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The Influence of Risk Analysis on the Economics of Carbon Steel and CRA Clad Flowlines

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Abstract

Recently a method was presented to assist in making the decision to install corrosion resistant alloy (CRA) pipelines or inhibited carbon steel. This method incorporated risk into the decision process. Previous economic analyses comparing solid and clad CRA pipelines to those constructed from inhibited carbon steel have only taken into account the costs for each option without considering the probability or cost of failure. This paper extends the earlier work by examining the effects of varying the assumed probability of failure of the clad pipeline and introducing utility effects.

Introduction

The need to transport unprocessed corrosive multiphase well streams has increased interest in clad CRA flowlines as an alternative to installing inhibited carbon steel. Handling unprocessed corrosive fluids then raises the issues of reliability, safety, and the costs of possible failures.

Although the initial capital costs of a clad pipeline are quite high, the subsequent operating cost over the life of the project are relatively low. The opposite is true for carbon steel where relatively low initial costs may be coupled with significant operating and repair costs. For this reason, a life cycle cost analysis provides a better measure of the overall costs of clad versus carbon steel flowlines.

Earlier work[1] incorporating a life cycle approach indicated that at long lengths, typically greater than 8 km (5 miles) and with increasing diameter, the net present value (NPV) cost for clad and duplex stainless steel (DSS) pipelines was higher and quickly diverged from carbon steel. However, more recent work[2] demonstrated that at shorter line lengths the curves for NPV cost crossed and the clad and DSS pipe were more economic. Moreover, when risk was included in the analysis, the economics were found to depend largely on the probability of failure and the cost implications of

References and figures at end of paper.

failure. A curve was developed that represented the expected monetary value (EMV) indifference between installing carbon steel and clad steel at assumed values for the NPV cost of carbon steel failure (or failures) and the probability of failure (POF) for carbon steel, Figure 1. For these cases the clad POF and the NPV cost of all clad failures were assumed to be 1% and $25 million, respectively. For example, if the NPV cost of all carbon steel failures during the life of a flowline (i.e., lost or deferred production and revenues, cost of repairs, environmental damage and fines, etc.) and the probability of carbon steel failure result in a point above the EMV indifference line, then clad flowlines should be installed. Likewise, Figure 2 shows the same series of curves for different line lengths. As noted, these curves of indifference do not consider a variable POF for the clad case nor do they consider a variable discount factor or the utility concept of money. All of these new factors are considered in this paper.

Impact of Assumed Clad Probability of Failure

To demonstrate the sensitivity of the 1% assumption for the probability of clad failure, a series of curves representing an assumed value for the NPV cost of carbon steel failure(s) were developed. In each case the total NPV cost of a clad flowline failure(s) was held constant at $25 million. These curves represent combinations for the POF of carbon steel and clad flowlines that result in equal EMVs and are accordingly EMV indifference curves similar to those shown in Figures 1 and 2. Figure 3 shows the EMV indifference curves for the case of a 6 5/8-inch O.D.,10-mile long flowline. Note that when the NPV cost of failure(s) for the two options are equal ($25 million), the indifference point for the POF for carbon steel is sensitive to the assumed value for the POF for the clad steel. However, with increasing NPV cost of carbon steel failure(s), the importance of the value assumed for the probability of clad failure diminishes, indicating that the choice between carbon steel and clad becomes less dependent on the assumed probability of a clad steel failure. As noted, all cases assume a constant NPV cost for the clad failure(s) of $25 million.

Using Figure 3, if the assumed POFs are 15% and 70% for clad and carbon steel, respectively, and the assumed NPV cost of a carbon steel failure is $25 million, clad would be the choice on an EMV basis. However, if the NPV cost of failure(s) for carbon steel increases to $100 million and the POF of the clad remains at 15%, the installation of clad flowlines is warranted at carbon steel POF values of 15% or greater.

Figure 4 shows the same data as Figure 3 plotted in a different fashion with lines of constant clad POF. Again, it can be seen that with increasing NPV cost of carbon steel failure(s) the tolerable POF of carbon steel becomes quite small.

