# *Section IV: Design of Database for Performing Qualitative and Quantitative Risk Assessment of Unpiggable Pipelines*

## Acknowledgement

I would like to thank James Choo for providing me with the visual basic programming expertise that brought this database to reality. Without his expert knowledge and experience, it would not have been feasible to implement my theory to the fullest. James performed all the programming on this database, while I developed the theory and the structure for the database.

I also want to thank Professor Bea for trusting me to work out the problems associated with the database on my own and for encouraging me to find a solution. Many times, I thought that this project would be difficult to manage in the last semester of school, but the perpetual support of Professor Bea reassured me that a solution was at hand.

# Introduction

The industrial world is leveraging the use of information technology for managing operations, and companies are developing integrated systems that are able to better handle operations. The first such use of computers by corporations has been to collect information about internal operations, but more and more the focus is switching to external data collection to assist strategic decision-makers.

The energy industry is also riding the wave of computer technology, and has been integrating computer systems into their operations for decades. However, the novelty of the current revolution is that managers and operators are able to track systems from their desks, and if need be, even from their laptops. The technology has been developed extensively to handle computations and large amounts of data, but the connecting software still has to be developed to realize the benefits of the technology.

Currently, the hottest growing occupation is that of database manager, which further reinforces the trend that data collection and analysis is taking a center stage for a large number of companies. Energy companies are currently in the midst of developing many databases that offer real-time information along with fast and reliable results. One area where database technology is being leveraged is the pipeline inspection and maintenance field.

Each energy company manages hundreds of pipelines in any given year, and therefore they are finding that it is worth while to invest in the technology that can manage their operations better. Pipelines are one of the major components of the energy industry and focus currently is on the management of these important lifelines. In the past, when there was a profusion of money in the industry, management of pipelines was less of a priority and money was diverted into exploration and development. With the increased competition worldwide however, it is becoming evident that pipeline management is an area where much money can be saved. Previously, pigging technology was not well developed, and therefore intelligent pigging was not considered a viable method of managing pipelines. Today on the other hand, pipelines are being designed so that they may be pigged, and at the same time pigs are becoming smaller, enabling more pipelines to be inspected.

Managing unpiggable pipelines poses an even more complicated question than managing piggable ones, because only a limited amount of data is available on unpiggable pipelines. The majority of pipelines in service can not be pigged, which leaves the question of, "How can the state of an unpiggable pipeline be determined?" One method of answering this question is to utilize data from piggable pipelines.

Every pipeline has certain identifying characteristics like the operating pressure, the material being transported, or the pH of the material being transported, and these characteristics can be used to match similar pipelines with each other. It should be realized however, that approaching the analysis from an "operating characteristics" angle only addresses one failure mode. The failure mode that is addressed is that associated with corrosion and flaws developed during corrosion processes. Corrosion processes are the leading cause of failure for pipelines and therefore it is a step in the right direction to analyze failure due to flaws caused by corrosion.

The database developed during this project addresses failure of pipelines due to corrosion, and both a quantitative and qualitative methodology is developed for addressing failure of unpiggable pipelines. The fundamental theory for the analysis has been summarized in the PIMPIS spring and summer reports, 1998 [2]. The quantitative theory for the database is summarized within this report however due to its complexity and to help the reader obtain a better grasp of the theory.

# List of Symbols

1. *b :* y intercept of regression line
2. $d_{avg.}$: average depth of flaws; unique to a flaw size; average of matched piggable records for a given time in the pipeline's history
3. *e:* 2.7182818…….
4. *f(t):* probability density function; time dependent
5. *h(t):* hazard function; time dependent
6. *H(t):* cumulative hazard function; time dependent
7. *m:* slope of regression line
8. *n:* strain hardening index
9. $n_{avg.}$: average number of flaws; unique to a flaw size; average of matched piggable records for a given time in the pipeline's history
10. $n_{exp..}$: expected number of flaws as calculated through the use of a piggable data
11. $\overline{p}_b$ : mean burst pressure
12. $p_b^{wl}$ : burst pressure of pipe with wall loss
13. $\overline{p}_o$ : mean operating pressure
14. $P_{fIndividual}$: probability of failure due to an individual flaw
15. $P_{fMax}$: maximum probability of failure allowed for operating pipeline
16. $P_{fSystem}$: probability of failure of system taking into account individual flaws
17. *R:* mean radius of pipeline
18. *S(t):* survivor function; time dependent
19. *t:* time
20. $t_{init..}$: initial thickness of pipeline
21. $t_{min}$: corroded thickness of pipeline
22. $x_i$: i$^{th}$ abscissa value used for regression calculations
23. $\overline{x}$ : mean of abscissa values
24. $y_i$: i$^{th}$ ordinate value used for regression calculations
25. $\overline{y}$ : mean of ordinate values
26. $\beta$: safety index
27. $\phi$ : fraction of circumference that is corroded
28. $\Phi(\beta)$: standard normal cumulative function
29. $\kappa$: shape parameter for Weibull distribution
30. $\lambda$: scale parameter for Weibull distribution
31. $\sigma_b$ : standard deviation of the burst pressure

*32.* $\sigma_{uts}$: ultimate tensile strength of pipeline material

*33.* $\sigma_o$ : standard deviation of the operating pressure

# Theory for Quantitative Analysis

Quantitative analysis is considered in many cases to be the most accurate form of analysis, because it is based upon numbers. For unpiggable pipelines it is hard to obtain estimates for flaw distributions, and therefore data pertaining to piggable pipelines is utilized as much as possible.

