAY_TYPE: type of roadway involved, used to inform congestion calculations.
- SERVICE_INTERRUPTED: indicates whether service has been interrupted.
- OUTAGE_HOURS_DURATION: duration of the service outage.
- NUM_CUSTOMERS_AFFECTED: number of customers affected.
- EXCAVATOR_DOWNTIME: duration of excavator downtime, used in certain calculations.

4.2 Tool parameters

The tool is developed in *Rust*, a programming language focused on performance and memory safety. This approach ensures fast execution, even for large databases containing thousands of damages, and high processing reliability.

4.2.1 Geolocation

The precise location of incidents is essential for several components of cost calculation. When GPS coordinates are already present in the DIRT database, they are used directly. Otherwise, a composite address is constructed from the address, city, and province fields, then sent to an external geocoding service. If geocoding fails, costs dependent on location are not calculated. However, incidents for which geolocation fails are recorded in a dedicated file, along with the original address and the composite address used for the geocoding attempt. This allows the user, if necessary, to manually correct incorrectly entered addresses in DIRT, knowing which incident is causing the issue.

The tool also links each incident to a census subdivision (CSD) (approximately 4,000 areas nationwide), enabling the calculation of local population density expressed in inhabitants per square kilometre. This density plays a key role in several calculations:

- A threshold[1] of 400 inhabitants per square kilometer is used to distinguish densely populated urban areas (above the threshold) from rural or suburban areas (below it).
- In the absence of identifiable census subdivision, the average provincial density is used as a proxy.

By associating each incident to its census subdivision (CSD), this approach also provides information on economic activity levels, the number of households, and residential/non-residential ratios at a very fine geographic level.

4.2.2 Classification of emergency services

The cost of fire service intervention varies depending on the type of organization mobilized. The identification of the three types of fire services and the associated compensation models are based on data from the 2024 Canadian Fire Service Census (Canadian Association of Fire Chiefs, 2024) as well as on interviews conducted. The following distinctions are made:

- Metropolitan fire departments (full-time): these are the fire departments of the 23 major cities that are members of the Big City Mayors' Caucus of the Federation of Canadian Municipalities (Federation of Canadian Municipalities, 2025); These departments have permanent full-time staff, heavy equipment, and a professional organizational structure, resulting in high hourly costs but a rapid and well-resourced response capability.
- Fire departments with professional firefighters: this category includes 94 medium-sized municipalities, all of which have full-time firefighters.
- Volunteer or mixed-staff fire departments: this includes all other municipalities whose fire department relies on volunteer firefighters or a mix of volunteers and professionals.

This classification of municipalities also determines the road traffic parameters, congestion times, detour distances, and the composition of emergency response teams used in the calculations.

4.2.3 Dynamic external data: vehicle fleet, fuel, and inflation

Vehicle fleet characteristics are derived from provincial data describing vehicle composition (Statistics Canada, 2025), including vehicle types, fuel types used, fuel

[1] This threshold is the one defined and used by Statistics Canada to distinguish a population center (urban area) from a rural area (https://www150.statcan.gc.ca/n1/pub/92-195-x/2011001/geo/pop/def-fra.htm).

consumption, and associated maintenance costs (CAA, 2025). Fuel prices are dynamically integrated using data from Statistics Canada (Statistics Canada, 2025b) for the year and month of each damage.

All costs estimated in the tool are adjusted to the year of the damage using inflation indices published by Statistics Canada.

4.2.4 Handling of missing data

One of the tool's major challenges lies in handling missing data, which is inevitable in an aggregated database such as DIRT. The tool employs a hierarchical imputation strategy, seeking to use as much of the information available in DIRT as possible before resorting to default values.

- Missing duration: imputed based on the type of infrastructure damaged and the magnitude of the incident. For cases with missing durations, default values—validated through our interviews—are applied according to the type of infrastructure and the magnitude (e.g., 6 hours for a minor electrical incident, 24 hours for a moderate incident).
- Missing GPS coordinates: the available address is geocoded. If this fails, location-dependent costs are not calculated for the incident in question.
- Missing density: the provincial average density is used when no census subdivision can be associated with the coordinates.
- Missing city size: In the absence of city information, the rural classification (the most conservative) is applied by default.
- Service interruption not specified: The service interruption status (yes/no) is a key variable for several cost modules: electricity, Internet, water, and evacuation costs are only triggered if an interruption is confirmed. When this field is missing in DIRT, the tool applies the following substitution rule: an incident is considered to have caused a service interruption if the number of affected customers (NUM_CUSTOMERS_AFFECTED) or the duration of the outage (OUTAGE_HOURS_DURATION) is entered and greater than zero.

