Utilization of Subsurface Utility Engineering to improve the effectiveness of Utility Relocation and Coordination efforts on Highway Projects in Ontario

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ABSTRACT

One of the first steps in any highway design project should be the accurate depiction of the existing utilities. Without an accurate map of what utility plant is present both above and below ground, it is impossible to effectively design and coordinate the necessary relocations that must take place to accommodate the highway design. Subsurface Utility Engineering (SUE) has been developed over the past 10-20 years to address this type of utility related issue. The American Society of Civil Engineers, in consultation with the engineering community, recently published a guideline CI/ASCE 38-02, which acknowledges SUE and sets forth the basis for the use of various techniques. Since it's inception around 2002, SUE and the CI/ASCE Standard 38-02 have been used successfully on over 140 projects in Ontario including several projects for the Ontario Ministry of Transportation (MTO).

One of the main aspects pertaining to SUE utilization that has not been adequately addressed in the literature is the analysis of how project-specific characteristics affect the Return On Investment (ROI) for SUE services. This is specifically important when considering budgetary constraints faced by most transportation agencies. As such, this paper will focus on two SUE Pilot Projects completed for MTO SW Region, on highway interchange reconstruction projects in southwestern Ontario:

- Hwy 401/ Homer Watson Blvd,
- Hwy 401/ Wellington Road, and

The authors will analyze how project specific conditions warranted the need for SUE investigations in order to enhance the utility coordination and relocation processes. The paper will discuss the processes used to gather utility information based on each project's specific conditions. The paper will also outline the discrepancies in utility locations that were identified by using this process that would not have been identified using the traditional utility investigation processes. Using the key cost saving criteria outlined in the literature, it will examine the cost impacts on the project(s), and determine the qualitative impacts that this information had on the entire utility coordination and utility relocation process.

The results from this paper will provide further information to evaluate the use of SUE as an effective and efficient technique for providing information to aid in the design and coordination of utility related issues on highway projects in Ontario and Canada.

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INTRODUCTION

This paper focuses on the results of Subsurface Utility Engineering (SUE) investigations completed in 2004/2005 for the Ministry of Transportation Ontario (MTO) South West Region. These investigations were completed as a Pilot Projects so that the MTO could evaluate the benefits of using SUE services in accordance with the CI/ASCE 38-02: "Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data".

The 2 projects outlined in the investigation include:

- Hwy 401/ Homer Watson Blvd – Kitchener, Ontario – MTO SW Region
- Hwy 401/ Wellington Road – London, Ontario – MTO SW Region

On both the assignments the SUE investigations revealed some significant discrepancies in the information that would have been available if just relying on utility records research companies, which would have been done, had not SUE been used. The availability of this information during the design stage of the projects allowed for effective Uutility coordination to occur. In some instances the accurate information allowed the designers to alter the design, and avoid utility relocations that were originally anticipated.

The cost savings associated with using the process are calculated using formulation developed by the University of Toronto in their paper titled "Subsurface Utility Engineering in Ontario: Challenges and Opportunities". The Homer Watson Project was included in the U of T study, and the information from that was replicated for the 401/Wellington Road projects.

BACKGROUND INFORMATION ON ASCE 38-02

The American Society of Civil Engineers (ASCE), published CI/ASCE 38-02: Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data in January of 2003. The standard is the backbone for the practice of SUE, an engineering discipline dedicated to accurately mapping and coordinating subsurface utility data. Information concerning existing underground utilities is vital during the design stage of construction projects as it provides the designers and engineers with an accurate, reliable map of the underground infrastructure. SUE allows them to determine how the existing infrastructure will be affected by

Quality Level Descriptions from ASCE Standard 38-02

Quality Level D – Information derived from existing records or oral recollections

Quality Level C – Information obtained by surveying and plotting visible above-ground utility features and by using professional judgment in correlating this information to quality level D information.

Quality Level B – Information obtained through the application of appropriate surface geophysical methods to determine the existence and approximate horizontal position of subsurface utilities. Quality level B data should be reproducible by surface geophysics at any point of their depiction. This information is surveyed to applicable tolerances defined by the project and reduced onto plan documents.

