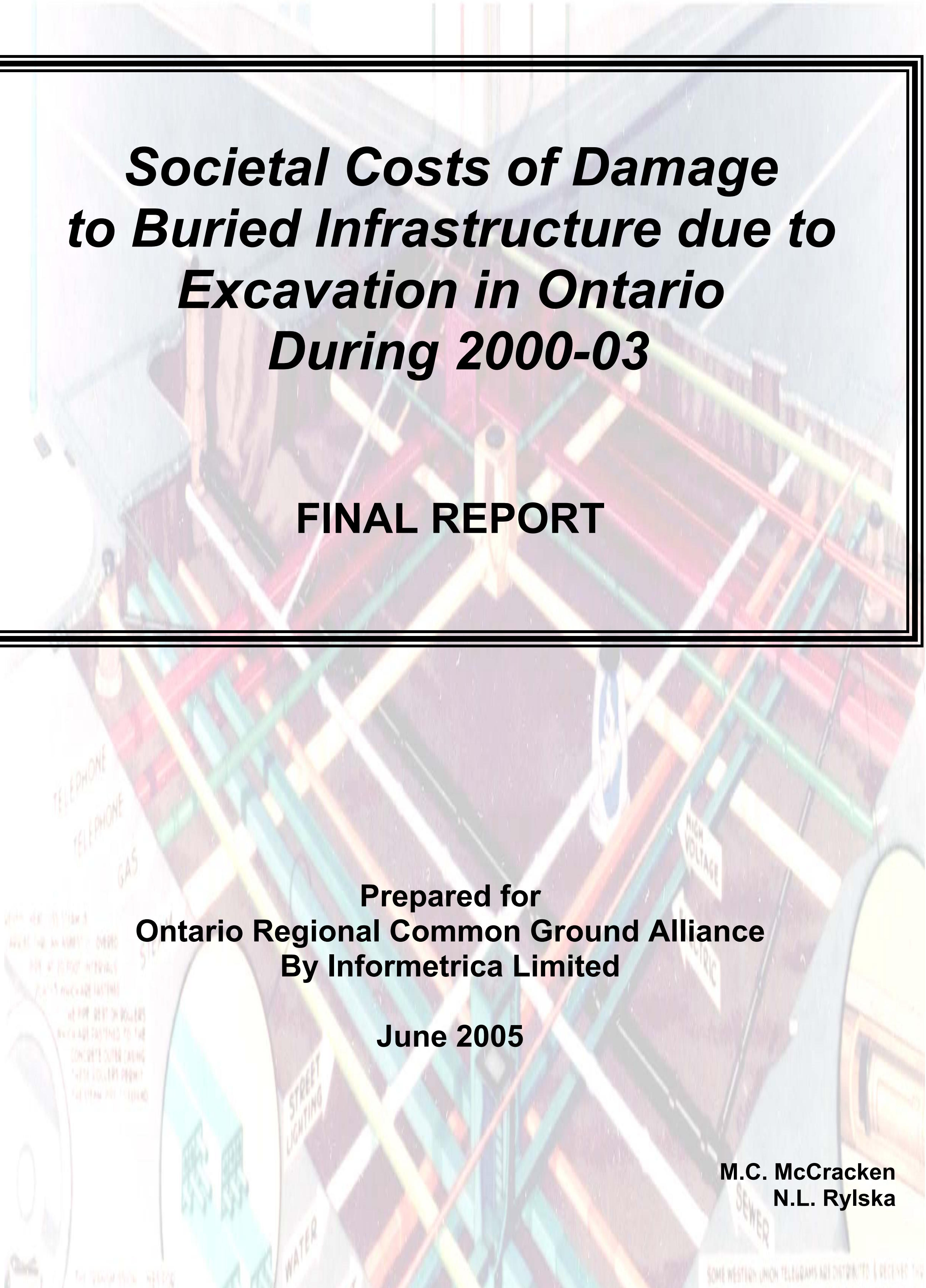

Societal Costs of Damage to Buried Infrastructure due to Excavation in Ontario During 2000-03

FINAL REPORT

Prepared for
Ontario Regional Common Ground Alliance
By Informetrica Limited

June 2005

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Acknowledgements

This is the final report of the study ***"Societal Costs of Damage to Buried Infrastructure due to Excavation in Ontario During 2000-03"***, commissioned by the Ontario Regional Common Ground Alliance (ORCGA).

This study is a product of remarkable cooperation from more than 100 representatives from the 17 stakeholder groups of ORCGA and external experts from the municipal, provincial and federal government departments, and special interest groups and associations in Ontario, as well as external experts in other jurisdictions of Canada and the United States.

The ORCGA study resulted in the development of the first applied universal framework on quantification of the frequency and costs of excavation damages to the underground utility infrastructure. This framework can be used internationally and customized for the future evaluation of programs and policies for underground damage prevention.

Informetrica Limited on behalf of ORCGA thank all study participants for their contributions to this project. The contributions ranged from direct data provision to the sharing of views, expert advice and estimates, and establishment of expert consultative processes for the validation of the assumptions and estimates.

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1 Introduction: Purpose, Scope and Novelty of the Study

In October 2004 ORCGA commissioned Informetrica Limited to undertake a study on the quantification of costs of excavation and digging damages to the underground infrastructure in Ontario.

Informetrica's work is distinguished by its concentration on the use of econometric and other statistical approaches critical to quantification, sector-specific and provincial detail, and design and implementation of theoretical frameworks applicable to the many unique issues that the company has confronted in the more than 30 years of support to governments, business and other private organizations. In addition to providing analytical support for client-specified projects, the company supplies services on a subscription basis to more than 200 organizations. Included in these services are projections and economic analysis employing models of more than 35,000 variables that explain national and provincial economic performance.

While damage to buried utility infrastructure can occur from natural physical phenomena (e.g. corrosion, environmental contamination, frost heave, etc.), this report deals exclusively with damage that occurs through digging operations, which is a form of human intervention and can therefore be modified by new behaviours, processes, technology improvements or regulation. The motivation for the ORCGA study implemented by Informetrica is five-fold:

1. Rising damages to underground utilities from excavation activities and their danger to public safety, reliability of the critical underground utility infrastructure, environment and economic stability in the province.
2. Need to develop a scientific framework for the measurement of the incidents of damage to underground utilities and the associated corporate and societal costs across all utility groups in the province.
3. Need to develop a scientific framework for the assessment of the severity of the damage to public safety, reliability of critical underground utility infrastructure, environment, general economic loss of productivity, and contribution to the future fiscal problems in the financing of the utility infrastructure damage.
4. Need to develop benchmarking indicators to assess Ontario's utility damage statistics and prevention programs/systems performance versus those of other jurisdictions.
5. Need to present statistically significant evidence of the magnitude of excavation/digging damage to underground utilities in Ontario to the relevant provincial legislative bodies in order to develop appropriate policy measures.

The study is a large-scale multi-stakeholder undertaking, combining the efforts of 17 groups, representing a universe of utilities and contractors in Ontario with underground utility assets worth $100 billion. The ORCGA study is the first of its kind and scale in North America. The available studies on damage to buried facilities dealt only with the establishment of one-call systems and locate programs. They have not attempted to provide comprehensive statistics on the occurrence of excavation/digging damage and the estimates of associated corporate and societal costs to the buried facilities. Also, the studies in other jurisdictions were financed primarily by governments, while the ORCGA study is initiated and financed through the non-profit ORCGA membership in its attempt to introduce best practices in the province.

The study covers six major types of underground utility infrastructure in Ontario that provide services to the residential, industrial, and public/community users:

- Gas distribution networks
- Water, sewer, storm and steam systems
- Electrical networks
- Telecommunications networks (including telephone, cable TV and fibre optics)
- Petroleum products pipelines
- Special products pipelines (air and chemical products)

Estimates are presented for the most significant groups of costs resulting from excavation/digging damage to the underground utility networks with disaggregation by located and non-located type:

1. ***Corporate costs***
    - Repair costs
    - Loss of product/revenue
    - Insurance liability costs
    - Regulatory costs
    - Customer loss of service use
    - Property damage costs
    - Environmental clean-up costs
2. ***Societal costs***
    - Health costs
    - Emergency response costs
    - Environmental costs
    - Traffic congestion costs
    - Evacuation costs

The study contains four (4) background papers for each sector with quantification of the corporate direct and indirect costs of the excavation/digging damages, and five (5) background papers for the major groups of societal costs of these damages. This Final Report is an overview of the findings in the background papers with a focus on costs of non-located excavation/digging damages. The section on **Profiles of the Underground Utilities Infrastructure and Excavating Community** in the province provides a preamble for the analysis of the problem, starting with a description of the standard practices of utility construction in Ontario, major groups of excavators, and a typical distribution of the damages to buried facilities due to excavation and digging. The **Methodology Section** outlines the study methodology, including the innovative theoretical framework and methods, and the data collection processes designed and implemented by Informetrica. The **Analysis of Costs Section** provides a summary of the estimates and resulting findings presented in each background paper. The **Inter-Jurisdictional Comparative Analysis** section compares the partial evidence on the patterns of third-party excavation/digging damage in United States jurisdictions with the statistics collected in this study for the province of Ontario. The **Policy** section summarizes key findings and provides general policy recommendations on the measures directed towards prevention of third-party excavation/digging damage in the province.

2 The Problem

In North America, there are three major trends inducing changes in the paradigm of the underground utility infrastructure construction and operation:

1. ***Technological and urban planning improvements***, leading to the increase in the ratio of the underground infrastructure to the overhead lines and increase in the density/congestion of the underground utility layers.
2. ***Deregulation of the utility markets***, leading to the emergence of multiple utility providers, weak control over the compliance to the standards, and fragmentation of the underground space.
3. ***Socio-economic changes***, leading to a business cycle boom in construction and renovation activity.

As noted in the report of the US Federal Laboratory Consortium's State and Local Government Committee's "Statement of Need: Utility Locating Technologies"[1]:

> *"The urban underground has become a spider's web of utility lines, including phones, electricity, gas, cable TV, fiber optics, traffic signals, street lighting circuits, drainage and flood control facilities, water mains and waste water pipes. In some locations, major oil and gas pipelines, national defence communication lines, mass transit, and rail and road tunnels also compete for space underground. The deregulation of utility services is adding to the problem as multiple service providers seek to place their networks underground. Utility lines are all susceptible to being damaged as construction and renovation equipment excavate in their vicinity. Records are often poor with inaccurate utility positions and/or depths. Some live services do not even show on the utility plans. This means that the ability to physically determine on-site the location, nature and depth of underground utility services is critical to reducing the risk and consequences of inadvertent damage during construction".*

The complexity and ever-changing nature of the layouts of the underground infrastructure emphasize the importance of identifying the location of the buried facilities, commonly referred to as a "locate", prior to the excavation/digging. Even in the case of an excavation/digging project when a locate is obtained, there is still a possibility of utility damage due to improper excavation practices, accidents, or locate errors; nevertheless, the civil engineering community maintains that the probability of located damage versus non-located damage in the same area must be lower.

Every time excavation occurs without a locate, multiple utility lines can be damaged, and the likelihood of this damage increases with the density of population, construction activity and the number of underground utilities in the area. Moreover, in case of non-located damage, it is likely that the damage will not be detected or reported immediately, and is more likely to have

[1] http://www.nal.usda.gov/ttic/utilfnl.htm

a higher negative impact. Because of this, non-located excavation/digging hits tend to have a "snowball effect", resulting in breaks to multiple utility lines. These breaks, in turn, can cause disruption of everyday life and business activities, damage to nearby private property and public facilities, buildings and the environment. This leads to undermining public safety and health, and significant costs to utilities, municipalities, consumers, businesses, community and society in general.

There are two major reasons for failure to obtain a locate:

1. Negligence or unawareness of the excavators, and frustration with the need for multiple calls.
2. Refusal of the utility companies to provide a locate in response to a request.

The first problem can be partially mitigated through safety and awareness programs, as well as prosecution of the offenders according to the legal norms, if locates are normally provided by the utilities. However, when excavators have to call multiple utilities for a locate, the procedure can become cumbersome and time consuming, creating problems for the excavators. The second problem is more difficult to solve, since, in many cases, utilities are not legally obligated to provide a locate. The best practice solution for both of these problems is the emergence of so-called "One Call" systems across the US and Canada, some of which are mandatory and some voluntary. Mandatory One-Call provision means that all utilities are obligated by law to provide a locate in response to a request from excavators. While most jurisdictions in the United States have introduced One-Call laws, Canada is lagging behind with only voluntary centres. In Ontario, less than 50% of the utilities in the province are members of Ontario One-Call Ltd.

The major argument of the adversaries of the One-Call systems is that there is no difference in the frequency and costs of damages whether a locate was obtained or not. The advocates of the One-Call maintain that the utility damages and associated costs are reduced significantly if locate is performed. The conclusion is based on the evidence from many US jurisdictions, and their company's statistics.

The aim of this study is to investigate objectively whether the provision of locates indeed makes a difference in utility damage prevention, both in terms of a reduction in the number of damages and in associated costs.

3 Profiles of the Underground Utilities Infrastructure and Excavating Community in Ontario

3.1 Typical organization of the excavation/digging work in Ontario

The excavation community is referred to as any party that engages in or is responsible for disturbing the ground, including but not limited to:

- Homeowners and tenants
- Farmers
- Land surveyors
- Home builders
- Specialized contractors (landscapers, sewer/watermain, paving and concrete, excavation, utility, earthmoving, fence and sign, drainage and irrigation, pipeline, electrical and mechanical, vertical and horizontal drilling and augering)
- Owners of buried facilities
- Consulting/geotechnical engineers
- Land developers
- Governments (municipal, provincial, federal)
- Railways
- Other

The excavation and digging work in the vicinity of buried facilities in Ontario's urban and rural areas is organized in three distinctive ways depending on the type of ownership of the buried facilities, availability of the in-house crews, sub-contractors, and requests from third parties:

1) ***Work on the utility-owned buried facilities:***
    a. Performed by in-house excavation/construction crews
    b. Performed by utility sub-contractors
    c. Performed by third-parties
2) ***Work on the public/municipal/government-owned areas with buried facilities:***
    a. Performed by in-house municipal/government excavation/construction crews
    b. Performed by municipal/government sub-contractors
    c. Performed by third-parties
3) ***Work on the private household areas with buried facilities:***
    a. Performed by household owners
    b. Performed by utilities in the case of special arrangements (easements)
    c. Performed by contractors hired by the household owners
4) ***Work on private business areas with buried facilities:***
    a. Performed by private business excavation/construction crews
    b. Performed by private business sub-contractors
    c. Performed by third-parties

Third parties that can perform excavation or digging in the vicinity of the underground infrastructure plants are defined as members of the excavating community that do not own, operate or maintain buried utility infrastructure on which they perform the work. Most of the excavation/digging projects are performed using powered equipment and machinery, and non-powered digging tools in the case of homeowners. The best practices of the organization of excavating/digging projects in Ontario involve the following steps:

- Locating buried facilities and marking prior to excavating/digging.
- Planning and mapping, taking into account the located buried facilities.
- Training of excavators on safety measures to avoid dangerous situations and to minimize the impact of damages in case of accidents.
- Excavating/digging with safety precautions, taking into account the located buried facilities to avoid breaks/ruptures/leaks.
- Implementing safety measures to minimize the impact of damage in case of an accident.
- Reporting in case of damages.

The process of obtaining a locate is a multi-step one that typically involves the following:

1. a call placed by an excavator to a call centre or utility locate program, which records the location of the proposed excavation and generates a locate request;
2. locate request information being transferred within a utility or owner of buried facilities in order to plan locating work; and
3. the physical marking of the ground surface identifying where the facility is buried. Often this work is performed by subcontracts of the utility, but in many circumstances, directly performed by the utility.

