Economic Impact Analysis to Optimize Investments in Damage Prevention for Pipeline Construction

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Abstract

The Federal Aviation Administration manages the air, the DOT's our roads, highways, and ferries, but who manages our critical underground infrastructure? Engineers are designing bridges, airplanes, buildings, cars, canals, but who designs our underground infrastructure? It is apparent that everything that is buried seems not to be important and does not need special care. Anybody who has read the files about accidents caused by a damaged utility line knows different.

While reports about underground utility damages due to excavation mishaps are abound, models for assessing the economic impact of such accidents have not been developed. The effort that is reported in this paper found that the total cost of utility damages are grossly underreported because only the direct costs of the emergency response and of repairing the damage are included. Generally the list of potentially impacted parties comprises not only the contractor, utility and property owners, people in the vicinity of the accidents but all the customer of a disrupted utility. An economic impact study that was conducted at NCSU covered the following parties: (1) municipal services including the fire and police departments, department of public works, and emergency medical services; (2) the utility company that owns the severed line; (3) the stores and businesses that were evacuated; and (4) the residents that were evacuated from the surrounding areas. It was found that the actual cost, without the lost gas and the lawyers' fees, was ten times the reported direct cost. The paper will present this economic model as a basis to justify higher investments in prevention.

Introduction

Every time a new factory, shopping center, or residential subdivision is built, lines for electric power, communications, cable television, water, sewer or natural gas are buried underground. There are several advantages to placing the utility lines

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underground, chiefly a minimal risk of damage from inclement weather (i.e., hurricanes, ice storm) and aesthetics. However, as the ground becomes more crowded with utilities, there is a greater potential for damage to the existing lines from additional digging. While there are large costs associated with utility damages, the primary concern is the deaths occurring each year from gas explosions, fires, and electrocutions. Reducing the number of deaths and injuries must be the main driver for protecting underground utility lines.

Any disruption of a utility can be costly to the companies and individuals affected. Disruptions caused by damage during subsurface construction because account for approximately 60% of the outages experienced by a large power company in a report by Donnally (1997). The data showed that there were twenty-four outages per hundred miles of power line caused by construction damages over the last eleven years. There are many different parties, both actively or passively, involved in the excavation and trenching process. Active participants include: 1) owners of a new facility, 2) designers, 3) planners, 4) contractors, 5) utilities, 6) locators, 7) construction workers, and 8) equipment operators

Reports on the consequence resulting from damaging a utility focus mainly on direct effects to the workers, equipment, and property at the scene of the accidents. However, there are normally a large number of passive participants that are affected by affected by the mishap such as the general public, bystanders, businesses, and private homes. The monetary consequences of small incidents can be drastic but are generally not accounted for. If one tries to develop an argument for better damage prevention, which will cost money, one needs to consider all the costs caused by a damage, referred to as the economic impact. The premise of assessing the total cost of damages to utility companies, businesses, homeowners, governmental agencies, contractors, and locators is to allow for optimization of construction, maintenance, education, and locating expenditures. At the present time, many of the participants do not realize the full implication of poor designs, mis-located lines or damage by a digging equipment. The accounting of the total costs could provide a foundation for a sound optimization of investments on prevention, thus decreasing the risk and the cost of damages.

Optimization Model for Protecting Pipelines

Optimizing damage prevention can be compared to optimizing car maintenance. Money spent on changing the oil and checking the antifreeze will save money in the long run. Money spent on damage prevention efforts is money saved on paying for the cost of accidents. The main objective of prevention is to reduce the risk of accidents. However, one can spend too much on such efforts, thus it is economically prudent to define an optimal range of investment in prevention. This section will discuss principles that are necessary to understand when establishing a damage prevention plan.

Risk and Risk Minimization

Utility companies can take actions which greatly decrease the likelihood of outages to their customers, such as burying the utilities further underground, running enough lines to each customer so that the probability of all of them being cut would be extremely low, or increasing the number and capacity of their plants to eliminate shortages. However, the cost of taking such actions must be compared with the benefit of the increased service reliability.