The theory for quantitative analysis involves matching operating characteristics belonging to unpiggable pipelines with those of piggable pipelines, and organizing the data in such a manner as to obtain an estimate for the flaw distribution in unpiggable pipelines. Therefore, the first requirement is to have enough data present to be able to perform the analysis. In this case, enough pipeline histories must be present in the database so that when a search is performed enough matches are found to perform an analysis. The next step is to analyze the data in a coherent manner to make the analysis valid.

Once a set of piggable pipelines have been matched with the unpiggable one being analyzed and the corresponding data retrieved from the database, it is necessary to also account for the age differences that might exist between pipelines. What is taking place is an averaging process of data from the piggable pipelines, and therefore it is necessary to sample the data from the same point for all the piggable pipelines for the analysis to be valid.

The two most important characteristics that are of interest are the distribution of depths and the distribution of flaws. Therefore, the trend of these two characteristics needs to be analyzed. For the reason of simplicity it is assumed that the trend of flaw growth and depth growth can be represented by a linear regression line that has a slope *m*, and a zero intercept. The slope of this line can be calculated using Equation 1.

$$m = \frac{\sum_{i=1}^{n} y_i x_i}{\sum_{i=1}^{n} x_i^2} \qquad \textbf{EQ. 1}$$

The resulting graph of the data looks like the graphs shown in Figure 1.

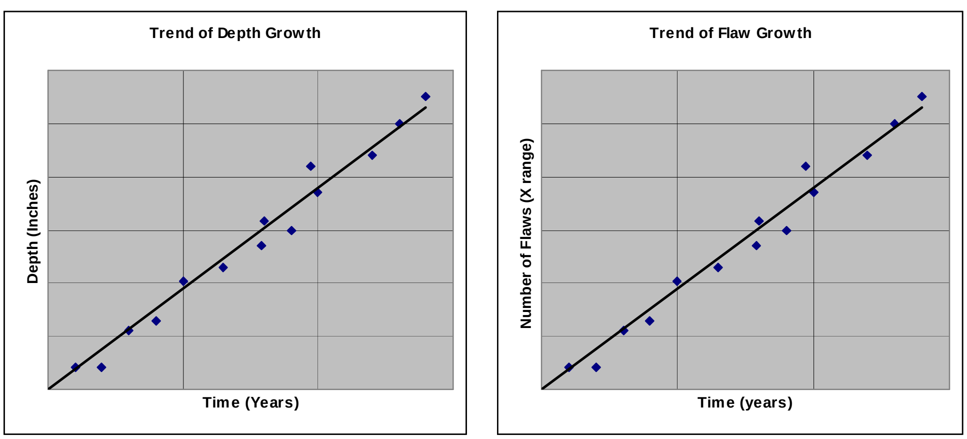



**Figure 1:** Trend analysis of flaws and depths for a piggable pipeline.

Next it is desired to develop a flaw and depth distribution for the unpiggable pipeline. To analyze the depth trend for an unpiggable pipeline, the first task is to "enter" the graph of each retrieved record for piggable pipelines along the time axis, where the value of time equals that of the age of the unpiggable piepline. See Figure 2.

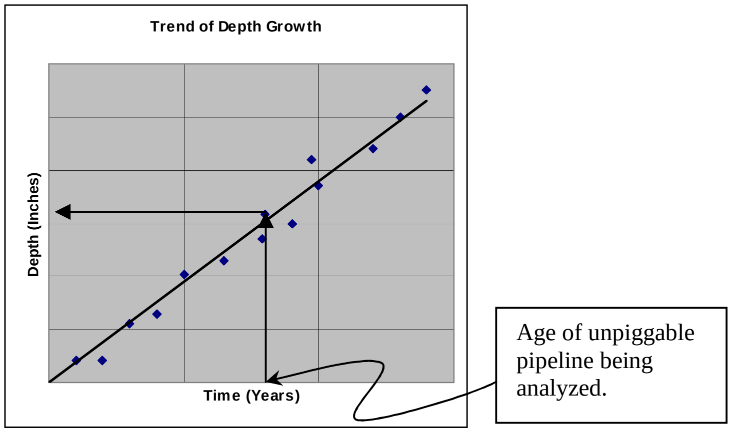



**Figure 2:** Determine number of flaws present, of a certain range in piggable pipeline, at time equal to age of unpiggable pipeline.

Once all the depths for the piggable pipelines have been calculated that correspond to the time equal to the age of the unpiggable pipeline, the data is collected and averaged. Therefore, now we can predict that at time *X* the unpiggable pipeline had a certain type of flaw with an average depth *Y* according to the data that is available to us. The next step is to determine the time distribution for developing *Y* depth for the flaws. For this step, the previous procedure is reversed, and the graph in Figure 2 is "entered" along the ordinate and a corresponding time is read for each piggable pipeline which in essence will provide a distribution for the unpiggable pipeline. See Figure 3.