Quality Level A – Precise horizontal and vertical location of utilities obtained by the actual exposure (or verification of previously exposed surveyed utilities) and subsequent measurement of surface utilities, usually at a specific point. Minimally intrusive excavation equipment is typically used to minimize the potential for utility damage. A precise horizontal and vertical location, as well as other utility attributes, is shown on plan documents. Accuracy is typically set to 15-mm vertical and to applicable horizontal survey and mapping accuracy as defined or expected by the project owner.

Figure #1 – Excerpt from ASCE 38-02

the project, so they can make adjustments and plan ahead to minimize impacts.

The ASCE Standard outlines the processes that should be utilized when collecting utility data for design purposes. Early on, during the planning stages, the engineer responsible for the SUE investigation should advise the owner of potential impacts the project could have on existing subsurface utilities and recommend a scope for the utility investigation. The earlier the process is started the greater the benefits that can be experienced.

SUE INVESTIGATION METHODOLOGY

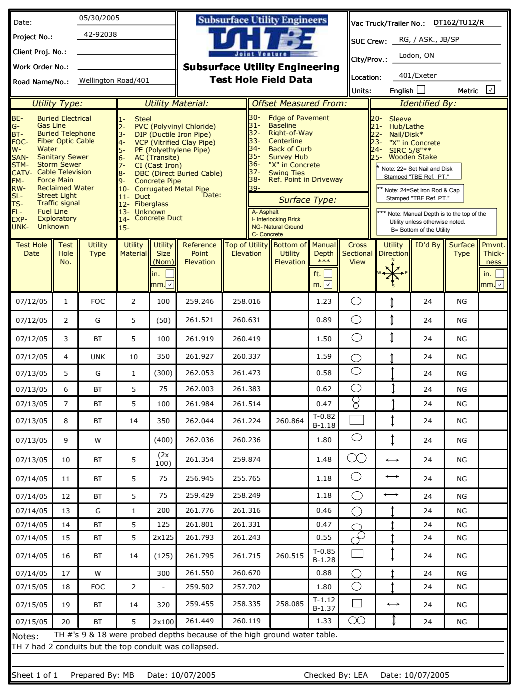
The SUE investigations for both projects were completed by TSH/TBE Subsurface Utility Engineers JV. All field investigation including utility designating and vacuum excavation were completed by TSH/TBE crews in accordance with CI/ASCE Standard 38-02.

The following provides a summary of the basic step by step procedures used to complete the field investigations for all of the projects.

Step #1: The first step in the investigations, as with all SUE investigations, was the collection of all available utility records. Base drawings and available utility information was provided by MTO and the projects TPM consultants. Where required, additional utility record information was collected by TSH/TBE from the various Utilities.

Step #2: The second stage was to collect QL-B information using multi-frequency electromagnetic cable locate instruments, ground penetrating radar and other geophysical methods. The designating efforts focused on the utility plant located in the key areas.

Step #3: The next step was to collect quality level A data at the key locations as identified during discussions between TSH/TBE, MTO and the TPM Consultants. An air based vacuum excavation unit was used to vacuum excavate the test holes and collect the precise vertical and horizontal position of the utilities. This data provides precise x,y,z information at the key areas, where knowing the depth, size, and nature of the existing utility is vital. The designating data, test hole locations, and surface features such as manholes were surveyed by a crew and depicted on the drawing.


Date: 05/30/2005
Project No.: 42-92038
Client Proj. No.:
Work Order No.:
Road Name/No.: Wellington Road/401

Subsurface Utility Engineers TSH TBE Joint Venture
Subsurface Utility Engineering
Test Hole Field Data

Vac Truck/Trailer No.: DT162/TU12/R
SUE Crew: RG, / ASK., JB/SP
City/Prov.: Lodon, ON
Location: 401/Exeter
Units: English ☐ Metric ☑

Utility Type:
BE- Buried Electrical
G- Gas Line
BT- Buried Telephone
FOC- Fiber Optic Cable
W- Water
SAN- Sanitary Sewer
STM- Storm Sewer
CATV- Cable Television
FM- Force Main
RW- Reclaimed Water
SL- Street Light
TS- Traffic signal
FL- Fuel Line
EXP- Exploratory
UNK- Unknown

