White Paper: Leak Detection System Components



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# Context & Problem

## Introduction

In the past there have been misunderstandings about leak detection. The Alaska Department of Environmental Conservation (ADEC) issued a Technical Review of Leak Detection Technologies whose preamble made the following statement: “… Recognizing the importance of leak detection in the **prevention** of oil spills … “ It is important to recognize however that leak detection systems in fact do not in any way prevent oil spills; that is they have no impact on the probability of a leak occurring.

A more accurate description of leak detection can be found in the U.S. Department of Transportation (US DOT)’s *Leak Detection Study – DTPH56-11-D-000001*: “A leak detection system has no effect in reducing the likelihood of a leak occurring. At the same time, pipeline maintenance, inspection, security, and other leak prevention measures can never reduce the probability of a leak to zero. Given there is always a likelihood of a leak occurring, a leak detection system is the first line of defense in reducing its impact, mostly by **limiting the size** of the eventual total spill.” In general, leak detection systems reduce the volume of an oil spill by notifying pipeline operations of a leak’s existence and by providing information that is useful for determining the best response.

ADEC’s Technical Review also states that “an effective and appropriately implemented leak detection program can easily pay for itself through **reduced spill volume** and an increase in public confidence.” Although this conclusion may have been drawn without supporting information it does highlight the fact that a leak detection system’s value should be measured by determining the amount of spill volume it has the potential to reduce.

Alyeska’s leak detection system (LDS) is comprised of multiple subsystems, which will be referred to as components. Each component uses different underlying technologies which have different capabilities and are subject to different limitations. These components can be categorized as either *continuous monitoring systems* or *scheduled surveillance systems*.

## Risk Reduction

1. US DOT’s leak detection study defines risk as “a probability-weighted cost [that] is defined in various forms depending on the application. In [the context of leak detection] it is useful to think of risk defined as follows:
2. Applying common units, this may be rates as Expected $ cost/year. If the total cost of the remedying a given leak is C, and the probability of this leak occurring in a given year is P, then the Risk is P\*C.” Defining risk in terms of USD is convenient for use in a cost-benefit analysis in the case that a component’s costs are well understood. When determining how leak detection systems reduce risk it is important to remember that “the economic benefit from a leak detection system is gained from a reduction in the consequential cost, or consequence of the leak. The leak detection system cannot reduce the probability P, which is the domain of mechanical safety, inspection, maintenance and repair.” The risk reduction is defined as follows:

where,

There is uncertainty in how a leak detection system will impact the economic impact of an oil spill. This impact is typically measured in terms of probability of detection i.e. the probability that the system will alarm to the control room. The probability of detection typically depends on location, leak rate, leak volume, and/or time required to detect. It is also important to acknowledge that “leak detection systems are never autonomous technologies. The true leak detector is the controller (i.e. people) and the technology and associated processes only truly take a supporting role.” This impacts the ability of the leak detection system to reduce risk because there is a probability that the controller will fail to properly respond to a leak detection system’s indication of a leak.

The economic impact of an oil spill can be estimated using the EPA’s Basic Oil Spill Cost Estimation Model which is detailed in Appendix B. This model produces a cost as a function of spill volume and the area’s environmental classification. This can be converted into a cost as a function of spill volume and pipeline length by using a hydraulic spill model and the environmental classification of the area surrounding the pipeline.

## Problem

The DOT study states that “if the reduction to risk [associated with leak detection systems] is not analyzed, there is simply no economic way to calculate cost-benefit.” The benefit of a leak detection system can be evaluated by determining how much risk it reduces. Section 2 of this document outlines a suggested approach to calculating this measurement.

# Proposed Solution

## Proposed Solution

1. To quantify the impact or value of a LDS component it is recommended that a new software tool be created. The tool will leverage Integrity Management’s Risk Analysis, Environment’s Area Classification and the EPA’s Basic Oil Spill Cost Estimation Model to accomplish the following:

* Assess the value of existing and proposed LDS components
* Determine the impact of LDS component degradation and/or improvements

The output of the tool would be the value of the system in terms of oil spill cost savings due to a change to TAPS leak detection.