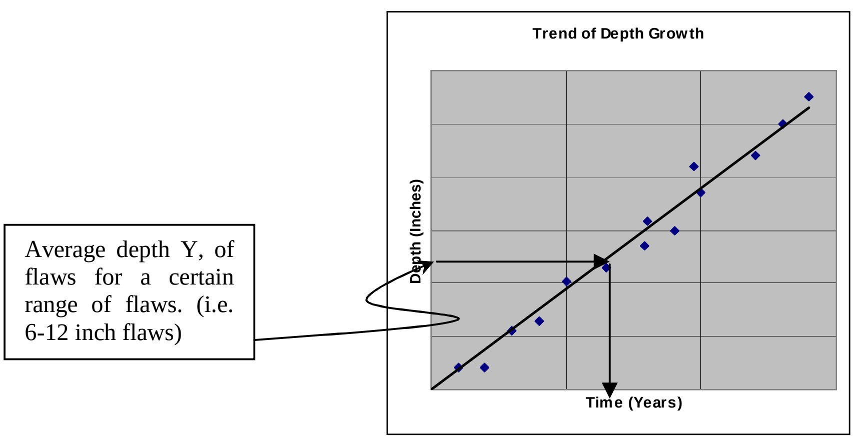



**Figure 3:** Time to develop *Y* depth for a certain flaw range (i.e. 6-12 inch flaws). Time value obtained from graph is subsequently used to develop a distribution for developing *Y* depth for a certain range of flaws.

Now that a range of duration to develop Y depth has been determined, the next step is to fit a distribution to these values. For our purpose the Weibull distribution was chosen due to its versatility in representing various distribution shapes. The Weibull distribution is described in Equation 2. For further details the reader is referred to the PIMPIS summer report of 1998 [2].

$$S(t)=e^{-(\lambda t)^{\kappa}} \quad f(t)=\kappa\lambda^{\kappa}t^{\kappa-1}e^{-(\lambda t)^{\kappa}} \quad h(t)=\kappa\lambda^{\kappa}t^{\kappa-1} \quad H(t)=(\lambda t)^{\kappa} \quad \text{EQ.2}$$

In Equation 2 for all time, t >0, $\lambda > 0$ and $\kappa > 0$ and are called the scale and shape parameters of the distribution, respectively. *S(t)* is the survivor function, *f(t)* is the probability density function, *h(t)* is the hazard function and *H(t)* is the cumulative hazard function.

To fit a set of data to the Weibull distribution, the data points first have to be arranged in ascending order. Once this has been done, each point is assigned a percentile that is respective of the order. For example, if there are 5 data points, the first point represents the 1/5 percentile (20%), the second is the 2/5 percentile and so on. This can be further expanded depending on how many points are available.

The next step is to fit the distribution, and this can most easily be performed graphically, but fundamentally it is a mathematical procedure. First the data points are plotted, as shown in Figure 4.

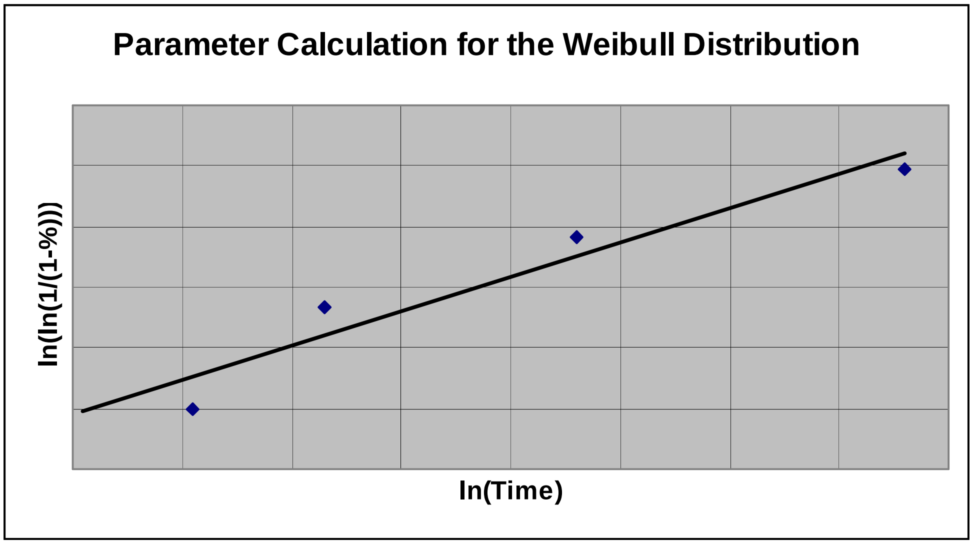



**Figure 4:** Calculation of the shape and scale parameter for the Weibull distribution.

A convenient feature of the Weibull distribution is that when it is plotted in the manner presented in Figure 4, the shape and scale parameters can be determined from the slope and intercept of the linear regression line. The slope of the line can be determined by using Equation 3.

$$m=\frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \qquad \textbf{EQ. 3}$$

