Cross Bore Safety Association
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CREATING HIGH CONFIDENCE - ESSENTIAL ELEMENTS FOR CROSS BORE ELIMINATION PROJECTS

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Abstract

Cross bores of sewers have been recognized in the U.S. and Canada to be a great threat to public and industry safety.

Integrity of gas lines cannot be assured if there are cross bores of sewers by gas distribution lines. Verification processes of the collected field data are essential and collected data needs to be 100% verified separately from the field personnel using various techniques. Collections of GPS points to identify extent of inspections and entry of this data into GIS databases can corroborate that field crews achieved project goals. Thorough processes which have auditable documentation the company ensures that it is paying for the inspections which achieve a high confidence level and that workers and the public are protected. Inspection programs that do not have the high confidence verification processes are suspect and provide little or no value and may be worse than no inspections at all - resulting in belief that lines have been cleared of cross bores¸ when they may not have been.

Implementation of a cross bore elimination program must include verification and auditing that all lines in a defined area have been inspected to the extent that is appropriate and cost effective.

Introduction to Cross Bores

Cross bores are defined as intersections of underground utilities. They are created by installation techniques and processes that do not allow for visual observation of the utility being installed. The most typical installation methods associated with cross bores are trenchless and include plows, percussion moles and horizontal directional drilling.

Photo: 1 Cross Bore

Cross bores of gas lines in sewers have resulted in property damage, injury and unfortunately death. The largest reported court award associated with a cross bore explosion of a residence was $30,000,000. The explosion not only caused the destruction of a home but resulted in the severe burning of two children. Cross bores of gas lines in sewers are often discovered when a drain cleaning technician services a backed up drain to a structure using mechanical root cutting tools. The cutting tool can cut the plastic gas line, allowing the pressurized gas to enter the structure through the sewer. Then an ignition source such as a furnace pilot light or electrical switch energizes the gas and a catastrophic explosion and fire results.[i] Less frequently, gas cross bores have ruptured years after creation from point loading of the plastic gas line on jagged edges at the sides of an intersected sewer, by high pressure jetting operations of sewer cleaning equipment and by strikes without full penetration of steel lines that later corrode and fail.

Insidiously, cross bores will never go away. They will be either discovered through inspections, through a drain cleaner's actions or by rupture. As time continues the risk increases. Over time sewers deteriorate, begin to leak, and eventually structurally fail which allows roots and soil to enter. A punctured sewer also blocks flow and allows roots and soil to enter. Therefore the risk of cutting a gas line cross bore of a sewer by drain cleaner action or otherwise accelerates with time.

Two cross bore inspection and elimination projects' results included finding a cross bore at a hospital and at a grade school together with hundreds of cross bores to homes services. The first record of a cross bore was investigated by NTSB in 1976.[ii] One cross bore elimination project involved 200 miles of mainline sewer and found over 430 cross bores in high risk areas. Density of services in some older portions of Midwest cities average approximately 100 per mile of main line, typical suburban areas may have a lesser density. In 1998 there were approximately 55,000,000 gas services in the United States, today the quantity is estimated at 67,000,000. Probability of cross bores in your town are likely to be high.

Fortunately there are good processes, locating techniques and inspections that can reduce risk of creating new cross bores. Pre-locating the horizontal position and estimating the vertical position of the existing utilities are essential to preventing cross bores. Traditionally, depth determination has not been a requirement of regulations. In some states there is no requirement for locating gravity sewers and some other utilities have specific exemptions. In other states the requirements do not meet the needs of the gas distribution installation contractor. As a result, the installation contractor and/or the utility owner of the new installation finds that the responsibility for locating existing utilities to accuracy and parameters required to avoid damage is left to them.

This paper's focus is to investigate the justification of using high quality process with high confidence factors for avoidance and identification of gas lines in sewers on a risk reduction vs. cost basis.

