1. Executive Summary

Natural gas leaks are a significant problem in transmission pipelines. If they are not detected, besides unintentional releases they can escalate, result in explosions, damaging the pipeline, surrounding area and causing deaths. Currently, the federal Pipeline Safety Improvement Act obliges operators to conduct periodical inspections to identify leakages. Depending on the surrounding population density leakage surveys must be realized with a frequency that ranges between 4.5 months and 15 months. Representative Scott is studying a new bill proposal that could improve the transmission pipeline safety, in Pennsylvania, by introducing advanced technologies, like unmanned aerial vehicles to perform leakage surveys. So far, the possible increase in inspection frequency has not been estimated.

In this report we investigate the benefits of introducing these advanced technologies to perform leakage surveys and how could inspection frequency be improved such that the resulting benefits outweigh investment costs.

We perform an assessment on the different available technologies that can be used to perform leakage surveys. These technologies range from Computational Pipeline Monitoring (CPM) improvements as well as ground and air support vehicles. Our proposed solution encompasses the acquisition of different unmanned aerial vehicles and investments in new sensors to increase CPM capacity. We also propose that the new bill can double the current frequency of inspections stated in federal regulation 49 CFR § 192.706. Savings in natural gas losses, property damage, death prevention, and significant incidents are expected. Even if the proposed investments sum up to a present value of $6.5 million, we would obtain a net benefit of $1.7 million in a 10 year time frame.

As the general public might have problems with unmanned aerial vehicles invasion of privacy, we do not suggest that the specific advanced technologies to be incorporated into Representative Scott's bill. Due to the small expected increase in costs of helicopters that can be incorporated without jeopardizing the net benefits, privacy concerns could be avoided.

In summary we recommend the new bill to reinforce inspection frequency, doubling it, but without specifying technologies to reach those goals. A supplementary document could be produced presenting the main findings of this report.

2. Introduction

In the natural gas transmission industry pipeline leaks are problems that besides causing unintentional releases of gas to the environment they can ignite and possibly turn into explosions. In an attempt to improve safety, federal regulation 49 CFR § 192.706 states that leakage surveys must be conducted in intervals between 4.5 and 15 months depending on pipeline classification. However, the Pipeline and Hazardous Materials Safety Administration (PHMSA) states that in reality currently only few natural gas transmission pipelines have integrity management programs that enforce continuous leakage inspections. Representative Scott is considering the creation of a new law in the state of Pennsylvania that might force an increase in leakage survey frequencies and the usage of new technologies to conduct them. Concurrently, FAA is developing new regulations to govern commercial use of unmanned aerial vehicles (UAVs) in the US airspace. These are expected to be released in 2015, the same start year Representative Scott desires the new law to be enforced. Still, social acceptability of UAVs is a concern as the general public is afraid that these aircrafts might invade their privacy.

In this document we first present an assessment of the current available technologies that can be used to improve leakage surveys. We follow by stating how transmission pipeline safety can be improved by increasing their frequency and why these changes present a net benefit. Social acceptability issues are then reviewed. We present our overall recommendations for the new transmission pipelines bill and lastly we conclude stating improvements that could be made in our analysis.

3. Do we have a problem?

Several incidents in transmission pipelines occurred in the near past. To name a few, in September, 2009 there was a major rupture in a residential in San Diego, California and in December, 2012 a pipeline exploded in Sissonville, West Virginia. Since the last amendment of 49 CFR § 192.706 in 1994, new inspection technologies are now available. Their benefits are not known yet and if they constitute an improvement in natural gas transmission safety, updating current regulations on leakage surveys should be considered.

4. Assessment of Leak Detection Technologies

Monitoring Devices (CPM with SCADA/Pressure Flow System and Fiber Optics)

The usage of a Supervisory Control and Data Acquisition (SCADA) system to monitor gas leaks along a pipeline allows the real-time detection, of gas leaks. In 89% of the incidents reported by PHMSA, a SCADA system was already implemented[1]. However, the probability of natural gas leak detection with such a system is just 17%[2]. To improve its capacity, a Pressure Flow system can be introduced, extending the Computational Pipeline Monitoring (CPM) detection capabilities. By distributing sensors along a pipeline, when a leak occurs, the change in pressure is detected in both the upstream and downstream sensors. On average a pressure sensor should be installed in the pipelines for each 100 miles[1].

Fiber Optic cables laid alongside a pipeline are able to sense changes in its refractive index due to the presence of methane as well as measure strain and temperature changes. This method is considerably more reliable than SCADA, having a 75% probability of detecting incidents[2]. As compared with fixed systems, fiber optic cables are considerably more expensive especially when legacy pipelines need to be retrofitted.

Chemical sensors are another technology that is spread through the pipelines that is used to identify leaks that pose an explosion threat. As these sensors are as good as the human nose when mercatin is not added to natural gas, they are extremely valuable specifically in transmission pipelines. These sensors should be placed every 35 miles[1].

