RELIABILITY MODELING FOR E & P FACILITIES IN THE TALLGRASS PRAIRIE

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INTRODUCTION

The aging infrastructure of the domestic petroleum industry poses both environmental and economic risk. There is a need to provide guidance on the allocation of resources that will minimize both types of risk. With the aim of providing a proactive risk management tool, a probabilistic reliability model designed to estimate the failure probability of equipment (including pipelines) typically found at production leases in the Tallgrass Prairie Preserve was developed. This model is based on combinations of failure modes and event trees that define the failure probability of an individual piece of equipment. It is necessary for the utility of the model that the estimated failure frequency be matched with historical observations. Through site visits and meetings with lease owners and operators, information about equipment characteristics and historic performance was collected. This information provided a basis for model calibration. We present the results of the calibration.

OBJECTIVES

Calibration of the model developed during the first stage of the project through comparison of simulation results to historical observations.

PREVIOUS WORK

Failure modes and effects analysis coupled with event tree simulations provide the basis for prediction of the combined probability that a piece of equipment will fail by at least one of its possible failure modes in a given time horizon.

The failure modes used in the analysis are presented Table 1. Each failure mode has an associated event tree with an initiating event followed by a series of events leading to a spill of produced fluids. The product of probabilities of occurrence of each event defines the failure probability associated with a particular failure mode. The combined probability of all failure modes is estimated by the model and compared to historical data.

Table 1. Failure modes identified for TPP E&P equipment.

Item	Failure Mode
Pipes	Corrosion, External Overpressure Blocked pipe, Plastic pipe melt
Tanks	Corrosion, Outlet nozzle plug External Overpressure Level glass fail
Oil / Water separator	Corrosion, Outlet nozzle plug External Overpressure Level glass fail
Pumps	Discharge plugged, Lubrication failure Downstream pipe blocked Suction obstructed, Shaft misalignment

METHODS

Estimation of the probability of equipment failure was based on reliability theory, and well know reliability distributions. The reliability distributions used were:

(1) Weibull distribution (applicable to random and early failure mechanisms)

$$F(t) = 1 - e^{-(t/c)^m}$$

Where c is the characteristic lifetime (63% of population failed) of the item and m is the shape factor (m=1 for random events and m<1 for early failure mechanisms).

(2) Normal distribution (applicable to wear out mechanisms**)**

$$F(t) = \int f(u)du$$

$$f(t) = \frac{1}{\sqrt{2\pi}\sigma} e^{\left[-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2\right]}$$

Where μ is the mean life time (50% of population failed) and σ is the standard deviation of the equipment lifetime.

Due to the lack of information regarding appropriate parameter values for the statistical failure distributions, Monte Carlo Simulation (MCS) was used to propagate the input uncertainty into output uncertainty. We generated the series of random values for some of the reliability parameters: mean lifetime and standard deviation for wear out failures; and characteristic lifetimes for corrosion-related- and completely-random events. Our expectation was that the characteristic lifetime for corrosion related random failure would be much shorter than the characteristic lifetime for completely random events.

Each random variate for a specific Monte Carlo simulation was chosen from a normal distribution with a pre specified mean and standard deviation. Each distribution of random variates was defined by a distinct random number generator in the simulation.

OCC Database

The Oklahoma Corporate Commission database is a compilation of the causes, sources and quantity of released oil and brine from exploration and production (E&P) operations in Oklahoma in the last ten years (1993 – 2003). Fisher and Sublette (2004)[5] analyzed the database and reported the number of spills associated with various equipment. Combining this with the annual report data on active leases from the OCC website to estimate the failure probabilities. Table 2 presents a summary of the primary sources of fluids released and the associated probability. The table reports the annual failure probability. The assumptions made to calculate the probabilities were: number of active leases = 51,611 (active leases in 2003), number of wells per lease = 5, number of tanks per lease =1 (oil and brine), length of oil pipe per lease = 2 miles, and length of brine pipe per lease= 1mile.

Table 2. Failure probabilities estimated from OCC database.