Utility Material:
1- Steel
2- PVC (Polyvinyl Chloride)
3- DIP (Ductile Iron Pipe)
4- VCP (Vitrified Clay Pipe)
5- PE (Polyethylene Pipe)
6- AC (Transite)
7- CI (Cast Iron)
8- DBC (Direct Buried Cable)
9- Concrete Pipe
10- Corrugated Metal Pipe
11- Duct
12- Fiberglass
13- Unknown
14- Concrete Duct
15-
Date:

Offset Measured From:
30- Edge of Pavement
31- Baseline
32- Right-of-Way
33- Centerline
34- Back of Curb
35- Survey Hub
36- "X" in Concrete
37- Swing Ties
38- Ref. Point in Driveway
39-

Surface Type:
A- Asphalt
I- Interlocking Brick
NG- Natural Ground
C- Concrete

Identified By:
20- Sleeve
21- Hub/Lathe
22- Nail/Disk*
23- "X" in Concrete
24- SIRC 5/8"**
25- Wooden Stake
* Note: 22= Set Nail and Disk Stamped "TBE Ref. PT."
** Note: 24=Set Iron Rod & Cap Stamped "TBE Ref. PT."
*** Note: Manual Depth is to the top of the Utility unless otherwise noted. B= Bottom of the Utility

Test Hole Date	Test Hole No.	Utility Type	Utility Material	Utility Size (Nom) in. ☐ mm. ☑	Reference Point Elevation	Top of Utility Elevation	Bottom of Utility Elevation	Manual Depth *** ft. ☐ m. ☑	Cross Sectional View	Utility Direction	ID'd By	Surface Type	Pmvnt. Thick-ness in. ☐ mm. ☑
07/12/05	1	FOC	2	100	259.246	258.016		1.23	○	↕	24	NG	
07/12/05	2	G	5	(50)	261.521	260.631		0.89	○	↕	24	NG	
07/12/05	3	BT	5	100	261.919	260.419		1.50	○	↕	24	NG	
07/12/05	4	UNK	10	350	261.927	260.337		1.59	○	↕	24	NG	
07/13/05	5	G	1	(300)	262.053	261.473		0.58	○	↕	24	NG	
07/13/05	6	BT	5	75	262.003	261.383		0.62	○	↕	24	NG	
07/13/05	7	BT	5	100	261.984	261.514		0.47	8	↕	24	NG	
07/13/05	8	BT	14	350	262.044	261.224	260.864	T-0.82 B-1.18	□	↕	24	NG	
07/13/05	9	W		(400)	262.036	260.236		1.80	○	↕	24	NG	
07/13/05	10	BT	5	(2x 100)	261.354	259.874		1.48	○○	↔	24	NG	
07/14/05	11	BT	5	75	256.945	255.765		1.18	○	↔	24	NG	
07/14/05	12	BT	5	75	259.429	258.249		1.18	○	↔	24	NG	
07/14/05	13	G	1	200	261.776	261.316		0.46	○	↕	24	NG	
07/14/05	14	BT	5	125	261.801	261.331		0.47	○	↕	24	NG	
07/14/05	15	BT	5	2x125	261.793	261.243		0.55	○○	↕	24	NG	
07/14/05	16	BT	14	(125)	261.795	261.715	260.515	T-0.85 B-1.28	□	↕	24	NG	
07/14/05	17	W		300	261.550	260.670		0.88	○	↕	24	NG	
07/15/05	18	FOC	2	-	259.502	257.702		1.80	○	↕	24	NG	
07/15/05	19	BT	14	320	259.455	258.335	258.085	T-1.12 B-1.37	□	↔	24	NG	
07/15/05	20	BT	5	2x100	261.449	260.119		1.33	○○	↕	24	NG	

Notes: TH #'s 9 & 18 were probed depths because of the high ground water table.
TH 7 had 2 conduits but the top conduit was collapsed.