Inspection Methods and Limitations

The types of prevention methods that are used to avoid creation of and to verify the presence or absence of a cross bore include:

1. Record verification
2. Pot holing
3. CCTV pre-construction inspection and sonde locating
4. CCTV post construction inspection
5. Legacy CCTV inspections
6. Ground penetration radar and other remote sensing methods

Record verification depends on the availability of accurate and thorough records. For instance, if a new gas installation is installed at the front of structures and all existing utilities are known to be located entirely at the rear of structures, it may be determined that no pre locating is needed. The weak point of this method results from the lack of "accurate and thorough" records.

In some cases, there are illegal or unknown connections such as gravity sewers found with sanitary sewer connections to storm sewers, multiple sanitary connections from one structure to the sewer and gutter drains that are connected to sanitary sewers. These types of connections and system "designs" are not currently accepted by sewer system operators and when found are required to be properly routed. However, whether they are legal or not does not exempt them from having another utility accidentally installed through them. Sewers that connect septic systems are of equal risk of explosion if intersected by a gas distribution line.

Pot holing allows visual confirmation that a new line safely passes a known existing utility. The distinct disadvantage of pot holing is that all existing utilities must be known if this method is to be successful. If there are multiple laterals from a structure and only one is known, adequate pot holes will not be created leaving the risk that a cross bore was created.

Pre construction inspection using CCTV with attached sondes for locating sewers and lateral connections has been used for over a decade. Current technology can provide locates with 5% or better accuracy, but errors occur. Interference of the transmitted signal has been noted where reinforcement exists in concrete, high concentration of radio signals from surface based transmitters exists and where other electro-magnetic signals are present. In areas of elevated interference, sondes in some cases may be selected with alternate frequencies to eliminate interference. Easier to interpret and higher resolution of signal interpretation by newer technology receivers have greatly reduced these interference issues.

However, accuracies of depths and horizontal locations at greater depths can deteriorate or signals may not be received at all. Inclined pipes can be interpreted as being at greater depth or offset from actual position due to the angle of the sonde's signal in an inclined pipe.[iii] A pipe at a 45 degree angle to the surface could be interpreted at a ratio of actual to measured of 1 to 1.41 (= tangent of 45 degrees) a forty one percent (41%) apparent error. Lateral cameras are less than three inches in diameter, allowing for travel through pipes that are three inches or larger. The size and power of transmitters that will fit in small diameter sondes mounted in combination with a CCTV camera are a limitation but improvements continue to increase capabilities at increased depths.

Additionally, the depth measurement from sondes must include an accuracy tolerance to allow for the sonde to be at the bottom of a sewer or riding up over sediments and roots. The sewer pipe diameter minus the sonde/camera diameter is the approximate tolerance on a mechanical basis. Allowance for bells on the pipe and the largest outside diameter (O.D.), must be added when interpreting the physical accuracy of the locate. Combined together, the electronic accuracy, angle of pipe and physical dimensions of the pipe often are expected to be within a twenty four inch (24" - 600 mm), accuracy. Large diameter sewers may require larger tolerances. The point is that the process needs to be thought through and requires evaluation of more variables than using a manufacturer's theoretical precision of sondes and receivers when planning for cross bore avoidance.

Accuracy of trenchless installation equipment must also be included in the planning process. Many configurations of plows will mechanically control depth and horizontal position very well. However smaller diameter horizontal directional drills (HDD) that are used for gas distribution pipelines use sondes for control. Larger more powerful sondes allow for better reception at the surface, however, precision and accuracy are still dependent upon depth and degree of interference. Tolerance for accuracy as well as precision must be made in the planning process. The author has observed installations where surface interference disrupted reception of the HDD bore sonde to the extent that the trenchless installation had to be abandoned. Sondes and receivers are continuing to improve with the potential for more consistently accurate installations. However even where existing utilities are accurately located, there have been numerous occasions where installations resulted in cross bores.

Percussion moles are aimed from the starting point towards the ending point. The method has been often called the "point and pray" method. The use of moles has been around for decades and is still widely used. The "aim" can be in error or deflected in transit by cobbles or hard soil. Therefore the path of travel is unknown, only interpolated. Some newer moles can be steered and the path tracked with a sonde.

Equipment limitations, interference and operator error can be detected by visual inspection of sewers after the construction process is completed. Therefore, post construction inspection of sewers for gas line cross bores is highly recommended for visual verification that the trenchless construction was installed as planned and cross bore free.