Risk and the Discount Factor

Discount rates are often used to account for both the time value of money and risk. In these cases the discount rate is referred to as the riskadjusted discount rate. The use of high discount rates in project evaluation is common in the industry and has the effect of favoring projects that generate cash rapidly (early in the life of the project) compared to longer life projects where much of the cash is received later in the life of the project. It is beyond the scope of this paper to discuss some of the issues with regard to using risk-adjusted discount rates. However, present value profile plots, where the NPV is plotted as a function of the discount rate, are a good method to determine the sensitivity of the NPV calculations to the assumed discount rate. The sensitivity of the discount rate assumption for the 10-mile 6-inch nominal diameter pipeline assumption of a high discount rate favors the case where a significant portion of the total cost is deferred into the future. This is the case for inhibited carbon steel pipelines relative to the CRA installations. For the carbon steel pipeline installation, the Time 0 costs are relatively small compared to the CRA cases.

The Utility Concept

The comparisons made between inhibited carbon steel and clad steel have considered only costs and the desirability of minimizing expected monetary value (EMV) costs with an assumed indifference for money. Research, however, indicates that when people consider the risk involved, they do not make the decision to minimize EMV costs. Utility theory can be used to develop a relationship between money and utility. When faced with a loss, people tend to be risk-adverse and make the decision to minimize expected utility value (where costs are positive). Figure 6 is an example utility curve. It is especially important to note the shape of the utility curve in the 3rd quadrant (labeled risk-adverse). This curve describes the situation where each increment of monetary loss has an increasing increment of negative utility. This behavior has been documented in the literature.[3,4] This behavior is especially important in making decisions having events with a low probability of occurrence coupled with a high cost of loss.

The application of utility theory to decision analysis is relatively straightforward. In this case since costs are assigned a positive value, the objective would be to minimize expected utility value (EUV). To demonstrate the impact of a risk-adverse investor, the relationship between utility and monetary values in the third quadrant were assumed to follow the relationship $y = x^2$ with utility = ($ NPV costs)^2 for this paper. Calculated values of utility were then used to calculate the EUV for each alternative similar to calculating the EMV. An example comparing the deterministic, EMV, and EUV methods is presented in the appendix.

Using this approach and utility function, EUV indifference curves were developed and compared to the EMV indifference curves as shown in Figure 7. This figure demonstrates the sensitivity of the relationship between the POF and NPV cost of failure(s) for carbon steel flowlines. Again, a low probability of failure for the carbon steel flowline coupled with relatively high NPV cost of failure(s) warrant consideration of clad flowlines using the EUV decision criterion.

Utility functions are subjective, vary from individual to individual, and have been demonstrated to be dependent on the amount the individual or company is accustomed to dealing with. Corporate utility functions, if they existed, would depend on the amount of loss that can be absorbed by a company, the strength of the balance sheet, and the corporation's penchant for risk. The objective in this paper is to demonstrate the application of utility theory to the decision to install inhibited carbon steel or CRA flowlines. The application of utility theory is one way to help resolve the issue of high cost - low probability of occurrence events.

Conclusions

The assumed POF of a clad flowline does not have a significant effect on the decision to install either a carbon steel or clad flowline. Rather, the total NPV cost of all failures of the carbon steel line becomes the most important variable. The choice of discount rate and the use of utility theory can have a significant effect on the outcome of such an analysis. The application of utility theory is especially useful when considering low probability of occurrence events that have a relatively large negative outcome.

Acknowledgment

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References

1. Craig, B.D., First International Conference on Clad Engineering, NiDI and ICorr, Aberdeen, Scotland, April 8, 1992.

2. Craig, B.D. and Thompson, R.S., "The Importance of Risk Analysis in Life Cycle Cost Evaluation of Carbon Steel and CRA Pipelines", paper presented at the UK Corrosion and Eurocorr '94, Bournemouth, England, Oct 31-Nov 3, 1994.

3. Swalm, R.O., "Utility Theory - Insights Into Risk Taking", Harvard Business Review, (Nov. - Dec. 1966) p. 123-136.

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Appendices

Examples 1-3 present a comparison of the deterministic, expected monetary value, and expected utility value methods.

Example 1
Deterministic Method

Comparing CRA Clad and inhibited Carbon Steel for a 10-mile, 6-inch O.D. offshore pipeline.

Install 10 miles of 6-inch O.D. carbon steel pipeline, NPV cost = $12 million[2], or

Install 10 miles of 6-inch O.D. Clad pipeline, NPV cost = $23 million[2]

Decision: Select the project having the lowest NPV cost. In this case install the carbon steel pipeline.