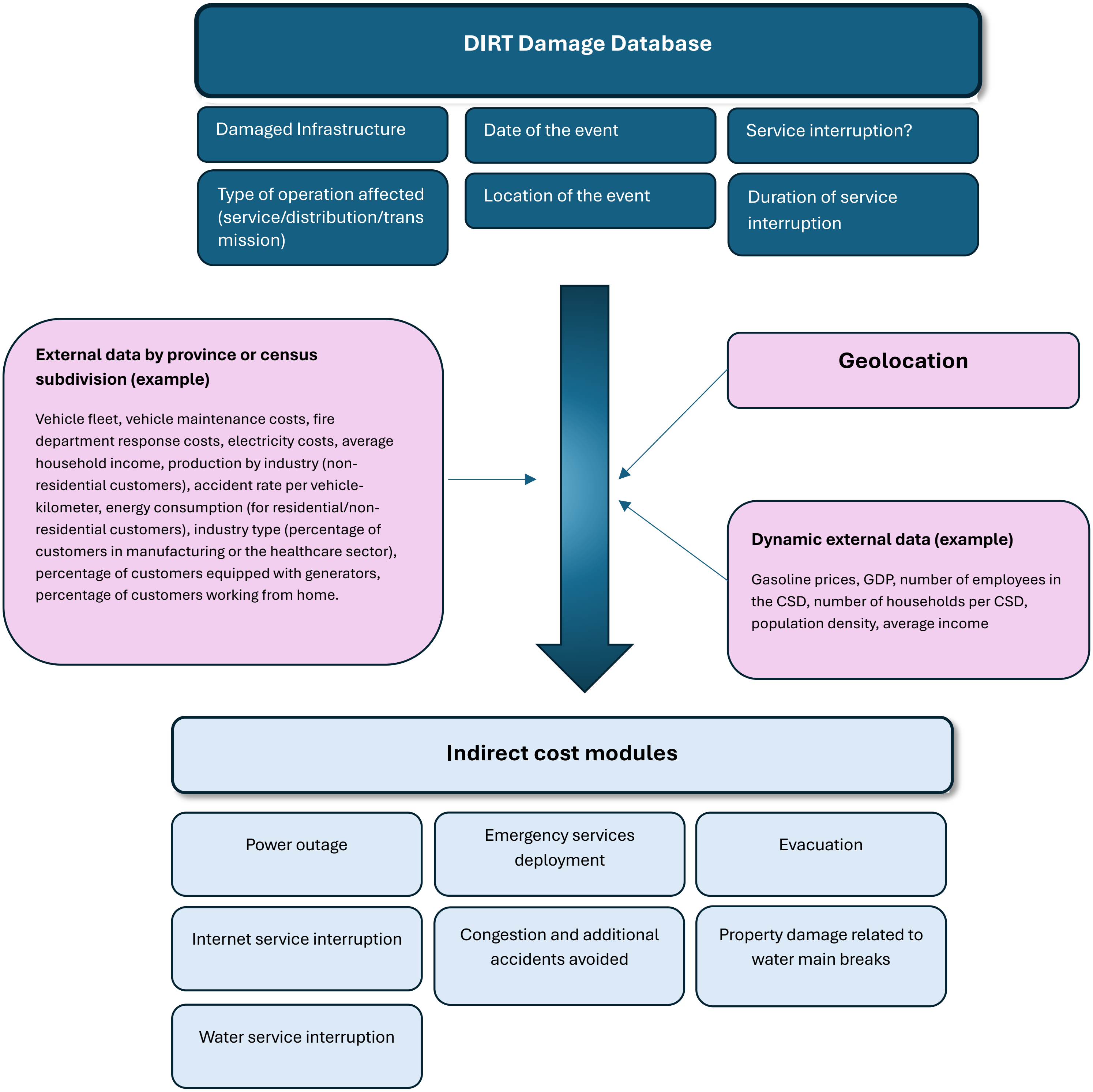

Figure1: CIRANO tool modeling for assessing the socio-economic costs of underground infrastructure damages

5 Detailed Review of Major Cost Categories

5.1 Costs of power outages

5.1.1 Scope of application

Electricity-related costs are calculated when the electrical infrastructure itself is damaged and there is a power outage. They also apply in the event of a natural gas line damage that results in a preventive power outage for safety reasons.

For natural gas incidents causing an indirect power outage, provincial adjustment factors are applied to account for the proportion of incidents that actually result in a power outage. These factors vary by province, incident severity, and local population density.

5.1.2 Methodological framework: Interruption Cost Estimate 2.1.0

The methodology is based on the Lawrence Berkeley National Laboratory's "Interruption Cost Estimator" framework, version 2.1.0, published in August 2025 (Berkeley Lab, 2025). Data from simulations using this framework were used in regression models to formulate power outage cost functions. The previous version of the tool used data collected between 1989 and 2012, and the 2025 update incorporates the most recent data.

The tool segments the impacts into two broad categories of customers, as their economic losses differ fundamentally:

- Residential customers: The cost is primarily based on the "willingness to pay" for a hypothetical substitute service for electricity. The model monetizes tangible elements of inconvenience and disruption to daily life associated with the absence of service, such as relocation costs, the purchase of emergency supplies, eating out, and the inability to work from home.
- Non-residential customers: The cost is calculated as the value of lost production plus interruption related costs (labor costs to restart the production process, costs resulting from damage to input feed stocks, cost to operate backup generation equipment), while subtracting savings realized during the outage (unpaid wages, unused fuel).

5.1.3 Variables and calculation methodology

The total cost for a province ($C_{elec,\ prov}$) varies depending on the total number of affected customers, the residential/non-residential ratio of the relevant census subdivision, the duration of the service outage, and finally the severity of the outage (minor, moderate, or major).