However, not all excavators comply to the best practices, starting with the failure to request a locate. In most cases, if the utility has a locate program, their own excavation crews and construction sub-contractors are likely to request a locate to perform work on their own systems. Third-party excavators/diggers are more likely to be responsible for the majority of the non-located damages.

3.2 Standard Positioning of the Buried Utility Infrastructure in Ontario

3.2.1 *Typical depth of cover for underground utility infrastructure*

The risk of excavation/digging damage is reduced with the depth of burial of the underground facilities and their bundling or trenching. Ontario utility companies maintain certain standards for the depth at which the networks are buried (Table 1).

Table 1. Standard Depth of Cover for Utilities, Metres[2]

Description	Curb stops	Gas	Hydro	Hydrant	Lights	Trees	Bell/TV	Water
Distance from property line	0.0	0.9	2.8	3.4	3.4	3.4	3.8	4.7
Typical depth of cover	0.0	1.0	1.0				1.0	1.8

According to the 2002 Gas Franchise Handbook, developed by the Ontario municipal sector and natural gas sector representatives, the water and sewer pipes should be buried at the depth

[2] Ontario Energy Board. "Gas Franchise Handbook", 2002.

of 1.8 meters, followed by telecommunications (1 meter), electrical (1 meter), and natural gas service lines (1 meter).

These practices are common in North America, according to the publication "Statement of Need: Utility Locating Technologies", prepared by the US Federal Laboratory Consortium, the Trenchless Technology Centre and the Technology Transfer Information Center[3]. Their report presents a summary of the standard ranges for the depth of cover used by major types of underground utilities in the United States (Table 2). The study also makes a direct link between the depth of underground networks, the diameter of pipes and cables, and the level of public safety risk of damage to these networks.

Table 2. Depth of Cover of Underground Utility Networks and Risks of Damages

Utility	Depth	Diameter	Public Safety Risk Of Damage	Costs Of Damage
Electrical transmission	0 - 3 m	25 - 100 mm	H	H
Electrical distribution	0 - 2 m	25 - 75 mm	H	H
Electrical service	0 - 1.5 m	10 - 50 mm	H	M
Gas transmission	0 - 4 m	0.2 - 1.5 m	H	H
Gas distribution	0 - 2 m	50 - 400 mm	H	H
Gas service	0 - 1.5 m	15 - 400 mm	H	H
Transportation control, traffic signals	0 - 1.5 m	10 - 25 mm	M	M
Oil transmission	0 - 4 m	0.5 - 2 m	M	H
Water transmission	0.5 -3 m	1 - 2 m	M	M
Cable television distribution	0 - 1.5 m	10 - 50 mm	L	M.
Electrical road lighting	0 - 2 m	10 - 50 mm	L	L
Oil distribution	0 - 3 m	200 - 500 mm	L	M
Sewer interceptor	2 - 200 m	0.5 - 15 m	L	L
Sewer sanitary	1 - 15 m	0.15 - 5 m	L	L
Sewer lateral	0.5 - 10 m	100 - 400 mm	L	L
Sewer storm/drainage	1 - 10 m	0.15 - 10 m	L	L
Sewer culvert	0.5 - 10 m	0.15 - 5 m	L	L
Telephone transmission	0 - 2 m	10 - 100 mm	L	H
Telephone distribution	0 - 2 m	10 - 50 mm	L	H
Telephone service	0 - 2 m	10 - 50 mm	L	M
Water distribution	0.5 - 1.5 m	100 - 500 mm	L	L
Water service	0.3 - 1.5 m	15 - 150 mm	L	L
Cable television service	0 - 1.5 m	10 - 50 mm	L	L

Ranks: H-high; M-moderate; L-Low.

Table 2 illustrates that the gas and electricity distribution networks, buried as deep as 4 meters underground, have the highest risk to public safety if damaged, and also the highest costs of

[3] http://www.nal.usda.gov/ttic/utilfnl.htm

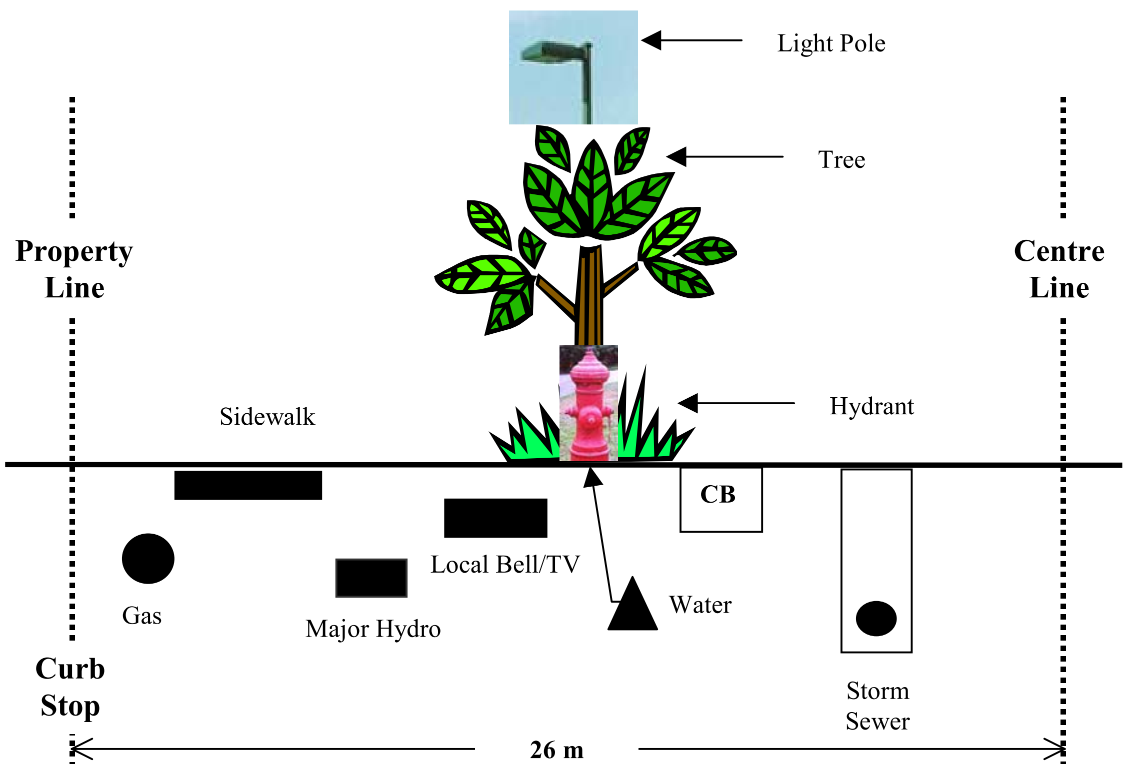
mitigating the damage. Traffic signals, oil and water transmission lines are ranked as posing a moderate risk. The rest of the utility infrastructure is ranked as having a relatively low risk of endangering the public. However, the economic burden of the damage is primarily high and moderate for the majority of the buried facilities.

3.2.2 *Typical road cross section*

Another example of the positioning of the underground utility networks in Ontario is the recommended layout of the utilities under the typical road cross section[4]:

1. Storm sewer and sanitary sewers are to be located between curbs.
2. Street lights may be located on either or both sides of the road.
3. Above-ground hydro is to be located on street light poles.
4. Sidewalks may be located on either, both or neither side of the roadway.

Figure 1. Typical Road Cross Section in Ontario[5]



The underground layers under the typical road cross section in Ontario are normally structured according to the drawing in Figure 1. As Figure 1 illustrates, the water, sewer and storm

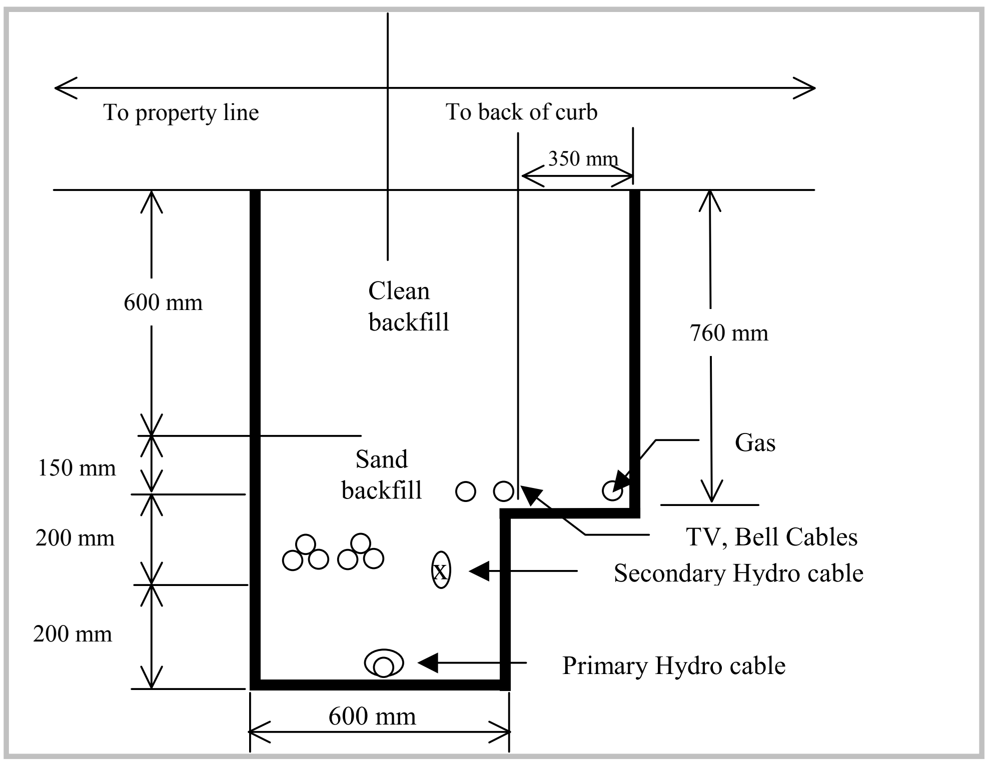
[4] Ontario Energy Board. "Gas Franchise Handbook", 2002, p.10
[5] Ontario Energy Board. "Gas Franchise Handbook", 2002, p.11

facilities are buried at the lowest level. Primary hydro lines are also buried at a substantial depth, as well as gas. Communication lines appear to be positioned the closest to the surface.

3.2.3 *Typical joint trench profile*

In the past few years, the infrastructure providers in Ontario have started to cooperate in their efforts to cut construction costs, by laying new service lines in joint trenches, combining all critical utility cables and lines (Figure 2).

Figure 2. Typical Joint Trench Profile in Ontario[6]



Joint trenches have been widely used in new subdivisions in major cities, and when building new community and public infrastructure buildings. Among the many advantages of joint trenching, the most significant are improved safety and efficiency in locating underground utilities.

[6] Ontario Energy Board. "Gas Franchise Handbook", 2002, p.11

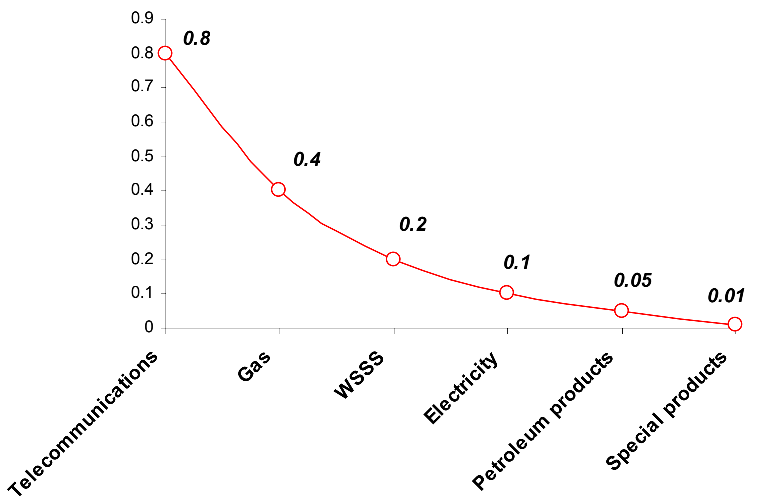
3.3 Typical Patterns of Excavation/Digging Work In the Vicinity of Underground Utility Infrastructure in Ontario

3.3.1 *Relative probabilities of third-party excavation/digging damages to major types of underground infrastructure in Ontario*

At the brainstorming session of the expert engineers from the companies - members of the ORCGA, the experts were asked to provide the relative ranking of the probability of third-party excavation/digging damage to the major types of utility networks. As a result, a relative probability curve was constructed (Figure 3).

The experts consistently ranked telecommunications and gas distribution networks as the most susceptible to third-party excavation/digging damage. Water, storm, steam, and sewer systems were ranked third, underground electricity lines - fourth, and the petroleum and special product pipelines the lowest.

Figure 3. ORCGA Brainstorming Session: Expert Consensus on Relative Probability of Third-Party Excavation/Digging Damage by Network Type

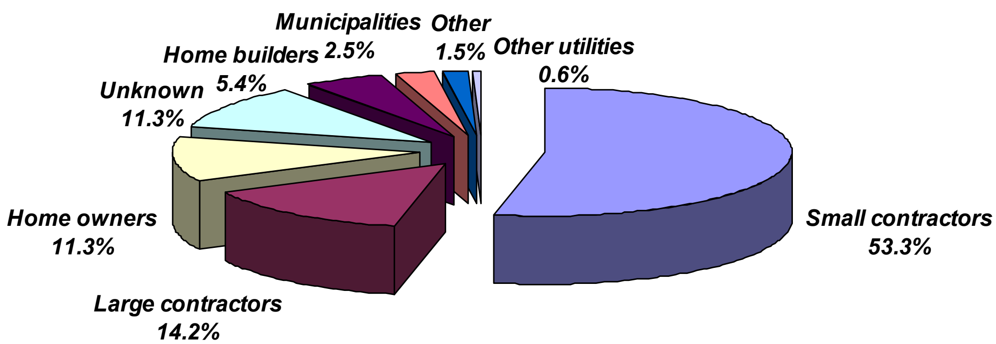


This expert consensus provided the insight with respect to the possible relative magnitude of third-party excavation/digging damages and data availability for the incidents of third-party excavation and digging damages to the underground utility networks in Ontario. The experts have also expressed a hypothesis that the probability of third-party excavation/digging damages would be much lower if locates were requested.

3.3.2 *Typical distribution of third-party excavation/digging damages to underground infrastructure by excavator types in Ontario*

Indicative of the patterns of excavation/digging damages in Ontario by the types of excavators is the distribution of these damages to natural gas pipelines. According to the data from key natural gas distribution companies in Ontario, their networks are most frequently damaged by small contractors, the share of which was 53.3% during 2000-03 (Figure 4). Large contractors are the second largest group of offenders (14.2%), followed by homeowners (11.3%). Homebuilders are responsible for about 5.4% of the damages, and municipalities contributed 2.5% to the problem. Not surprisingly, the share of other utilities is very small - 0.6%. However, the sub-contractors of other utilities can be in either a large or small contractor group.

Figure 4. Average Distribution of Third-Party Excavation/Digging Damages to Natural Gas Distribution Networks in Ontario by Excavator Type, 2000-03.