Example 2

Expected Monetary Value Method

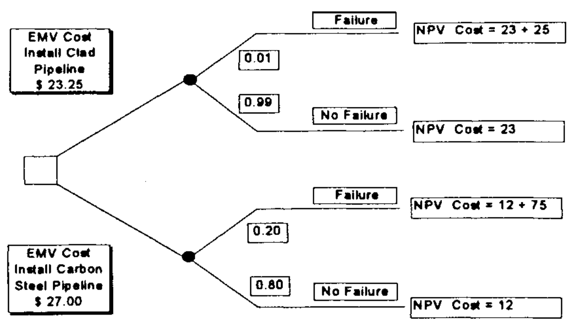
Comparing CRA Clad and inhibited Carbon Steel for a 10-mile, 6-inch O.D. offshore pipeline.

Assumptions:
Clad Pipeline, 1% Probability of a single event or multiple events having a NPV cost = $25 million.

Carbon Steel, 20% Probability of a single event or multiple events having a NPV cost = $75 million.

The NPV costs are in addition to the costs assumed in the base case.

Decision Tree



Expected Monetary Value (EMV) Calculations:
The EMV Cost for the Clad Pipeline:

$0.01 \times (23 + 25) + 0.99 \times (23) = \$\ 23.25$ million.

The EMV Cost for the Carbon Steel Pipeline:

$0.20 \times (12+75) + 0.80 \times (12) = \$\ 27.00$ million.

Decision: Select the alternative with the lowest EMV Cost. In this case, install the Clad Pipeline

Example 3

Expected Utility Value Method

Comparing CRA Clad and inhibited Carbon Steel for a 10-mile, 6-inch O.D. offshore pipeline.

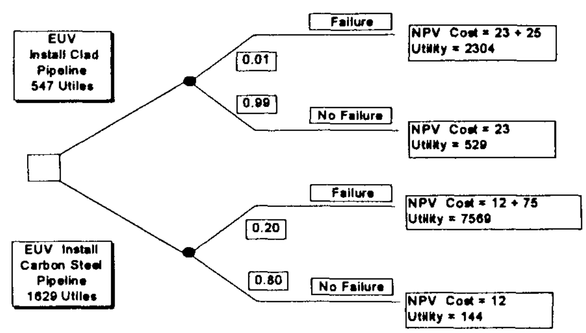
Assumptions:
Clad Pipeline, 1% Probability of a single event or multiple events having a NPV cost = $25 million.

Carbon Steel, 20% Probability of a single event or multiple events having a NPV cost = $75 million.

The NPV costs are in addition to the costs assumed in the base case.

Using the utility function: Utility = $(\text{NPV cost})^2$

Decision Tree



Expected Utility Value (EUV) Calculations:
The EUV for the Clad Pipeline:

$0.01 \times (2304) + 0.99 \times (529) = 547$ utiles

The EUV for the Carbon Steel Pipeline:

$0.20 \times (7569) + 0.80 \times (144) = 1629$ utiles

Decision: Select the alternative with the lowest EUV. In this case, install the Clad Pipeline

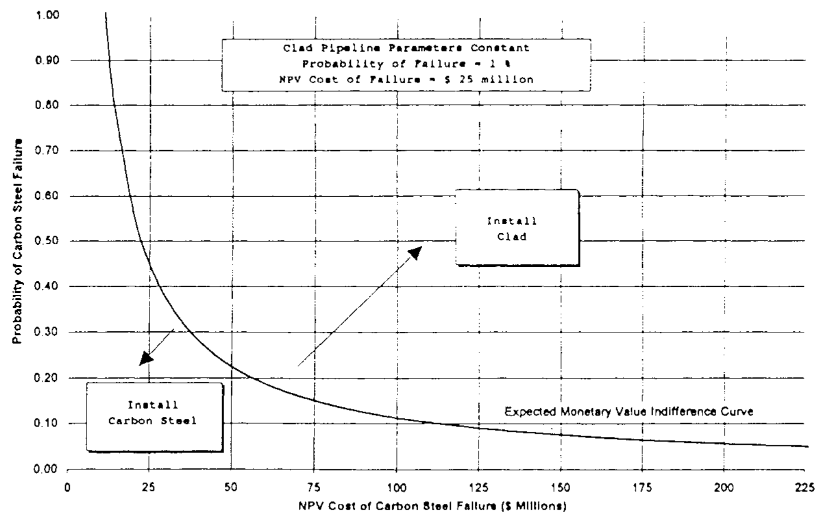


Figure 1. Probability Limit Curve for carbon steel failure, clad versus carbon steel for 10-mile, 6-inch nominal O.D.