This residential/business ratio is derived from Statistics Canada census data (Statistics Canada, 2025a) and data from the business register (Statistics Canada, 2025f) and allows the calculation to be adapted to local economic conditions.

$$C_{elec,prov} = \left[N_{tot,i} * \frac{N_{res,CSD}}{N_{res,CSD} + N_{businesses,CSD}} * C_{res,h}\right] + \left[N_{tot,i} * \left(1 - \frac{N_{res,CSD}}{N_{res,CSD} + N_{businesses,CSD}}\right) * C_{businesses,\ prov,\ h}\right]$$

Where

- *CSD* = census subdivision
- *i* = type of outage (minor, moderate, or major)
- $N_{res,\ CSD}$ = number of residential customers in the census subdivision where the damage occurred
- $N_{businesses,\ CSD}$ = number of non-residential customers in the census subdivision where the damage occurred
- $N_{tot,\ i}$: total number of customers affected by outage type i
- $C_{res,\ h}$: cost function for residential customers
- $C_{businesses,\ prov,\ h}$: cost function for non-residential customers, by province

It is assumed that the local customer mix mirrors the composition of the corresponding census subdivision.

The Berkeley Lab calculator was used to perform the regression models to determine the cost functions. The calculator was fed with multiple variables differentiated by province:

- Temporal: The duration of the power outage (from 10 minutes to 24 hours), the season, and the day of the week (costs differ on weekends).
- Geographic and economic: average household income and income distribution (Statistics Canada, 2023), output by industry (Statistics Canada, 2020a, 2020b), average energy consumption for residential customers (Statistics Canada, 2021) and non-residential customers by province[2].
- Structural: the distribution of predominant industries within the service interruption area (manufacturing, healthcare, and others) (Statistics Canada,

[2] To estimate the average consumption of non-residential customers, we used the default values provided in the Berkeley Lab tool for several U.S. states with economic characteristics comparable to those of Canadian provinces, particularly in terms of sectoral structure (distribution of businesses by major industry sectors). For each province, two to three reference states were selected, and the average consumption used corresponds to the average of the values observed for these states.

2024c), the percentage of customers with a generator (Statistics Canada, 2025e), and the proportion of workers who telework (Statistics Canada, 2022).

When the total number of customers affected by the outage and the duration of the outage are not recorded in the DIRT database, these parameters are estimated based on the characteristics of the affected infrastructure—i.e., service/drop, distribution, or transmission—as well as the type of area, urban (density > 400 inhabitants/km^2) or rural.

For each damage severity category, weighted averages calculated from the last three years of the Ontario DIRT database—which contains very few missing data points—were used. These estimates were then validated using our expert interviews and by comparison with a report from Electricity Canada(2025).

In conclusion, to assess these costs, the following internal and external inputs are required:

- Internal inputs (DIRT): Province, location, type of infrastructure damaged (electricity or natural gas), type of facility affected (service, distribution, transmission), duration of service interruption, number of affected customers, date (for weekend/summer status), and duration of the excavator's interruption.

- External inputs: number of households and number of businesses per census subdivision (CSD), population density at the location of the damage, average household income, household income distribution, production by industry (non-residential customers), average energy consumption for residential and non-residential customers by province, distribution of predominant industries in the CSD of the damage (manufacturing, healthcare, and others), percentage of customers with a generator, and proportion of workers who telework.

5.2 Internet service interruption costs

5.2.1 Scope

This module applies to incidents affecting telecommunications infrastructure, limited to incidents of medium or major magnitude (minor incidents are excluded). If the Internet service interruption results from a power outage, the costs are already captured in electricity costs to avoid double counting.

5.2.2 Variables and calculation methodology

The formula used to estimate costs related to Internet service interruptions is as follows:

$$C_{internet} = N_{clients} \times T \times C_h$$

where

- $N_{customers}$ is the number of affected customers,
- T is the duration of the outage, and
- C_h is the unit cost per person per hour.

The hourly unit cost C_h ($0.155 per person per hour) is derived from an estimate of GDP losses associated with temporary Internet interruptions (Deloitte, 2016) adjusted using the Canadian Total Consumer Price Index (Statistics Canada, 2025d).

When the total number of customers affected by the interruption and the duration of the outage are not recorded in the DIRT database, these parameters were calibrated using actual data provided by a major national telecommunications operator, collected over the past three years. A distinction is made based on the type of damage: a fiber-optic break (categorized as transport in DIRT) or a coaxial cable break (categorized as distribution). For reference, here are the predefined numbers of affected customers used in the tool: 268 customers for an average incident, 2,376 customers for a major incident.

5.3 Water service outage costs

5.3.1 Scope of application

These costs apply when the damaged infrastructure is a water main or sewer line. Minor breaks (service lines/droppings) are excluded from the calculation—only medium-level breaks (distribution—secondary network) and major breaks (transmission—primary network) are included in the estimate.

5.3.2 Variables and calculation methodology

The total cost is the sum of two components: $C_{water\_total} = C_{water\_residents} + C_{water\_businesses}$ because the calculation methodology differs depending on whether we are discussing the indirect costs of water service interruptions for households or for businesses.

Costs for residents

The residential cost is based on households' willingness to pay to avoid a water interruption, according to two outage duration thresholds:

- Interruption of less than 8 hours: we use a value derived from a Seattle Public Utilities study (2006), which estimated the willingness to pay per person per hour to avoid a short interruption (average reference duration of 4 hours) at U.S.$1.40. This amount was converted to Canadian dollars using the average USD/CAD exchange rate for the 2012–2024 period, then adjusted for inflation from 2015 to 2024. This yields a value of $2.61/h.
- Interruption of 8 hours or more: We use a value derived from Aubuchon and Morley (2013), who propose a cost of U.S.$160 per person per day for interruptions lasting a full day or longer. The same conversions and inflation adjustments were applied to arrive at an average cost of $10.94/h.

These two reference studies are cited in a report by the Water Research Foundation (Raucher et al., 2017).