## Implementation

1. The proposed LDS component benefit analysis tool would calculate the benefit of a LDS component by: (a) using stochastic simulation to create a probability distribution of the marginal cost savings due to the use of the LDS component in question, and (b) converting that distribution into an expected value and variance of the marginal cost savings associated with the LDS component.

### Stochastic Simulation

A stochastic simulation generates random outcomes so as to imitate the randomness inherent in the original problem. In this manner, a solution to a rather complex problem can be inferred from the behavior of these random outcomes. In effect, the simulation creates a probability distribution of the estimated marginal benefit. The use of stochastic simulation is recommended over the development of a direct equation due to the inherent uncertainty involved in oil spill risks and leak detection system performance.

A breakdown for this simulation is detailed in Appendix A. Details for the oil spill cost model are described in Appendix B. An overview of the data needed for the models and simulation are detailed in Appendix C.

### Calculating Expected Value & Variance

1. With a probability distribution developed, calculating the expected value and variance of the marginal benefit is a process of applying two statistical equations. The expected value and variance are outputted by the tool for immediate use.

## Reasons to Pursue a Solution

1. The benefit of quantifying LDS impact or value include the following:

* Leak detection systems could be compared, and projects could be better prioritized.
* Unnecessary systems could be identified and their removal justified.
* Cost effective risk reduction in high impact areas could be achieved.
* The models could be adapted for use by other spill/leak-conscious departments.

###### Simulation Breakdown

Introduction

1. This appendix describes the breakdown of the stochastic simulation mentioned in Section 2. The simulation should be run numerous times, and the outputs should be compiled into a probability distribution of the marginal benefit of the LDS component in question. Each run of the simulation aims at accomplishing the following calculation:
2. *benefit of a LDS component =*
3. *estimated spill costs with that LDS component – estimated spill costs without that LDS component*
4. Each run of the simulation must contain two models of the pipeline with nearly identical sets of LDS components. The leaks for these pipelines’ models are identical. Each pipeline’s set of LDS components attempts to detect their leak. Oil spill costs are calculated for each pipeline. The difference in these costs is the marginal benefit, and numerous marginal benefit values can produce a useful probability distribution.

Simulation Steps

1. On a high level, the simulation breaks down into four steps:
2. A leak is generated.
3. Two “onset to response” times are generated, one for the pipeline with the LDS component in question and one for the pipeline without.
4. Two oil spill costs are estimated, based on the identical leaks and different response times.
5. The marginal cost benefit of the LDS in question is calculated.

This is shown in Figure 1.

time

Estimate time to respond with **all** **LDS components** (FB2)

Estimate oil spill cost (FB3)

date

milepost

flow rate

dollars

Start of simulation

time

Generate leak (FB1)

Estimate time to respond with **all** **but one LDS component** (FB2)

Estimate oil spill cost (FB3)

date

milepost

flow rate

dollars

Calculate Difference

Marginal Benefit

1. Simulation Process for Estimating Marginal Benefit

Generating Uncertain Values

1. In stochastic simulation, uncertain values are generated using the following process:
2. The probability distribution of the value is converted into an inverse cumulative distribution.
3. A uniformly distributed random number is generated.
4. The random number is fed into the inverse cumulative distribution to create a pseudo-random number that "imitate(s) the randomness inherent" to the value being simulated.

The process is used to generate all of the simulation’s uncertain values. This requires knowing the probabilities for each of these uncertainties.

Leak Generation

1. In the leak generation step of the simulation, values for the leak rate, leak location, and time until leak onset are generated using the process mentioned in A.3. See Figure 2 for how this is implemented.