Table 1. Summary of acquisition and maintenance costs of available monitoring devices

Equipment		**Acquisition Cost ($)**	**Maintenance Cost ($)**
SCADA system		100,000	18,000
Pressure Flow	System	250,000	45,000
	Pressure Sensors (100 units)	1,500,000	-
Fiber Optic	System	50,000	27,000
	Cable Costs (10846 miles)	5,4230,000	-
	Burying Costs (10846 miles)	286,334,400	-
Chemical Sensors	Point Sensor Costs(300 units)	600,000	-

Different leak detection methods can be used simultaneously and integrated with SCADA to improve its performance. Increasing the amount of collected data both in terms of the number of sensors as well as the different types of gathered data allow the development of more sophisticated algorithms that account for the different readings to perform a diagnostic on the existence of leaks.

We present a summary of the costs of these technologies in Table 1. Besides the acquisition costs, we also present annual maintenance costs, which represent 18% of the former costs excluding sensors[1]. SCADA, pressure flow and chemical sensors all amount to $2.5 million and annual maintenance is approximately $300 thousand. These are relatively cheap when compared to fiber optic cables which considering the burying costs are 2 orders of magnitude higher. Even if we consider the advantages of this latter technology, retrofitting the whole network seems unreasonable.

Aircrafts

Considering that monitoring devices are not able to detect all gas leaks and even when they are able to identify one, they are not able to identify exactly where the leak is occurring, other complementary methods must be used. Aircrafts equipped with laser technologies sensitive to the presence of methane can be used to do an airborne scan of the pipelines.

Several options are available for unmanned aircrafts. As for manned flight, helicopters are generally preferred due to their maneuverability. Of the unmanned aerial vehicles several options are available: Lehman Aviation LP960, Luna NG, AAI Shadow RQ-7B and Predator[3]. Both Shadow RQ-7B and Predator where not considered in this analysis. The Shadow RQ-7B UAV because it has an unspecified cost of several million dollars, and the Predator also because of its $4.5 million cost and the number of people it needs to operate. These are military UAVs that seem excessive for natural gas leak surveys especially when more economical options are available.

The Lehman Aviation LP960 is a compact UAV that due to its short range, impossibility of recording data and lack of a GPS unit should only be used to identify the precise location of a leak after it has already been reported. Due to its size it is practical to transport it using a ground vehicle like a pickup truck to the operations site. For leak detection uses, only light sensors can be installed. The Crowcon device is ideal but restricts the altitude these UAVs can fly to its recommended minimum.

The Luna NG is a considerably bigger UAV (wing span of 5.3 m). Being able to survey more than 12 hours uninterruptedly at a 90 km/hour speed, it is a faster option to search leaks in the transmission pipelines. It should be noted that its data link range is only 100 km. To operate it throughout all of Pennsylvania it must be folded and, as with the Lehman Aviation LP960, transported in a truck. Three sensors are available that can be installed in these aircrafts: Boreal GasFinder AB and Apogee LDS. All these three sensors have similar characteristics so picking one over another is mostly a choice between manufacturers.

Table 2. Main characteristics of the different aircrafts and sensors combinations.

Aircraft		**Lehman Aviation LP960**	**Luna NG**	**Luna NG**	**Helicopter**	**Helicopter**	**Helicopter**	**Pergam Suisse**	**Lidar**
Sensor Manufacturer		**Crowcon**	**Boreal**	**Apogee**	**Boreal**	**Apogee**	**CHARM**	**Alma G2**	**Boreal**
Altitude (m)		30	60	15-70	60	15-70	80-140	50	60
Speed (km/hour)		20-80	90						
Data-Recording + GPS		No	Yes						
Price of Aircraft ($)[1]	**Min**	-	-	-	250,000	250,000	250,000	-	
	Avg	10,000	1,000,000	1,000,000	1,125,000	1,125,000	1,125,000	-	
	Max	-	-	-	2,000,000	2,000,000	2,000,000	-	
Price of Sensor ($)		15,000	60,000	65,000	60,000	65,000	?	-	
Total Price ($)	**Min**	-	-	-	310,000	315,000	?	-	
	Avg	25,000	1,060,000	1,065,000	1,185,000	1,190,000	?	-	
	Max	-	-	-	2,060,000	2,065,000	?	-	
Annual Costs ($)[2]		70,500	190,000		210,000			-	
Cost per survey ($)		-	-	-	-	-	-	870,000	
Survey time (months)		4-5	2-3						

[1] http://www.commercialtrucktrader.com/

Helicopters are another possibility for aerial surveys. They can be either bought or rented. If buying these aircrafts is preferred the same sensors by Boreal and Apogee can be installed. Another option is the CHARM sensor. As no price to this latter sensor is provided this option cannot be selected even though it might have a similar price to the other two, as technical characteristics are also similar. Renting is available by the companies Pergam and Lidar. Once again, technically they are similar but considering the extension of the Pennsylvanian transmission pipelines, a single survey would cost almost as much as the acquisition of the helicopter.