The number of residents affected is estimated using Statistics Canada census data (2023) at the census subdivision (CSD) level, weighted by the fraction of the area covered by the break's impact radius.

Costs to businesses

For businesses, the calculation is based on the productivity of on-site employees, weighted by sector-specific disruption coefficients for water interruptions. This methodology is inspired by a study by Wood et al. (2017), which was initially developed in the context of tsunami-related evacuations to estimate the economic disruptions suffered by businesses located in an impact zone. While the original context may seem distant, the transposition is methodologically justified: in both cases, the goal is to estimate productivity losses caused by a sudden, unplanned, and geographically limited disruption that forces employees to interrupt their on-site activities for a specified period. The model's structure—based on employee presence, hourly value added by sector, and a sectoral disruption coefficient—is independent of the nature of the triggering hazard and applies consistently to any service interruption affecting a local area, whether it be a flood wave or a water main break.

The number of employees affected by each NAICS code is estimated using a data table titled "Number of Canadian Businesses with Employees" from Statistics Canada (Statistics Canada, 2024d) at the census subdivision (CSD) level, weighted by the fraction of the area covered by the break's impact radius.

For each economic sector (coded according to the two-digit NAICS), the cost is calculated using the formula:

$$C_{eau\_entreprises,i} = \sum_{i} \left[N_i * PP * \left(\frac{PIB_i}{Emploi_i * Heures\_an} \right) * CP_i * h \right]$$

Where

- N_i = total number of employees in the CSD of the disruption by sector i
- PP = proportion of employees present on-site relative to the total number of employees = 2/3, a uniform assumption for all provinces and sectors.
- GDP_i = average GDP per employee per hour by sector i, calculated from GDP by industry in Canada by NAICS code (Statistics Canada Table 36-10-0434-06) divided by the total number of employees by NAICS code and the average number of hours worked per year (Table 36-10-0489-01).
- CP_i = sectoral disruption coefficients, which reflects the proportion of economic activity actually interrupted during a water main break. These coefficients, based on a report by the Water Research Foundation (Raucher et al., 2017), range from 10% (sectors with low water dependency, such as finance, education, or professional services) to 80% (sectors heavily disrupted, such as retail and food services). The manufacturing, construction, transportation, and healthcare sectors are assigned an intermediate value of 30%.
- h = duration of the outage, taken from the OUTAGE_HOURS_DURATION field in the DIRT database if available; otherwise, an average value validated by our interviews is assigned to each type of damage.

5.3.3 Geographic scope and weighting

Costs are not calculated for minor damages. For moderate and major damages, the impact area is defined by a circular radius around the point of damage, and the fraction of the CSD covered by this radius is calculated as follows:

$$Fraction_{CSD} = \frac{\pi \times r^2}{Surface_{CSD}}$$

where r = 20 meters for a moderate damage and r = 100 meters for a major damage.

The total cost calculated for the entire CSD is then multiplied by this fraction, so that only the portion of the area actually affected is accounted for. It is assumed that the economic and demographic composition of the impact area is the same as that of the entire CSD to which it belongs.

5.4 Congestion costs

5.4.1 Scope of application and key assumptions

This module applies only to incidents occurring on public roads. It is based on three fundamental assumptions.

- First, any incident on a public road generates a level of traffic disruption—either congestion or a detour.
- Second, drivers adapt rationally and optimize their routes (often using tools like Waze), leading to an equilibrium where detour time is approximately equal to congestion time. In this context, part of the traffic remains in the congestion, while another part is rerouted to alternative routes. The relative proportion of congestion and detours depends heavily on the type of road. In the tool, these proportions are calibrated based on the literature on traffic disruptions and interviews with stakeholders, leading, for example, to an assumption of approximately 70% of vehicles rerouted on urban streets and 20% on highways, where detour options are more limited.
- Third, the model captures both direct congestion (delayed vehicles) and indirect detours (rerouted vehicles).

The disruption period is based on the excavator's downtime, not on the total duration of the repair or breakdown.

5.4.2 Variables and calculation methodology

Four cost components are calculated:

$$C_{congestion\_total} = C_{time} + C_{fuel} + C_{maintenance} + C_{pollution}$$

Each cost component is adjusted based on several factors:

- the type of road (residential, collector, arterial, or highway);
- the type of vehicle, according to eight categories combining the type of fuel (gasoline or electric) and the vehicle category (sedan, SUV, van, or pickup truck);
- the geographic context (urban or rural).

Finally, all parameters are weighted based on the actual composition of the provincial vehicle fleet, derived from Statistics Canada data (Statistics Canada, 2024b).

Estimation of the number of vehicles affected by congestion or detours and their average distance traveled

To estimate the number of vehicles affected by an incident—whether they are stuck in traffic or rerouted to a detour—the tool uses the Annual Average Daily Traffic (AADT). This measure represents the average number of vehicles traveling on a given road segment during a typical day.

The AADT values used in the model vary according to two factors: the type of road (residential, collector, arterial, or highway) and the geographic context (urban or rural). These two factors jointly determine the volume of traffic exposed to the disruption, and thus the number of vehicles in congestion (Nc) and on detours (Nd) included in the cost calculation.