The intercept on the other hand can be determined by the use of Equation 4.

$$b=\bar{y}-m\bar{x} \qquad \textbf{EQ. 4}$$

Reverting back to Equation 2, the scale and shape parameters are $\lambda$ and $\kappa$ for the distribution respectively. The slope of the graph yields the shape parameter, and the scale parameter is equivalent to $e^{(b/m)}$. Knowing these two values, the distribution for the flaws can be plotted. The distribution therefore represents the probability of having *Y* number of flaws in the unpiggable pipeline at various times. It must also be kept in mind that the distribution is fitted according to the age of the unpiggable pipeline and therefore is most accurate at the "present time" of analysis. At any other "time" the reliability of the results tends to decrease. For a more accurate time-history analysis it is recommended that various scenarios are investigated and a trend obtained from such an analysis. Weibull distributions with various shape parameters are shown in Figure 5.

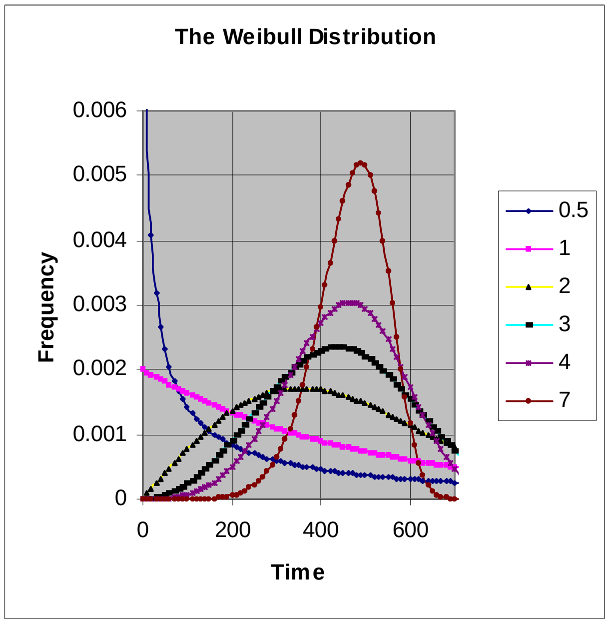



**Figure 5:** The varying shape of the Weibull distribution as the shape parameter changes. More peaked curves represent higher shape parameters.

Proceeding further with the analysis, the next step is to determine the burst pressure for a particular flaw type. The burst pressure equation used to calculate the burst pressure, $p^{wl}{}_{b}$, is shown in Equation 5. [5]

$$p_b^{wl} = \left(\frac{2}{1-\phi}\right)^n \frac{t_{\min}}{R}\left[\left(\frac{1}{2}\right)^{n+1} + \left(\frac{1}{\sqrt{3}}\right)^{n+1}\right]\sigma_{uts} \qquad \textbf{EQ. 5}$$

$\phi$ in Equation 5 represents the percentage of the circumference that has been corroded, $n$ is the strain hardening index, $t_{\min}$ is the minimum thickness, $R$ is the radius, and $\sigma_{uts}$ is the ultimate tensile strength of the steel used for the pipe. $t_{\min}$ however is dependent on the distribution of the flaw depths, and therefore can be represented by Equation 6.

$$t_{\min} = t_{init.} - d_{avg.}\left(1 - e^{-(\lambda t)^{\kappa}}\right) \qquad \textbf{EQ. 6}$$

In Equation 6, $d_{avg.}$ is the average depth of a certain range of flaws, which was calculated using the numbers obtained from the piggable pipeline data. It is emphasized, once again that this average depth is calculated using the pipeline characteristics and the age of the unpiggable pipeline. Therefore, this is an "average depth" that is multiplied by the probability of its occurrence, and does not per se represent a depth that is changing dynamically. What is changing dynamically however is the probability that a depth equal to the average depth will occur in any given year. Performing the analysis on an unpiggable pipeline at different ages yields different results and therefore it is recommended that this analysis be performed every year.

The number of flaws also plays an important part in the calculations, and a similar analysis can be performed. The number of flaws expected at any given time can be calculated using Equation 7.

$$n_{\exp} = n_{avg}\left(1 - e^{-(\lambda t)^{\kappa}}\right) \qquad \textbf{EQ. 7}$$

Equation 7 is utilized when the total probability of failure is desired, and it is applied to Equation 7a.

$$P_{fSystem} = 1 - \left(1 - P_{fIndividual}\right)^{n_{\exp}} \le P_{fMax} \qquad \textbf{EQ. 7a}$$

To calculate the probability of failure associated with the corroded thickness $t_{\min}$, Equation 8 can be utilized.

$$P_{fIndividual} = 1 - \Phi(\beta) \qquad \textbf{EQ. 8}$$

$\beta$ is the safety index and can be evaluated through the use of Equation 9 and $\Phi$ is the standard normal cumulative function.

$$\beta = \frac{\bar{p}_b - \bar{p}_o}{\sqrt{\sigma_b^2 + \sigma_o^2}} \qquad \textbf{EQ. 9}$$