Sheet 1 of 1 Prepared By: MB Date: 10/07/2005 Checked By: LEA Date: 10/07/2005

Figure #2 – Test Hole Data Sheet

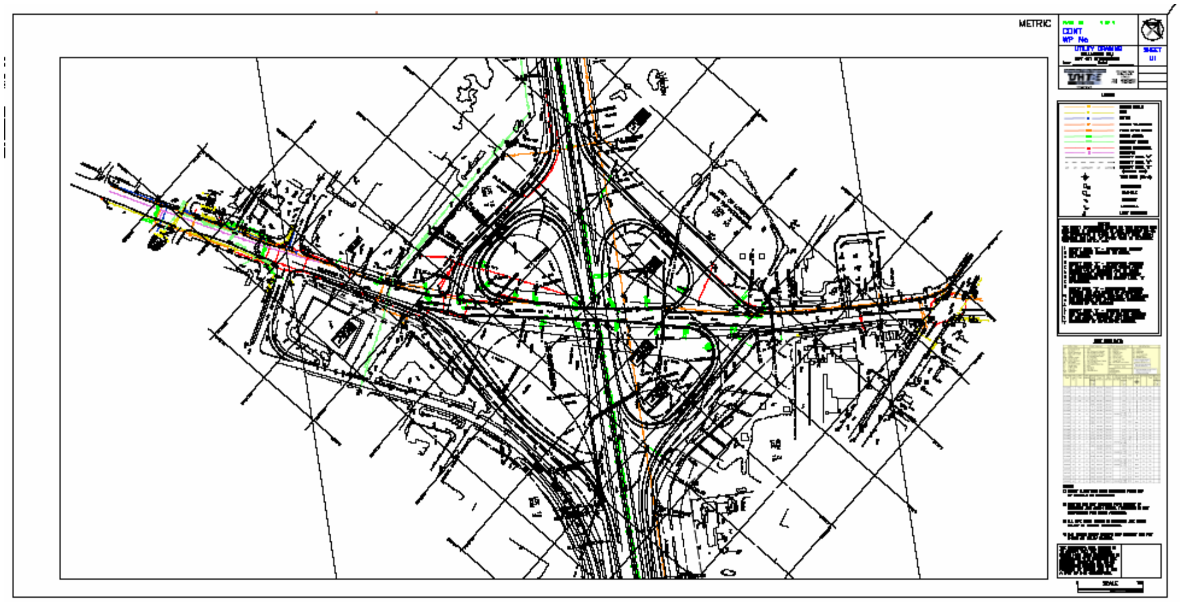


Figure #3 – Composite Utility Drawing for 401/Wellington

Step #4: Using AutoCAD the utility information was imported into a distinct layer on MTO's base drawing. The final composite utility is an accurate depiction of the location of utilities as per the appropriate quality level.

SUE COST SAVINGS

Performing a SUE investigation leads to more accurate depiction of underground utilities which in-turn will-lead to several benefits to all project proponents, particularly coordination of utility relocations. Attempting to place a dollar value on these benefits is a complicated undertaking that involves the creation of so-called 'what-if' scenarios that assume design and construction to have taken place without SUE information. The first step in this process is identifying the cost saving categories. Generally speaking cost savings due to SUE can be classified in four main categories:

Costs that contribute towards increasing the quality of utility information (alternatives to SUE)

UIC: Utility Information Cost. The cost & time that the designer or owner would spend to gather information from different utilities and possibly do any field stakeouts using their own crews or by hiring subcontractors.

UVC: Utility Verification Cost. The cost that the contractor must pay to verify the location of plant (by vacuum excavating, locating, etc.). This cost gets included in the bid price.

Costs directly incurred by the designer/owner

URC: Utility relocation cost

DSC: Design cost. The existence of reliable information provides for a more efficient design process.

OCC: Overall construction cost: Information revealed by SUE will sometimes lead to a more efficient design that will decrease overall construction costs.