Other infrequently used reactive methods for cross bore avoidance are acoustic listening devices, ground penetrating radar, and fluid pressure loss indicators on HDD machines that indicate a problem which could be a cross bore. The listening device concept is to place a headset on a person that receives its signal from a microphone dropped in a sewer system close to the trenchless installation. In 2010, a poll of approximately fifty individuals related to the gas distribution industry including contractors, inspection companies and utilities indicated that while acoustics were amazingly clear, the confidence in the system was low. Those polled felt that the method was not repeatable or verifiable independently, but more importantly, no one expected that a person would leave headsets in place 100% of the time and would not be interrupted by others.

A recently patented system is being evaluated that identifies drill fluid pressure loss as an indicator that a void has been encountered. Follow-up with potholing or other type of inspection such as CCTV still would be required for verification. Ground penetrating radar with additional multiple sensor devices deployed from the surface can effectively map the underground in certain types of soil. Currently, it is often used for large area investigations and is not thought to be cost effective for most gas distribution installations.
Correctly evaluating the specific need for inspections, planning the project and determining the QA/QC process are essential components for cost effective cross bore elimination projects.

Elements of Cross Bore Inspections and Prevention Project
The task elements of inspections can be widely variable depending on scope of work. Inspection elements to consider are:

1. Legacy (existing gas line installations)
    a. Determine if only trenchless installations need to be inspected.
        i. Determine if a portion of trenchless installations can be verified that intersections are not possible from a records search. i.e. sewers in rear, gas in front
    b. CCTV camera visual verification, sonde required to determine limits of inspection
        i. Inspect main line sanitary sewer using robotic camera
            1. Identify each lateral, depth, quantity of taps and location
            2. Inspect each lateral from mainline
                a. Travel to structure foundation, includes potential for cross bore of sewer by gas mainline and gas lateral, verify limits with sonde.
                or
                b. Travel to X feet beyond gas mainline, verify limits with sonde – may be appropriate if no gas laterals were replaced or if the laterals were rehabilitated with slip lining.
            3. Inspect portions of each lateral sewer that were not accessible from the mainline due to length, debris, roots, etc.
        ii. Inspect storm sewer (some gas utilities require this for high confidence verification)
            1. Identify each lateral, if any. Most often few are expected.
            2. Inspect each lateral from mainline
                a. Travel to structure foundation, includes potential for cross bore of sewer by gas mainline and gas lateral, verify limits with sonde, or,

        b. Travel to X feet beyond gas mainline, verify limits to which the inspection travel using sonde – may be appropriate if no gas laterals were replaced or if the laterals were rehabilitated with slip lining.
    iii. Report data to data analysts
  c. Require separate review of data and data analysis (videos)
    i. 100% video review is required by some utilities
    ii. The review may be by separate qualified inspection company personnel or directly by utility personnel.
  d. Require GPS points of the inspection limits, taps and points of direction change of the sewer.
    i. Used for creating GIS mapping
      1. Used to run the project
      2. Used to report to public which lines are inspected and "cleared" or which lines should not be drained cleaned without notification to the gas utility.
      3. Used for QA/QC verification
      4. Used for claims mitigation and process confidence evidence
  e. Data storage
    i. Long term storage is required in event of claims
    ii. Access to all records, including videos is advisable for evidence
    iii. GIS systems provide a system for managing and storing data for long term access
    iv. Fast access for use to report if lines are free of cross bores to public or drain cleaners
      1. Slow processes or lack of detail that prevent homeowners immediate response will limit the effectiveness of drain cleaner/public support
  f. Report final data to client.