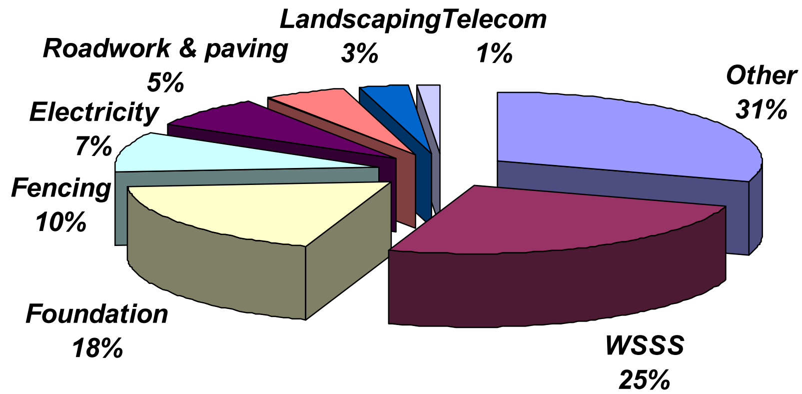


3.3.3 *Typical distribution of third-party excavation/digging damages to underground infrastructure by types of work in Ontario*

To illustrate the patterns of excavation/digging damages in Ontario by the types of work performed by third-parties in the vicinity of other networks, the data for the two most affected sectors are selected: gas distribution and telecommunication networks.

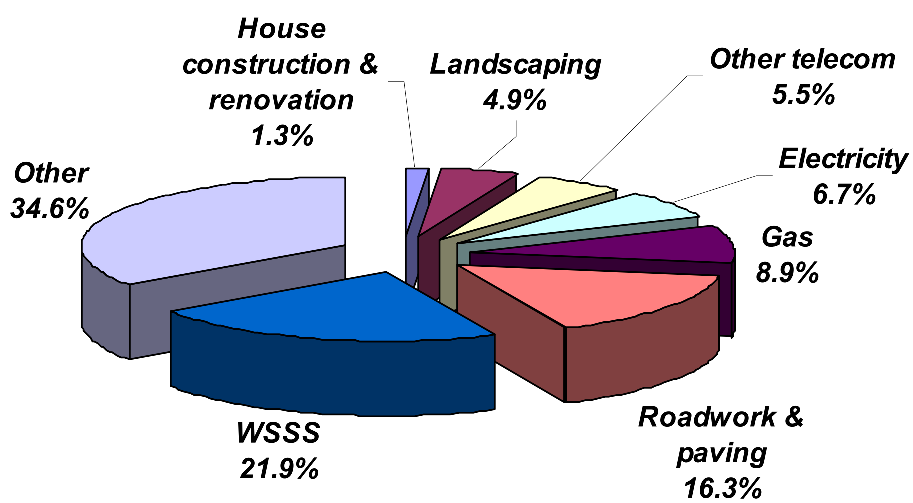
Processing of the data from the major gas distribution companies in Ontario with respect to the breakdown of third-party damages by work type showed that during 2000-03 work on municipal underground water, storm, steam and sewer systems was the major cause of damage (about 25% of the total). Next largest cause, foundation, roadwork and paving, produced about 23% of the damages. Such work as landscaping and fencing, ordered primarily by homeowners, caused about 13% of the damages. Work on the hydro networks resulted in an estimated 7% of third-party damages, while the share of the damages related to the work on telecommunication systems is very small (1%).

Figure 5. Average Distribution of Third-Party Excavation/Digging Damages to the Natural Gas Distribution Networks in Ontario by Work Type, 2000-03.



Statistics from the major telecommunication companies in Ontario on distribution of third-party damages by work type indicated that during 2000-03 work on municipal underground water, storm, steam and sewer systems was the major cause of damage, contributing about 22% to the total (Figure 6). Roadwork and paving projects caused 16.3% of the damages. Landscaping and fencing generated about 13% of the damages. The combined share of other utilities was approximately 21%, and homeowners contributed about 6%.

Figure 6. Average Distribution of Third-Party Excavation/Digging Damages to Telecommunication Networks in Ontario by Work Type, 2000-03.



4 Methodology

4.1 Theoretical framework

Due to the novelty of the ORCGA study, Informetrica developed a unique theoretical framework to quantify the impacts and costs of third-party damages: a Theory of Third-Party Excavation/Digging Damages to Underground Utility Infrastructure or **Theory of DEDs®.**

Research works of Selig, Leewis, Mather, Blackmore, Petrie, Treves, Lewandowski, Kiefner, Vieth, Orban, and Feder[7] on damages to buried facilities and pipelines due to excavation and digging, propose several algorithms of third-party damage estimation. Across all of these algorithms, there are several common elements, which allow specification of third-party damages to underground utility networks due to excavation and digging as follows:

$$NDED = f\{NS, CA, CLS, ENC, ECC\}$$

Where:

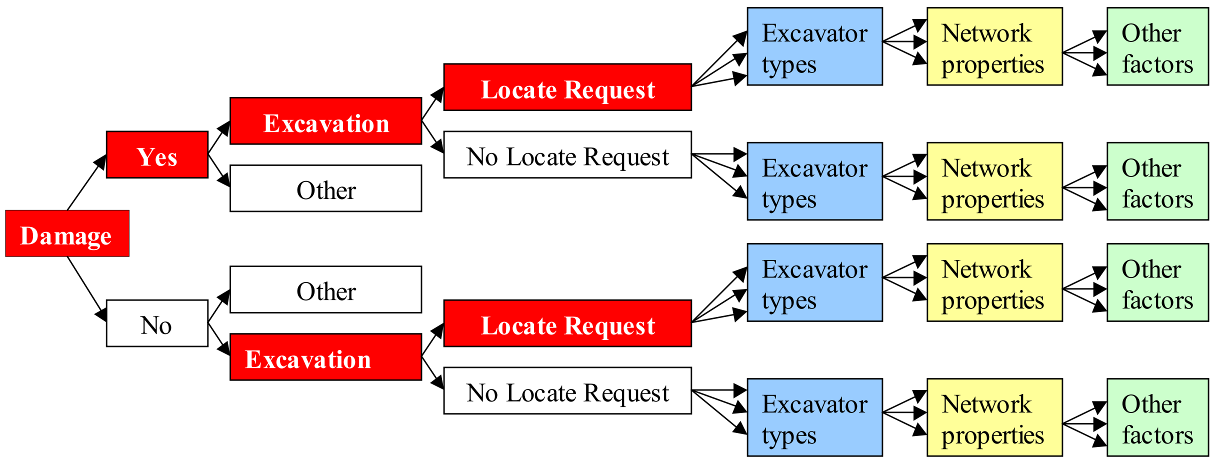
NDED = Number of Third-Party Damages to underground utility networks due to Excavation and Digging.
NS = Network Size (i.e. length of network (km), population, number of households in the area, land area, street length, number of customers, etc.).
CA = Construction Activity (i.e. housing starts, number of digs, number of construction companies in the area, etc.).
CLS = Availability of the One-Call Locate system and utility locate programs in the area.
ENC = Engineering Network Characteristics (i.e. physical characteristics of the buried facilities such as diameter, materials, pressure, type of product transported, etc.).
ECC = Excavation Community Characteristics (small/large contractors, skills, etc.).

The equation suggests that third-party damages to underground networks are a function of the network size, location, construction activity in the area, availability of the one-call locate system, network engineering characteristics, and characteristics of the excavation/digging community. The following assumptions and theoretical predictions can be derived from the above formula and literature review:

1. The greater the density of the network, the higher the number of DEDs.
2. The greater the construction activity, the higher the number of DEDs.
3. Availability of the One-Call Locate system or utility locate program prevents more than 30% of DEDs.
4. Certain physical characteristics of the underground facilities as well as their age and engineering are correlated with the pattern and frequency of DEDs.
5. The larger the size of the excavating firm, the more likely the excavators are to be better trained and skilled, and more responsive to safety measures, including locate requests; this is reflected in a lower number of DEDs..

[7] See List of References

Figure 7. Simplified Probability Tree of DEDs When One-Call Locate System or Utility Locate Programs Are Available



As Figure 7 illustrates, the probability of a DED largely depends on whether a locate was requested through a One-Call System or Utility Locate program, excavator type, network properties, and other multiple factor groups specified in the equation above. A literature review indicated that the most commonly used assumption by academics and researchers for the distribution of underground infrastructure damage or failure due to damage is Poisson distribution. The Poisson distribution is used to model the number of random occurrences of some rare phenomenon in a specified unit of space or time. For a Poisson random variable, the probability that *X* is some value *x* (density function) is given by the formula[8]:

$$P(X = x) = f(x) = \frac{\lambda^x e^{-\lambda}}{x!}, x = 0,1,...$$

where λ is the average number of occurrences in the specified interval. The distribution parameter λ is greater than zero ($\lambda > 0$), and is also a mean and variance of the Poisson distribution, indicating the rate of DEDs per unit of time, distance, or area. The domain of the distribution is $x \notin \{0,1,2,...\infty\}$. The Poisson distribution specifies that probability of the large number of events occurring at a certain time and location is very small[9].

Every time a DED occurs, it creates a number of negative consequences in the respective geographic area, having an effect on the owners of the underground utility networks, the excavators, the customers of the utilities, and members of the community (residences, businesses, community/public infrastructure, etc.).

[8] Palisade Corporation. "@Risk: Advanced Risk Analysis for Spreadsheets", 2004, p.249.
[9] Palisade Corporation. "@Risk: Advanced Risk Analysis for Spreadsheets", 2004, p.249.

Theoretically, the **generalized equation for the costs of DEDs** to the underground utility infrastructure can be specified as a function of the annual frequency and magnitude of these events followed by the multiple negative impacts of DEDs, assigned with monetary value, as follows:

$$C_{DED_i} = f\{ NDED_i^l , MI^k_{DED_i^l} , CI^k_{DED_i^l} \}$$

Where:

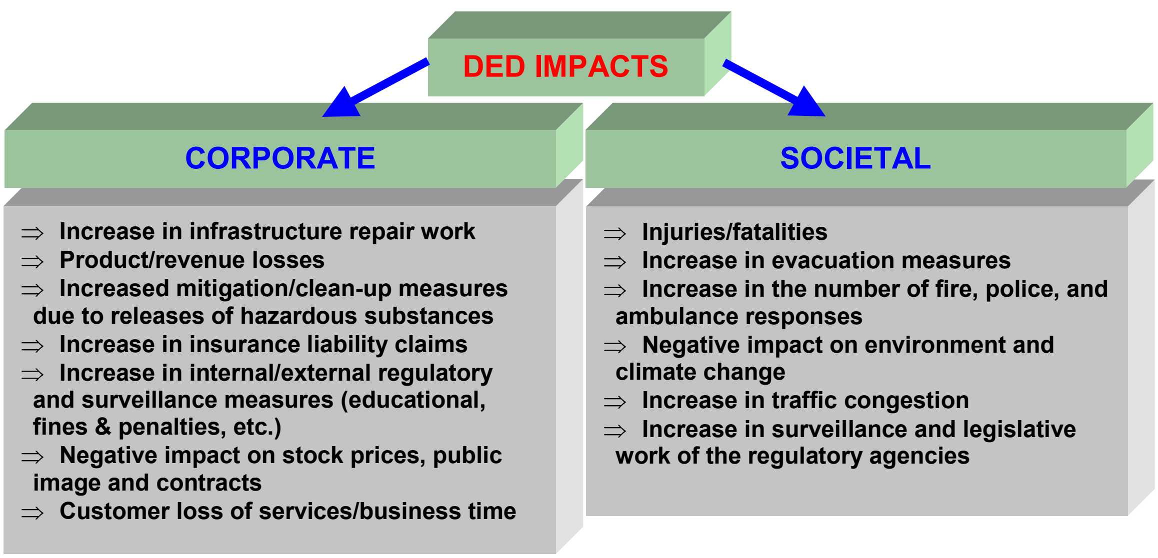
$NDED_i^l$ = Number of DEDs for underground infrastructure type *"i"* and located/non-located type *"l"*.

$MI^k_{DED_i^l}$ = Magnitude of DED Impact by consequence type *"k"*, located/non-located type *"l"*, and underground infrastructure type *"i"*.

$CI^k_{DED_i^l}$ = Cost of DED Impact by consequence type *"k"*, located/non-located type *"l"*, and underground infrastructure type *"i"*.

The major DED impacts (consequences) are illustrated in Figure 8, and are divided into two groups: corporate and societal impacts.

Figure 8. Major Groups of DED Impacts

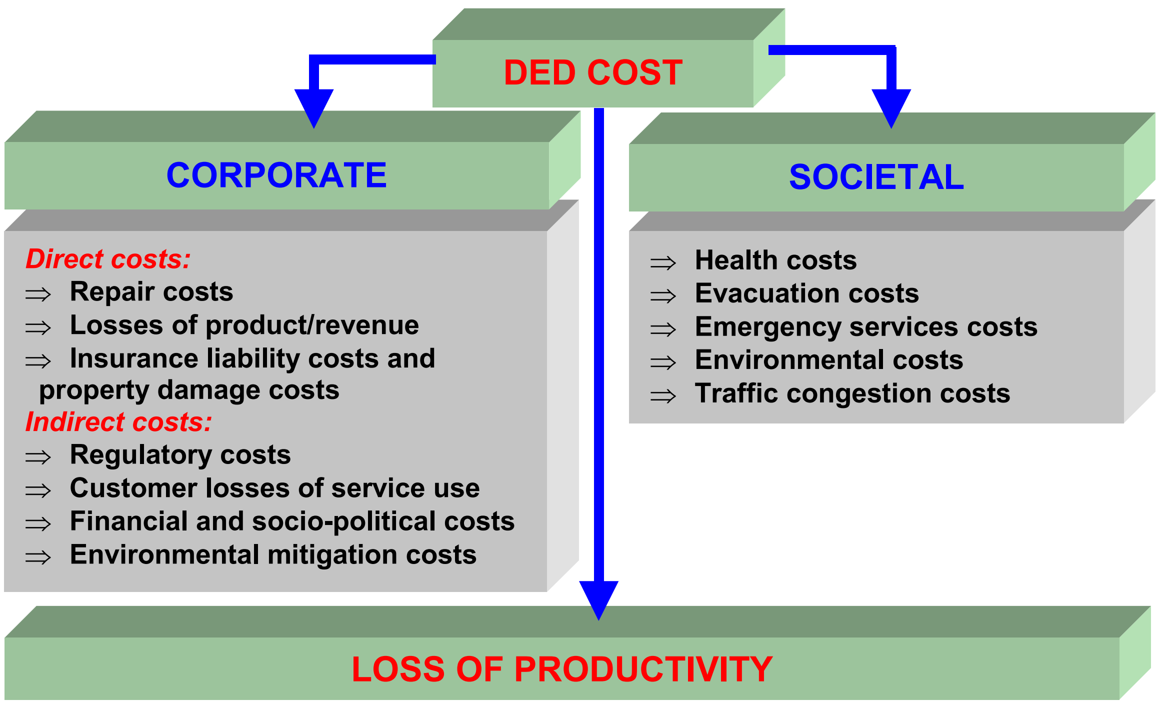


Corporate/sectoral impacts of DEDs are associated with short-term and long-term consequences of the DEDs, resulting in increased volumes of repair work, losses of product/revenue, clean-up after the spills of hazardous substances, payments for insurance liability claims and increased premiums, increased regulatory pressure and surveillance, fines and penalties, affect on stock prices, public image and contracts, and customers/community losses of services and time.

Societal impacts of DEDs are associated with a broad range of primarily long-term negative spillover effects of the accidents, usually difficult to express in monetary terms. These refer to such effects as injuries and fatalities due to DED accidents, evacuations, increased volumes of emergency responses to calls for fire, police and ambulance services, impact on local environment and climate change, and increase in traffic congestion.

Each of these impacts generates losses and costs carried by the utility owners, customers, businesses/community groups, and ultimately by the taxpayers. Most of the corporate impacts of DEDs are mitigated or paid by corporations, owners of the utilities. However, in many cases the customers and the businesses/community groups also share the costs. Societal costs of DEDs are born primarily by taxpayers. For the economy, the aggregation of DED costs results in the overall loss of productivity (Figure 8).