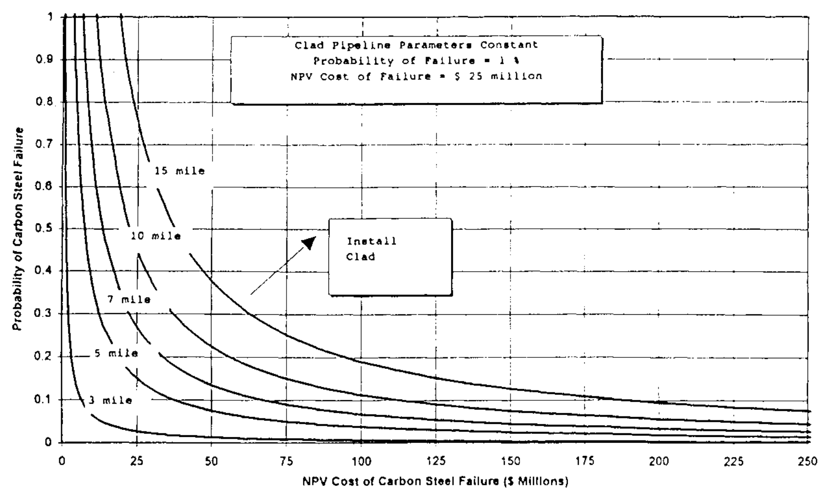


Figure 2. Probability Limit Curves for carbon steel failure, clad versus carbon steel for 6-inch nominal O.D. pipeline, various pipeline lengths.

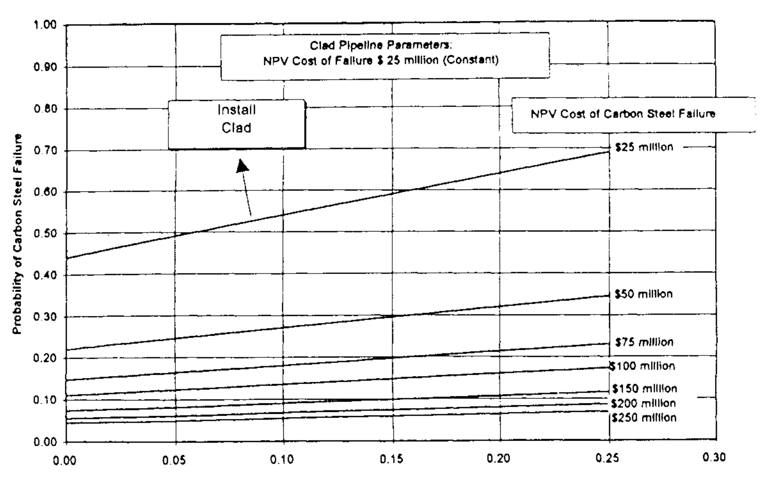


Figure 3. The probability of carbon steel failure versus the probability of clad pipe failure for 10-mile, 6-inch nominal O.D., various NPV costs of carton steel failure.

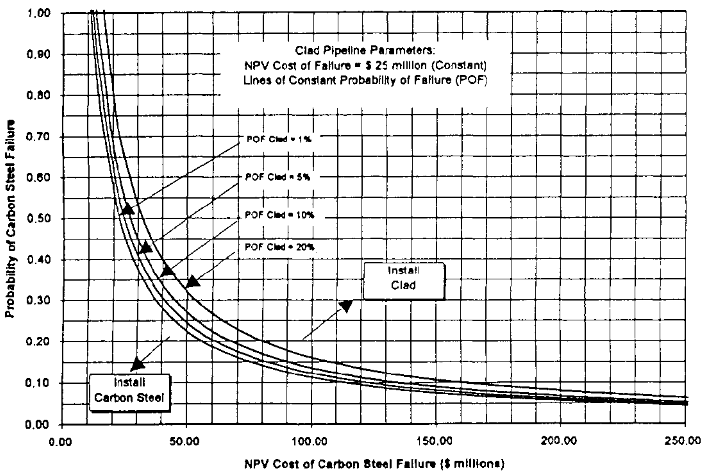


Figure 4. Probability Limit Curves for carbon steel failure, clad versus carbon steel for 10-mile, 6-inch nominal O.D., various probability of failure for clad steel.