2. New Construction Inspections
  a. Pre construction CCTV/sonde locating of sewers
    i. Determine if only trenchless installations need to be inspected.
      1. In some cases where pre inspections are difficult and costly (i.e. impassable or difficult to access lines), the design may be converted to open trench.
    ii. Determine if a portion of trenchless installations can verified that intersections are not possible from a records search. i.e. sewers in rear, gas in front
    iii. Inspect main line sanitary sewer of project area
      1. Identify each lateral, quantity and location
      2. Inspect each lateral from mainline
        a. Travel to construction limits plus "X" (usually 5 to 10 ft)
      3. As needed, locate with manual push CCTV/sonde from cleanout, vent stack or inside structure (pull toilet) portions of each lateral sewer that was not accessible from the mainline due to length, debris, roots, etc.
      4. Where limits of mainline inspection and manual push camera inspections do not meet, coordinate with client for additional action including possible installation of cleanout or creation of a pot hole. Further inspection may not be necessary if proximity of gas and sewer is adequately distant-usually determined by utility inspector.
      Note: Payment for unsubstantiated claims for construction damage to the sewers are often averted by review of the sewer video in the preconstruction state.

b. Inspect storm sewer and cleanouts (this is a result of improper connections, by today's standards. (Should be considered for high confidence verification.)
    1. Identify each lateral, if any. Most often few storm connections are expected.
    2. Inspect each lateral from mainline
        a. Travel past construction limits plus "X" (usually 5 to 10 ft)
            i. As determined by installer or utility drawings.
        b. As necessary, access cleanouts or interior of structure to complete lateral inspection construction limits plus "X"

ii. Report data to data analysts.

iii. Require separate review of data (videos) and mapping points
    1. Ensure each mainline sanitary and storm connection has an associated inspection of the lateral
    2. Review that the travel of the inspection/s is beyond construction limits plus "X". GPS points helps verify limits of inspection using GIS maps.
    3. The review may be by qualified inspection company personnel or directly by utility personnel.
    4. Report any cross bores to the client – stay on site until released by client.

iv. Require collection of GPS points of the inspection limits, taps and points of direction change of the sewer
    1. Used for creating GIS mapping
    2. Used to run the project, coordinate construction timing and QA/QC
    3. Used to report to public which lines are inspected and "cleared" or which lines should not be drained cleaned without notification to the gas utility.

c. Report final data to client.

3. Post Construction
    a. Inspect each main line sanitary sewer, storm sewer and storm catch basins for cross bores.
        1. Inspect each lateral from mainline to construction limits plus "X" (usually 5 to 10 ft)
        2. Locate with manual push CCTV/sonde from cleanout or inside structure (pull toilet) portions of each lateral sewer that was not accessible from the mainline due to length, debris, roots, etc.
        3. Where limits of mainline inspection and manual push camera inspections do not meet, coordinate with client for additional action including possible installation of cleanout or creation of a pot hole (normally during construction).
    b. Inspect storm sewer and cleanouts
        1. Inspect each lateral from mainline storm sewer
            a. Travel to structure foundation, includes potential for cross bore of sewer by gas mainline and gas lateral, verify limits with sonde.
            b. Travel to X feet beyond gas mainline, verify limits with sonde – may be appropriate if no gas laterals were replaced or if the laterals were rehabilitated with slip lining. High confidence of gas mapping is required.

ii. Report data to data analysts

iii. Require separate review of data (videos) and mapping points
    1. Ensure each mainline connection has an associated post construction inspection

2. Review that the lateral distance traveled is beyond construction limits plus "X". GPS helps verification.
3. The review may be by qualified inspection company personnel or directly by utility personnel.

iv. Require collection of GPS points of the inspection limits
1. Used for creating GIS mapping
2. Used to run the project, coordinate gas up of new lines and QA/QC verification
3. Used to report to public which lines are inspected and "cleared" or which lines should not be drained cleaned without notification to the gas utility.

c. Report data to client.

Inspection Method Variations

The options for differing levels of inspection detail can be derived from the above list. Risk reduction and costs are affected by the level of confidence that the client desires. Some may argue that the logical choices are few and that the process must be complete in full detail to have a very high confidence factor and to have measureable benefit or value. The choices are listed below for illustration and for the readers determination based upon a legacy project:

a. Do only trenchless installations need to be inspected?
   i. Is solid information available for the determination?
b. Can a portion of trenchless installations be verifiable from records that intersections were not possible. i.e. sewers in rear, gas in front
   i. Is sewer mapping and gas mapping accurate to confident?
c. Do inspections need to go to the foundation?
   i. Is mainline construction only trenchless?
   ii. Were gas laterals were 100% slip lined?
   iii. Were gas laterals installed by HDD, moles or plows?
d. Do storm sewers & catch basins need to be inspected?
e. Does 100% of the video need to be reviewed?
f. Do GPS points and GIS mapping provide valuable confirmation to the inspection and verify the limits of the inspections?
g. Do other options allow record keeping methods to be accessible, cost effective or have high confidence over decades of need?