In Equation 9, $\sigma_b$ is the standard deviation of the mean burst pressure, $\sigma_o$ is the standard deviation of the mean operating pressure, and the terms in the numerator are the mean burst and operating pressures for the pipeline. For the calculations in Equation 9, all terms are provided for in the database, except for the standard deviation of the burst pressure. The standard deviation of the mean burst pressure is taken to be 20% of the mean burst pressure for all cases. In the future, this aspect of the calculation can be made more dynamic, but for the present time, it is deemed satisfactory for calculating the probability of failure. [6]

Due to the fact that Equation 8 can not be evaluated directly, the series in Equation 10 was utilized to obtain a value for the standard normal cumulative distribution, $\Phi$.

$$P(\beta) = \frac{1}{2} + \frac{1}{\sqrt{2\pi}} \sum_{n=0}^{\infty} \frac{(-1)^n \beta^{2n+1}}{n! 2^n (2n+1)} \qquad \textbf{EQ. 10}$$

In Equation 10, $n$ is the number of iterations used and $\beta$ is the safety index, same as defined before. This concludes the quantitative analysis of the probability of failure for unpiggable pipelines, and next the qualitative analysis is discussed.

# Theory for Qualitative Analysis

The qualitative analysis for the database was the application of the theory developed during the spring of 1998, which was also accompanied by a report. Summarizing the findings of that report briefly is Equation 11.

$$CorrosionLoss = \left[1 + e^{(1-Nt)}\right]\left[\log(1+t)\right]^{P}\left[1 + \frac{1}{(1+t)}\right]\left[t^{\frac{1}{3}}\right] \qquad \textbf{EQ. 11}$$

The corrosion loss of a metal can be estimated by Equation 11, but certain parameters like N and P must be determined first. The corrosion loss is calculated in mils and *t* has the units of years. The initial value of N and P are dependent upon the type of steel that is being used for the pipe, and Table 1 summarizes what these values are for various metals. For further details refer to the Spring 1998 PIMPIS report [1].

| *VALUES FOR ATMOSPHERIC CORROSION | **P** | **N** |
|---|---|---|
| **Mild Steel** | 14 | 1.5 |
| **Low Alloy Steel** | 10 | 2 |
| **Nickel Iron Alloys** | 5 | 3.5 |
| **Stainless Steel** | 1.5 | 7 |
| **Titanium** | 0.25 | 10 |

**Table 1:** Derived values of N and P for Equation 11.

These values, as stated in the table, have been derived for atmospheric corrosion, and therefore need to be adjusted for the specific condition that is present in the pipeline. The major characteristics that were accounted for is pH, and flow characteristics, because both play an important role in the metal's ability to develop a passive film. The relationship of pH to N and P is summarized by Equation 12.

$$P_{new} = P_{orig}^{\left(\frac{2.8}{pH^{0.47}}\right)} \qquad N_{new} = N_{orig}^{\left(\frac{2.8}{pH^{0.47}}\right)^{-1}} \qquad \textbf{EQ. 12 (a \& b)}$$

Next, the relationship between head-loss and flow characteristics is accounted for by the use of Equation 13. For a more in depth explanation of the theory for these calculations, the reader is referred to the Spring 1998 PIMPIS report.

$$P_{new}^{*} = P_{new}\left[\left(1.05 - \frac{\%HL_{TotalLength}}{100}\right)\frac{\%Length}{100} + \frac{\%HL_{TotalLength}}{100} + 0.20\right] \qquad \textbf{EQ. 13}$$

*N* is not affected by the flow characteristics, and therefore does not need to be adjusted. *P* on the other hand needs a multiplication factor that changes with varying head loss over the total length of the pipeline, and also according to the location of the analysis along the pipeline's length. For example if the calculation is desired at the mid point of the pipeline's length, the value of %Length would be 50% and so on. Upon entering all the relevant data into the database the probability of failure is calculated in the same manner as for the qualitative analysis. Refer to

Equations 8, 9 and 10. The standard deviation for the burst pressure however is taken to be 0.4 times the burst pressure calculated using the given data. [1]

# Database Installation Instructions

The database for the PIMPIS project is in Access 97 format and is called Pipeline Management. The data that accompanies the database structure is included in the file named Pipeline Management Data. When opening the database activate the Pipeline Management file, not the data portion.

If the database is copied to another disk or hard drive, some additional steps must be performed. After copying the database it is always necessary to link tables, because the copying process eliminates the links between the data and the control module of the database. The disk that is included with this report has a fully functioning version of the database, but if a copy of the database is desired on another disk the tables have to be linked once the copying process is finished. To link the tables follow the procedure outlined below:

- Click the **Tools** button on the header
  - Then **Add-Ins** and select
    - **Linked Table Manager** - **Select all** and press **OK**
    - Select the **Pipeline Management Data** file component of the database and press **OK**

Now the database can be operated.

The disk included with this report also contains an MDE version if the database, which is a version of the database that can not be edited. All the tables can be updated with new data, tables can be modified minimally, and queries can be changed, but the forms and programmed modules can not be edited. Changes to this file might prevent the database from functioning correctly so caution must be used if editing is desired.