Figure 9. Major Cost Groups of DEDs



Major groups of corporate costs of DEDs are repair costs, loss of product revenue, insurance liability costs, regulatory costs, customer losses of service use, financial and socio-political and environmental mitigation costs.

Direct Corporate/Sectoral Costs of DEDs to underground utility networks consist of the following:

- **Repair Costs:** restoration costs of the damaged underground networks owned by the utility company. These include material and labour costs, such as costs to cut out failed sections, costs of root cause analysis, access and permitting costs, costs of subcontracted repairs, costs of in-house labour (i.e., to arrange, monitor, and inspect work of contracted and own repair crews), costs of repair of right-of-way, etc.

- **Loss of Revenue:** loss of product tariff revenues due to service interruptions caused by DEDs.
- **Insurance Liability Costs:** insurance payments resulting from DED-related damage to properties/systems other than utility-owned (i.e. other utilities, households, businesses, public service and community properties) and injuries/fatalities caused by releases of hazardous smokes or outages of service, and which the utility has to pay to the claimant if the claim is successful. These costs may also include increased insurance premiums.

Indirect Corporate/Sectoral Costs of DEDs to underground utility networks consist of the following:
- **Regulatory Costs**: costs of regulatory inspections by the provincial/federal regulatory agencies and costs of utility company's safety departments on prevention, investigation and mitigation of DEDs.
- **Customer Loss of Service Use:** costs associated with the inconveniences and negative effects of service interruptions (outages), often resulting in residential and nonresidential evacuations, and/or stoppages of manufacturing, business and public service processes, requiring the setting up of back-up systems or buying them, and resulting in a general loss of productivity.
- **Financial & Socio-Political Impact Costs:** costs associated with impacts of the DEDs on the public image of the utility companies, impact on stock prices, lost contracts and reduced distribution volumes, increased surveillance of the company's operations by external regulators and governments, etc.
- **Environmental Mitigation Costs:** costs of cleaning up spills and releases due to DEDs, usually incurred by the utilities owning the underground network.

Societal Costs of DEDs to underground utility networks consist of the following:
- **Health Costs:** costs of injuries and fatalities resulting from DEDs such as costs of insurance benefits of injuries/fatalities, provincial health care system burden of injuries, morbidity costs of injuries, workplace costs of injuries and mortality costs of injuries.
- **Evacuation Costs:** costs of evacuations of the apartment, business, community service, government, residential buildings, schools, hospitals, hotels, etc. due to DEDs consisting of the costs of lost revenues or interrupted production/output, lost labour productivity, and wages/leisure.
- **Emergency Services Costs:** costs of emergency responses to the cases of DEDs of the fire, police and paramedic services.
- **Environmental Costs:**
    - **Environmental Mitigation Costs** are costs of cleaning up spills and releases due to DEDs, usually incurred by the utilities owning the underground network; sometimes, governments get involved if the spill is significant.
    - **Environmental Impact Costs** are imputed costs of the environmental impacts of the hazardous releases.
    - **Environmental Regulatory Costs** are costs associated with monitoring, regulation and prosecution of environmental offenders that cause DEDs. Specifically, these costs include budgets of the various environmental government departments tracking the environmental incidents related to DEDs, conducting inspections and investigations, and levying associated fines, penalties and convictions.

- **Traffic congestion costs**: costs of traffic congestion caused by DEDs and resulting in losses associated with person delays, vehicle use, costs of lost fuel, air pollution and Greenhouse Gas emissions.

Informetrica developed **nine (9) stylized sub-theories for each group of DED impacts and costs**. A detailed description of each sub-theory for the specific cost group, including cost equations, is provided in the individual background papers:

1. Societal Costs of Damage to Underground Gas Distribution Networks due to Excavation in Ontario During 2000-03.
2. Societal Costs of Evacuation due to Excavation Damage to Buried Infrastructure in Ontario During 2000-03.
3. Societal Costs of Emergency Responses due to Excavation Damage to Buried Infrastructure in Ontario During 2000-03.
4. Societal Costs of Damage to Underground Water, Sewer, Storm and Steam Systems due to Excavation in Ontario During 2000-03.
5. Societal Costs of Damage to Underground Electrical Distribution Networks due to Excavation in Ontario During 2000-03.
6. Societal Costs of Health Impacts of Damage to Buried Infrastructure due to Excavation in Ontario During 2000-03.
7. Societal Costs of Traffic Congestion of Damage to Buried Infrastructure due to Excavation in Ontario During 2000-03.
8. Societal Costs of Environmental Impacts of Damage to Buried Infrastructure due to Excavation in Ontario During 2000-03.
9. Societal Costs of Damage to Other Utilities Networks due to Excavation in Ontario During 2000-03.

4.2 Data collection processes

Initial research revealed that statistics on DEDs and their costs are not available at the provincial or national levels, nor are there any databases that would be useful for the purposes of this study. The task was to design a data collection methodology that would allow the compiling of the comprehensive statistics from the organizations that deal with major impacts of DEDs or have the highest exposure to DEDs. Informetrica's data collection methodology involved three processes: primary, secondary and tertiary data collection. The data were collected for the period 2000-03 for a range of indicators common across utility and non-utility groups. The major principle applied in a sample selection was to achieve statistical significance where possible, using the following approaches:

1. For underground infrastructure and public service sectors with market/organizational structures defined by municipal geography (electricity distribution (EDN), water, sewer, steam and storm systems (WSSS), emergency response services (ER)) the targeted groups should represent areas servicing at least 50% of the Ontario population.
2. For utility sectors with market structures independent of municipal geography (gas distribution, telecommunications, petroleum products pipelines, special products pipelines) the targeted groups should constitute at least 50% of the provincial market.
3. For public service sectors (i.e. Environment, Traffic, Health, Evacuation) having exposure to societal DED impacts, the targeted organizations should include major service providers with at least a 50% representation of the sector.

4.2.1 *Confidentiality guarantees*

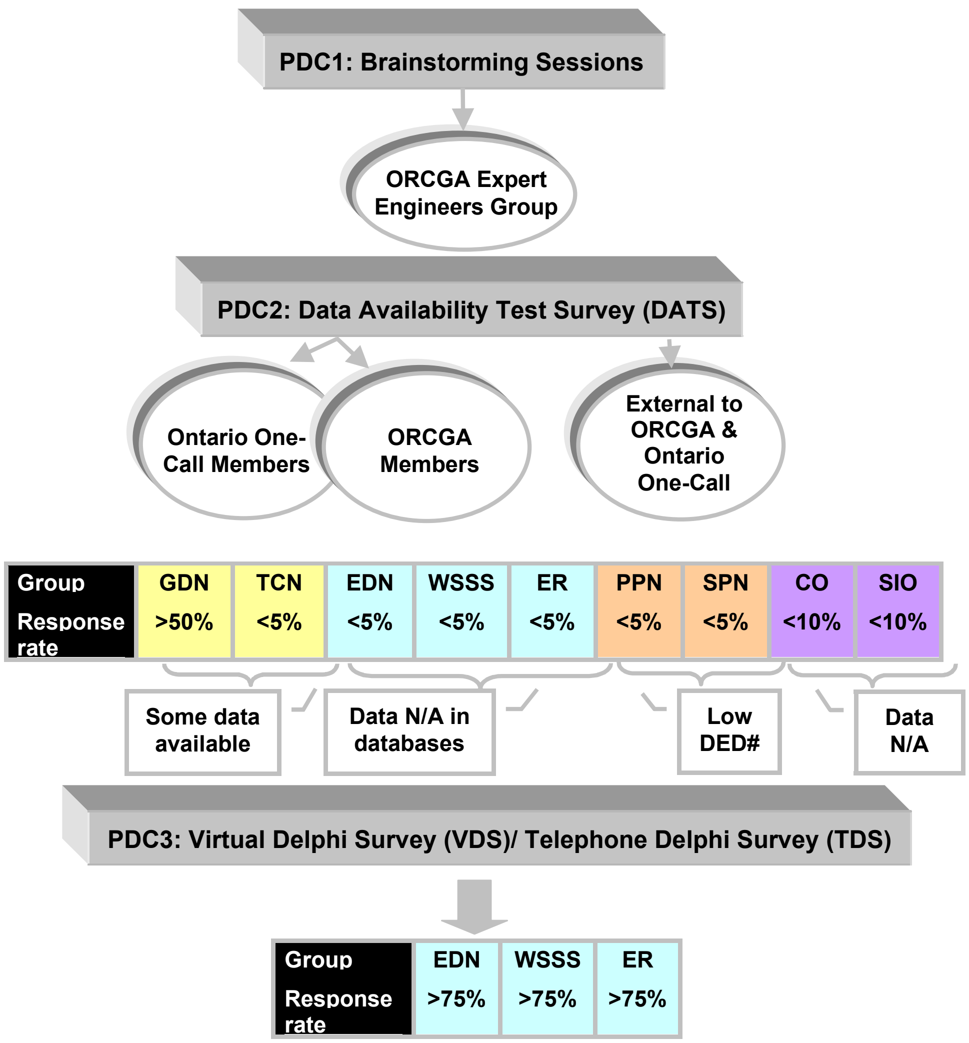
Due to the novelty of the ORCGA study and expected sensitivities of the targeted response groups, the decision was made to conduct any data collection under strict confidentiality guarantees. Each participant was provided with an introductory official ORCGA letter stating the purpose of the study and the provision of confidentiality guarantees. In terms of the collection of the expert estimates, each database record was appropriately coded in order to assure that there would be no linkage between the identity of the respondent and the actual data. Also, respondents were assured that their data were used only to generate statistics for the relevant samples, and would never be disclosed to ORCGA. The letter was also used during consultations with the Canadian and US government departments and agencies, various research groups and associations.

4.2.2 *Primary data collection*

Primary data collection processes involved design and implementation of the brainstorming sessions and surveys targeted at the members of the ORCGA, Ontario One-Call and various associations and organizations that have a certain level of exposure to DED impacts (Figure 10). The primary data collection was organized in three consecutive stages during the period October 2004-March 2005 and involved the following:

1. **Brainstorming sessions** of the ORCGA expert engineers.
2. **Data Availability Test Survey (DATS**) targeted at organizations, members of the Ontario Regional Common Ground Alliance (ORCGA) and Ontario One-Call, and non-member organizations with possible exposure to DED impacts.
3. **Virtual Delphi Survey (VDS)** of experts at those utilities that indicated partial availability of data (electricity and water, sewer, steam and storm sectors).
4. **Telephone Delphi Survey (TDS)** of experts of the municipal emergency services groups (fire, police, paramedic).

Figure 10. Primary Data Collection Process



The following groups of companies with buried facilities were contacted by telephone and/or e-mail using various methods of data collection:

1. Gas Distribution Networks **(GDN)**: 11 organizations.
2. Telecommunications Networks **(TCN)**: 23 companies.
3. Electricity Distribution Networks **(EDN)**: 50 hydro companies.

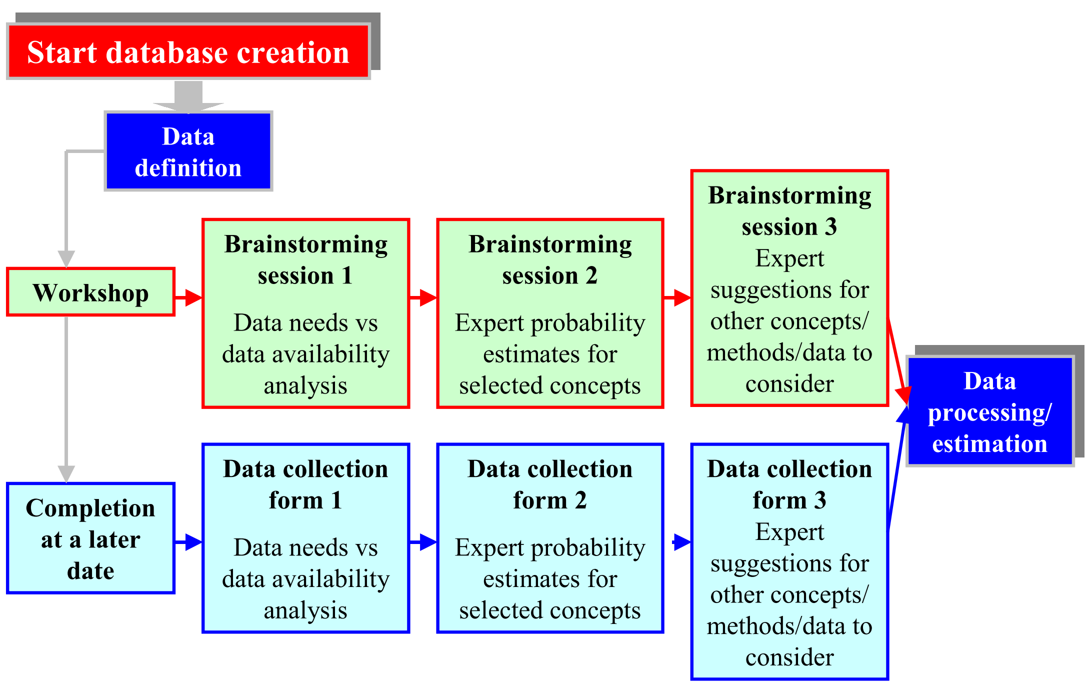
4. Water, Sewer, Steam and Storm systems **(WSSS)**: 30 municipal public works departments.
5. Emergency Response Services **(ERS)**: 30 municipal and provincial fire, police and paramedic organizations.
6. Petroleum Products Pipeline Networks **(PPN)**: 6 companies.
7. Special Products Pipeline Networks **(SPN)**: 4 companies.
8. Contractors Organizations **(CO)**: 12 associations of contractors, excavators and locators companies.
9. Special Interest Organizations **(SIO)**: 8 organizations that represent such groups as engineers, public works departments, police, fire and paramedic services organizations, and associations of utilities.

Descriptions of the procedures and results of each stage of the primary data collection are provided in the sections below.

4.2.2.1 Brainstorming sessions

The ORCGA study began on October 15, 2004 with the implementation of the brainstorming sessions of the group of executive engineers, representing various utility companies, members of the ORCGA. The logistics of the brainstorming sessions is illustrated in Figure 11.

Figure 11. Brainstorming Session of ORCGA Expert Engineers



The experts were given a choice to provide the answers at the sessions or later by e-mail. The collective purpose of these brainstorming sessions was to start a data definition process leading to a database creation, and to conduct a field test of the survey instruments.

The purpose of **Brainstorming Session 1 "Data Needs Versus Data Availability Analysis"** was to obtain expert opinions on the key data requirements and the likelihood of data availability for all major underground utility types. Experts were asked to fill out the draft Data Availability Test Survey (DATS) instruments in order to test for their effectiveness for data collection in the field. The outcome of this session was that the expert engineers found the instrument comprehensive and suitable for surveying the wide range of ORCGA and Ontario One-Call stakeholder groups, and can be applied in a large-scale survey after customization for each utility type.

Brainstorming Session 2 "Expert Probability Estimates for Selected Concepts" was conducted with the aim to obtain expert reaction on the various notions of probabilities of DEDs such as: 1) relative probability of DED occurrence for major types of utilities; 2) relative fragility of exposure to DEDs; and 3) relative damage ratios by major types of infrastructure networks, geographic units, and work and excavator types. Experts were asked to express their opinion at the session or to fill out specifically-designed forms and return them later.

The brainstorming sessions revealed that not all experts were comfortable in releasing the data or opinions, pointing out to the sensitive nature of the statistics. Many experts have also noted that significant inter-departmental and stakeholder cooperation is required in order to obtain key statistics. There was also a clear indication that utility companies have heterogeneous systems and patterns of reporting DEDs, indicating the need to design data collection instruments custom-tailored to the specifics of each utility group.