‘Costs directly incurred by the contractor
CCC: Contractor contingency costs.
CCO: Contractor claims & change order costs.
CIC: Contractor injury cost. The cost of injuries to contractor staff due to damaging existing utilities.
Costs directly incurred by users/public
UDC: Utility damage cost. The cost of damage to existing utilities during construction.
PIC: Public injury cost. The cost of injuries to the public due to damaging existing utilities.
TDC: Travel delay cost. The cost of travel delays to the motoring public (function of the amount of project delay).
BIC: Business impact cost. The cost of impact on businesses (function of the amount of project delay).
SIC: Service Interruption Cost. The cost of loss of service to utility customers.

Several studies have been conducted to investigate the potential cost savings of performing SUE. One of the more well-cited studies was that conducted by Purdue University on behalf of the U.S. Federal Highway Administration The study investigated 71 highway construction projects in 4 U.S. states and reported an average return on investment of $4.26 for every $1 spent on SUE.

In Ontario, a similar study was conducted by the University of Toronto on behalf of the Ontario Sewer & Watermain Contractors Association (Osman & El-Diraby, 2005). The study examined 9 projects across southwestern Ontario where a SUE investigation was performed. Eight of the projects were municipal utility reconstruction projects in relatively congested urban areas and one project was a highway interchange re-construction project (the Homer Watson project described in this paper). All nine projects reported a positive ROI that ranged from $2.05 to $6.59 for each $1 spent on SUE. The percentage of SUE costs to total project costs varied considerably depending on the extent of the SUE investigation. On average, a typical SUE investigation cost 1.6% of the total project costs.

Of the 13 cost saving items that were identified, the bulk of the cost savings were concentrated in two main items. 51% of all cost savings were reported to be attained through the reduction of contractor claim costs, while 31% of cost savings were attained through reduction in utility relocation costs. The remaining 18% was attained through all other cost items. Also worth noting was the difficulty to place an accurate dollar figure on many of the less-tangible items (TDC, SIC, UDC, etc…). In the absence of reliable data, no accurate estimate can be made for these items. Nevertheless, an attempt was made to quantify the savings due to travel delay costs associated with prolonged road closures. The study team utilized a travel delay model based on estimates for average incomes in Canada (Tighe et. al., 2002, Tighe et. al. 1999). Applying this model on one of the projects that would have experienced a 4-day excessive road closure if the SUE investigation was not performed, travel delay costs were estimated at $50,000 which represented almost 50% of the other tangible cost savings that were attained. The implications of excessive road closures are expected to manifest themselves in the context of urban freeway reconstruction, making a sounder case for SUE in these circumstances.

Table-1 Summary of the main figures reported by the University of Toronto Study

	Mean	Minimum	Maximum
Project Cost	**$5,387,000**	**$500,000**	**$9,000,000**
SUE Cost	**$29,890**	**$9,340**	**$91,000**
SUE % of project cost	**1.6%**	**0.25%**	**3.5%**
ROI	**3.41**	**2.05**	**6.59**

PROJECT RESULTS

Hwy 401/ Homer Watson Blvd

Project Background

The investigation was focused on the areas around the Homer Watson Boulevard / Highway 401 Interchange. The roads north of the 401 are urban with curb and storm sewers. There are a number of businesses along Homer Watson Boulevard and along New Dundee Road. The area south of the 401 is a rural setting with ditching on either side of the road. There are no buildings that will be impacted. There is a fairly high traffic volume on Homer Watson Boulevard, and less so on New Dundee Road/Conestoga College Boulevard.

The interchange improvement will involve the construction of a new wider bridge on Homer Watson Boulevard crossing Highway 401, as well as a new Pedestrian Bridge approximately 800m East of Homer Watson Boulevard. The ramps to the Highway will also be re-configured which will include some adjustments to New Dundee Road. Homer Watson Boulevard will be widened to match with the new bridge. The parking area in the South West corner will be expanded to accommodate additional cars.

Figure #4 - Aerial Photo of Project Area – 401/Homer Watson Blvd Interchange

Information revealed by SUE

The main discrepancies revealed by SUE include:

1- The discovery of a telecommunications fiber optic cable crossing the 401 that was not known to exist. The cable was located on the site of a proposed pedestrian bridge that was to be constructed across the highway. Excavation for the abutments would have been in direct conflict with the cable. Because the cable belonged to a small telecommunications company that was not part of the Ontario One Call system, chances are that the cable would only have been discovered during excavations.