On the other hand, changes to the full file called Pipeline Management can be made. Changes to one part of the database might affect another part so changes to all the relevant parts of the database must be performed which the initial change affects. To do this however a complete understanding of the database structure is necessary.

# Database User Interface

The interface of a database is functionally a gateway for the user to access the data in the database and to manipulate it. Users in the future might potentially use the database many times a day, and therefore it must be designed in an ergonomic fashion. The interface of the PIMPIS database still needs improvement, but the foundations have been set for future work.

Upon opening the database, the user is met with the main switchboard that contains three options. See Figure 6. The three options are labeled as "Operating Characteristics - Piggable", "Inspection Results" and "Operating Characteristics - Unpiggable".

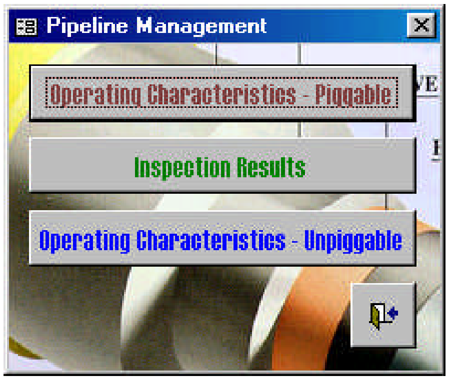
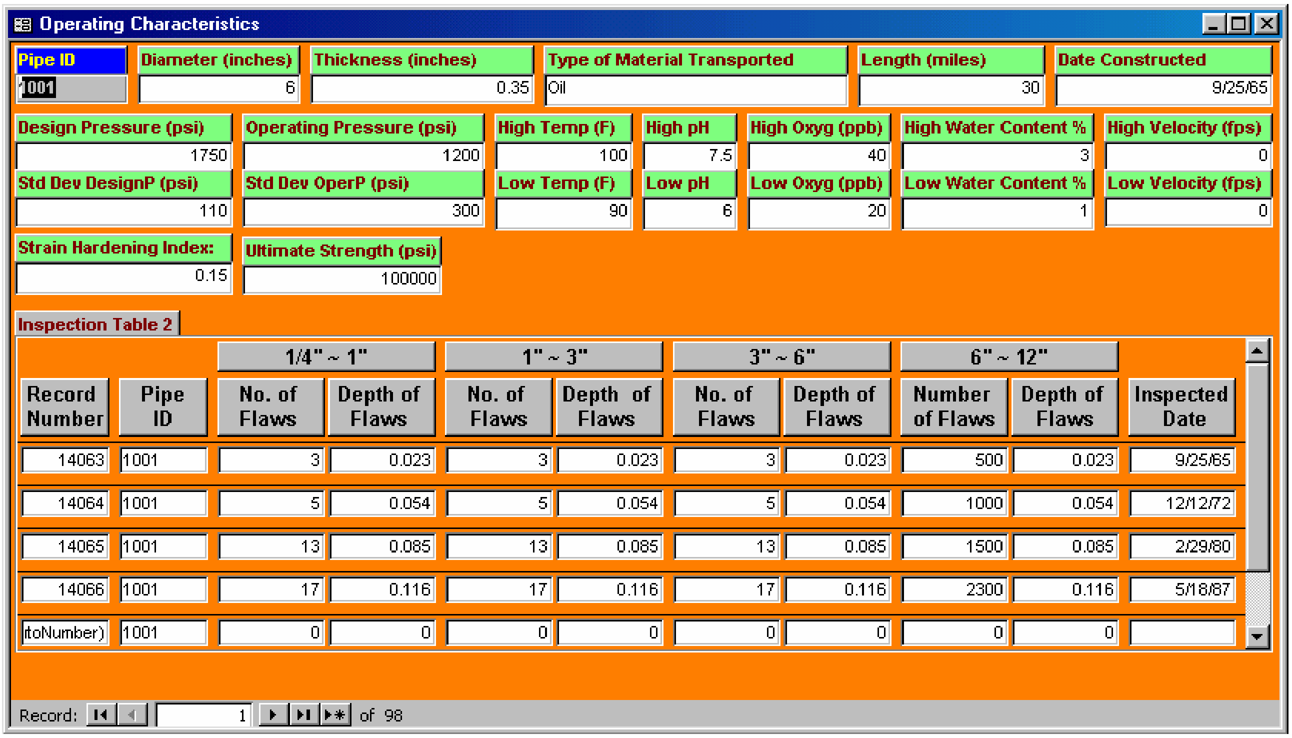



**Figure 6:** Main switchboard for PIMPIS.

Upon clicking on the "Operating Characteristics - Piggable" button the form in Figure 7 is activated. This form contains information on the operating characteristics of the piggable pipeline, as well as the inspection results that were done with pigs.