Table 2 summarizes specifications of all mentioned combinations of aircrafts and sensors. To calculate the required survey time of each equipment, and to include preparation and reporting time we use the reference values of 10-12 days per 2500 miles of the rented helicopters. In the case of the Lehman Aviation LP960 UAV we adjust it by its average speed. Regarding annual costs we assume that two people are required. As references, for the helicopter personnel we use the average costs of a helicopter pilot[3], \$80 thousand, and a pipeline technician[4], \$70,000. For the Luna NG we assign two pipeline technicians and for the Lehman Aviation LP960 one pipeline technician. Other costs, like fuel and maintenance, were assumed 5% of the average aircraft price.

Ground Vehicles

In our assessment of available technologies we include trucks as these units are capable of providing assistance in leakage surveys. One possibility is that no sensor is installed which allows these vehicles to assist with smaller surveillance operations or as units to check reported incidents where its precise location is uncertain. Another usage is to install sensors like in aircrafts. Boreal GasFinder AB and Apogee LDS sensors are two possibilities. Even though that technically this is a possibility, we do not recommend them as reaching some transmission pipelines in a field might not be feasible. Hence considering only ground vehicles instead of air support, might result in portions of the network not being surveyed. To increase their surveillance capacity we suggest that these transport a Lehman Aviation LP960. This way it

[3] http://www1.salary.com/Helicopter-Pilot-Salary.html
[4] http://swz.salary.com/salarywizard/Pipeline-Technician-II-Job-Description.aspx

would be possible to conduct both ground operations and in situations where the truck cannot reach the transmission pipeline the UAV could be used.

Table 3. Main characteristics of trucks and equipped sensors.

Vehicle		Truck	Truck	Truck
Sensor Manufacturer		Boreal	Apogee	-
Handheld Sensor		General Tools Model NGD8800		
Speed (km/hour)		45		
Data-Recording + GPS		Yes		No
Price of Vehicle ($)	Min	30,000		
	Avg	35,000		
	Max	40,000		
Price of Sensor ($)		60,000	65,000	-
Total Price ($)	Min	90,000	95,000	30,000
	Avg	95,000	100,000	35,000
	Max	100,000	105,000	40,000
Annual Costs ($)		70,000		
Survey time (months)		5-6		-

In Table 3 we show the possible combinations of trucks and sensors. Many brands and models exist and independently of a sensor being installed or not, most have a cost between \$30,000 and \$40,000[5]. Trucks equipped with sensors would have a price range between \$90,000 and \$105,000. In all cases handheld sensors should be included in these trucks. We propose the General Tools Model NGD8800 and we do not include its cost as it is just \$160 per unit. Also, in all these figures the Lehman Aviation LP960 cost is not included. To operate these trucks a single technician is required adding an annual cost of \$70,000.

[5] http://www.commercialtrucktrader.com/

5. Leak Detection Plan Proposal

5.1. Frequency of Inspections

According to the federal Pipeline Safety Improvement Act (PSIA) operators of natural gas transmission pipelines are obliged to conduct periodical inspections to identify leakages.

There are many ways that natural gas leaks can be detected and only about half of them are identified either by the pipeline operator or its contractors. Of all the identified leaks, on average 38% are notified by the public. Computational Pipeline Monitoring detection is the initial identifier in just 21 % of the cases and air and ground patrols account only for 13%[1].

PSIA distinguishes patrols from leak surveys. Patrols can be defined as activities *"to observe surface conditions on and adjacent to the transmission line right-of-way for indications of leaks, construction activity, and other factors affecting safety and operation"* (49 CFR § 192.705). Even though leaks can be detected in patrols they are not their main focus as only in leakage surveys, leak detector equipment is required (49 CFR § 192.706).

We expect that if leakage survey frequencies are increased we will have leaks that were previously identified by people with no relation to the operator being now identified by the operator, other previously non identified leaks will now be identified and more serious incidents might be prevented. Not only damages in the pipeline and nearby properties can be reduced but also the risk of people dying accidentally can be decreased.

In terms of the reduction of unintentional natural gas release reduction, an increase in inspection frequency can reduce it by allowing leaks to be identified sooner and more leaks are identified by the operator instead of the public. A more frequent leakage identification process gives less time for natural gas to escape and as internal incident reports have a smaller response time, if more of the incidents are detected by the operator the average response time will tend to decrease and so will the lost natural gas [1].

To improve the maintenance program of transmission pipelines, increasing safety for citizens and reducing the lost natural gas environmental impact the requirements currently set by the federal PSIA have to be improved.

Table 4. Current and proposed leakage survey requirements based on pipeline classification.