2- A watermain that ran across the south ramp of the 401 had a torturous path. SUE was able to reveal the exact locations of the bends along the pipe alignment. This information assisted the designer in avoiding design conflicts at a very early stage of design.

3- A service road that ran across the west ramp of the 401 had several buried utilities along its ROW (water, sewer, telephone, gas). QL-A SUE investigation helped the designer make an informed decision to lower some of these utilities as they would conflict with the proposed excavations of the new ramp.

4- SUE helped pickup a lot of buried electrical and signal utilities that were not indicated on any records.

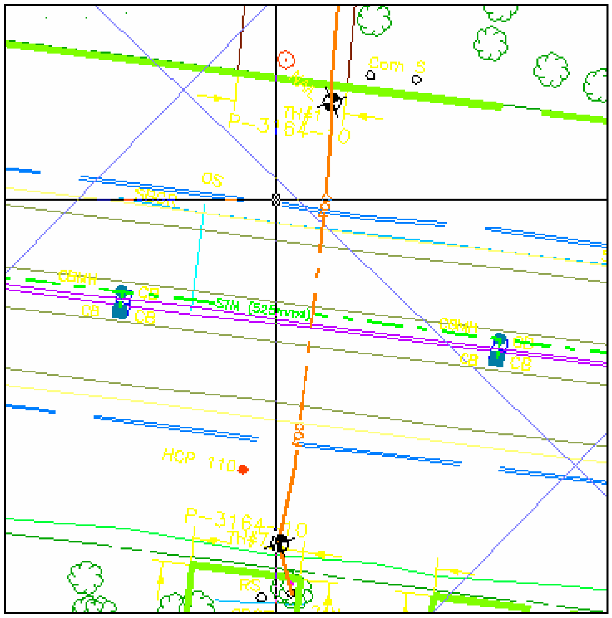


Figure #5 - Fiber optic cable crossing the 401

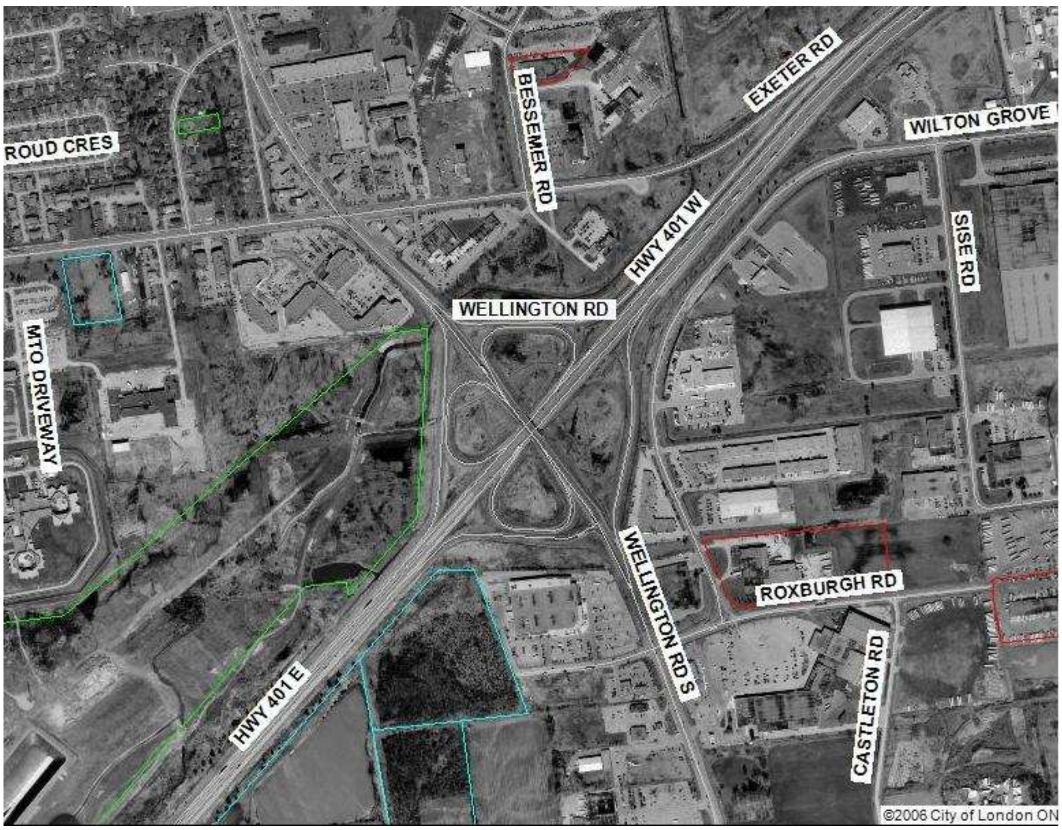
Cost Implications

Impact of SUE information	Cost Implication	Cost
The conflict between the fiber optic cable and the abutments of the bridge. It is highly likely that this conflict would only have been discovered during excavations which would have led to contractor stoppage and highly expected damage to the cable.	At least 2 days in contractor down time until the conflict could be resolved and crews redirected (very conservative estimate considering the expected size of crews working on the job).	$40,000
	Expenses associated with coordinating the relocation of the cable in an expedited fashion.	$2,000
	Repairs to fiber optic cable (not incurred by owner)	-
Exact depth of utilities along service road helped designer make informed decision during design to lower these utilities. If this decision was made during construction and not included in the contractor's work scope, the contractor would defiantly request extra amounts for the added work	Extra amounts for added work (lowering utilities in conflict with the alignment of the proposed new ramp).	$20,000
	Total Cost Savings	**$62,000**
	Cost of SUE	**$25,000**
	Return on Investment in SUE	**2.48**

Hwy 401 / Wellington Road

The investigation was focused on the areas around the Wellington Road / Highway 401 Interchange. Wellington Road is mainly an urban road with curb and storm sewers. There are a number of large box stores, restaurants, shopping malls and other businesses along Wellington Boulevard. There is a fairly high traffic volume on Wellington Road.