In practice, these values are derived from a combination of national and municipal sources, including: the Canadian Transportation Association's Guide to Geometric Design of Canadian Roads (2017), reports from the City of Toronto (Toronto City, 2025 a; Toronto Transportation Services, 2013), open data on traffic volumes from the Government of Quebec (2025), a report from the U.S. Department of Transportation (Federal Highway Administration), 2023), a report from the Water Research Foundation (Raucher et al., 2017), as well as various interviews conducted with stakeholders as part of the project. Detour times and congestion levels are averages per vehicle for a typical construction site with reduced capacity, calibrated based on practices from previous reports and empirical feedback.

Costs related to time loss

Costs related to time loss apply to **all vehicles affected by the incident**, whether they are vehicles stuck in congestion or vehicles that have opted for a detour. They are based on the value of travel time, vehicle occupancy rates, the proportion of business trips, and the provincial hourly wage.

The formula is as follows:

$$C_{time} = O \times (F_t \times W) \times (N_c \times T_c + N_d \times T_d)$$

where:

- **N_c** = number of vehicles caught in congestion
- **N_d** = number of vehicles that took the detour
- **O** = average vehicle occupancy rate (people/vehicle)
- **W** = average wage for the region (per hour, per person)
- **T_c** = average duration of the traffic jam (in hours)
- **T_d** = average duration of the detour (in hours)
- **F_t** = weighting factor for business/personal trips

The average vehicle occupancy rate is set at 1.2 people per vehicle (Ministry of Transportation, 2023). The monetary value of lost time is estimated based on the regional average hourly wage (S), differentiated by province. However, not all trips have the same economic value. A distinction is made based on the reason for the trip:

- 10% of trips are business trips, for which time is valued at 100% of the hourly wage, as the time lost corresponds to productive work time directly subtracted from the economy.
- 90% of trips are personal trips (commuting, leisure, grocery, etc.), for which time is valued at 60% of the hourly wage, reflecting the fact that the opportunity cost of personal time is lower than that of work time.

These proportions are based on two complementary sources: the Quebec Ministry of Transport's Guide to the Benefits and Costs of Public Projects (2023), and a Statistics Canada report (2024a) on travel motives. The wage weighting by travel motive is derived from a publication by the U.S. Department of Transportation (2011).

These two components are combined into a single weighting factor Ft, calculated as follows: $Ft = 0.1 \times 1.0 + 0.9 \times 0.6 = 0.64$. In other words, the average value of time lost is 64% of the regional hourly wage.

For each hour lost, whether waiting in congestion or due to a longer detour, the economic loss is equal to the number of people in the affected vehicles (Nc or Nd multiplied by O), multiplied by the average value of their time (Ft × W). The two terms in the sum separately capture the cost incurred by vehicles stuck in traffic (Nc × Tc) and that incurred by rerouted vehicles (Nd × Td), before being aggregated into a total cost of time loss.

It should be noted that, in accordance with the assumption of rational driver behavior—where drivers optimize their routes using navigation tools such as Waze—congestion time (Tc) and detour time (Td) are assumed to be approximately equal at equilibrium, meaning that both groups incur a comparable time loss.

Costs related to additional fuel consumption

The fuel cost C_{fuel} is calculated for each typical vehicle/fuel combination (gasoline or electric) involved in the detour, using prices dynamically retrieved from Statistics Canada (2025 a) for gasoline and from the CAA tool (2025) for the electricity costs.

Costs related to wear and tear

Vehicle wear and depreciation costs are calculated based on the vehicle type and the additional distance traveled Dd (for vehicles taking the detour only). These costs are estimated using the CAA tool (2025), assuming an average annual mileage of between 15,000 km and 20,000 km and a city/highway usage split of 55/45.

$$C_{maintenance} = N_d * D_d * C_{maint,CAA}$$

Where

- N_d = number of vehicles that took the detour
- D_d = average detour distance (km)
- $C_{maint,\ CAA}$ = vehicule operating cost (maintenance) ($/km)

Pollution-related costs

Pollution costs account for six distinct pollutants that are quantified and then converted into monetary costs ($/ton), with emission rates differentiated according to traffic speed (~5 km/h in congestion, ~30 km/h for detours).

$$C_{pollution} = (N_c \times D_c) \times \sum \left(E_{i,5} \times C_i\right) + (N_d \times D_c) \times \sum \left(E_{i,30} \times C_i\right)$$

Where

- $E_{i,30}$ = emission rate of pollutant i at 30 km/h
- $E_{i,5}$ = emission rate of pollutant i at 5 km/h
- N_d = number of vehicles that took the detour
- N_c = number of vehicles caught in congestion or on the detour
- D_c = distance traveled in congestion (0.5 km)
- D_d = average detour distance (km)
- C_i = cost per ton of pollutant i

The values used for pollutant emission rates and their costs (expressed in dollars per metric ton) are taken from the Quebec Ministry of Transport's Guide to the Cost-Benefit Analysis of Public Projects (Ministry of Transport, 2023).

5.5 Costs of additional road accidents avoided

5.5.1 Scope of application

Just like congestion costs, this cost category applies to all types of road damage, regardless of the infrastructure involved. The only condition for inclusion is that the damage occurs on a public road.

Indeed, a disruption on a public road causes traffic to be diverted to alternative routes. This detour involves additional kilometres, which statistically increases the number of likely accidents. The tool estimates the social cost of these additional accidents—fatalities and injuries—resulting from the longer travel distances caused by the incident.