Class	Current Leakage surveys		Proposed Leakage surveys	
	Maximum interval between leakage surveys (months)	Minimum number per calendar year	Maximum interval between leakage surveys (months)	Minimum number per calendar year
1, 2	15	1	7.5	2
3	7.5	2	4.5	4
4	4.5	4	2	8

Pipeline classification is based on the amount of buildings intended for human occupancy in the area constrained by 1 mile of pipeline and 220 yards on either side. In Table 4 we summarize the current PSIA leakage survey requirements (49 CFR § 192.706). We accordingly present our proposal for its improvement. As is further presented, doubling the required leakage surveys for each class of transmission pipeline allows a cost-effective improvement in safety. Even though we realize that current technologies could possibly increase the frequency of inspections, for instance to three times a year for Class 1 and 2 transmission pipelines, due to the uncertainties present in this analysis we only recommend an incremental change. With time, after the law is in effect, data can be collected regarding its success and new adjustments might be made according to needs.

5.2. Prospective Benefits Modeling

Key variables are first presented individually, explaining their modeling procedure, and we follow by bringing them up together to estimate these costs. Afterwards we compare with the required investments. Due to the benefits uncertainty of the proposed investments we perform a sensitivity analysis to compare the results with more conservative and optimistic scenarios.

Natural Gas Losses

The range of natural gas losses due to leaks depends in both the frequency of incidents occurrence as well as how much gas is lost in each of them. Considering the results from the Lasen, Inc. survey, an incident happens approximately once every 3.5 miles. Assuming that in each mile of transmission pipeline only one incident happens a year, the probability of having a gas leak in a particular mile of pipeline amounts to 27%. Regarding the amount of natural gas lost, we use the distribution of unintentional natural gas released[2] considering it as representative of the losses in different incidents.

We use Monte Carlo simulation, using the software @Risk, to obtain the distribution of losses in a given year[6]. In each iteration, and for each mile of pipeline (out of 10846 miles), we check if there has been a leak, given the above probability. If an incident occurs then we randomly assign a loss. Lastly, we sum up the obtained results in each iteration, in a total of 10,000 iterations, to obtain the range of losses in a year in the transmission pipelines of Pennsylvania.

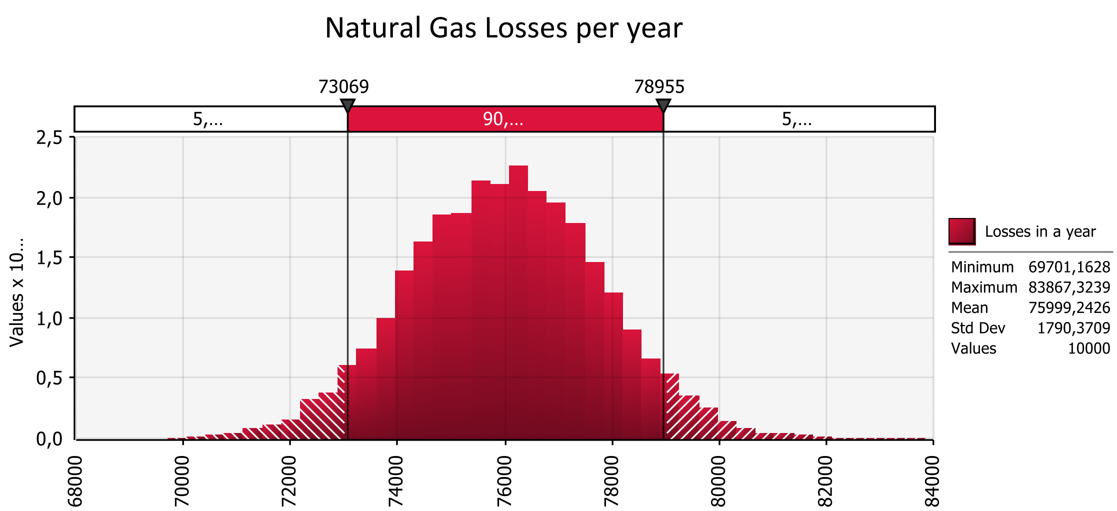

Figure 1. Probability density function of natural gas losses per year (thousand cubic feet)

In Figure 1 we present the simulation results. In 90% of the cases, the losses lie within the interval of 73 to 79 thousand cubic feet. The mean value and standard deviation, respectively 76 thousand and 1.8 thousand cubic feet, will be used as parameters of a Normal distribution to estimate the losses that occur in each year.

[6] We already know that the natural gas losses in a year cab be approximated by a Normal distribution as we are adding up a considerable number of random variables with finite mean and variance. These are sufficient conditions to apply the Central Limit Theorem.

Natural Gas Prices

All natural gas losses due to leakage in transmission pipelines must have an associated cost. The wellhead price of U.S. natural gas is considered as this is the one paid to producers. If leakages would prevent consumers from using natural gas then the citygate price would have to be considered due to opportunity costs. Using data for the U.S. natural gas wellhead prices[7], we verify that in the past 5 years returns have an annualized loss of 0.13% and a standard deviation of 3.5%. Given that it is expected that natural gas prices will tend to increase [4], we will not use this negative historical trend value, substituting it by 5%, but we will keep the standard deviation to model price evolution through time. As is typical with price time series we assume that these follow a geometric Brownian motion with drift. The price for the year of 2012 is the last observed value, $2.71 per thousand cubic feet.