4.2.2.2 Data Availability Test Survey (DATS)

Data Availability Test Survey (DATS) was targeted at the major utility and contractor groups, members of Ontario One Call, ORCGA and other key non-member organizations representative of the infrastructure systems in Ontario. The DATS instrument was customized to reflect the specifics of each group. It was administered during the period November 2004-February 2005.

The DATS instrument contained questions about the actual availability and format of the wide range of relevant indicators that might be collected in the accounting and operating systems of the organizations. The idea was to find common or uniform indicators across all jurisdictions. Survey participants were given considerable freedom in specifying what they have in their systems that would be relevant for the purposes of this study. Each survey participant received an introductory ORCGA letter informing them about the purpose of the study and providing confidentiality guarantees.

The response rates of the first round of the DATS were relatively low. Responses of the gas distribution companies (GDNs) indicated that major companies representing at least 95% of the market have the key statistics and are willing to provide them.
Less than 5% of the telecommunications companies (TCNs) responded, however those that did, were the largest in the sector and indicated that they have some partial statistics. Only two electric distribution companies (EDNs) responded out of 50 contacted. The same situation was with the WSSS sector and Emergency Response Services. The response of the petroleum and

special products pipelines (PPNs and SPNs) indicated that the incidence of DEDs is negligible or zero in their systems, and thus there is not much data available. Less than 10% of the contractors and special interest organizations (COs and SIOs) responded, indicating that they do not keep statistics on the incidence and costs of DEDs; thus, CO and SIO companies were eliminated from further data collection processes.

In the second round of DATS, the Informetrica team implemented 5 to 10 follow-ups in the form of direct telephone calls and short e-mail letters, thanking participants and asking them to provide available data. As a result, major GDN, TCN, PPN and SPN companies provided partial DED statistics.

However, EDN, WSSS and ER organizations did not respond to the second round of DATS. An alternative data collection approach had to be implemented to reach these groups. Details of DATS outcomes are presented in background papers, where relevant.

4.2.2.3 Virtual Delphi Survey (VDS) and Telephone Delphi Survey (TDS)

VDS for EDN and WSSS Sectors

The DATS indicated that the organizations in the private and municipal electricity distribution sector (EDNs) and water, sewer, steam and storm systems (WSSS) have some partial information about the frequencies and costs of DEDs to their underground infrastructure, but are reluctant to provide it. The major reasons for this reluctance are:

1. Absence or shortage of personnel dealing with DEDs.
2. Absence of adequate DED reporting systems, accounting for major consequences and costs of DEDs
3. Restructuring in many organizations in EDN and WSSS sectors, resulting in the loss of continuity in the database formation and maintenance.
4. Bureaucratic procedures restricting access to data.

In cases where actual data are not available, or require substantial effort on behalf of the study participants to produce an estimate, methods of expert opinion collection are employed to derive the range of most probable estimates. One of the most successful and frequently used methods in the research practice is the Delphi Method of Expert Consensus Generation[10]. Virtual Delphi workshops (via e-mail) are the least costly and often the fastest method of applying the Delphi technique.

The Delphi technique involves the selection of a panel of geographically dispersed participants, who are very familiar with the situation in their jurisdictions, and are able to produce a reasonable range of estimates. Delphi surveys are implemented in two rounds. In the **first round,** the experts are given a short anonymous questionnaire (10-20 questions) that they can fill out quickly. The questionnaire normally contains questions aimed at establishing a reasonable range of average frequencies, rankings and magnitudes of various indicators that can be applied in relation to the reference samples. The responses of the first round are

[10] See List of References

processed to derive the average estimates. The **second round** involves sending a short description of the average results to the participants. Each participant has the option to revise the initial expert figures in comparison to the group averages, and modify the estimates if necessary. The final results are based on the new average and range.

The Virtual Delphi Survey instrument (VDS) addressed the participants with a letter explaining the purpose of the survey, followed by 12-14 questions. The VDS instrument also provided confidentiality and anonymity guarantees to each survey participant. The first question asked participants was to provide indicators for the size of their service area and system, while the remaining questions focused on third-party damage impacts and costs. Each question provided the approximate average indicator, and asked the participants to state whether their average is higher, lower or similar to a provided number. Additional space was allocated for comments, if the participant could provide more detailed responses or actual data.

In the case of WSSS systems, since Ontario has more than 400 cities/municipalities, the survey coverage had to be restricted to a smaller number of cities with representative characteristics. The following four groups of municipalities/cities were selected for sampling purposes (Table 3):

1. Reference cities.
2. Cities with a population above 50,000 excluding reference cities.
3. Cities with a population of 10,000 to 50,000.
4. Cities with a population of less than 10,000.

Table 3. Sample Size Characteristics of the Ontario Municipal Groups, 2000-03

Indicators	Housing Starts				Population 2001 Census	Households 2001 Census
	2000	2001	2002	2003		
Reference cities (RC)	50,166	52,646	57,858	58,386	6,395,100	1,456,383
Cities/municipalities with population above 50,000 (excluding RC)	15,409	15,145	19,146	19,042	1,944,537	1,602,143
Cities/municipalities with population from 10,000 to 50,000	1,848	2,471	2,611	3,505	2,090,117	805,447
Cities/municipalities with population less than 10,000	4,098	3,020	3,982	4,247	980,292	504,320
Total Ontario	**71,521**	**73,282**	**83,597**	**85,180**	**11,410,046**	**4,368,293**

Sources: "Census Geo-Suite2001", Statistics Canada; Canada Housing and Mortgage Corporation, "Housing Starts", 2000-03.

Reference cities are the largest cities in the province representing more than 50% of the Ontario population, i.e. Toronto, Ottawa, Kingston, Kitchener, St. Catharines. For each sample group, one or two cities in the mid-range of that group size were selected as representative cities. These representative cities are Windsor, Brockville, Smiths Falls, Thunder Bay, Temiskaming Shores, and Elliot Lake. This sampling allows correlating sample size statistics for these groups of municipalities/cities (population, number of households, housing starts in Ontario, and other socio-demographic statistics) with the expert consensus estimates of the impacts and costs of third-party damages to the underground utility systems in the reference and representative cities.

Selection of the reference and representative cities determined the selection of the public works departments. Using the ORCGA members telephone list and websites of the respective sample cities/municipalities, several rounds of telephone calls were made to find experts in the WSSS departments willing to participate in the study. Upon receipt of the participant's consent to participate in the Virtual Delphi Survey, the participants were sent the survey instrument by e-mail with an agreement to respond within a two-week timeframe in the 1st Round of VDS. Of the 11 experts, 8 were able to present estimates for all indicators. The results from the 1st Round VDS were tabulated in order to derive minimum, maximum and average estimates for each indicator. These tabulations were then used to design the 2nd Round VDS instrument, that contained an introductory letter thanking the expert panel for their efforts, and inviting them to participate in the 2nd Round of VDS in order to see the sample statistics and to revise their estimates if necessary. None of the experts wished to change their initial estimates, and thus they were included in the database with uniform indicators for this sector **DED-WSSS.**

In the case of the Electricity Distribution Networks, the approach was to target the hydro companies in the same municipal samples specified above and the ORCGA members. The 1st Round VDS instrument was sent to 16 experts by e-mail, of which 6 experts responded. The same VDS procedures as for the WSSS sector were applied, leading to the formation of the database **DED-EDN.**

Details of the VDS procedures for WSSS and EDN sectors can be found in Background Paper 4 and 5.

TDS for Emergency Response Services

The Telephone Delphi Survey (TDS) was designed and implemented in order to collect expert estimates on the frequency of the provincial emergency responses to DEDs and their costs, detailed in Background Paper 3.

Informetrica's methodological approach was to target field emergency service personnel in critical Ontario municipalities for each emergency response service group: Fire, Police and Paramedic Emergency Responses (ERs). Data collection methodology was based on several key steps:

1. Design of the data requirements.
2. Design of the telephone survey instruments relevant for each type of emergency response service.
3. Selection of the representative Ontario municipalities, surveying which would provide a statistically significant (more than 60%) coverage of the provincial geographic area and would allow accounting for the size of the municipal underground networks and socio-economic characteristics of these areas.

4. Creation of a list of key field emergency service personnel in each emergency response category willing to participate in the study.
5. Contact of the experts and recording of their responses.
6. Creation of a database for each type of emergency response.

The same four groups of Ontario municipalities/cities were selected for sampling purposes[11]as in the case of VDS. The Informetrica team developed three (3) TDS instruments aimed at reaching field experts at each emergency service system, i.e. fire, police and paramedic, in each of the selected jurisdictions. During the course of the TDS, Informetrica's team made an observation that municipal emergency services are not usually required to collect these statistics, so they often asked for the ORCGA letter explaining the project. Then the data request would get bureaucratic vetting from a senior person in the municipality. Because there are three types of jurisdictions involved in providing data (municipalities, counties, and regions), different rules of accessibility are often in place for different kinds of data.

The TDS was a substantial undertaking. During a five-month period it took, on average, 10 phone calls to find an individual willing to participate in the study, and more than 5 rounds of follow-up calls to actually retrieve the expert estimates, and/or to provide answers to the questions, etc. The expert estimates collection approach in the TDS was restricted to several major indicators due to the absence or lack of actual statistics. Nevertheless, the expert estimates were collected from 28 emergency response organizations, representing fire, police and paramedic services, which allowed constructing a database with uniform indicators **DED-ER**. These expert estimates were processed to obtain average sample statistics. Each participant was contacted again in the 2nd Round of TDS, provided with these estimates, and asked to make changes to their original data if necessary; however, none of the experts wished to make revisions. Details of these processes are presented in Background Paper 3.

4.2.3 *Secondary data collection*

The secondary data collection process was structured to support estimation of the major DED impacts and costs with the key secondary statistics at the aggregate provincial/national level and comparative international indicators, as illustrated in Table 3. Reference studies and reports refer to those publications, estimates from which could be used for formulas in the Informetrica estimation procedures or comparative analysis. Initial research showed that there are no published studies on DED impacts and costs. However, in most cases, there were publications available, estimates from which were applied to calculate certain indicators. Unfortunately, there were no publications relevant for the telecommunications and special products pipelines, WSSS systems, special products pipelines, emergency response services, and evacuation costs. Also, the research indicated that there are no databases on the impacts and costs of DEDs at the municipal, provincial or federal government level, relevant to study. Only in the case of health, environmental and evacuation costs provincial departments had partial relevant data that could be extracted after a significant programming effort.

[11] see sample size characteristics in Table 3

Table 4. Secondary Data Collection Process

DED Impact & Cost Groups	SDC1 Published Reference Studies & Reports	SDC2 Databases & Special Data Requests	SDC3 Consultations
Gas Distribution Networks	National Energy Board, Alberta Energy & Utilities Board	US Office of Pipeline Safety; Common Ground Alliance (CGA); American Gas Association (AGA); National Energy Board; Utility Notification Centre of Colorado (UNCC); Alberta One Call; Alberta Gas Distribution Utilities; Ontario One Call	Statistics Canada Energy Section, Ontario Energy Board, US Office of Pipeline Safety, National Energy Board, Alberta Energy & Utilities Board; Pipe Line Contractors Association of Canada
Telecommunications	N/A	Common Ground Alliance (CGA); Utility Notification Centre of Colorado (UNCC); Ontario One Call	Statistics Canada, Canadian Radio-Television and Telecommunications Commission
Electricity Distribution Networks	Canadian Electricity Association; US Department of Energy	Canadian Electricity Association; Ministry of Labour Electrical Accidents Reports; Utility Notification Centre of Colorado (UNCC); Ontario One Call; Alberta One Call	Canadian Electricity Association, Statistics Canada, University of Saskatchewan, The Independent Electricity System Operator (IESO), Ontario Energy Board, National Energy Board, Electrical Safety Authority (ESA), Ontario Ministry of Labour (MOL)
Water, Sewer, Steam and Storm Systems	N/A	Utility Notification Centre of Colorado (UNCC); Ontario One Call; Alberta One Call	Ontario Ministry of Municipal Affairs and Housing
Petroleum Products Pipelines	National Energy Board, Alberta Energy & Utilities Board, US Office of Pipeline Safety	National Energy Board; Utility Notification Centre of Colorado (UNCC); Ontario One Call; Alberta One Call	Statistics Canada Energy Section, Ontario Energy Board, US Office of Pipeline Safety, National Energy Board, Alberta Energy & Utilities Board; Pipe Line Contractors Association of Canada
Special Products Pipelines	N/A	Utility Notification Centre of Colorado (UNCC); Ontario One Call; Alberta One Call	N/A
Emergency Response	N/A	N/A	Ontario Ministry of Municipal Affairs and Housing, Ontario Fire Marshal's Office, Ontario Ministry of Health and Long-term Care, Association of Municipal Emergency Measures Service of Ontario, Ontario Ministry of Finance, Ontario Provincial Police
Evacuation	N/A	Ontario Spills and Action Centre Database (SAC); National Pollutant Release Inventory (NPRI) of Environment Canada; Canadian Institute for Health Information (CIHI); Natural Resources Canada	Ontario Spills and Action Centre; Ontario Ministry of Environment; Canadian Housing and Mortgage Association, Ontario Ministry of Education, Statistics Canada
Environment	US Department of Energy, Bernow et al, Chernick-Caverhill, Christoffersen	Ontario Spills and Action Centre Database (SAC), Environment Canada National Pollutant Release Inventory (NPRI), Environment Canada Greenhouse Gas Inventory	Environment Canada, Ontario Ministry of Environment Spills and Action Centre and Investigations and Enforcement Branch, Converger Research (US)
Health	Workers Safety and Insurance Board (WSIB), Health Canada, Public Health Agency of Canada	Workers Safety and Insurance Board (WSIB) , Ontario Ministry of Labour (MOL) Electrical Accidents Report; Health Canada Injuries Surveillance Online	WSIB, Health Canada, MOL, Construction Safety Association of Ontario. Electrical Safety Authority (ESA)
Traffic Congestion	Texas Transportation Institute, US Oak Ridge National Laboratory, Quebec Ministry of Transport	N/A	Ontario Ministry of Transportation, Federal Highway Administration, Transport Canada, Construction Safety Association of Ontario

For all sectors and cost groups, except special products' pipelines, the Informetrica team had to conduct consultations with the municipal, provincial and federal authorities on the availability of relevant statistical and market structure information.

4.2.4 *Tertiary data collection*

Table 4 outlines the sources of the tertiary data or supplementary information used primarily to check for the availability of data or alternative estimates, validation of the Informetrica estimates, testing of the hypotheses and calculation of the indicators (Table 5).