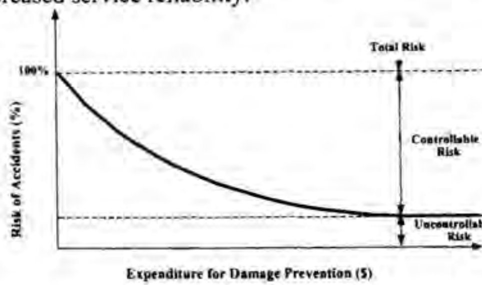

Figure 1. Correlation between Prevention Efforts and Risks of Accidents

Fig. 1 depicts the relationship between risk and expenditures for damage prevention. The non-linear curve indicates that damage prevention dollars reduce the risk referred to as the Controllable Risk in the diagram. No matter how much you spend, there is going to be a small amount of Uncontrollable Risk, however. Perfectly reliable service is too costly compared with what it is worth to customers, as can be inferred by the fact that service interruptions do occur. Perfect accident avoidance is similar in nature.

Optimization Using Marginal Costs

In an optimal setting, firms would be faced with incentives to take the total expected value of their damages into account when they are deciding on the level of care to take in their operations. In a best case scenario, damages could be measured perfectly, and the firm(s) found liable would be forced to fully compensate all impacted parties. When firms are forced to fully compensate for all damages that they are responsible for, they will rationally choose to take the optimal level of care to maximize the present value of their long-run stream of profits. They will increase loss prevention until the marginal benefit of being more careful is just equal to the expected marginal cost of additional loss prevention.

The goal of optimizing prevention is to achieve minimal total cost which is the sum of cost of damages (C-B) plus the cost of prevention (A-B). As indicated in Fig. 2, the two selected points on the non-linear function, B and B', have a sharply different distribution of the total cost. The first case has very little maintenance expenditure but a large amount of damage costs the second case shows a large portion of the total cost is spent on prevention, which results in a much lower cost for damages (B'-C' instead of B-C.) In this range of the curve, # 100 increase in prevention results in only # 15 in savings for damages.

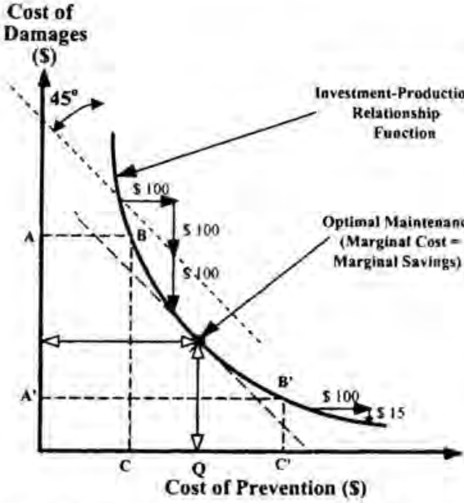

Figure 2. Principles of Marginal Cost Optimization

The optimal point on the non-linear curve is defined by the 45 degree tangent that represents the line where $ 100 in additional cost will result in exactly $ 100 savings, referred to as marginal cost. The key to using marginal cost analysis, however, is a valid cost-savings function.

Effect of Insurance Options on Optimizing Prevention Expenditures

When firms are able to acquire insurance against loss, the fact that they have insurance is likely to change their choice of actions. Under insurance contracts, the insured firms do not bear the entire loss themselves. Instead, the insurance company will pay at least a portion of the cost of damages. Therefore, the insured firms have less of an incentive to be careful than firms without insurance. Under full insurance, the firm will have exactly the same net income whether they incur losses or not in the short run, which removes its incentive to avoid losses.

Fig. 3 presents qualitative cost functions for five different accident costing schemes that can be used to optimize amount of money spent on prevention. As was discussed earlier, the optimal damage prevention effort can be calculated using the marginal cost analysis, represented by the dashed 45 degree tangents to each cost curve. The linear relationships between cost of accidents and damage prevention, as indicated by *Curve 1*, is the result of buying an insurance policy which pays in full when a damage occurs. Here, the *insurance premium* is based on past performance, an indication of the risk of having another accident. More accidents in the past result in higher premiums. It is apparent, that no 45 degree tangent can be drawn. Thus the optimal prevention strategy is to spend $ 0 (= 1x). Function *Curve 2* differs from Curve 1 only in that the insurance company adds a *predetermined deductible* to every accident. Again, no tangent can be drawn and the optimum is still $ 0.