For legacy cross bore elimination projects, the confidence that as-built drawings were entered correctly, updated during the intervening years and had a verifiable QA/QC component is probably low. If confidence is low, then the decision to exclude some areas from inspection is high risk.

Do storm sewers and catch basins need to be inspected? This is a harder decision. First there may be some liability transfer to structure owner if a structure has connections to storm sewers that are "illegal" by today's construction standards. What if the connections were not regulated in the past or were unknown to the current owner? Or if the occupants, that could be subject to injuries, were unknowing. It becomes a legal and moral question. All that can be confirmed is that some gas utilities do require this inspection. From the cost perspective, it may be in the range of <10% add on to a project's cost since few laterals would be expected to be connected to the storm sewer.

One hundred percent (100%) of the collected CCTV video needs to be reviewed. It is essential that field crews be checked by separate personnel. Whether it is in a qualified QA/QC system that the inspection company has established or by the client's separate processes, all video should be checked to verify the absence of gas lines in sewers and that the quantity and limits of the inspections are adequate.

There is a growing trend in the gas industry to collect and store data integrating GPS and GIS data bases. With the data geographically sensitized, serving data to field crews operating an ongoing project becomes simpler, the management of inspection crews is facilitated, retrieval of data for future operations management is faster and up to date and the basis for providing information to the public, including drain cleaners, is enhanced.

Risk Analysis

Risk analysis versus inspection cost must be weighed. Is a confidence factor of 95% good enough? Is 99% confidence good enough? How about 99.9%? With the potentials for one failure to have a measurable cost of thirty million dollars, as well as the public's reduced perception of the safety of natural gas, justification for higher confidence results becomes more apparent.

Accurate statistics related to cross bores of gas lines in sewers are at best very sparse and incomplete. Current U.S. DOT, PHMSA reporting requirements of DIRT[iv] do not require specifically reporting cross bore damage. The example calculation below tries to compare actual inspection costs associated with different confidence factors verses the potential financial damage costs associated with legal action based upon estimation of reasonable values. The example uses a $10,000,000 judgment (1/3 of the amount of the largest award) for each cross bore explosion.

Example A: Utility wants to inspect 65,000 gas services/laterals and associated mainline sewers for cross bores:

- Number of services/structures to be inspected = 65,000.
- Assumed legal damages associated with each explosion = $10,000,000.
- Frequency of cross bores = 0.4 per mile.
  - Some project results show maximums of 2 to 3 per mile on high risk areas. Discount to 0.4 cross bores per mile for average of lower and high risk areas.
- Services per mile = 100.
  - Varies according to housing spacing and whether houses are on both sides of a street with gas laterals from a single gas main line or from gas main lines on each side of the street. This value is system specific and should be tailored to each project.
- Confidence rate of all the processes, field work and QA/QC of finding all cross bores. Evaluate for 95.4 and 99.7%.
  - Statistical methods show confidence factors of 2σ (2 X sigma) results in a 95.4% confidence factor and 3σ (3 X sigma) results in a confidence factor of 99.7%. This results in failure rates of, 4.6% and 0.3% respectively [v]
- Percentage of remaining cross bores that will eventually result in an explosion = 20%.
  - During life of sewer and gas pipeline, estimated at 100 years plus, not all cross bores will result in an explosion. Drain cleaners have found yellow plastic on tools and stopped root cleaning activities. Some drains may not backup and no cleaning activity occurs. The rate of 20% is selected as an estimate. [5]

Costs for service/lateral inspections to eliminate cross bores vary substantially. Variables include the density of inspections, i.e. single inspections at greater distances vs. inspection of every structure in a contiguous manner. Significant variables to cost include the level of QA/QC, use of GPS, GIS integration, whether long distance to the foundation are required, storm sewers are included, cleaning requirements of sewers to be inspected, etc. Other damages should be factored into costs. Repairs to sewers, injury to operating personnel, injury to contractors, legal expenses, internal utility management, utility overhead, etc. are costs that appropriate for inclusion when determining claim costs on average.