Table 5. Tertiary Data Collection Process

DED Impact & Cost Groups	TDC1 Statistics Canada Data	TDC2 The Informetrica Model (TIM) Database	TDC3 Websites
Gas Distribution Networks	Gas Sector Statistics Publications; CANSIM; Canadian Business Register; CENSUS GEO-SUITE	National Income and Expenditure Accounts and Labour Productivity Modules	Annual reports of the gas distribution companies, Ontario Ministry of Energy, Ontario Energy Board, Pipe Line Contractors Association of Canada, Ontario Energy Association, Canadian Energy Pipeline Association
Telecommunications	Telecommunications Sector Statistics Publications; CANSIM; Business Register; CENSUS GEO-SUITE	National Income and Expenditure Accounts and Labour Productivity Modules	Annual reports of the telecommunications companies, Ontario Energy Association, Ontario Energy Board,
Electricity Distribution Networks	Electricity Sector Statistics Publications; CANSIM; Business Register; CENSUS GEO-SUITE	National Income and Expenditure Accounts and Labour Productivity Modules	Annual reports of the gas distribution companies and related associations, Ontario Ministry of Energy, Ontario Energy Board, National Energy Board, The Independent Electricity System Operator (IESO)
Water, Sewer, Steam and Storm Systems	CANSIM; Business Register; CENSUS GEO-SUITE	National Income and Expenditure Accounts and Labour Productivity Modules	Annual reports of the municipal public works departments
Petroleum Products Pipelines	CANSIM; Business Register; CENSUS GEO-SUITE	National Income and Expenditure Accounts and Labour Productivity Modules	Websites of the companies, Ontario Ministry of Energy, Ontario Energy Board, Pipe Line Contractors Association of Canada; Ontario Energy Association, Canadian Energy Pipeline Association
Special Product Pipelines	CANSIM; Business Register; CENSUS GEO-SUITE	National Income and Expenditure Accounts and Labour Productivity Modules	Websites of the companies
Emergency Response	CANSIM; Business Register; CENSUS GEO-SUITE	N/A	Annual reports and publications of the municipal/regional police, fire, public health/ambulance and financial departments;
Evacuation	Publications on Education in Canada	National Income and Expenditure Accounts and Labour Productivity Modules; Provincial Minimum Wage database	Hotels, YMCA, CMHC
Environment	N/A	N/A	OECD, Ontario Public Service Employees Union, Health and Safety Executive, Environment Canada
Health	CANSIM	National Income and Expenditure Accounts and Labour Productivity Modules	WSIB Annual Statistical Supplements to the reports; WSIB online publications
Traffic Congestion	Geography Working Paper Series, CENSUS GEO-SUITE	N/A	Ontario Ministry of Transportation, Transport Canada

The information was collected from the following major sources:

1. Statistics Canada: CANSIM online database, Census Geo-Suite CD-ROM, Canadian Business Register CD-ROM, Publications
2. Informetrica TIM Model Databases
3. Websites of the members of the ORCGA and Ontario One Call, municipal, provincial and federal government departments, associations and other groups with relevant information posted online.

All of the relevant Statistics Canada data and publications were purchased by Informetrica for the purposes of this study. Estimates and data from the Informetrica TIM Model represent time-series based on the data published by Statistics Canada and other government departments.

4.3 Estimation methods

Due to significant differences among the underground utility sectors and major societal cost groups, a separate estimation methodology was designed and implemented for each group.

4.3.1 *Estimation approach for GDN Costs of DEDs*

Estimation of the DED impacts and costs for the Ontario underground **Gas Distribution Networks (GDN)** was performed as follows:

- The Ontario GDN sector was divided into two samples: companies regulated by the Ontario Energy Board (OEB) and companies not regulated by the Ontario Energy Board.
- More than 95% of the estimates are based on the actual data from the DATS survey for OEB-regulated companies.
- The estimates for Non-OEB-regulated companies were derived using a three-tier Informetrica DED Impacts and Costs Simulation Model (DED-ICSM) based on the theory of discrete probability. The model utilized various average annual indicators and regression coefficients, and sample probability distributions, linking the DED frequencies and costs with various provincial and company statistics on the construction activity, size of network, tariffs, length of networks, etc. Statistics Canada data were heavily utilised.
- Average annual measure of the Ontario productivity loss was used to derive the customer loss of service use indicators.
- Disaggregation by located/non-located DED type for the OEB-regulated group was based on actual distribution, while this breakdown was simulated for the Non-OEB group.
- The estimations produced annual time series for each indicator for the period 2000-03.

4.3.2 *Estimation approach for WSSS Costs of DEDs*

Estimation of the DED impacts and costs of the Ontario underground **Water, Sewer, Steam and Storm systems (WSSS)** was performed as follows:

- The Ontario WSSS sector was divided into three samples: cities with a population above 50 thousand, cities with population from 10 to 50 thousand, and cities with population below 10 thousand. Sample statistics were based on the Statistics Canada data.
- The average annual VDS expert estimates for the representative cities in each sample were applied using statistical inference equations to produce aggregates for each sample.
- The equations linked the DED frequency and costs estimates with the sample statistics on the housing starts and number of households.
- Average annual measure of the Ontario productivity loss was used to derive the customer loss of service use indicators.
- Disaggregation by located/non-located DED type for all samples was based on the average annual distribution reported by the experts in the VDS survey
- The estimations produced average annual estimates for each indicator for the period 2000-03.
-

4.3.3 *Estimation approach for EDN Costs of DEDs*

Estimation of the DED impacts and costs for the Ontario underground **Electricity Distribution Networks (EDNs)** was performed using the following approach:

- The estimates for the Ontario EDN sector were based on the application of the market shares and related statistics to the VDS expert estimates for each EDN company in the statistical inference equations.
- The equations linked the DED frequency and cost estimates with the statistics on the electricity distribution volumes, housing starts, number of households and other company and provincial statistics to derive lower and upper bound estimates.
- Since the actual distribution of the VDS-reported outages for the Ontario electrical distribution utilities by the time of day and season is not known, the Tobit regression estimates from the US Department of Energy reference study for the **"willingness to pay" measures (WTP)** of the customer outage costs were applied for the calculation of the customer outage costs for Ontario (after appropriate conversion into Canadian currency).
- Provincial market structure data from Statistics Canada publications and annual reports of the companies were utilized.
- Average annual measure of the Ontario productivity loss was used to derive the customer loss of service use indicators.
- Disaggregation by located/non-located DED type for all samples was based on the average annual distribution reported by the experts in the VDS survey.
- The estimations produced average annual estimates for each indicator for the period 2000-03.

4.3.4 *Estimation approach for OUN Costs of DEDs*

Estimation of the DED impacts and costs for the Ontario underground **Other Utility Networks (OUNs)** was performed as follows:

- Due to the poor response to the DATS survey and absence of provincial aggregate statistics for the sectors, statistical inference or probabilistic simulation methods could not be applied.
- The estimation was limited to the aggregation of the actual data on the basis of various average annual indicators separately for each sub-sample: 1) telecommunications; 2) petroleum products pipelines; 3) special products pipelines.
- Average annual measure of the Ontario productivity loss was used to derive the customer loss of service use indicators.
- Disaggregation by located/non-located DED type for all samples was based on the combination of the actual distributions reported in the DATS survey and derived average annual distributions.
- The estimations produced time series estimates for each indicator for the period 2000-03.

4.3.5 *Estimation approach for Health Costs of DEDs*

Estimation of the provincial **Health Costs of DEDs** was based on the following approach:

- Estimation of the health costs was limited to four major groups: 1) health costs of injuries from excavation/digging machinery, excavation/trenching cave-in, collapsing structure and materials; 2) health costs of injuries from exposure to hazardous liquids, vapours and steam; 3) health costs of injuries/fatalities from fire, smoke, and explosions; 4) health costs of injuries/fatalities from contact with underground electric current.
- The equations and respective calculations for the costs relied significantly on the special statistical runs requested from WSIB, and published estimates of Health Canada and Ontario Ministry of Labour.
- Available actual injury and fatality statistics reported in the DATS and VDS survey for GDN and WSSS sectors was aggregated and represented the lower bound estimates.
- Disaggregation by located/non-located DED type for all samples was based on the combination of the actual distributions reported in the DATS and VDS survey and derived average annual distributions.
- The estimations produced time series estimates for each indicator for the period 2000-03.

4.3.6 *Estimation approach for Evacuation Costs of DEDs*

Estimation of the **Evacuation Costs of DEDs** to underground utility networks in Ontario utilized the following approach:

- Due to the absence of comprehensive data on the company and provincial aggregate level and relevant reference studies, the probabilistic methods of estimation were applied.

- The estimation was limited to the simulated inputs for the GDN sector only, and does not include evacuation costs for other sectors.
- The probability distribution of the actual reported evacuation time per building type from the Spills and Action Centre (SAC) database of the Ontario Ministry of Environment was linked with the simulated evacuation time estimates derived on the basis of the DATS survey for GDN companies.
- Disaggregation by located/non-located DED type was based on the combination of the actual distributions reported in the DATS survey and derived average annual distributions.
- The estimations produced time series estimates for each indicator for the period 2000-03.

4.3.7 *Estimation approach for Emergency Response Costs of DEDs*

Estimation of the DED impacts and costs for the Ontario **Emergency Response Services (ERs)** was performed as follows:

- Each Ontario municipal emergency response services sector (Fire, Police, Paramedic) was divided into three samples: cities with population above 50 thousand, cities with population from 10 to 50 thousand, and cities with population below 10 thousand. Sample statistics were based on the Statistics Canada published data.
- The estimates represent only the organizational budget-related estimated costs of the ERs to DEDs, and are not exhaustive.
- The time series based on TDS expert estimates for the representative cities in each sample were applied using statistical inference equations for each sector to produce aggregates for each sample and sector, summation of which allowed derivation of the provincial figures.
- Disaggregation by located/non-located DED type for all samples was based on the average annual distribution reported by the experts in the TDS survey.
- The estimations produced time series estimates for each indicator for the period 2000-03.

4.3.8 *Estimation approach for Environmental Costs of DEDs*

Estimation of the **Environmental Costs of DEDs** to Ontario underground utility networks was performed as follows:

- An estimation procedure, using a combination of the simulated DATS and VDS survey estimates, published estimates from several US reference studies, and average budget costs for the Spills and Action Centre of the Ontario Ministry of Environment was applied. Only three major cost groups are represented: environmental mitigation, environmental impact, and regulatory costs.
- The environmental costs represent the most significant costs that occur in the GDN and WSSS sector in the case of DEDs, as well as costs of regulatory government and non-government organizations, and are not exhaustive.

- Disaggregation by located/non-located DED type for all samples was based on the combination of the actual distributions reported in the DATS and VDS survey and derived average annual distributions.
- The estimations produced time series estimates for each indicator for the period 2000-03.

4.3.9 Estimation approach for Traffic Congestion Costs of DEDs

Estimation of the provincial **Traffic Congestion Costs of DEDs** to underground utility infrastructure was performed as follows:

- Estimation techniques utilizing a combination of several US and Canadian reference studies, Statistics Canada data and consultations with various transportation experts were applied.
- The traffic congestion costs of DEDs represent only the estimated costs for 11 major cities in Ontario DEDs in Ontario, and thus are not exhaustive.
- Disaggregation by located/non-located DED type for all samples was based on the combination of the actual distributions reported in DATS, VDS and TDS surveys and derived average annual distributions.
- The estimations produced time series estimates for each indicator for the period 2000-03.

Detailed descriptions of the models, equations, assumptions and sources used in the estimations are provided in the individual background papers.

4.4 Expert Review Processes

In order to ensure accuracy of the findings and broad representation of the views and expertise across all stakeholders, Informetrica and ORCGA organized expert reviews of the background papers. Each paper was scrutinized by a panel of 3 to10 members of ORCGA. These panels were comprised of experts, specific for each sector or cost group. This process resulted in many useful suggestions and additions to the papers. Informetrica found these Expert Review Processes very constructive and objective.

5 Analysis of the Ontario Costs of Non-Located DEDs to Underground Utility Networks

5.1 Costs of Non-Located DEDs to Gas Distribution Networks in Ontario

The aggregation of estimates for each cost group incurred due to non-located DEDs to GDNs allowed establishing the magnitude of their average annual provincial impacts and costs, as presented in Table 6.

Average Annual Direct Costs of DEDs to underground GDNs are:

- Repair costs: $1.5 million.
- Product/revenue loss: $44.5 thousand.
- Insurance liability costs: $0.5 million.

Average Annual Indirect Costs of DEDs to underground GDNs are:

- Customer loss of service use: $224.1 thousand.
- Regulatory costs: $6.5 million.

Annually in Ontario during 2000-03 around 2.8 thousand non-located DEDs to the underground natural gas pipelines occurred, resulting in 142.2 thousand cubic meters of natural gas lost, 131 insurance liability claims filed, 6.6 thousand hours of service use lost to the customers, 261 investigation and at least 1 prosecution of the regulatory agency (TSSA).

Table 6. Total Ontario Provincial Average Annual Costs of Non-Located DEDs to Underground Gas Distribution Networks in Ontario, 2000-03, $CDN

Indicators	Average Annual Estimates, $	Average Annual Shares, %
Frequency Indicators		
Number of non-located DEDs	2,750	-
Quantity of lost product, cubic meters	142,212	-
Number of insurance liability claims	131	-
Time of service interruptions, hours	6,579	-
Number of TSSA investigations of DED cases	261	-
Number of TSSA prosecutions of DED cases	1	-
Cost Indicators		
Repair costs	1,523,751	17.5%
Product/revenue losses	44,458	0.5%
Insurance liability costs	445,585	5.1%
Customer loss of service use	224,100	2.6%
Regulatory costs	6,484,679	74.3%
Total costs o f non-located DEDs to GDNs	**8,722,573**	**100.0%**
Costs per non-located DED	**3,172**	

These non-located DEDs induce costs of significant magnitude: around $8.7 million per year on average. The largest share is attributed to the internal corporate and external agencies regulatory costs (74.3%) with a price tag of $6.5 million. Second largest cost group is repair costs with a share of 17.5% of the total, amounting to almost $1.6 million. Insurance liability costs of non-located DEDs to the underground gas distribution networks are the third largest cost group with a share of 5.1% costing almost half a million. The customer loss of service use group constitutes around a quarter million (2.6%), and the product/revenue losses contribute around $45 thousand (0.5%).

Therefore, the average annual societal cost of one non-located DED to the underground gas distribution networks is estimated around $3.2 thousand.

Further, the trend and regression analysis indicated that the incidence and costs of non-located DEDs to underground GDNs are rising due to several factors, such as an increase in the construction activity in Ontario during 2000-03 and partial effectiveness of the existing voluntary One-Call system in the province. The comparative analysis of the frequencies of the non-located DEDs per 1,000 km of the natural gas pipelines revealed that this indicator is higher in Ontario than in Alberta and the United States throughout 2000-03.

5.2 Costs of Non-Located DEDs to WSSS Networks in Ontario

The aggregation of provincial estimates by each cost group and sample allowed establishing the average annual provincial impacts and costs of non-located DEDs to the underground WSSS systems, as presented in Table 7.

According to the results of the Virtual Delphi Survey, annually in Ontario around 304 non-located DEDs to underground WSSS infrastructure occur.

Table 7. Average Annual Provincial Costs of Non-Located DEDs to Underground WSSS Systems in Ontario, 2000-03, $CDN

Indicators	Average Annual Estimates,$	Average Annual Shares, %
Frequency Indicators		
Number of non-located DEDs	304	-
Number of insurance liability claims	222	-
Number of customer-hours of service use loss	10,811	-
Quantity of hazardous releases, m^3	1,816	-
Cost Indicators		
Repair costs	578,880	33.6%
Private property damage costs	519,840	30.2%
Costs of insurance liability claims	123,696	7.2%
Customer loss of service use	320,684	18.6%
Costs of environmental clean-up	178,470	10.4%
Total costs of non-located DEDs to WSSS systems	**1,721,570**	**100.0%**
Costs per non-located DED	**5,663**	

Consequently, these damages result in at least 304 repair crew deployments to do the restoration work, and 222 cases of the respective property damage. This causes approximately 10.8 thousands of customer-hours loss of service use, resulting in the loss of productivity. Moreover, these damages cause spills of hazardous substances into the environment in average annual amounts of approximately 1.8 thousand cubic meters.

Average annual direct costs of non-located DEDs to underground WSSS systems are:
- Repair costs: $578.8 thousand.
- Private property damage costs: $619.8 thousand.
- Insurance liability costs: $123.6 thousand.

Average annual indirect costs of DEDs to WSSS systems are:
- Customer loss of service use: $320.6 thousand.
- Environmental clean-up costs: $178.5 thousand.

The total annual average provincial direct costs of non-located DEDs to underground WSSS systems are estimated at around $1.2 million, and constitute, on average, 71% of total costs. The total annual average indirect costs of DEDs to underground WSSS systems are approximately $0.5 million, representing about 29% of total costs.