The interchange improvement will involve the construction of a new bridge on Wellington Road just east of the existing bridge. The ramps to the Highway will also be re-configured to accommodate the new bridge and the elimination of the current double on-ramp for Wellington Road/Exeter Road.



Fligure #6 – Aerial Photo of Project Area – 401/Wellington Road

Information revealed by SUE

1 - Identifying the precise location of a major Bell telecommunication duct that ran along the north side of the highway helped Bell make an informed decision to relocate the structure during an early phase of the project. The decision to relocate was made because: a) Pilling activities were expected in close proximity to the structure, and b)The Bell duct was a critical telecommunication link that serves the Toronto – Windsor corridor and any compromise in its performance would be too risky for Bell.

2 - Although the utilities records revealed there was a fiber optic cable west of the Wellington Road bridge it did not identify the true location or whether it was OH or underground. The designating revealed that the underground cable could be impacted by the new ramp configurations. The test holes provided depths such to determine the extent of the potential conflicts. This information was vital to avoid conflicts between the ramps and the structure.
3 - The unknown utility running down the center of Wellington Road from approximately Roxborough south, was found to be in direct conflict with the proposed road drainage system. The system was designed to avoid all conflict points.
4 - No records were available for the electrical systems associated with the signal lights. This was identified during the investigation which should assist with the electrical design for the new interchange configuration.
5 - The Sanitary Sewer crossing at 24+700 was not clearly identified by the record drawings, however was confirmed to cross the road by means of visible inspection in each of the manholes.
6 - The depths on the Bell, Water and Gas crossings east of Wellington road will provide vital information to determine the extent of any potential conflicts.