Cross bore inspections with comprehensive QA/QC processes costs are reported in the range of $200 to $300 dollars per service on larger projects with contiguous inspections. Comprehensive processes often assume access to the main lines and full travel of sewers to foundations of structures. The magnitude of difficulty can increase exponentially with long lateral distances in poor condition sewers. Low confidence will result if project processes omit inspections of lateral sewers all the way to foundations of structures where gas laterals have been installed by trenchless methods. More comprehensive processes typically will include both more inspection contractor and utility management costs, as described in the above estimates.

Lower costs of inspection have been reported for partial processes that exclude comprehensive use of full tools, QA/QC and other processes. The calculations below will assume a cost of $150 to $200 per service/lateral for lower confidence processes in high density areas with clean sewers and convenient access points to the sewers. These estimates include utility project management costs.

The following Table and Figure 1 summarize the variables and calculations. A user of this format must substitute appropriate values for the project area that is relative to their cross bore identification and elimination project.

Cross Bore Elimination Project Description, Example A:		
Number of Services, meters, in Project Area:	65,000	Based upon Project Information
Average Spacing of Laterals, ft:	52.8	Average in project.
Average Number of Cross Bores Created per Mile:	0.4	Estimated. Highest reported max = 3/mile.
Average Cost of Claim for Explosion, Enter $:	$10,000,000	Estimated average.
Percentage of Cross Bores that Result in Explosion Claim	20%	Estimated see discussion above[5]
Total Miles of Mainline in Project Area:	578.6	Calculated
Service Laterals per Mile:	100.0	Calculated
Cost Calculations **Based Upon Confidence Factor for High Quality Inspections**		
Confidence Factor of Locate / Inspection	95.4%	99.7%
Total Cross Bores Expected to Exist in Project Area	231.4	231.4
Cross Bores Not Expected to be Found	10.65	0.69
Cross Bores Not Found & Expected to Result In Explosion Claims (20% of above)	2.13	0.14
Expected $ Cost of Cross Bore Explosion Claims	$21,292,424	$1,388,636
Explosion Claims per Total Services in Project Area	$328	$21
Average Inspection Cost per Lateral, includes in-house and contractor costs	$175	$250
Total Apparent Costs per Service/Lateral	**$503**	**$271**

Cost effectiveness of high confidence inspections is illustrated in the analysis using estimated data. The results from 99.7% confidence factor is shown to be have savings in the range of $232 dollars per service.

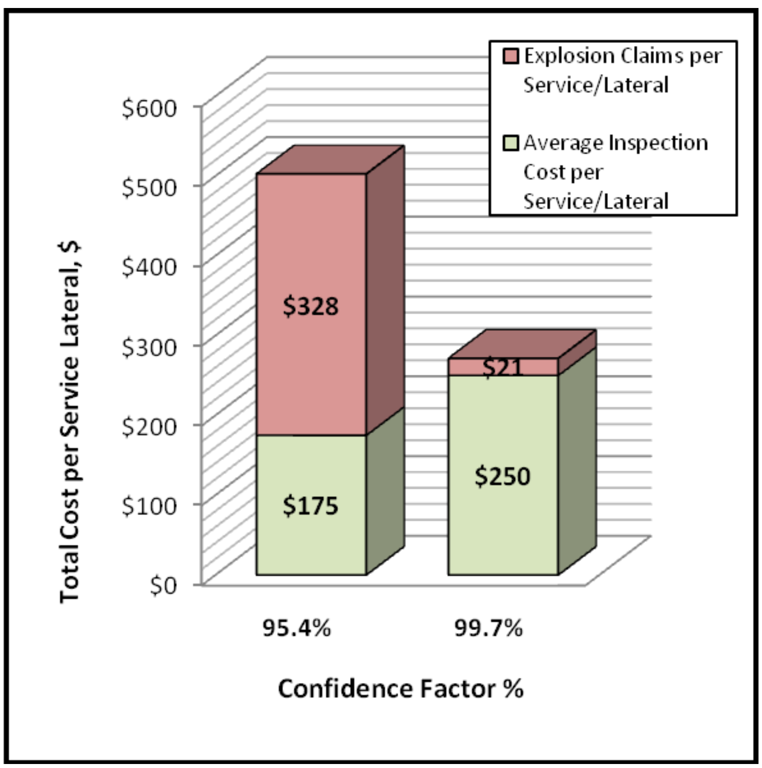
For the 65,000 service project area, the project area is expected to have 231 cross bores at a rate 0.4 cross bores per mile. At 95.4% (=2σ) confidence of accuracy 21.3 cross bores would remain after cross bore elimination inspections. For a 99.7% (=3σ) confidence factor, 0.69 cross bores would remain after the completion of the inspection project.