The expert consensus is that during 2000-03, the total average annual provincial costs of the non-located DEDs were around $1.7 million. For Ontario taxpayers and municipal public works departments, one non-located DED to the underground WSSS systems costs a minimum of $5.6 thousand per year. Since the VDS provided only the average annual estimates during 2000-03, the trend for these costs is unknown at this stage of the research.

5.3 Costs of Non-Located DEDs to Electricity Distribution Networks in Ontario

The aggregation of provincial estimates by each cost group and sample allowed establishing the average annual provincial impacts and costs of non-located DEDs to the underground Electricity Distribution Networks (EDNs) in Ontario, as presented in Table 8.

According to the results of the Virtual Delphi Survey, annually in Ontario around 123 non-located DEDs to underground EDNs occur, resulting in at least 123 repair crew deployments to do the restoration work, 46 insurance liability claims filed, and causing approximately 7.5 thousand hours of customer-service interruptions.

Table 8. Average Annual Provincial Costs of Non-Located DEDs to Underground Electricity Distribution Networks (EDNs) in Ontario, 2000-03, $CDN

Indicators	Average Annual Estimates,$	Average Annual Shares,%
Frequency Indicators		
Number of non-located DEDs	123	-
Number of customer-hours of service interruptions	7,497	-
Number of insurance liability claims	46	-
Number of customer-service interruptions	2,509	-
Cost Indicators		
Repair costs	281,501	4.80%
Revenue loss	1,391	0.02%
Insurance liability costs	288,954	4.93%
Customer loss of service use	5,288,715	90.24%
Total costs of non-located DEDs to EDNs	**5,860,561**	**100.00%**
Costs per non-located DED	**47,647**	

Average annual direct costs of non-located DEDs to underground EDNs are:

- Repair costs: $281.5 thousand.
- Revenue loss: $1.4 thousand.
- Insurance liability costs: $289 thousand.

Average annual indirect costs of DEDs to underground EDNs are:

- Customer loss of service use: $5.3 million.

The total annual average provincial direct costs of non-located DEDs to underground EDNs are estimated at around $0.6 million, and constitute, on average, 9.8% of total. The total annual average indirect costs of non-located DEDs to underground EDNs are approximately $5.3 million, representing about 90.2% of total costs.

The expert consensus is that during 2000-03, the total average annual provincial costs of the non-located DEDs were around $5.9 million. One non-located DED to the underground EDNs costs a minimum of $47.6 thousand per year. Since the VDS provided only the average annual estimates during 2000-03, the trend for these costs is unknown at this stage of the research.

5.4 Costs of Non-Located DEDs to Other Utility Networks in Ontario

The aggregation of estimates for each cost group allowed establishing the magnitude of total average annual provincial impacts and costs of non-located DEDs to the underground telecommunications, petroleum and special products pipelines classified as other utilities networks (OUNs) in Ontario, as presented in Table 9.

Annually in Ontario during 2000-03 at least 2.5 thousand of non-located DEDs to other utilities networks occur, resulting in about 148 thousand hours of customer loss of service use.

Table 9. Total Ontario Provincial Average Annual Costs of Non-Located DEDs to Underground OUNs in Ontario, 2000-03, $CDN

Indicators	Average Annual Estimates, $	Average Annual Shares, %
Frequency Indicators		
Number of non-located DEDs	2,447	-
Time of service interruptions, hours	148,518	-
Cost Indicators		
Repair costs	2,262,081	31.0%
Customer loss of service use	5,038,894	69.0%
Total costs of non-located DEDs to OUNs	**7,300,975**	**100.0%**
Costs per non-located DED	**2,984**	

These impacts induce costs of around $7.3 million per year, on average. Repair costs constitute approximately $2.3 million or 31% of the total, while the magnitude of customer loss of service use is higher - around $5 million or 69%. As a result, one non-located DED to underground telecommunications and other utility networks costs around $3,000.

5.5 Health Costs of Non-Located DEDs

Informetrica's conservative lower bound estimates indicate that the magnitude of the health costs associated with the health impacts of non-located DEDs in Ontario during 2000-03 is approximately $5.7million (Table 10).

Average Annual Provincial Direct Health Costs due to DEDs are:

- Average costs of insurance benefits of injuries: $1.6 million.
- Average costs of provincial health care burden of injuries: $0.2 million.
- Average costs of insurance benefits of fatalities: $0.5 million

Average Annual Provincial Indirect Health Costs due to DEDs are:
- Average morbidity costs of injuries: $2.2 million.
- Average workplace costs of injuries: $0.3 million.
- Average mortality costs of fatalities: $0.9 million.

Injuries due to non-located DEDs to underground utility networks in the province constitute around 0.75%-2.25% of all injuries in these sectors. On average, the annual societal cost of one injury due to non-located DED is approximately $75 thousand, while the societal losses of one fatality due to DED are estimated to be around $1 million. Annually, about 6.5 thousand of working days are lost because of the injuries and fatalities caused by non-located DEDs.

Table 10. Total Ontario Provincial Average Annual Health Costs of Non-Located DEDs to Underground Infrastructure in Ontario, 2000-03, $CDN

Indicators	Average Annual Estimates, $	Average Annual Shares, %
Frequency Indicators		
Average number of WSIB allowed lost-time claims for injuries	58	-
Average number of days lost due to injuries	6,511	-
Average number of WSIB allowed fatality claims	2	-
Cost Indicators		
Direct health costs of non-located DEDs	**2,429,018**	**42.4%**
Average costs of insurance benefits of injuries	1,646,023	28.7%
Average costs of provincial health care burden of injuries	232,953	4.1%
Average costs of insurance benefits of fatalities	550,042	9.6%
Indirect health costs of non-located DEDs	**3,301,581**	**57.6%**
Average morbidity costs of injuries	2,164,269	37.8%
Average workplace costs of injuries	286,716	5.0%
Average mortality costs of fatalities	850,597	14.8%
Total health costs of non-located DEDs	**5,730,600**	**100.0%**
Health costs per 1,000 households	**1,312**	

5.6 Emergency Response Costs of Non-Located DEDs

As shown in Table 11, the costs of ERs due to non-located DEDs by emergency response type were estimated to be approximately:
1. Fire Service Emergency Responses (FSERs): $1.8 million per year.
2. Police Service Emergency Responses (PSERs): $384 thousand per year.
3. Paramedic Service Emergency Responses (PMSERs): $197 thousand per year.

Annually throughout 2000-03 Emergency Response (ER) teams in Ontario addressed 2.6 thousand calls due to non-located DEDs. Although these numbers appear negligible in comparison to the total volume of the ERs in the province (5-9 million), the number of ERs to utility damage incidents has been increasing. Consequently, costs increased proportionately.

The total provincial costs of ERs to non-located DEDs fluctuated around $2.4 million. For Ontario taxpayers, one emergency response to a non-located DED results in an annual $549 of societal loss per thousand of household units.

Table 11. Total Ontario Provincial Average Annual Costs of Emergency Responses to Non-Located DEDs to Underground Infrastructure in Ontario, 2000-03, $CDN

Indicators	Average Annual Estimates, $	Average Annual Shares, $
Frequency Indicators		
Number of Fire Service Emergency Responses (FSERs) to non-located DEDs	689	26.5%
Number of Police Service Emergency Responses (PSERs) to non-located DEDs	1,044	40.1%
Number of Paramedic Service Emergency Responses (PMSERs) to non-located DEDs	870	33.4%
Total number of Emergency Responses to DEDs	**2,602**	**100.0%**
Cost Indicators		
Costs of FSERs due to non-located DEDs	1,819,524	75.8%
Costs of PSERs due to non-located DEDs	383,650	16.0%
Costs of PMSERs due to non-located DEDs	197,084	8.2%
Total emergency response costs of non-located DEDs	**2,400,258**	**100.0%**
Costs of ERs per 1,000 households	**549**	

5.7 Evacuation Costs of Non-Located DEDs

For the period 2000-03, the evacuation costs of non-located DEDs by building type were estimated around $782 thousand (Table 12).

Business buildings evacuations due to non-located DEDs contributed the largest share of the costs: 37.8%. The Government buildings' evacuation costs ranked the second (24.3%), and the schools and apartments ranked the third in terms of the magnitude of the costs (around 12.5%).

For Ontario taxpayers, these costs accumulate to an annual $179 of societal loss per thousand of household units.

Table 12. Total Ontario Provincial Average Annual Evacuation Costs due to Non-Located DEDs to Underground Infrastructure in Ontario, 2000-03, $CDN

Evacuation costs by building type	Average Annual Estimates, $	Average Annual Shares, %
Apartments	99,106	12.7%
Business Buildings	295,646	37.8%
Community Service Buildings	868	0.1%
Government Buildings	189,584	24.3%
Residential Houses	30,931	4.0%
Hospitals	54,534	7.0%
Hotels	13,290	1.7%
Schools	97,508	12.5%
Total evacuation costs of non-located DEDs	**781,467**	**100.0%**
Evacuation costs per 1,000 households	**179**	

5.8 Traffic Congestion Costs of Non-Located DEDs

For the period 2000-03, the traffic congestion costs of non-located DEDs were estimated around $460.5 thousand (Table 13). Costs of person delay caused by traffic congestion due to non-located DEDs are the largest among the traffic congestion costs, representing almost 90% of the total. Vehicle use costs are the second largest, and constitute around 7%.

For Ontario taxpayers, this results in an annual $105 of societal loss per thousand of household units, resulting from the traffic congestion due to non-located DEDs.

Table 13. Total Ontario Provincial Average Annual Traffic Congestion Costs due to Non-Located DEDs to Underground Infrastructure in Ontario, 2000-03, $CDN

Indicators	Average Annual Estimate, $	Average Annual Shares, %
Costs of Person-Delay	413,809	89.9%
Costs of Vehicle Use	32,322	7.0%
Costs of Fuel	7,368	1.6%
Costs of Air Pollution	4,752	1.0%
Costs of GHG Emissions	2,246	0.5%
Total traffic congestion costs	**460,497**	**100.0%**
Traffic congestion costs per 1,000 household	**105**	

5.9 Environmental Costs of Non-Located DEDs

For the period 2000-03, the environmental costs of non-located DEDs were estimated around $311.7 thousand (Table 14). Environmental mitigation costs due to non-located DEDs, usully born by corporations and governments, are the largest among the other types of the environmental costs, representing almost 57.3% of the total or about $178.5 thousand. Environmental impact and regulatory costs are 2-3 times smaller.

For Ontario taxpayers, the total environmental impact of non-located DEDs results in an annual $71 of societal loss per thousand of household units.

Table 14. Total Ontario Provincial Average Annual Environmental Costs due to Non-Located DEDs to Underground Infrastructure in Ontario, 2000-03, $CDN

Indicators	Average Annual Estimates, $	Average Annual Shares, %
Environmental mitigation costs	178,470	57.3%
Environmental impact costs	73,216	23.5%
Environmental regulatory costs	60,021	19.3%
Total environmental costs	**311,707**	**100.0%**
Environmental costs per 1,000 of households	**71**	

5.10 Aggregate Provincial Costs of Non-Located DEDs to Underground Utilities in Ontario

The total provincial costs of non-located DEDs are estimated around $33.4 million, of which 71% is carried by the utility sectors, and the rest is shared by the Ontario taxpayers (Table 15).

The gas distribution sector's share is the largest among the utility providers in the province: 26.1%. And the most significant societal burden of the non-located DEDs is reflected in the injuries and fatalities and resulting in the average annual cost of $5.7 million or 17.1% of the total costs.

The average annual costs of non-located DEDs per 1,000 households in Ontario are estimated to be around $7.7 thousand.

Table 15. Total Ontario Provincial Ontario Average Annual Costs of Non-Located DEDs to Underground Infrastructure in Ontario, 2000-03, $CDN

Indicators	Average Annual Estimates, $	Average Annual Shares, %
Utility Sectors Costs	**23,754,197**	**71.0%**
Gas Distribution Networks	8,722,573	26.1%
Water, Sewer, Steam and Storm Systems	1,721,570	5.1%
Electricity Distribution Networks	5,860,561	17.5%
Telecommunications and Other Utilities	7,449,493	22.3%
Societal Costs	**9,684,529**	**29.0%**
Health	5,730,600	17.1%
Emergency Response	2,400,258	7.2%
Evacuation	781,467	2.3%
Traffic Congestion	460,497	1.4%
Environment	311,707	0.9%
Total Costs of Non-Located DEDs	**33,438,726**	**100.0%**
Costs of Non-Located DEDs per 1,000 households	**7,655**	
Costs per Non-Located DED	**5,946**	

6 Inter-Jurisdictional Comparative Analysis

How does Ontario compare to other Canadian provinces and the United States in terms of DED frequencies? Three major concepts were used in this study due to data restrictions:

1. Average annual number of non-located DEDs per 1,000 households by utility type.
2. Annual number of total DEDs per 1,000 locate requests by utility type.
3. Annual number of total and non-located DEDs per 1,000 km of underground networks by utility type.

The following jurisdictions were selected for comparison:

1. **Colorado state**, United States, due to having the best DEDs and locates (LRs) statistics available in the United States and a distinguished mandatory One-Call System operated via the Utility Notification Centre of Colorado.
2. **Alberta province**, Canada, due to the similarities in the structure of the voluntary One-Call System and underground facilities with Ontario.

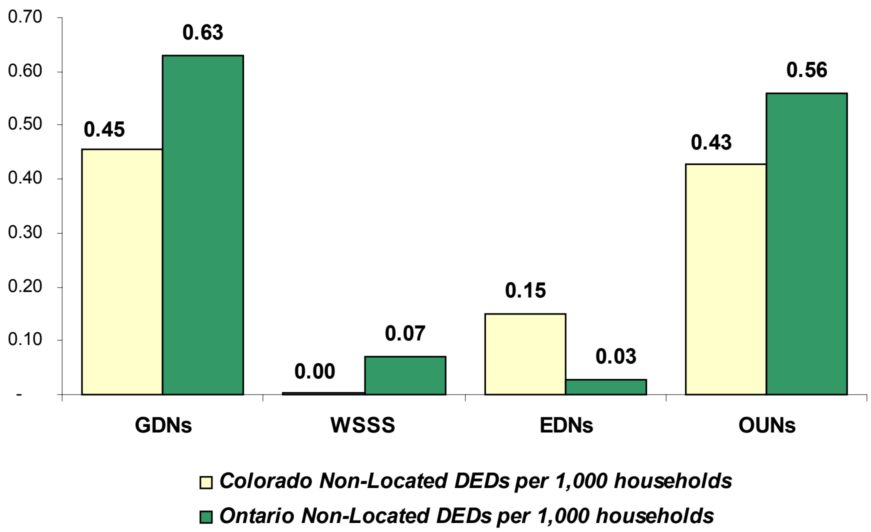
Canadian provinces have only voluntary One Call centres, while practically all states in the US have mandatory systems. In Colorado state, the mandatory One Call System was introduced in 1987, and the damage statistics are collected systematically at the Utility Notification Centre of Colorado (UNCC) on the mandatory basis since 2001. A special data set was requested from UNCC by Informetrica on the following indicators for the period 2001-03:

- Number of DEDs (total and non-located) by utility types according to Informetrica definitions of utility sectors;
- Number of net transmissions (locate requests) by utility types according to Informetrica definitions of utility sectors.

A matching data request was also sent to the Ontario One Call Centre for statistics on the number of net notifications (locate requests) by utility type. However, the Ontario One Call centre does not collect the statistics on the number of DEDs. The Informetrica estimates are therefore used as the representative average annual frequency of DEDs per utility type for Ontario.