Rand()

Inverse Cumulative

Probability distribution for when leak will occur

Rand()

Inverse Cumulative Distribution

Probability distribution function for leak rate

Rand()

Inverse Cumulative Distribution

Probability distribution function for leak location

Date of leak

Leak rate

Leak location

1. (FB 1) For each run, a leak date, a leak rate and a leak location are generated.

Response Time Estimation

1. In this stage, two pipelines are being simulated with identical leaks. One pipeline uses all LDS components, and the other pipeline uses all components except for the one in question. The full suite of each pipeline’s LDS components are simulated as shown in Figure 3.

success T/F

success T/F

time

time

Component #1 simulation (FB2.1)

Leak rate

Leak

location

Component #2 simulation (FB2.1)

ith Component

simulation

(FB2.1)

<

**...**

**...**

**...**

**...**

minimum response time

**...**

Oil flow model

**...**

success T/F

time

flow rate

milepost

Time until leak

date

1. (FB 2) For each LDS component, the systems attempt to detect the leak is generated. If successful, the time required from leak onset to operator response is generated. Then, the minimum response time is chosen.
2. The pipeline’s LDS components run in parallel. Each component generates its own detection attempt and onset-to-response time based on the factors and characteristics inherit to that system, as well as, the leak rate and location. The fastest hypothetical response is considered to be the pipeline's true response time, and this value is fed into the oil spill cost model.
3. To accurately simulate each LDS component, all steps, from that system’s initial detection attempt to that system’s final response, need to be factored into the simulation. The goal is for each component simulation block to accurately imitate the real leak detection system it is modeling. A generic template for the simulation block is shown in Figure 4.

milepost

flow rate

date

**...**

**...**

time

**...**

Gen. 1st stage’s attempt to detect/respond

Leak location

Gen. 1st stage’s time to detect/respond

Leak rate

success T/F

Gen. 2nd stage’s attempt to detect/respond

Gen. 2nd stage’s time to detect/respond

**...**

**...**

Gen. jth stage’s attempt to detect/respond

Gen. jth stage’s time to detect/respond

Find minimum hypothetical time to respond

overall success T/F

Σ

time

time

total time

Time until leak

Within than useful life of the LDS

T/F

1. (FB 2.1) Calculate the response time for each leak detection system by splitting up into as many components as necessary and compute.
2. Each simulation block breaks up into stages of detection. As shown in Figure 4, each stage should consist of both an attempt and a time. The generation of these attempts and times follows the process in A.3 and should accurately imitate the event, system, or person it is modeling.
3. For example, the TVB LDS might be split into a TVB stage and an operator stage. In the TVB stage, TVB’s success or failure at detecting the leak would need to be generated based on the leak rate and location and how TVB performs given that rate and location. If successful, the time to alarm would need to be generated. In the second stage, the operator attempts to diagnose the TVB leak alarm. The success or failure of this stage is generated, and if successful, a time for this stage is generated as well. If both stages succeed, then TVB hypothetically resulted in a spill response. In that case, the times for both stages are added up and outputted as the total time from leak onset to response initiation. All LDS components in the simulation will output an overall attempt and possibly output a total time.

Oil Spill Cost Estimation

1. In the third stage of the stochastic simulation, two oil spill costs are calculated using the leak information and the minimum onset-to-response times. The leak rate, location and final onset-to-response time are combined with topographic data for that location, using a hydraulic spill model. This hydraulic spill model will be an adaption of the model used by Integrity Management. The result of using the model will be two spill boundary maps.
2. Each spill boundary map is fed into an oil spill cost model, which takes into account the spill’s environment, area type, economic value, cultural value and other cost factors to calculate total cost of the spill. This cost is then converted into a cost in current dollars by using Alyeska’s internal rate of return and an assumed inflation rate. Details on this cost model can be found in Appendix B. The two final costs are then output to the last stage.
3. This cost estimation process is summarized in Figure 5.