Operating Characteristics

| Pipe ID | Diameter (inches) | Thickness (inches) | Type of Material Transported | Length (miles) | Date Constructed |
|---|---|---|---|---|---|
| 1001 | 6 | 0.35 | Oil | 30 | 9/25/65 |

| Design Pressure (psi) | Operating Pressure (psi) | High Temp (F) | High pH | High Oxyg (ppb) | High Water Content % | High Velocity (fps) |
|---|---|---|---|---|---|---|
| 1750 | 1200 | 100 | 7.5 | 40 | 3 | 0 |

| Std Dev DesignP (psi) | Std Dev OperP (psi) | Low Temp (F) | Low pH | Low Oxyg (ppb) | Low Water Content % | Low Velocity (fps) |
|---|---|---|---|---|---|---|
| 110 | 300 | 90 | 6 | 20 | 1 | 0 |

| Strain Hardening Index: | Ultimate Strength (psi) |
|---|---|
| 0.15 | 100000 |

Inspection Table 2

| | | 1/4" ~ 1" | | 1" ~ 3" | | 3" ~ 6" | | 6" ~ 12" | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Record Number | Pipe ID | No. of Flaws | Depth of Flaws | No. of Flaws | Depth of Flaws | No. of Flaws | Depth of Flaws | Number of Flaws | Depth of Flaws | Inspected Date |
| 14063 | 1001 | 3 | 0.023 | 3 | 0.023 | 3 | 0.023 | 500 | 0.023 | 9/25/65 |
| 14064 | 1001 | 5 | 0.054 | 5 | 0.054 | 5 | 0.054 | 1000 | 0.054 | 12/12/72 |
| 14065 | 1001 | 13 | 0.085 | 13 | 0.085 | 13 | 0.085 | 1500 | 0.085 | 2/29/80 |
| 14066 | 1001 | 17 | 0.116 | 17 | 0.116 | 17 | 0.116 | 2300 | 0.116 | 5/18/87 |
| itoNumber) | 1001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

Record: 1 of 98

**Figure 7:** Operating characteristics form for piggable pipelines.

The data on the form can be organized into three different categories. The three categories are: physical characteristics, operating characteristics, and inspection results. Each of these categories is further subdivided as shown in Table 2.

| Physical Characteristics | Operating Characteristics | Inspection Results |
|---|---|---|
| Diameter (inches) | Design Pressure | 1/4"-1" No. Flaws |
| Thickness (inches) | Std. Dev. Design Pressure | 1/4"-1" Flaw Depth |
| Length (miles) | Operating Pressure | 1"-3" No. Flaws |
| Date Constructed | Std. Dev. Operating Pressure | 1"-3" Flaw Depth |
| Strain Hardening Index | High Temperature ($^0$F) | 3"-6" No. Flaws |
| Ultimate Tensile Strength | Low Temperature ($^0$F) | 3"-6" Flaw Depth |
| | High pH | 6"-12" No. Flaws |
| | Low pH | 6"-12" Flaw Depth |
| | High Oxygen Content (ppb) | |
| | Low Oxygen Content (ppb) | |
| | High Water Content (%) | |
| | Low Water Content (%) | |
| | High Velocity (fps) | |
| | Low Velocity (fps) | |

**Table 2:** List of fields on the Operating Characteristics Form.

The physical characteristics listed in the Table 2 were chosen according to how important they were in the calculation of the probability of failure. The physical characteristics represented in Table 2 are the most basic characteristics and if it is desired in the future to augment this portion of the database it can be done so without difficulty. The operating characteristics to be listed in the database were chosen as the characteristics that are most important to predicting corrosion in a pipeline. Therefore when performing searches of the database to analyze an unpiggable pipeline, it is recommended that the operating characteristics be used to search the database as much as possible.

The inspection results of the database is divided into several categories of flaw sizes and their depth. The number of flaws in each range of flaw sizes is a count of the number of flaws that are in that range per mile. Even though in a database many records can be entered, it has been designed to only store ranges of flaws to minimize the number of records in it. If the characteristic of each flaw is recorded in the database every time an inspection is performed, the memory requirements would be very large, a task for which Access is not suited for. The flaw size refers to the circumferential length of the flaw, but usually the longitudinal length is as large or larger than the circumferential length. The important concept here is to realize that for burst calculations the circumferential length of the flaw is what controls the burst pressure. Figure 8 shows the form used to enter the inspection results for piggable pipelines into the database.