Cost Implications

Impact of SUE information	Cost Implication	Cost
Identifying the precise location of a major Bell telecommunication duct that ran along the north side of the highway helped Bell make an informed decision to relocate the structure during an early phase of the project.	Estimated 2-3 days of contractor down-time to allow for crews to be redirected and FOC repaired or relocated.	50,000
	Damage to Bell utility	-
Identifying the exact location and depth of the unknown utility that was found to conflict with some of the road drainage structures.	Expected contractor down-time of 1 day if conflict was discovered.	20,000
Expected savings in design costs that SUE provides by involving less guess-work by the design team	Value ranges from 5-10% of design time	10,000
Identifying the exact location and depth of the fiber optic cable. The conflict between the ramp grade and the cable was avoided	Estimated 1-2 days of contractor down-time to allow for crews to be redirected and FOC repaired	35,000
	Damage to FOC during construction (not incurred by owner)	-
	Total Cost Savings	**$115,000**
	Cost of SUE	**$43,000**
		2.67

CONCLUSIONS

The information provided by the SUE investigation for these projects provided key information that was vital to the effective utility coordination efforts associated with both the projects. Without the accurate information during the early stages of design, utility coordination efforts would not have identified all the potential conflicts associated with the projects and would have resulted in utilities either not being relocated prior to construction or being relocated unnecessarily.

The process outlined in the ASCE Standard 38-02, and used for these investigations clearly identifies the process used to identify the utilities locations and thus provides the designers/ utility coordinators have an understanding of how reliable the information is in any given area. The investigation was completed such that an appropriate quality level was used for each area such that the designers/utility coordinators were confident in the information provided, particularly in the key conflict areas.

For all the assignments the collection of the utility data was an iterative process. During the initial phases of the investigations, it was not clear which utilities would be in potential conflict until the design progressed to the point where those issues could be identified. Once the potential conflicts were identified the test holes could be installed to provide x,y,z data and clearly identify the exact impact of each potential conflict. Having this accurate utility information early in the process allowed designers the opportunity to design around existing utilities and reduce the overall impact of the design.

The average cost savings of using SUE on these two projects was $2.58/$1. Although this is a very small sample group to compare results, it is consistent with the average savings identified by the U of T study which was $3.41/$1 and the Purdue Study in the US of $4.62/$1. These costs savings

Following the guidelines of the ASCE 38-02 Standard, provided clear guidance as to the scope of the investigation. The standard allows provides consistency in the final deliverables provided for the highway design projects.

RECOMMENDATIONS

The foundation of any utility coordination assignment is a clear understanding of the presence of and location of the existing utilities, as well as their impact on the overall project design. The ASCE Standard 38-02 outlines a framework by which this utility information can be collected and depicted in a clear concise manner that creates consistency for all assignments.

The ASCE 38-02 guidelines should be used as the basis for all projects thus creating this consistent nature for all assignments. Inherently those projects with limited utility impacts would rely on lower quality utility information, and those with highly congested utilities and numerous conflicts would have to rely on higher quality level data in order to properly manage the risks associated with the utilities.

Another key recommendation from the study of these projects, was that the earlier in the process that the data is collected the more useful and more beneficial the data becomes. High quality data provided at the 30% design stage of projects, will allow utility coordinators to effectively initiate coordination with utilities and develop and efficient strategy for utility relocation and protection on the project.

ACKNOWLEDGEMENTS

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REFERENCES

1. American Society of Civil Engineers. (2003) Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data, Standard #38-02, Reston, Virginia.

2. Purdue University. (1999), Cost Savings on Highway Projects Utilizing Subsurface Utility Engineering, Prepared for the Federal Highway Administration, Washington D.C, as per FHWA Contract Number DTFH61-96-00090.

3. Osman, Hesham & El-Diraby, Tamer (2005), Subsurface Utility Engineering in Ontario: Challenges and Opportunities. Centre for Information Systems in Infrastructure & Construction. University of Toronto.

4. Tighe, S., Lee, T., McKim, R., and Haas, R. (1999). Traffic delay cost savings associated with trenchless technology. ASCE Journal of Infrastructure Systems, 5, 2: 45–51.

5. Tighe, S., Knight, M., Papoutsis, D., Rodriguez, V. and Walker, C. (2002) User cost savings in eliminating pavement excavations through employing trenchless technologies. Canadian Journal of Civil Engineering, NRC Press, 29:751-761.