Calculate leak volume

Location

Leak rate

Time to response

Topography of location

Spill Model

Reference area types of location

Reference economic values of location

Reference cultural values of location

Calculate cost

Map of area type cost modifiers

Map of economic value cost modifiers

Map of cultural value cost modifiers

Spill boundary map

dollars

Oil spill cost

Topographic map

Volume

milepost

time

rate

1. (FB 2.3) Estimate the cost of the resulting leak volume using a spill hydraulic model and oil spill cost-estimation model.

###### EPA Basic Oil Spill Cost Estimation Model Methodology

1. BOSCEM was developed to provide the US Environmental Protection Agency Program with a methodology for estimating oil spill costs. The model parameters are based on hypothetical spills in Etkin et al. (2002, 2003) with oil fate modeling by Applied Science Associates’ SIMAP in French-McCay et al. 2002. These parameters can be adjusted to accommodate the socio-economic, environmental and oil response costs along the TAPS right of way. Below is a brief description of BOSCEM (Etkin, 2004). This version of BOSCEM considers three separate contributions to the total oil spill cost: spill response, socio-economic and environmental.
2. Where the spill response cost (CR ), socio-economic cost (CS ) and environmental cost (CE ) are given below:
3. In the event that there is a spill that covers multiple area types calculate the cost associated with each area type individually and then aggregate the costs. Suggested values for the per volume cost ( ), and multipliers (α, β) are given intables 1-6.

|  |  |  |  |  |  |  |  |  |  |
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| **Table 1: Per-Gallon Oil Spill Response Costs Applied in EPA BOSCEM1 ()**  Table from Etkin et al., 2004. | | | | | | | | | |
| **Oil Type** | **Volume (gallons)** | **Mechanical2,4** | | | | **Dispersants3,4** | | **In-Situ Burn5** | |
| **0%** | **10%** | **20%** | **50%** | **Low** | **High** | **50%** | **80%** |
| **Crude Oil8** | **<500** | $220 | **$199** | $189 | $153 | $85 | $53 | $75 | $48 |
| **500-1,000** | $218 | **$197** | $187 | $151 | $84 | $52 | $74 | $47 |
| **1,000-10,000** | $215 | **$195** | $185 | $149 | $82 | $51 | $72 | $46 |
| **10,000-100,000** | $195 | **$185** | $174 | $138 | $74 | $31 | $62 | $31 |
| **100,000-1,000,000** | $123 | **$118** | $113 | $92 | $49 | $29 | $36 | $16 |
| **>1,000,000** | $92 | **$82** | $76 | $64 | $58 | $13 | $22 | $11 |

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| **Table 2: Socioeconomic and Environmental Base Per-Gallon Cost For Use in EPA BOSCEM1**  Table from Etkin et al., 2004. | | | |
| **Oil Type** | **Volume (gallons)** | **Base Cost ($/gallon)** | |
| **Socioeconomic ()** | **Environmental ()** |
| **Crude Oil5** | **<500** | $50 | $90 |
| **500-1,000** | $200 | $87 |
| **1,000-10,000** | $300 | $80 |
| **10,000-100,000** | $140 | $73 |
| **100,000-1,000,000** | $70 | $35 |
| **>1,000,000** | $60 | $30 |
| 1Based on hypothetical spills in Etkin *et al.* (2002,2003) with oil fate modeling as in French-McCay *et al*., 2002, and historical cases with oil type impact based on characteristics as modeled by NOAA ADIOS 2. 5Crude (except specifically-identified heavy- or light- crudes, intermediate fuel oils, waxes, animal fats, other oils, edible oils, non-edible vegetable oils, and mineral oils. | | | |

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| **Table 3: EPA BOSCEM Response Cost Modifiers for Location Medium Type Categories1 ()**  Table from Etkin et al., 2004. | |
| **Category** | **Cost Modifier Value2** |
| **Open Water/Shore\*** | 1.0 |
| **Soil/Sand** | 0.6 |
| **Pavement/Rock** | 0.5 |
| **Wetland** | 1.6 |
| **Mudflat** | 1.4 |
| **Grassland** | 0.7 |
| **Forest** | 0.8 |
| **Taiga** | 0.9 |
| **Tundra** | 1.3 |
| 1Category description in Table 2. 2Based on tendency for oil spread or deep penetration in area sensitive to impact of response equipment/personnel (higher values). \*Default value. | |