5.5.2 Variables and calculation methodology

Here is the formula used to estimate the costs of avoided accidents

$$C_{acc} = h \times D_{add} \times \left(\frac{T_{injuries}}{100\ 000\ 000} \times C_{injuries} + \frac{T_{fatalities}}{100\ 000\ 000} \times C_{fatalities}\right)$$

Where

- h = duration of the damage (in hours)
- D_{add} = number of additional kilometres travelled per hour of damage (all vehicles combined, by road type—see table below)
- $T_{fatalities}$ = fatality rate per 100 million vehicle-kilometers traveled (specific to each province)
- $T_{injuries}$ = injury rate per 100 million vehicle-kilometers traveled (specific to each province)
- $C_{fatalities}$ = average cost of a fatality
- $C_{injuries}$ = average cost of an injury

Accident rates by province are taken from Road Traffic Collision Statistics in Canada: 2023, a report by Transport Canada(2023). For example, in Ontario, the number of injuries per 100 million vehicle-kilometers traveled is 19.87, and the number of fatalities per 100 million vehicle-kilometers traveled is 0.34 (in BC, it is respectively 26.12 and 0.62).

To assign a monetary value to each victim, the CIRANO tool uses the willingness-to-pay method. This method measures the social value of preventing an accident based on what individuals would collectively be willing to pay to reduce their risk of an accident, rather than solely on the loss of future income (human capital method). It is recognized as the benchmark method for the socio-economic evaluation of road safety policies in Canada. The unit values used are $4,182,625 (in 2019 Canadian dollars) for a fatality, $1,045,656 for a serious injury, and $103,701 for a minor injury (Ministry of Transport, 2023).

The ratio of serious injuries to minor injuries observed in Canada (9,261/118,838) (Transport Canada, 2023) allows for the calculation of a weighted average cost of injuries, used as a single value $C_{injuries}$ in the formula.

The number of additional kilometers generated per hour of disruption (D_{add}) is estimated based on the average annual daily traffic volume (AADT) for each road type, the proportion of vehicles taking a detour, and the additional distance of that detour. The values used are calculated based on an average of 12 hours of significant traffic.

5.6 Costs of evacuations

5.6.1 Scope of application

Evacuations are considered only for damage to natural gas infrastructure resulting in a gas service interruption.

5.6.2 Variables and calculation methodology

The costs associated with evacuation consist of two components.

- Costs for businesses located in the affected area: Productivity losses for businesses are estimated using the same methodology as that used to assess the costs associated with the interruption of water service.
- Costs for households: Costs for households are estimated as a flat, arbitrary amount of $100 per evacuated household, applicable only when the evacuation lasts longer than two hours.

These gross costs are then weighted by an evacuation probability, which varies by province, population density, and the scale of the incident. These probabilities were established based on interviews conducted across Canada.

For example, in Saskatchewan, the probability is estimated at 50% in densely populated areas in the case of minor damage, and at 80% for moderate incidents, compared to 10% in rural areas for both minor and moderate incidents. For major incidents, the probability of evacuation is set at 100% in densely populated areas and 20% in rural areas.

To estimate the number of people affected, we use an impact radius based on Transport Canada's guidelines for natural gas emergency management (2024), the value of which varies depending on the type of infrastructure affected (service, distribution, or transmission). For a minor damage, a radius of 20 m around the point of damage is considered. For a moderate-scale damage, the radius corresponds to one city block (100 m). Finally, for a major rupture, an impact radius of 800 m is used.

5.7 Costs associated with the deployment of emergency services

5.7.1 Scope of application

This cost category applies exclusively to natural gas pipeline damages. As soon as a gas leak is reported, the fire department is systematically called to the scene, regardless of the magnitude of the leak, due to the risk of explosion and fire inherent in this type of incident (even if there is no interruption in gas service).

5.7.2 Variables and calculation methodology

The cost of these responses depends directly on the type of fire department deployed to the scene. The tool developed by CIRANO distinguishes three categories, identified based on the 2024 Canadian Fire Service Census (Canadian Association of Fire Chiefs, 2024).

Each type of service is characterized by three dimensions that jointly determine the total cost of the response:

- Response force refers to all resources deployed to the incident site: number of pumpers, number of aerial ladders, number of pump-ladders, number of firefighters and officers per vehicle, and finally the number of fire chiefs. This response force varies depending on the type of service (metropolitan, professional firefighters or volunteer fire departments) and the magnitude of the incident (minor, moderate, major). The tool's assumptions were validated through our interviews.
- The hourly cost structure is calculated based on equipment and personnel expenses, differentiated by province based on our interviews and reports from some Canadian cities (Edmonton, 2025; Ottawa, 2024; Rural Municipality of Corman Park, 2025; Toronto City, 2025b).

- Response time depends directly on the size of the department and the severity of the incident, according to the tool's three-tier classification (minor, moderate, or major damage).

The geolocation of each damage, combined with data from the 2024 Canadian Fire Service Census, allows each incident to be automatically linked to the type of emergency service corresponding to its actual location.

5.8 Costs of property damage related to water main damages

5.8.1 Scope of application

This category of costs is recorded when the damaged infrastructure is a water main or sewer line. It is intended to capture property damage caused to third parties by uncontrolled flooding resulting from a pipe break: damage to basements and house foundations, damage to nearby businesses, damaged vehicles, deterioration of roadways and adjacent infrastructure, etc.

Minor breaks (service/drop) are excluded; only medium-level (distribution) and major (transmission) damages are likely to cause significant collateral damage.