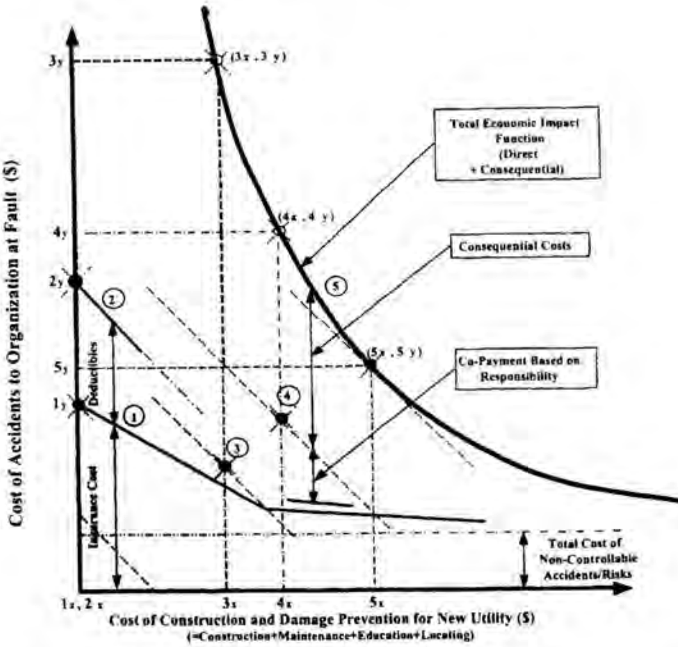

Figure 3. Optimal Damage Prevention for Various Cost Functions

This changes with the first non-linear relationship function, *Curve 3*. Here, the insurance will deduct a flexible amount from the total cost that is based on what kind of damage prevention that the responsible organization had implemented. A company that spends on prevention will enjoy a large deduction while a company that spends very little or nothing will be heavily penalize. As noted in Fig. 3, the optimal point for spending on prevention moved from $ 0 to $ 3 x on the y-axis. This means, depending on the shape of the curve, the organization seizes a cost saving opportunity when it invests in prevention either during construction, maintenance, education, or in locating. In a life cycle model, the total cost for new utilities includes all the costs, construction, prevention, and total economic impact of damages. *Curve 4* is based on a large co-payment by the insured, rather then a deductible. On a macro-economic level we can see that the Total Utility Cost has been sharply reduced by a steep drop in cost of accidents which moved down from 3y to 4y. At the same time the prevention cost increased a much smaller amount from 3x to 4x resulting in an overall much "cheaper" optimal point on *Curve 4*. Finally, *Curve 5* represents the *total economic impact*, direct as well as consequential costs, of underground utility damages (the figure is not to scale!). It has in general the shape of a risk curve, presented earlier. This is apparent in the fact that no prevention will increase the risk of accidents but at the same time will most probably lead to more sever accidents.

Not surprisingly, the optimal point for prevention efforts moves further to the right from 4 x to 5 x.

Cost of a Utility Outage to its Consumer

By reviewing the literature it was found that the electrical industry has developed models for the analysis of outage cost to consumers. Its incentive was the optimization of service reliability based on the risk function discussed earlier. It was determined that although there are some differences in the costs associated with utility outages other than electricity, the methods could provide a useful basis.

Surveys are the primary source of information on outage costs because it is possible to find out how outage costs vary with outage characteristics and to get a distribution of outage costs over the target population, unlike the other methods, which do not allow this type of differentiation. Following the discussion in Caves (et al., 1990), there are several major types of surveys.

The major type of survey is the direct cost survey. Utility customers are asked to place a dollar value on the costs that they would incur during an interruption in service. This type of survey is likely to yield good results for industrial and commercial customers, especially if they have had some direct outage experience.

Table 1: Outage Costs in Sweden in SEK/kWh (Andersson and Taylor, 1986)

	0.5 h Outage		2 h Outage		8 h Outage	
Customers	1969	1980	1969	1980	1969	1980
General Industry	2.8	10.2	8.0	23.5	33.5	62.5
Households	5.0	1.0	20.0	5.4	72.5	62.5
Agriculture	6.3	2.0	25.0	9.3	92.5	56.0
Offices	6.3	26.0	25.0	107.0	100.0	451.0
Commerce	5.0	23.0	20.0	62.0	80.0	218.0
Railroads	4.8	8.2	14.0	24.5	51.5	89.9
Other Transport	1.8	2.5	7.0	10.0	28.0	40.0
Urban Areas	6.5	18.4	23.3	52.6	75.8	197.6
Rural Areas	5.0	8.6	20.0	22.9	72.5	102.6
Entire Country	4.0	8.8	13.0	27.2	—	111.8

Table 1 presents a study done in Sweden that compares estimated outage costs for different customer groups and outage duration in 1969 to estimates for 1980. As one can see, major shifts have taken place between 1969 and 1980. For example, outage costs for households and agriculture have fallen while the outage cost for offices and commerce has quadrupled. It is also apparent that some customers have sharp increases in outage costs if the outage lasts for more than 2 hours (e.g., agriculture.)