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| **Table 4: EPA BOSCEM Socioeconomic & Cultural Value Rankings1 ()**  Table from Etkin et al., 2004. | | | |
| **Value Rank** | **Spill Impact Site(s) Description** | **Examples** | **Cost Modifier Value** |
| **Extreme** | Predominated by areas with high socioeconomic value that may potentially experience a large degree of *long-term­*2 impact if oiled. | Subsistence/ commercial fishing, aquaculture areas | 2.0 |
| **Very High** | Predominated by areas with high socioeconomic value that may potentially experience some *long-term*2 impact if oiled. | National park/ reserves for ecotourism/nature viewing; historic areas | 1.7 |
| **High** | Predominated by areas with medium socioeconomic value that may potentially experience some *long-term*2 impact if oiled. | Recreational areas; sport fishing, farm/ranchland | 1.0 |
| **Moderate** | Predominated by areas with medium socioeconomic value that may potentially experience *short-term*3 impact if oiling occurs. | Residential areas; urban/suburban parks; roadsides | 0.7\* |
| **Minimal** | Predominated by areas with a small amount of socioeconomic value that may potentially experience *short-term*3 impact if oiling occurs. | Light industrial areas; commercial zones; urban areas | 0.3 |
| **None** | Predominated by areas already moderately to highly polluted or contaminated or of little socioeconomic or cultural import that would experience little short- or long-term impact if oiled. | Heavy industrial areas; designated dump sites | 0.1 |
| 1Default value is shaded. 2Long-term impacts are those impacts that are expected to last *months to years* after the spill or be relatively irreversible. 3Short-term impacts are those impacts that are expected to *last days to weeks* after the spill occurs and are generally considered to be reasonable reversible. \*Default value. | | | |

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| **Table 5: EPA BOSCEM Freshwater Vulnerability Categories**  Table from Etkin et al., 2004. | |
| **Category** | **Cost Modifier Value** |
| **Wildlife Use** | 1.7 |
| **Drinking** | 1.6 |
| **Recreation** | 1.0 |
| **Industrial** | 0.4 |
| **Tributaries to Drinking/Recreation** | 1.2 |
| **Non-Specific\*** | **0.9** |
| \*Default value shaded. | |

|  |  |
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| **Table 6: EPA BOSCEM Habitat and Wildlife Sensitivity Categories1**  Table from Etkin et al., 2004. | |
| **Category** | **Cost Modifier Value1,2** |
| **Urban/Industrial** | 0.4 |
| **Roadside/Suburb** | 0.7 |
| **River/Stream\*** | 1.5 |
| **Wetland** | 4.0 |
| **Agricultural** | 2.2 |
| **Dry Grassland** | 0.5 |
| **Lake/Pond** | 3.8 |
| **Estuary** | 1.2 |
| **Forest** | 2.9 |
| **Taiga** | 3.0 |
| **Tundra** | 2.5 |
| **Other Sensitive** | 3.2 |
| 1Values based on relative time to recovery (based on Fingas 2001). 2If more than one category is relevant, the one that most closely represent the majority of the area, or, if there is a relatively even distribution of categories, the category that represents the greater sensitivity or vulnerability (*i.e.* with the higher modifier value) should be chosen. Alternatively, a weighted average of different categories can be used in these cases. \*Default value shaded. | |

###### Alternative Method for Acquiring Simulation and Model Data

1. Appendix B provides a structure which describes what information would be required from a qualitative analysis in order to run the leak detection marginal benefit estimation tool. The first piece of data needed is an understanding of the probability distribution of the time distance between the simulation start time and a leak occurring. This can be deduced from the data provided in order to complete table C1.