Occasionally cross bores are identified incidentally without major damage or injury. As a result, the calculations estimate that only 20% of the remaining cross bores would result in an explosion, a cost of $21.3 million for the lower confidence process for an explosion cost that calculates at $328 per service/lateral within the entire project area.

Higher quality processes will result in lower numbers of unidentified cross bores. At 99.7% confidence rate (=3σ) results the cost for explosions drops to $21 per service/lateral.

The combined costs, inspection plus explosion, for lower confidence is $503 at a rate that is 85% more expensive than the costs for higher confidence processes of $271. The low confidence processes are not cost effective.

Figure 1: Inspection Costs + Failure to Find Costs (Explosions)



Conclusion

This paper demonstrates methodology to estimate the financial validity of selecting higher confidence cross bore prevention and elimination processes.

Gas cross bores of sewers are prevalent, dangerous, expensive and preventable. There are many tools that may be used to prevent the creation of cross bore and eliminate those already created. Processes for selection of areas based upon likelihood of cross bores from use of trenchless construction and the proximity of gas and sewer lines are known.

Decisions to use better processes, QA/QC and long term storage of data with convenient accessibility must be based upon comparison of cost of failure versus the cost of avoidance. Lower quality work, QA/QC and inferior process that produce statistical confidence in the range of 95%, appears to be unacceptable both as effective means for protecting system integrity and on a cost effective financial basis. Higher confidence has been demonstrated to be very cost effective, 85% savings on a total cost basis.

More over processes with a failure rate of 5% is unlikely acceptable to the general public, regulators and corporate management.

At some level of low quality and low confidence it would be expected that the entire project area would need to be completely re-inspected for cross bores. The processes of current and past projects need to be reevaluated to determine if the inspection processes were of adequate confidence to meet the needs of safety and system integrity.

Lower quality is no bargain.

Poor quality processes that have results that bring continuing failures may discredit the industry efforts to the demise of the gas utility owners, installation contractors, inspection companies and their suppliers. Today's solutions could then become discredited, without alternate options. Use of trenchless technology could then be in jeopardy with substantially higher installation costs and inconvenience.

It is clear that gas utility management must select and verify that high confidence cross bore elimination processes are used.

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[i] http://www.crossboresafety.org/Papers%20and%20Presentations.htm

[ii] National Transportation Safety Board, Washington, D.C., Nov. 12, 1976, Letter to Mr. C. S. McNeer, Wisconsin Natural Gas Company, from Webster B. Todd, Chairman NTSB, http://www.crossboresafety.org/documents/NTSB%20Cross%20Bore%20Recommendation%2012November1976.pdf

[iii] http://www.crossboresafety.org/Papers%20and%20Presentations.htm

[iv] http://phmsa.dot.gov/pipeline, Incident Report – Gas Distribution System, 49 CFT Part 191

[v] *Process Management: Creating Value Along the Supply Chain*, Joel D. Wisner, Linda L. Stanley, 2008 Thomson Learning, Inc., page 510 - 519