Deaths

In the last decade Pennsylvania had a clean track record on deaths associated with transmission pipeline accidents. Considering the rarity of such an event and the small sample size, we should not discard the probability of such an event occurring. Given that there are about 2-3 deaths per year in the U.S., and based on the amount of transmission pipeline in Pennsylvania as compared to the total amount in the country, we compute the probability of a death occurring at 9% per year.

The value of statistical life considered, $7.9 million, is based on the United States Environmental Protection Agency[8] reference.

Property Damage

Property loss changes considerably throughout the years, in 2002 and 2003 there were no damages due to problems in the transmission pipelines. So, we assume that in a given year, 20% of the times there will be no damage. Considering only the years where damage occurred, we modeled a triangular distribution using the minimum value of $0, the average value of damages as the mode value and that there is only a 5% of damages being higher than the highest observed value ($2.9 million).

[7] http://www.eia.gov/dnav/ng/hist/n9190us3M.htm
[8] http://www.epa.gov/airquality/combustion/docs/ciswireconfinalria.pdf

Significant Repairs

Damages in the transmission pipelines can be of several kinds and sizes. Improving the frequency of leakage surveys does not reduce the number of leaks. However, faster incident reporting can decrease the effects of those leaks. We assume that there are no repair costs changes in small incidents. Considering the data on significant pipeline incidents, those which result in damages bigger than $100,000 measured in 2012 dollars[9], provided by PHMSA[10], we model the total yearly damage using once again a triangular distribution. As the minimum value we consider $100,000 and, adjusted to the percent of the Pennsylvanian pipeline faced to the total in the United States, the 2007-2011 average, $6.3 million, as the mode value and $17.4 million for the lower bound of the top 5% cases.

5.3. Investment Plan and Cost Savings

We were not able to quantify the marginal contribution of each system or vehicle on the leakage survey system. The selection of investments was then based on their description, in terms of what they perform and in the time they require to complete them.

Our reasoning suggests that the more we improve CPM, adding sensors that collect more data and from different sources, more incidents can be found as soon as they happen. Excepting for fiber optics sensor that have a prohibitive cost due to the need to retrofit the existing transmission pipelines, all the other available technologies, pressure flow and chemical sensors should be incorporated. Considering the number of operators already using SCADA (89%) [1], we assume that it is already being used in Pennsylvania.

Our new requirements proposal suggests doubling the frequency of leakage surveys. In order to accomplish it we suggest the operator to acquire one aircraft. Except for the Lehman Aviation LP960, which is recommended only for smaller surveys, either the Luna NG and a Helicopter are able to perform a survey of the whole network in 2 to 3 months. As costs are

9 *http://www.calculator.net/inflation-calculator.html*

10 http://primis.phmsa.dot.gov/comm/reports/safety/SigPSI.html?nocache=1523#_ngtranson

also similar, we choose henceforth the cheapest option, the Luna NG equipped with the Boreal GasFinder AB sensor.

Classes 3 and 4 transmission pipelines require more frequent leakage surveys. Incidents reported using CPM without having a precise location of the leak also require smaller surveys to be conducted. Considering the geography of Pennsylvania, two trucks carrying each one Lehman Aviation LP960 unit can be placed one in the East and one in the West for these purposes allowing a response time smaller than 3 hours.

Table 5. Proposed investment plan to meet the requirements proposal.

Equipment	Quantity	Acquisition Cost ($)	Annual Cost ($)	Discounted Annual Costs for a 10 year period ($)
SCADA	-	-	18,000	114,257
Pressure Flow	-	1,750,000	45,000	285,644
Chemical Sensors	-	600,000	-	-
LUNA NG -Boreal	1	1,060,000	190,000	1,206,051
LP960	2	50,000	141,000	895,017
Trucks	2	70,000	70,000	444,335
Subtotal	-	3,530,000	464,000	2,945,304
Total	-	6,475,304		

In Table 5 we present a list of the suggested investments to comply with our proposed requirements. We expect the acquisitions costs to round $3.5 million. As we do not have information about the average lifespan of the CPM components and aircrafts, we assume 10 years. Besides the different scenarios we also present a sensitivity analysis of this uncertainty to understand its impact on the cost-effectiveness of the proposed transmission pipeline requirements. Considering a discount rate of 9.25% [5], the discounted value of 10 years of operation is $3 million. In total our investment proposal has a present value of $6.5 million.