5.8.2 Variables and calculation methodology

The cost formula is as follows

$$C_{water\_damages} = 3500 \times h_{uncontrolled} \times F_{density} \times F_{diameter}$$

where:

- \$3,500 = base hourly cost of property damage, representing the total damage budget per hour of uncontrolled break. This value is derived from the Wachs Water Service Model, cited in the Water Research Foundation report (Raucher et coll., 2017)
- $u_{ncontrolled}$ = duration of the uncontrolled break (in hours), corresponding to the period during which water flows freely before the break is contained. If values are entered in the OUTAGE_HOURS field of the DIRT database, these values are used first. In their absence, default durations are applied.
- $F_{density}$ = correction factor based on the urban or rural context of the damage, reflecting the density of exposed property in the impact zone. A factor of 0.7 is applied for damage in a rural area (density <400 inhabitants/km^2) and a factor of 1.6 for more densely populated areas.
- $F_{diameter}$ = correction factor based on the size of the damaged pipe, reflecting the released water flow and thus the potential extent of damage. Three

damage severity levels are used here: minor ($F_{diameter}$ = 0), moderate ($F_{diameter}$ = 1), and major ($F_{diameter}$ = 2).

5.9 Categories of indirect costs considered based on the type of infrastructure damaged

The tool provides an assessment for the eight categories of indirect costs detailed above. Not all apply to all types of infrastructure, and their occurrence may depend on whether or not a service interruption (SI) occurs. The table below summarizes the correspondences.

Categories of indirect costs considered by type of affected infrastructure

	Electric	Natural gas	Telecommunications	Water & Sewer	Other Unknown
Costs of power outages	✓ if SI	✓ if gas SI			
Internet service interruption costs			✓ If SI		
Cost of water service interruption				✓ If SI	
Congestion costs	✓	✓	✓	✓	✓
Costs of additional accidents avoided	✓	✓	✓	✓	✓
Evacuation costs		✓ If gas SI			
Emergency services intervention costs		✓			
Property damage costs related to water main breaks				✓	

Table1: Categories of indirect costs considered based on the type of infrastructure affected

Thus, congestion costs and costs of avoided accidents are accounted for even if the damage does not cause a service interruption. However, these costs always depend on the location of the break and the type of road where the damage occurred.

Two rules against double-counting apply: Internet outage costs are not included when they result directly from a power outage (the associated productivity losses are already captured in electricity costs); gas service outage costs are implicitly captured in evacuation costs and are therefore not calculated separately.

6 Results and Analysis of Estimated Indirect Costs for Canada

6.1 Volume and distribution of incidents for the year 2024

In 2024, the total number of damages in Canada is 8,293, excluding unauthorized activities on pipelines.

Number of damages by Canadian province in 2024	
British Columbia	895
Alberta	1,993
Manitoba	155
Saskatchewan	522
Ontario	3,976
Quebec	724
Atlantic Provinces	28
TOTAL NUMBER OF DAMAGES (Excluding unauthorized activities on pipelines)	**8,293**

Table2: Number of damages by type of infrastructure involved

In terms of distribution by infrastructure type, telecommunications and natural gas dominate the picture, together accounting for around 83% of damage incidents. Telecommunications damage is the most frequent category.

Breakdown of damage by infrastructure type in Canada in 2024 (including unauthorized activities)	
Gaz naturel	3 893 — 46,7 %
Télécommunications	3 009 — 36,1 %
Électrique	793 — 9,5 %
Aqueduc et égouts	386 — 4,6 %
Pipelines	55 — 0,7 %
Inconnu / autre	199 — 2,4 %
Total Canada	8 335 bris

Table3: Breakdown of damage by infrastructure type in Canada in 2024

6.2 Estimated total indirect costs

The tool was applied to data from all Canadian provinces for 2024 to illustrate its functionality and estimate the indirect costs associated with underground infrastructure damage. Based on the 8,293 recorded incidents in Canada that year, the tool estimates total indirect costs at $160 million. However, these estimates remain conservative due to certain limitations inherent in the damage database, as previously outlined.

Estimated Indirect Costs for Underground Infrastructure Damages in Canada in 2024	
Number of damages *(excluding unauthorized activities)*	**8,293 damages**
Power outage costs	$121,719,977
Internet service interruption costs	$789,888
Congestion costs and costs of avoided accidents	$2,501,956
Evacuation costs	$803,145
Emergency response intervention costs	$32,616,185
Costs of water service interruptions and property damage costs related to water main breaks	$1,919,452
TOTAL INDIRECT COSTS	**$160,350,603**

Table4: Estimated indirect costs for underground infrastructure damages in Canada in 2024

Costs associated with power outages dominate, accounting for 75% of total indirect costs in 2024. This result is driven by two main factors. First, although damage to electrical infrastructure is relatively infrequent (9.5% of incidents), it generates very high unit costs due to the large number of customers affected simultaneously and the high economic value of electricity, particularly for commercial and industrial users. Second, natural gas line failures (47% of incidents) often trigger preventive power outages as a safety measure. As a result, each gas-related damage involving a service interruption generates a double cost—its own (e.g., evacuation, fire services) as well as additional electricity-related costs.

Emergency services (20.3% of total costs) represent the second-largest cost category, reflecting the high frequency of gas leaks that systematically require fire department intervention. Other cost categories—congestion, Internet, and evacuation—remain marginal at the national level, although they can be significant locally depending on the urban or rural context.

Finally, property damage costs related to water main breaks and costs associated with water service interruptions are virtually negligible at the national level. This is largely due to the fact that very few municipalities—typically the owners of this infrastructure—report such incidents in the DIRT database.