A Comprehensive Cost Model for Utility Damages

In an effort to establish a generic framework of all possible cost categories that are related to protecting and accounting for all economic impacts of accidents, a three tiered hierarchy of costs was established. As shown in Fig. 4, the three tiers consist of: 1) Direct Cost, 2) Consequential Cost, and 3) Prevention/Mitigation Cost.

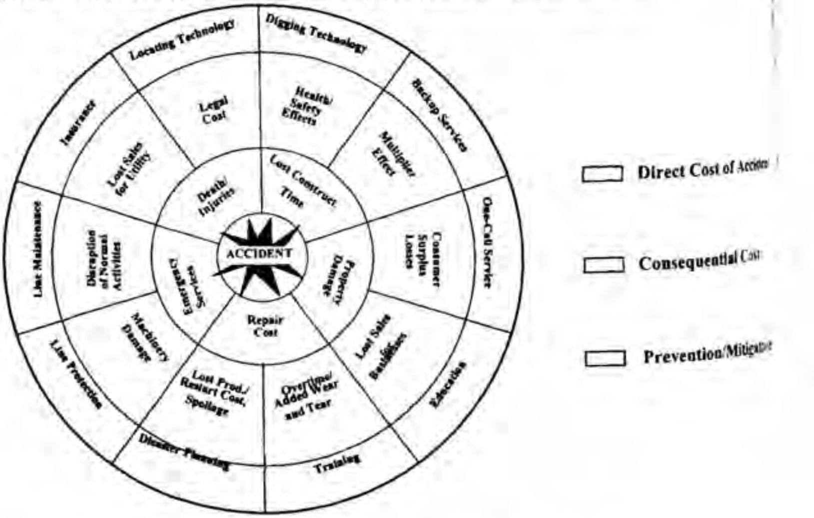

Figure 4. Three-Tiered Comprehensive Cost Structure

Each of the tiers, represented by three rings, is made up of various cost accounts. The first ring lists 5 categories representing the direct costs of an accident: 1) Emergency Services, 2) Death/Injury, 3) Repair, 4) Property Damage, and 5) Losses in Time and Material. This list and the other two lists are not intended to be comprehensive but to establish the basic principle. The second ring shows 10 Consequential Cost categories while the outer ring presents 10 categories of Prevention and Mitigation both briefly discussed in the next two sections.

Consequential Cost Impacts Many Parties

The list of impacted parties comprises not only the contractor, utility and property owners, people in the vicinity of the accidents but all the customer of a disrupted utility. Some of these customer groups include: a) private homes, b) governmental agencies, c) service companies, d) schools, e) hospitals, f) industrial firms, g) transportation systems like airports, taxi services, freight trains and trucking, h) retailers, and i) utilities themselves. As will be shown in the next section, even this list is incomplete since evacuations due to a gas leak my impact organizations that don't even use gas. The following is a discussion of generic indirect/consequential cost categories that may be valid in one or more user groups.

Loss of Production: A long utility outage will require firms to make adjustments in their production schedules creating several types of costs.

Equipment Damages: Power interruptions can cause damage to sensitive electronics, or mechanical equipment when an industrial process is stopped suddenly in the middle of a continuous batch process.
Restart Costs: Many processes require machinery to be readied or calibrated or the initial units produced won't meet specifications and are therefore, discarded.
Emergency Response Teams: Many customer groups may need train and maintain an emergency response unit to be available in the case of a utility outage.
Multiplier Effect on Other Industries: In a time where Just-in-Time materials management is popular, firms that depend on products from impaired firms may be affected as well. Lack of key materials in stock will cause delays and downtime of their own while waiting to be re-supplied by the suppliers.
Commerce: Commercial firms will tend to have higher outage costs in the case of a communications outage. In addition, commercial firms will tend to be less likely to have backup systems than industrial firms because they do not have to be as concerned about machinery damage, spoilage, or restart costs.
Disruption of Household Activities: This is the major cost normally assumed by residential utility customers (Sarkar, 1991; Sanghvi, 1982; Yabroff, 1981). In some studies of the residential costs of outages, it is assumed that all household production and leisure is entirely lost during an outage.