Table 6. Cost savings by type and according to scenarios

Costs Savings	Conservative Scenario	Expected Scenario	Optimistic Scenario
Leaked Gas	10%	30%	50%
Property Damage	25%	50%	75%
Death Prevention	0%	10%	20%
Significant Repairs	2.5%	5%	7.5%

To model the benefits associated with the improvement in the capabilities of leakage detection we must compare the current incident costs with the new incident reduced costs.

Table 6 summarizes our expectations for cost reductions by improving the detection capacity. We also include our best and worst estimates for these values. As we intend to double the number of leakage surveys in each year, on average we should halve the time each incident unintentionally releases natural gas. However, as leaks also depend on response time we reduce our savings to just 30%. Still this value of 50% is considered our most optimistic guess. The same reasoning is used for property damage, introducing this plan should reduce property damage by 75% [1]. Placing a lower bound of 25% lets us obtain an expected value of 50%. Death prevention and savings in significant repairs are harder to assess. We consider that by improving inspections to transmission pipelines some deaths can be prevented, our best estimate is 20%, our expected value is 10% and naturally we also consider that no deaths can be prevented as our worst estimate. Lastly, significant repairs savings can be avoided due to the introduction of chemical sensors. As reasons besides leakages can contribute to these costs, we consider a saving equal to property damage reduced by one order of magnitude.

Considering that new expansions to the transmission pipelines are being executed we assume that on average 100 new miles are built each year.

Using Monte Carlo we randomly generate 10,000 iterations. In each of them and for each year in the analysis a cost is generated as presented in section 5.2. As the expected starting date for the law resulting from the recommendations is 2015, we consider that prices start evolving randomly since the beginning of 2013.

For each cost, savings are calculated by multiplying the obtained values by the percentages in Table 6. The only exception is death prevention as this is not a continuous variable. If a death occurs in the current incident costs calculations, a new random number is generated to check if it is avoided.

To obtain the Net Present Value (NPV) all savings are discounted with the same 9.25% rate given the year of their occurrence, summed up together and the investment costs are subtracted considering that they refer to the year 2014. This is the metric used to show the cost-effectiveness of the present proposal.

5.5. Results and Sensitivity Analysis

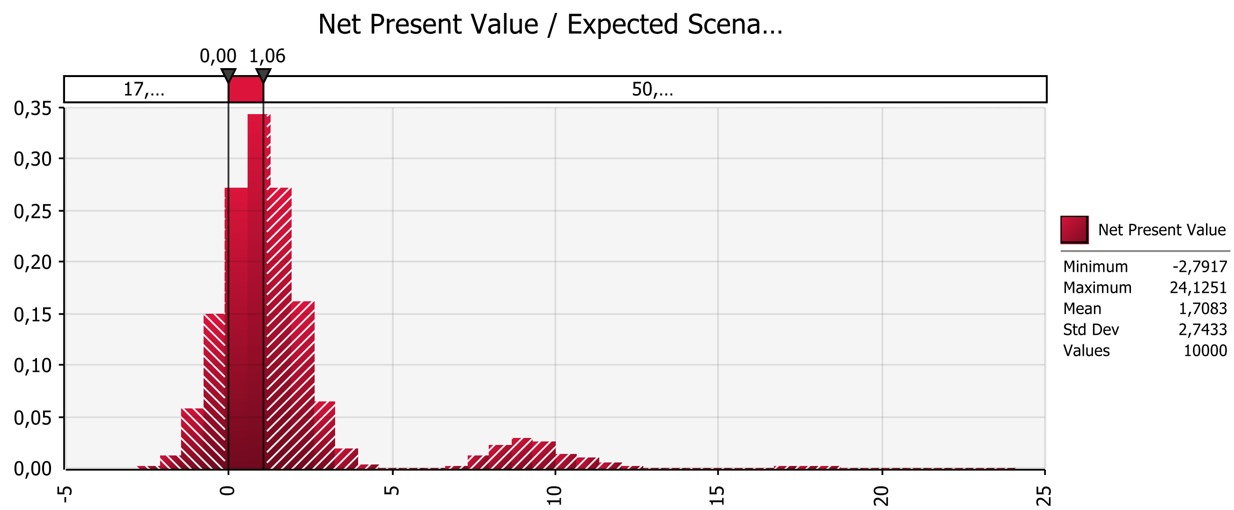

Figure 2. Net Present Value's probability density function of the Expected Scenario in a 10 year timespan ($ million)

Considering the Expected Scenario and the 10 year timespan, we can verify in Figure 2 that doubling frequencies of transmission pipeline leakage surveys provides an expected net benefit of $1.7 million. Due to the skewness of this probability distribution function the median value is smaller ($1 million) and there is a 17% probability of obtaining a negative result. The lumps observed result from death prevention. As the value of statistical life is not continuous, for each prevented death there is a corresponding NPV of $7.9 million. So, there is some likelihood that in the considered timespan one or two people might be saved.

To account for the already mentioned uncertainties, we perform sensitivity analysis to further understand the implications of our assumptions. Optimistic and conservative scenarios for the amount of savings were considered as well as shorter and longer lifespans.