Leak Probabilities

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| --- | --- | --- | --- |
| **Table C1: Frequency Distribution of Leak Occurring** | | | |
| Spill Size (BBL) | Mean Frequency | 90th Percentile | 10th Percentile |
| Below Ground |  |  |  |

1. Once a leak occurs a probability distribution of the leak location should be estimated. A method for doing this is to assume that the probability is equal at all above ground locations and all below ground locations. With these assumptions a relative likelihood specified in Table C2 can be used to determine the probability distribution using information about the pipeline itself.

|  |  |
| --- | --- |
| **Table C2: Relative Likelihood of a Leak Above Ground/Below Ground** | |
| AG/BG | Relative Likelihood |
| Below Ground | **1** |
| Above Ground |  |

1. The probability distribution of the leak rate can be determined by estimating the relative likelihood of each leak rate as specified in table C3. These numbers can be translated into a distribution function.

|  |  |
| --- | --- |
| **Table C3: Relative Leak Rate Probabilities** | |
| Spill Size (BBL) | Relative Frequency |
| .1 BBL/Hr. or Less | **1** |
| 1 BBL/Hr. |  |
| 10 BBL/Hr. |  |
| 100 BBL/Hr. |  |
| 1,000 BBL/Hr. |  |
| 10,000 BBL/Hr. |  |
| 50,000 BBL/Hr. |  |

Leak Detection System Performance

1. For each leak detection system, including the system being analyzed, the performance needs to be specified. Because each system functions differently there may be different performance criteria used to estimate the performance. However this analysis is done, the result should be sufficient enough to fill out either Table C4 or Table C5. Table C4 is geared towards measuring performance in terms of leak rates and time to detect. Table C5 is geared towards measuring performance in terms of frequency of observation and oil spill volume. For these systems the performance will most likely depend on location as well, so this factor must be considered.

|  |  |  |  |
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| **Table C4 Form Used to Assist in Qualitative System Performance Analysis** | | | |
| **Milepost** |  | **Date** |  |
|  | Detection Success | Time to Detect | |
| Leak Rate (BBL/Hr.) | Probability | Average | Standard Deviation |
| 1 or Less |  |  |  |
| 10 |  |  |  |
| 100 |  |  |  |
| 1,000 |  |  |  |
| 10,000 |  |  |  |
| 100,000 |  |  |  |
| 1,000,000 or Greater |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| **Table C5: Form Used to Assist in Qualitative System Performance Analysis** | | | |
| **Milepost** |  | **Date** |  |
|  | Detection Success | Frequency | |
| Leak Volume (BBL) | Probability | Average | Standard Deviation |
| 1 or Less |  |  |  |
| 10 |  |  |  |
| 100 |  |  |  |
| 1,000 |  |  |  |
| 10,000 |  |  |  |
| 100,000 |  |  |  |
| 1,000,000 or Greater |  |  |  |

Leak Costs

1. It is advisable to consider at a minimum the oil spill response, environmental and socio-economic costs of an oil spill. The hydraulics of the oil spill should be considered when determining the cost of a leak volume at each milepost. This is required because the oil spill costs depend heavily on the environmental classification of the area that is impacted. A topographical map of the location under consideration should be the minimum requirement to complete these objectives. Taken these into consideration the data specified in Table C6 should be estimated.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Table C6: Leak Volume Cost At Different Mile Posts** | | | | | |
| **Milepost** |  | | **Date** | |  |
| **Leak Volume Cost** | | | | | |
| Spill Size (BBL) | | Approximate Cost (2013 USD) | | Marginal Cost (2013 USD) | |
| 1 or Less | |  | | N/A | |
| 10 | |  | |  | |
| 100 | |  | |  | |
| 1,000 | |  | |  | |
| 10,000 | |  | |  | |
| 100,000 | |  | |  | |
| 1,000,000 or Greater | |  | |  | |