Costs of Prevention/Mitigation

Prevention can be executed at many different levels and in different ways. The following section will present some of the main concepts of prevention.

Education/Training: Education and training about underground facilities helps in avoiding underground line damages.
Locating: Locating and marking utilities depends on non-destructive sensing technologies and skilled operators. As discussed earlier, One-Call Centers all over the nation provide the necessary services to support an organization that manages the locating and marking before any digging occurs.
Insurance Costs: The insurance costs must be divided into insurance which is carried to protect against underground utility damages and insurance purchased in order to protect the contractor against other construction damages.
Cost of Backup Services: The initial cost of purchasing using the backup, its maintenance, and its use during the outage has to be considered.

A Case Study

The case that was studied in a preliminary attempt to quantify the economic impact originated with a miscommunication resulting in a backhoe rupturing a gas main with a 1 ft (33 cm) diameter. The gas under high pressure shot 200 ft (66 m) into the air until a main valve was closed. Fortunately, the gas did not ignite. Nevertheless, the gas spread quickly into the neighborhood which had to be evacuated. One of the properties that was within the evacuation zone was a major mall with 120 businesses. Our study covered the following parties: (1) municipal services including the fire and police departments, department of public works, and emergency medical services; (2)

the utility company that owns the severed line; (3) the stores and businesses that were evacuated; and (4) the residents that were evacuated from the surrounding areas. The municipal services mentioned, willingly participated in the survey. The utility company, however, was more cautious in releasing information because of continuing litigation. Seventy-two stores, about sixty percent of the mall stores, chose to participate in the survey. One hundred twenty-two residents were surveyed, forty returned complete surveys and fourteen were returned marked "return to sender." The calculated costs are displayed in Table 2.

Table 2. Cost Breakdown of Natural Gas Line Rupture

Cost to Fire Department	$7,477.15
Cost to Police Department	$3,759.00
Cost to Dept. of Public Works & Utilities	$4,532.35
Cost to Rescue	$1,025.00
Cost to Utility Company	$20,000.00*
Subtotal 1:	**$36,793.50***

* Rough Estimate that does not include cost of the lost natural gas

Some of the data collected from the businesses in was in the form of direct monetary losses. The impact of the accident onto the businesses and employees in the mall are displayed in Table 3.

Table 3. Monetary Penalty of Evacuation to Stores

Estimated total loss of sales due to a six hour evacuation on a weekday afternoon	$262,810.00
Estimated total wages lost to hourly employees	$13,370.00
Subtotal 2:	**$276,180.00**
Subtotal 1 + Subtotal 2 = Total Cost:	**$312,973.50***

* Figure does not include cost of lost natural gas

Summary and Conclusion

Despite the successful implementation of One-Call system in most of the states, accidents caused by damaging underground utilities resulting in wide variety of impacts reaching from a clogged residential sewer line to a gas explosion causing death and destruction. In TEA 21, the U.S. Congress has noted the significant negative effects such incidents have on the public, businesses, and critical public services such as air traffic control. Government has responded with a Common Ground report that establishes a list of best practices but does not call for a different approach to what is already being done. This paper proposes one possible new framework for optimizing prevention efforts based on the consideration of the total economic impact of an accident. The final model should consider not only the different circumstances of each accident, such as time and duration, but also the utility dependent characteristics of the impacted citizens and businesses.

It is argued that business organizations are making economic decision using the marginal cost model to optimize. In order to utilize the same approach to decide about how much to invest for prevention, economic functions for mathematical modeling need to be established. This will require a broad based study and the establishment of a large data base to ensure statistical validity.

Acknowledgement

The contributions of several of my students are acknowledged. Ms. Julie Heinrich established the case study during the summer of 1996 as an NSF sponsored REU (Research Education for Undergraduates.) Mr. Robert H. Beach, a graduate student in economics established an extensive literature review. Funding for the work has been provided by the National Institute of Safety and Health (NIOSH) under contract 5R01 CCR41305102.

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