Given the values used for the different scenarios the resulting savings are almost linear. As shown in Figure 3 (below), the conservative scenario results in a negative NPV of 2.9 million, hence the proposed increase in leakage survey frequency is not viable. Regarding the optimistic scenario, we verify that NPV increases to $6.3 million. Not only would these new requirements generate a significantly positive return but even more frequent could inspections be made for the sake of preventing deaths. We can then conclude that this analysis could be improved if more quantified information on the advantages of each technology was available.

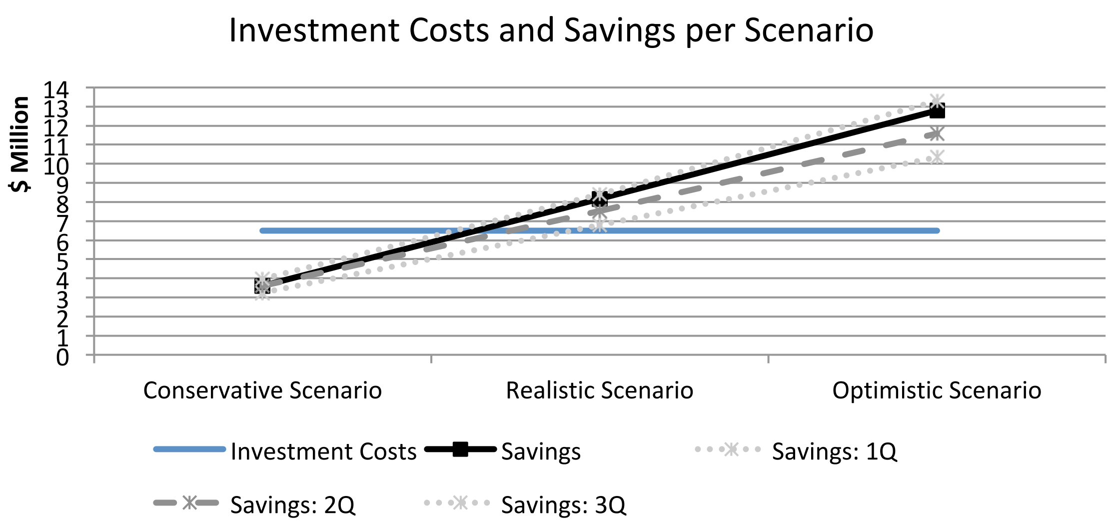

Figure 3. Sensitivity analysis results for the different scenarios ($ million)

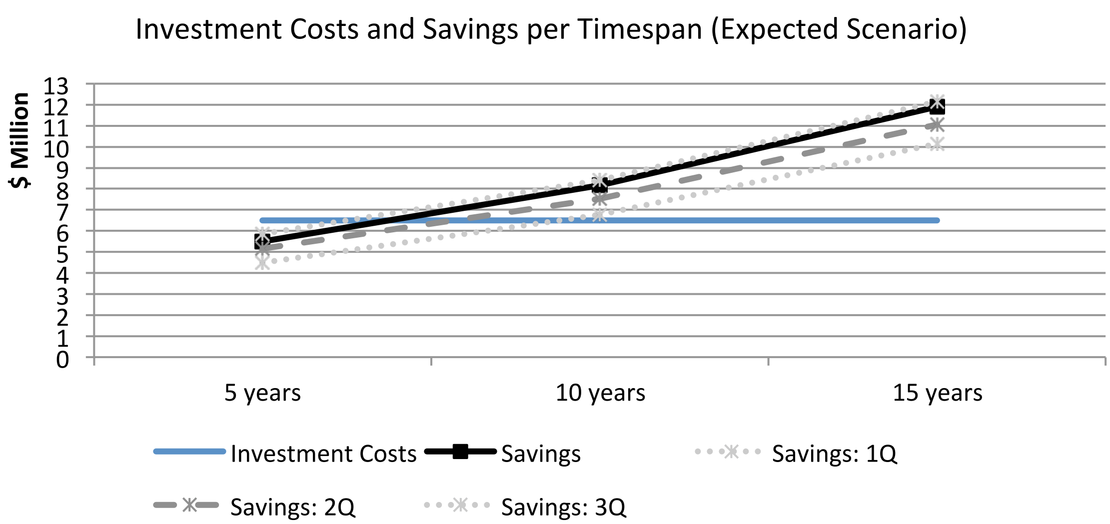

Figure 4. Sensitivity analysis results of timespans in the Expected Scenario ($ million)

Similarly to the previous results, there is a positive relationship with changes in the timespan of equipments and NPV (Figure 4). Also, if CPM improvements and vehicles have a shorter life than we expect, our conclusions might be challenged.