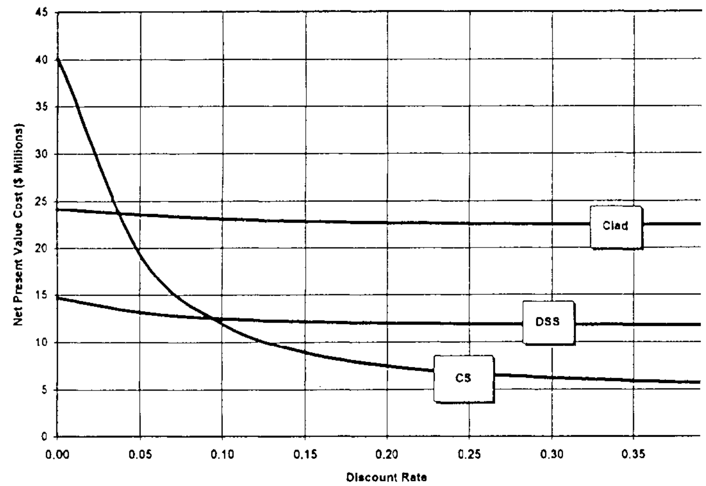


Figure 5. Present Value Profile Plot, 10-mile, 6-inch nominal O.D. Effect of the discount rate on the NPV cost.

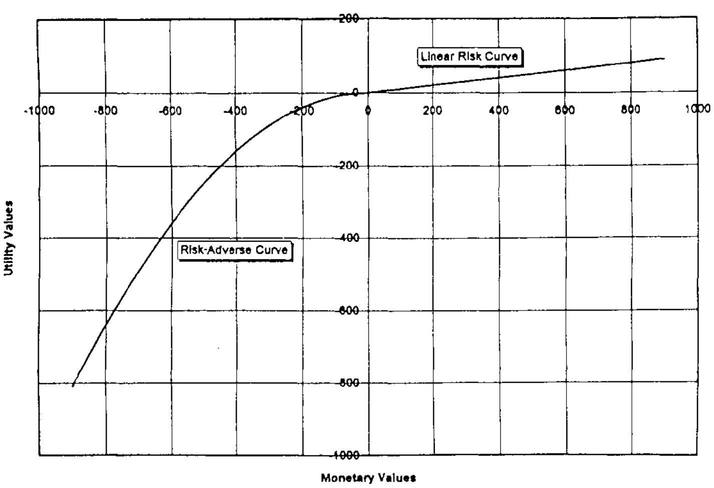


Figure 6. Example Utility function.

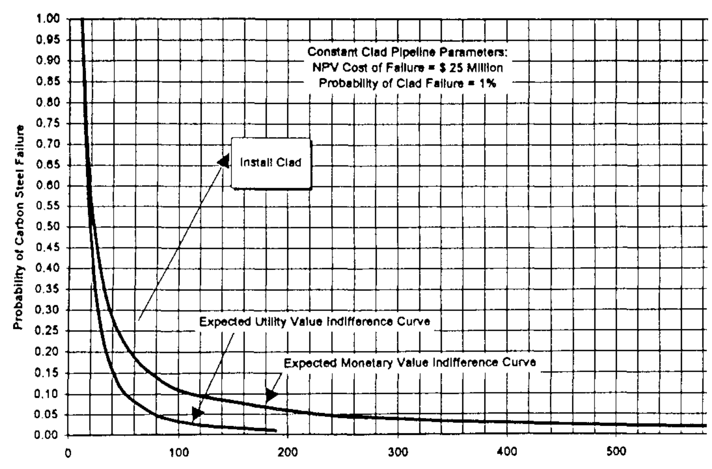


Figure 7. Probability Limit Curves for carbon steel failure, clad versus carbon steel, expected monetary and utility values for 10-mile, 6-inch nominal O.D.