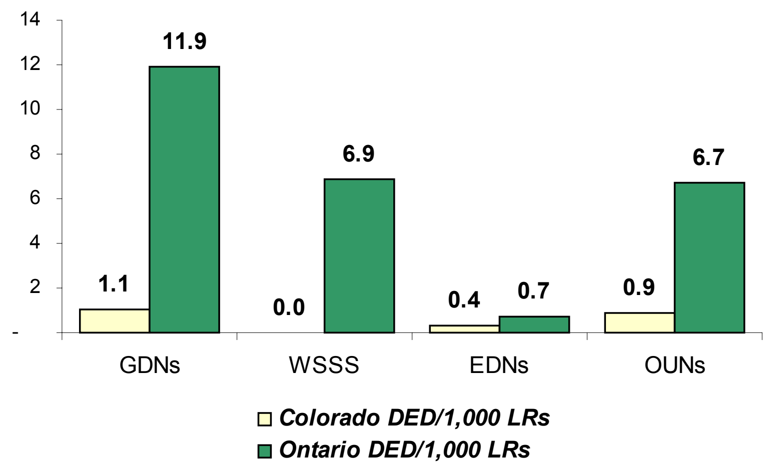
The ***first benchmarking indicator*** allows testing the hypothesis that jurisdictions have different probabilities of damage due to the density of the household units in the service areas, varying by the utility types (Figure 12). The analysis showed that Ontario has a higher average annual frequency of non-located DEDs per 1,000 households for all facility types, except Electricity Distribution Networks (EDNs). In the case of the latter, there is a suspicion that the number of DEDs to EDNs was significantly underreported in the Virtual Delphi Survey (VDS). Nevertheless, this indicator provides some signal that because of the higher probability of non-located DEDs in Ontario, damage prevention measures and policies have to be more pro-active in the province.

Figure 12. Comparison of the Average Annual Ratio of DEDs per 1,000 Households Between Ontario and Colorado by Utility Type[12]



The ***second benchmarking indicator*** is useful in testing the hypothesis that mandatory One-Call locate systems are more efficient than voluntary One-Call locate systems in the reduction of DEDs, and whether, indeed, Ontario's performance is different than that of other jurisdictions due to this factor (Figure 13).

Figure 13. Comparison of the Average Annual Ratio of DEDs per 1,000 Locate Requests Between Ontario and Colorado by Utility Type, 2000-03[13]



[12] Number of households is fixed at 2001 level to make Canadian 2001 Census data comparable to Colorado statistics. Source of Colorado household estimates: http://dola.colorado.gov/demog/Housing/MuniPopHsng01.pdf. Colorado data are for the period 2001-03. Ontario data are for the period 2000-03.

[13] Ontario number of net notifications was adjusted to represent 100% coverage of the systems (factors from 1.1 to 1.5) and to match the number of estimated DEDs. Colorado data are for the period 2001-03. Ontario data are for the period 2000-03.

In Figure 13 the number of locates for Ontario is estimated due to the fact that utility members of the Ontario One-Call cover only about 85% of the system networks in the province, while non-members administer locates through their own programs. Adjustments were made to the number of net notifications provided by Ontario One-Call using a factor ranging from 1.1 to 1.5 depending on the utility type, to represent 100% coverage of the underground networks in the province. Even this overestimated number of notifications for Ontario could not mask the fact that the Ontario frequency of DEDs per 1,000 locate requests is 2 to 11 times higher than in Colorado. This gives partial evidence to support the hypothesis that mandatory One-Call systems are more effective than voluntary systems.

The ***third benchmarking indicator*** would provide an indication of whether Ontario has special underlying factors for the occurrence of DEDs, such as construction activity, excavation practices or any other socio-economic conditions that result in significant differences in comparison to other jurisdictions. Although it would not point out the causes of these differences, it will indicate the levels of probability of excavation/digging damage across jurisdictions.

For this type of comparison, we found that there is no aggregate data available for other Canadian provinces or the United States. Therefore, a decision was made to use only one utility sector with the highest likelihood of data availability on the number of DEDs and length of networks, and with the least number of market participants. Usually, the gas distribution sector has an oligopolistic structure in most provinces across Canada and the United States, and therefore was chosen for the comparison.

Special data requests were made to the Alberta One-Call Centre and Alberta gas distribution utilities to obtain the following indicators for the period 2000-03:

1. Number of net notifications (locate requests) by facility type.
2. Number of located and non-located DEDs for Gas Distribution Networks (GDNs) for each company.
3. Length of GDNs for each company.

In Alberta, three companies comprise the provincial gas distribution market: ATCO Gas, AltaGas Utilities, and Rural Gas Coop. Alberta also does not have a mandatory One-Call system, but a voluntary one. Table 16 illustrates the differences in the third benchmarking indicator between Ontario and Alberta gas distribution sectors. Clearly, Ontario Gas Distribution Sector has much higher annual frequencies of DEDs per 1,000 km: 6 to 16 times higher. Furthermore, volatility in total DEDs is attributable to the non-located DEDs. This means that Ontario has a much higher probability of non-located damage independent of whether or not there is a mandatory One-Call system. The reason behind this disparity is unknown, and should be investigated in the next stage of research. It may be anything from the differences in the density of number of customers per 1,000 km to definitional problems.

Also, we found that the second benchmarking indicator applied for the Alberta-Ontario pair signalled that Ontario was performing much worse during 2000-03, such that the ratio of the DEDs per 1,000 located requests (LRs) was twice as high in Ontario than in Alberta: 9.6 DEDs per 1,000 LRs versus 4.8 DEDs per 1,000 LRs.

Table 16. Comparison of the Annual Ratio of Total, Located and Non-Located DEDs per 1,000 km of Gas Distribution Networks (GDNs) Between Ontario and Alberta, 2000-03

Indicators	2000	2001	2002	2003	Average
Frequency of Total DEDs per 1,000 km of Alberta GDNs	5.1	4.7	5.7	5.3	5.2
Frequency of Total DEDs per 1,000 km of Ontario GDNs	40.4	53.6	46.4	32.5	43.2
Frequency of Located DEDs per 1,000 km of Alberta GDNs	2.8	2.6	3.1	3.0	2.9
Frequency of Located DEDs per 1,000 km of Ontario GDNs	20.0	19.9	19.5	17.1	19.1
Frequency of Non-Located DEDs per 1,000 km of Alberta GDNs	2.3	2.1	2.5	2.3	2.3
Frequency of Non-Located DEDs per 1,000 km of Ontario GDNs	20.4	33.7	26.9	15.4	24.1

Due to data limitations, a more comprehensive and accurate inter-jurisdictional comparative analysis could not be conducted at this stage of the research.

7 Key Findings, Conclusions and Policy Recommendations

As a result of this ORCGA study, Informetrica found strong evidence of a significant problem in Ontario. The rising costs of DEDs to underground infrastructure networks are attributable to increased construction and development activity in the province, combined with an increasing share of buried networks to above-ground infrastructure, restructuring of the utility markets, and resulting regulatory, standardization and legislative gaps.

First major finding: the occurrence of DEDs and the magnitude of associated costs are significant in Ontario, and represent a substantial financial burden to the utility operators and taxpayers:

- The total provincial costs of non-located DEDs are estimated to be around $33.4 million, of which 71% is carried by the underground infrastructure sectors, i.e. utilities and their customers, and the rest (29%) is shared by Ontario taxpayers.
- The gas distribution sector's share is the largest among the utility providers in the province: 26.1%.
- The most significant societal burden of the non-located DEDs is reflected in injuries and fatalities caused by non-located DEDs, and resulting in an average annual cost of $5.7 million or 17.1% of the total costs.
- The average annual costs of non-located DEDs per 1,000 households in Ontario are estimated to be around $7.7 thousand.
- One non-located DED costs Ontario about $6 thousand per year.

The upward trend was established for the incidence and costs of non-located DEDs for the emergency response and health impacts, while the trend for the rest of the societal cost groups is indeterminate due to the lack of time-series data or the non-exhaustive nature of these cost groups. For the majority of the underground infrastructure sectors, the trend of the incidence and costs of DEDs could not be determined due to the lack of time-series data. However, for the gas distribution sector, there is a declining trend due to intensification of damage prevention measures by the utilities in the last five years.

The respective ***first conclusion*** is that there is substantial evidence that the non-located DEDs are a significant risk to public safety and the integrity of Ontario's buried infrastructure, as well as a growing financial burden to the utility providers and taxpayers. This finding provides evidentiary support to the argument that indeed provision of locates significantly reduces the risk of damages to underground utility networks due to excavation.

Second major finding: there is significant cross-damage between the utilities, since most of the excavators are utility sub-contractors, with respective cross-liabilities for DEDs and their impacts. This is a direct result of the lack of communication and common approach for damage prevention between Ontario's providers of utility infrastructure, and the fact that less than 50% of them are members of Ontario One Call Ltd.

Logically, ***a second conclusion*** is that there is a need for greater cooperation between Ontario utility providers and a joint effort in the development of a common approach in damage prevention, particularly of DEDs.

Third major finding: during the course of the study Informetrica encountered significant problems in data collection, uncovering a lack of systematic records on the incidence and costs of DEDs on the company, municipal and provincial levels for the study period. This is related to the absence of a consistent risk management framework that would allow integration of the DED concepts in Ontario's utility organizations. Most of the Ontario utilities with buried facilities, either private or public, have not yet established proper reporting and accounting systems to track with sufficient detail the occurrence and costs of the excavation/digging damages. Even the largest utilities with substantial damage prevention budgets have problems with the evolution of their damage statistics databases. This is caused by many factors, including loss of continuity or integrity of the recording procedures due to insufficient attention of the executive management, and restructuring in the utility systems in the province, etc.

The consultative processes and surveys conducted by Informetrica, indicated that across a majority of the utilities, there is partial evidence of practices of underestimation of the magnitude of the problem, overestimation of the resource requirements for the establishment of comprehensive reporting frameworks, and misalignment between the operating damage prevention systems and respective accounting and risk management systems. Such frequent lack of inter-departmental cooperation and an overall holistic understanding of the state of the problem leads to decision-making uncertainties and deficiencies, gaps in damage monitoring, control, prevention, emergency response measures, and ultimately presents a risk to public health and safety.

The ***third conclusion*** is that Ontario utility providers have reached the point, when establishment of the comprehensive DED reporting and accounting frameworks is a necessity, and not just to contain immediate dangers of DEDs, but as a management tool for the reduction of the economic impacts of DEDs.

Fourth major finding: a comparative analysis of the incidence of DEDs in Ontario versus Colorado State indicated that Ontario has a greater frequency of DEDs per 1,000 locate requests. The Ontario indicators are 2 to 11 times higher depending on the type of utility. Also, the comparison of the ratio of the located DEDs per 1,000 locate requests for gas distribution sector shows that Ontario number is three times higher than in Colorado, and by 1.6 times higher than in Alberta. Both Alberta and Ontario have higher ratio of located DEDs per 1,000 locate requests, than Colorado. This leads to the ***fourth conclusion***, that mandatory One-Call locate systems, similar to those established in the United States, seem to be more effective in DED reduction than voluntary One-Call systems, like the Alberta and Ontario ones.

Fifth major finding: Informetrica's econometric estimations showed a significant positive relationship between DEDs and indicators of construction activity and network size, such as housing starts, number of households and population in the utility service areas. The more construction activity there is and the larger the size of the network, the higher the incidence and costs of DEDs.

In addition, Informetrica has found partial support for the hypothesis that the availability of the One-Call locate systems and locate programs in the utility service areas significantly reduce the probability of DEDs. This was reflected in the consultative processes with the ORCGA and external experts. However, due to the lack of detailed data across all utilities with required distribution by geographic areas, engineering network characteristics, and excavation community characteristics, the confirmation of this hypothesis has to be undertaken in the next stages of research.

The ***fifth conclusion*** is that Informetrica's framework on the estimation of the economic impact of DEDs might be utilized as one of the applied scientific frameworks for the DED economic impact assessment on the utility, municipal and provincial level. The approach can also be customized and modified to serve as a module of the damage risk models utilized by the utility operators.

Nevertheless, further research is necessary to test other hypotheses such as:

1. Engineering network characteristics, such as diameter, materials, pressure, location, and type of product transported, are highly correlated with the incidence and costs of DEDs.
2. Excavation community characteristics such as type, size, skills and damage prevention practices of the excavators are highly correlated with the incidence and costs of DEDs.
3. Construction and excavation work types in various geographic areas are highly correlated with the incidence and costs of DEDs.

Ideally, future studies on DED impacts and costs should aim at mapping Ontario's buried infrastructure networks according to the risk scores of the various determinants of the DEDs and their cumulative risk in order to build spatial risk profiles of the networks for each utility type across Ontario. These maps would allow continuous monitoring of the changes in the DED risks and would serve as a decision tool for damage prevention policies. These profiles can be constructed on utility, municipal and provincial levels.

As a result of the above-stated findings and conclusions, the following policy measures are recommended:

1. Request for locates on behalf of excavators should be legislated across the province after introduction of the mandatory One-Call System in the province.
2. Ontario's utility providers and other stakeholders be encouraged to cooperate and to adopt a common approach to the prevention of DEDs, and participation in the joint committees on best practices.
3. Utility providers and other stakeholders be encouraged to develop internal DED accounting systems, as well as to support the provincial Damage Information Reporting Tool (DIRT), operated by ORCGA for continuous DED trends monitoring and benchmarking practices.
4. Utilities be legislatively required to provide locates on demand and to participate in the mandatory province-wide One-Call system to provide a better service to the excavating community, and to reduce the incidence of DEDs. It is our view that the establishment of the mandatory One-Call System in Ontario is a prerequisite for the legislation of the mandatory locate requests.
5. Utility providers and other stakeholders be encouraged to develop corporate/organizational frameworks on the assessment of the economic impacts of excavation damages within their

risk and damage prevention systems in order to establish appropriate DED prevention policies.

Figure 14. Roadmap to Policy Measures

Findings	Conclusions	Policy Measures
1. Evidence of the magnitude of the frequencies, impacts and societal costs of non-located DEDs to Ontario buried infrastructure	1. Locates are necessary in reducing the risk of DEDs	1. Request for locates on behalf of excavators should be legislated across the province after introduction of mandatory One-Call System in the province
2. Evidence of significant cross-damage and cross-liability between Ontario utility providers	2. Cooperation and a common approach to DED prevention between Ontario utility providers is necessary	2. Ontario's utility providers and other stakeholders be encouraged to cooperate and to adopt a common approach to the prevention of DEDs, and participation in the joint committees on best practices
3. Most utility providers do not have systematic statistics on DED incidence and costs to support continuous and informative decision-making for the purposes of damage prevention	3. Establishment of a comprehensive DED reporting and accounting framework is necessary across utility providers to improve their understanding of the problem and provide tools for damage prevention policies development	3. Utility providers and other stakeholders should be encouraged to develop internal DED accounting systems, as well as to support the provincial Damage Information Reporting Tool (DIRT), operated by ORCGA, for continuous DED trends monitoring and introduction of benchmarking indicators
4. Comparative analysis of DED indicators from Ontario and Colorado suggests Ontario has a higher frequency of DEDs per 1,000 locates	4.There are some indications that Ontario's voluntary One-Call locate system is less effective than Colorado's mandatory One-Call locate system	4. Utilities should be legislatively required to provide locates on demand, and to participate in the mandatory province-wide One-Call system to provide a better service to the excavating community and to reduce the incidence of DEDs
5. Econometric evidence on the validity of the key determinants of DEDs according to Informetrica's Theory of DEDs	5.Informetrica's theory of DEDs might be utilized as one of the applied scientific frameworks for the DED economic impact assessment at the utility, municipal and provincial levels; and can serve as a module for the damage risk models	5. Utility providers and other stakeholders be encouraged to develop corporate/organizational frameworks on the assessment of the economic impacts of excavation damages within their risk and damage prevention systems in order to establish appropriate DED prevention policies