6. Social Acceptability and Privacy Issues

Unmanned aerial vehicles, or drones, can be used in the natural gas transmission industry for maintenance purposes. Improving maintenance however is not something that provides benefits for the transmission pipelines operators alone. As seen above, a more active surveillance can significantly improve the reduction of property damages as well as accidental deaths due to undetected problems in the pipelines. Discarding the potential usage of drones to guarantee that privacy is safeguarded is an option that should be avoided. Legislation must distinguish drones usage by operation intention and according to needs limit their activities.

One of the biggest issues referring to the usage of drones is that they can be provided with equipment that allows tracking human targets. Not only regular cameras, as well as infrared, motion detection sensors or even facial recognition technology can be implemented. Depending on altitude they can be used to clandestinely track individuals.

In what refers to natural gas transmission pipelines operators, they are not concerned with the surveillance of individuals. Therefore, a distinction should be made between drones used for civil purposes and drones used for law enforcement. To reduce the concern with drones used for natural gas leaks surveillance, limitations could be raised in the type of sensors they employ. Another issue is the possibility of outfitting drones with weapons. Once again, considering the goal of drones in the natural gas industry these are not necessary and could be forbidden.

There is public concern on retention and disclosure of surveillance data. EPIC already supports a bill to prohibit the sharing of this data[6]. Considering the operations that this industry wants to do using UAVs it is of their best interest that this bill or a similar one is passed, restricting the sharing of sensitive data, improving public awareness of drone usage. According to 18 PA. CONS. STAT. ANN. § 7507.1 invasion of privacy is defined as knowingly viewing, recording or sharing another person images that depicts, without that person's knowledge, their intimate parts. It should be emphasized that only when this activity is done on purpose, which will not happen during leakage surveys, could the usage of drones be considered an invasion of privacy.

In a technical perspective there are three issues to be concerned with: 1) avoiding collisions 2) loss of control and 3) maintenance.

Currently UAVs do not have the capability of sensing and avoiding other aircrafts[7]. Naturally if drones are closely controlled by a human on the ground it is possible to avoid collisions. That does not mean however that people in general perceive no risk of these unmanned aircrafts colliding and causing deaths or property damage. Another technical consideration is that GPS contact can be lost either intentionally by third-parties or unintentionally. The ease with which jamming or spoofing of UAVs can be done raises a risk of losing control of the aircraft[7]. This loss of control, even if momentary, could make the aircraft head in an undesired direction or worse, make it crash on the ground, damaging property or injuring people. Lastly, due to being unmanned there might a tendency to contemn proper maintenance of UAVs[8].

These three UAVs technical limitations impose a real risk that is 100 time as high as manned aircrafts[8]. Unfortunately only developments in the technology can mitigate it.

It is important that new legislation is drafted in the timeliest manner. As long as drones are not limited in terms of their capacities and areas of operation, public opinion might not improve.

Trust in a government entity is relevant aspect in risk perception and resulting opposition to new policies [9]. Considering the previous recommendations, restricting the usage of equipment based on function and limiting the areas of operation might reduce privacy risk concerns. Complementarily, allowing public participation in the draft of the new FAA bill on UAV regulation can also help in decreasing surveillance concerns. Several possibilities exist that could be explored. Public hearings might allow legislators to know new and different points of view that they might not have considered. A second possibility is to create a Citizen Advisory Committee. In comparison with the former, this has the advantage that more complex and fruitful discussions can be made, and more realistic compromises between all involved parties will allow the bill draft to improve [10].

7. Recommendations

Our results show that improving the frequency of leakage surveys has benefits that surpass the required investment costs. Considering the sensitivity analysis there is a chance that our assumptions, if proved wrong, can undermine our conclusions.

Given the social acceptability issues that might be faced if unmanned aerial vehicles are used in leakage surveys, it is possible to reduce this risk by switching drones with helicopters. As technically these aircrafts have similar performances, and given that we could eliminate this concern, there is a cash surplus that could be used to proceed with this substitution. Regardless of the operator's aircraft choice the proposed requirements are not affected as these two vehicles have similar characteristics and costs.

Considering the specifications and cost differences between UAVs and helicopters, we do not advise the new bill to oblige the usage of new technologies to conduct leakage surveys. We recommend that the survey frequency is doubled as described in Table 4. Possibly the new bill can exemplify some of the available technologies or a separate supplementary document could be developed to explain how operators can meet the new leakage survey criteria and the cost-effective reasoning behind it.

8. Areas of further research

A comparison of current and prospective regulations on transmission pipelines leakage surveys in other countries would be valuable to look for other practices that we might not have considered in the present analysis. In this study we would focus particularly on those countries where fewer accidents happen and in their occurrence the impacts they have both in terms of damages and deaths.

Even though we are confident with the obtained results, knowing the marginal contribution of the different technologies as well as their lifespans could reduce the overall uncertainty in the benefits we envision for our proposed investment plan. It would be interesting to look for places where at least some of these technologies are being employed to verify the gains obtained with their usage. In their absence pilot studies should be performed.

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