Source	Oil Release	Saltwater Release
Lines	0.002	0.00463
Tanks	0.00364	0.00352
Wells (pumps)	0.0005	0.001

PRELIMINARY RESULTS

The characteristic lifetimes for random events (corrosion and non corrosion related) were used as adjustable parameters for matching the modeled failure probability with the OCC database derived estimate. The values determined, by trial and error, were 600 years with a standard deviation of 120 years for random failures; while, the characteristic lifetime for random events related to corrosion was set to 400 years with a standard deviation of 120 years.

Table 3. Predicted failure probabilities with calibrated values for characteristic lifetimes of random events.

Name:	Type:	Material:	Location:	Fluid:	Probability:
COGIBBS#1	pump	cs	aboveground	mixed	2.09E-05
gibbswestbanard1aoil	pipe	cs	aboveground	oil	0.003
SOCWestBarnard#2T	tank	cs	aboveground	brine	0.003

The probability of failure per year estimated by the calibrated model for pipes and tanks is close to the information reported in the OCC database.

Based on information collected during site visits and interviews with producers, an analysis of a lease in the TPP was performed. The estimated failure frequencies for a one year time horizon for some of the equipment on the lease are presented below.

Table 4. Predicted annual failure probability for leases in the TPP.

Name:	Type:	Material:	Location:	Fluid:	Probability:
COGIBBS#1	pump	cs	aboveground	mixed	2.10E-05
SOCWestBarnard#2T	tank	cs	aboveground	brine	0.0026
SOCWestBarnardtb#8	tank	cs	aboveground	oil	0.0026
SOCWestBarnardtb#5	tank	cs	aboveground	brine	0.0026
SOCWBtboilWatersep	tank	cs	aboveground	mixed	0.0026
COGIBBS#4	pump	cs	aboveground	mixed	2.10E-05
COGIBBS#2	pump	cs	aboveground	mixed	2.08E-05
COGIBBS#3	pump	cs	aboveground	mixed	2.09E-05
gibbs1	pipe	cs	aboveground	mixed	0.0027
gibbs5	pipe	plastic	buried	mixed	3.30E-05
gibbswestbanard3	pipe	plastic	buried	brine	3.30E-05
gibbswestbanard1aoil	pipe	cs	aboveground	oil	0.0027

A further analysis of the model output, allows the generation of histograms that describe the uncertainty in the reported failure probability (the mean value of the distribution in the histogram). Below, is the histogram for failure frequency of a steel pipe. The information of 5000 MCS was used to generate the histogram.

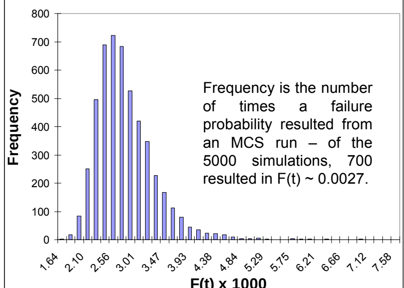

Figure 1. Histogram describing the uncertainty in the predicted failure probability for pipeline failure in the TPP.

CONCLUSIONS

The failure probabilities per year, of pipelines and tanks, estimated with the calibrated model are close to the probabilities derived from the OCC.

The results obtained for polymeric pipes differ from the information reported in the database. However, these specific type of pipes are expected to have lower probabilities of failures. Polymeric pipes have been installed recently and are exposed to different failure modes than steel pipes – specifically they are not subject to corrosion.

The probabilities predicted for pumps are considerably lower than those derived from the OCC. This suggests that either we have underestimated the number of pumps in service, or that additional failure modes exist that are not included in the model.

The histogram can be modeled as a lognormal distribution. The mean value of the probability of failure will be used as the metric for comparison of the failure probability across different items and locations. This comparison, coupled with predictive modeling of the consequences of the spill (see the companion poster) can be used to assist in resource allocation decisions.

FUTURE WORK

With these results, in future work, the number of failures expected in a time horizon, Δt, can be calculated as:

$$Number\_failures/\Delta t = (F(t+\Delta t) - F(t)) * N$$

Where N= number of items currently in operation.

Further analysis of the distribution of failure probabilities will be used as a tool for the decision-making process where knowledge of the degree of uncertainty in the predicted failure rate may be important.

ACKNOLEDGEMENTS

The authors wish to thanks The Nature Conservancy for access to the site and the National Petroleum Technology Office of U.S. Department of Energy (DE-FC26-01BC15332) for funding this work.

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