7 Scope, Limitations, and Strategic Value of the Tool

7.1 Accurate but conservative estimates

The results produced by the 2026 version of the tool are more accurate and methodologically consistent than those of the previous version developed in 2015. They are based on a scientifically validated and reproducible assessment framework, combining incident data from the DIRT database with economic and demographic information at the household and business levels, derived from Statistics Canada data at the census subdivision level.

It is important to note, however, that these estimates are very conservative and represent a lower bound of the actual costs. Several structural factors limit the tool's ability to capture the full socio-economic impacts of damage to underground infrastructure.

7.2 The quality of DIRT Data: the main challenge

The quality and completeness of the data in the DIRT database are the main factors limiting the accuracy of the estimates. Without more complete and standardized data, even the most sophisticated models cannot fully capture the actual costs of the damage. Several structural gaps have been identified:

- **Voluntary reporting and structural underreporting**. Damage is recorded in the DIRT database on a voluntary basis by infrastructure owners. An unknown proportion of actual damage is therefore never reported, leading to a systematic underestimation of the number of incidents and, consequently, of total costs. This limitation is inherent in how the database operates and cannot be corrected by the tool itself: it requires an improvement in reporting practices at the source.
- **Incomplete geographic coverage**. Some Canadian provinces do not have a DIRT database, or their participation rates are insufficient to produce

representative estimates. The tool's results therefore cannot be generalized to the entire Canadian territory without accounting for these coverage gaps.

- **Missing or incomplete data**. Many records in DIRT contain missing, incomplete, or inconsistent information—including the duration of the service outage, the number of affected customers, the type of infrastructure affected, or the status of the service outage (Was there a service interruption? Yes or No). Although the tool has an imputation strategy to address some of these gaps, the substituted values remain approximations that introduce uncertainty into the results. Several key variables are frequently reported as *"Unknown"* or coded as "99." However, this "99" value is used in some provinces for variables such as the duration of the service interruption to indicate "unknown or not collected," not an actual duration of 99 hours. Another particularly telling example is that of natural gas damages in Ontario: of approximately 1,900 gas incidents recorded in the database, nearly 1,850 have the "service interruption" variable entered as *Unknown*. We have developed a robust and defensible methodological solution to include a proportion of these events, but this example illustrates how a single variable——that is systematically misreported can invalidate the results for an entire province.
- **Loss of precision due to the storage of responses by ranges**. A structural problem was identified in the way the DIRT system records certain variables when the user must choose from ranges of values rather than an exact value. For variables such as the number of affected customers, the duration of the outage, or the repair cost, the user must choose from different proposed ranges—for example, "1 to 6 hours." However, only the lower limit of this range is stored in the database—that is, "1 hour" in this example. In practice, all incidents lasting between 1 and 6 hours appear in DIRT as one-hour incidents. Since the duration of the outage is one of the most critical variables in calculating electricity costs in particular, this systematic bias toward the lower limit leads to a structural underestimation of costs. We programmed the tool to use the midpoint of each range instead to address this issue.
- **Geolocation impossible**. Some incidents cannot be geolocated due to missing, incorrect, or overly imprecise addresses that prevent reliable geocoding. As a rough estimate, this proportion ranges from 0.2% to 4.8% of outages in 2024, depending on the province. These incidents are therefore excluded from location-dependent calculations—including costs related to congestion, traffic accidents, evacuation, and emergency services—which leads to an underestimation of costs for these incidents.

These four categories of limitations point to a fundamental conclusion: even a methodologically sound model cannot compensate for structurally flawed or incomplete input data. Therefore, the more complete, accurate, and standardized the data entered into DIRT is, the more credible and actionable the cost estimates produced by the tool will be.

Every improvement in data entry quality—whether it involves better reporting of interruption status or standardizing addresses—directly translates into more accurate, representative, and actionable estimates for prevention efforts.

7.3 Strategic value for stakeholders and decision-makers

Beyond the numbers themselves, the tool offers significant strategic value for all stakeholders involved in preventing damage to underground infrastructure. Three main uses emerge.

- **Guiding evidence-based investments in prevention**. By making the socio-economic costs of damage visible and measurable, the tool allows for an objective comparison of the cost of a failure with the cost of preventive measures that could have avoided it. It thus provides a solid analytical basis for prioritizing prevention investments where the socio-economic return is highest, by targeting the most costly types of incidents.
- **Provide a credible basis for public communication**. The estimates generated by the tool can inform the communication efforts of operators, regulators, and industry associations regarding the real—and often overlooked—costs of damage to underground infrastructure to the community. Making these costs tangible helps raise awareness among the public, elected officials, and the media about the importance of prevention and of following procedures to contact a location center (One Call Center or Info-Excavation in Quebec) before carrying out excavation work.
- **Support training and awareness-raising for contractors and operators**. By concretely illustrating the economic consequences of a damage based on its type, location, and magnitude, the tool serves as a powerful educational resource for training programs for excavators and owners of underground infrastructure. It helps contextualize safety and prevention issues within a concrete, quantifiable economic framework, thereby reinforcing the legitimacy of safe work practices.

By making the disruptions experienced by citizens, businesses, and society at large visible and quantifiable, the tool developed by CIRANO provides public decision makers and industry stakeholders with concrete support for guiding strategies for the prevention and management of risks related to underground infrastructure.

As data improves through the Underground Infrastructure Damage Reporting Tool (DIRT), these estimates will become even more accurate, thereby strengthening stakeholders' ability to prevent damage and protect the collective value of infrastructure.

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