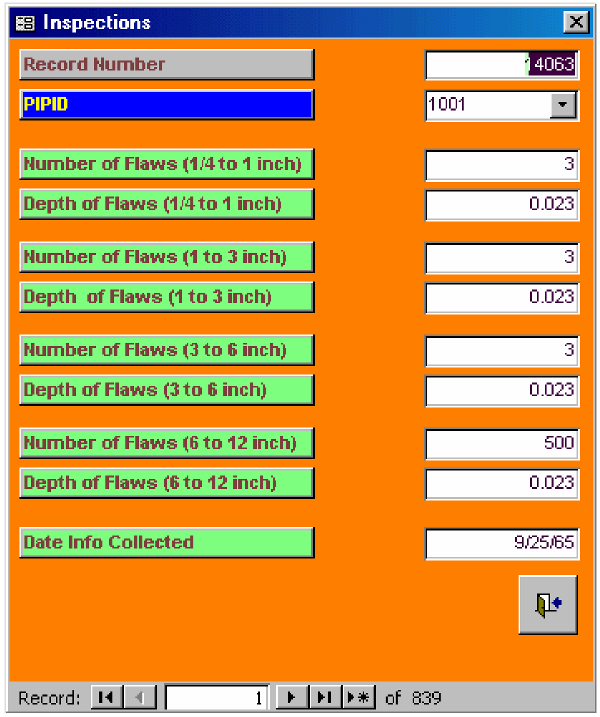



**Figure 8:** Inspections form for piggable pipelines.

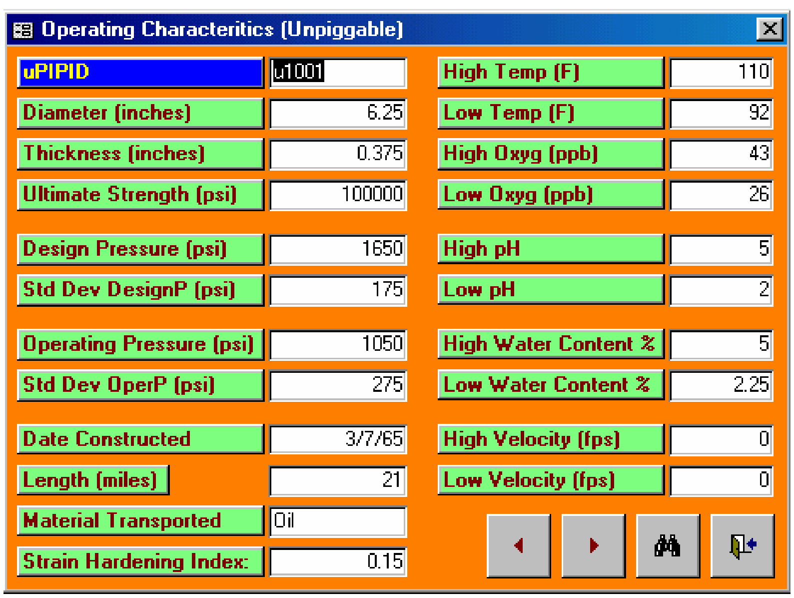



**Figure 9:** Operating characteristics form for unpiggable pipelines.

The operating characteristics recorded for the unpiggable pipelines are the same as those recorded for the piggable pipelines, but this is the only information that is known about these pipelines. These characteristics are used to search the piggable pipeline record set to perform any analysis on the unpiggable pipelines. The corresponding form can be found in Figure 9. To search the database, the button on the form with the binoculars is utilized. Upon pushing the button, the form in Figure 10 is activated.

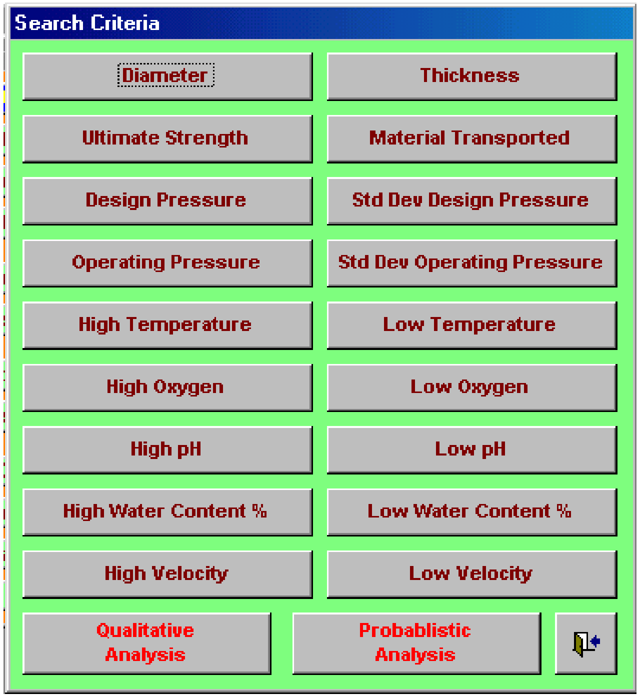



**Figure 10:** Search criteria form where selections are made to control the search of the database.

In the search criteria form, when a button is activated, the database is searched according to the criteria listed on the button. Operating characteristics are searched according to high and low recorded values, and physical characteristics are searched according to values that are between 25% above and below the specific physical characteristic chosen. For example, if the button with the word "Thickness" on it is activated, the database is searched for piggable pipelines that have a thickness that falls between 0.75 and 1.25 times the thickness of the unpiggable pipeline. The same is performed for the diameter, design pressure, and operating pressure characteristics. The buttons for the standard deviation are also shown, and searches for these characteristics are performed in the same manner as for the characteristics listed above.

To perform the analysis, the appropriate buttons are chosen, and the button for "Probabilistic Analysis" is activated. If matching records are found, then the form in Figure 11 is activated. The two fields on the left hand side of the form show the average number of years that the searched pipelines require to develop a certain depth or number of flaws. For a review of the theory behind the quantitative analysis the reader is referred to the quantitative analysis section of this report and to Figure 3.

The three fields to the right illustrate the expected depth and the expected number of flaws as calculated by the database for each year that the pipeline is in operation. To print reports of the probability of failure and the expected number of flaws and the expected remaining thickness of the pipeline, the buttons at the bottom of the form can be utilized.

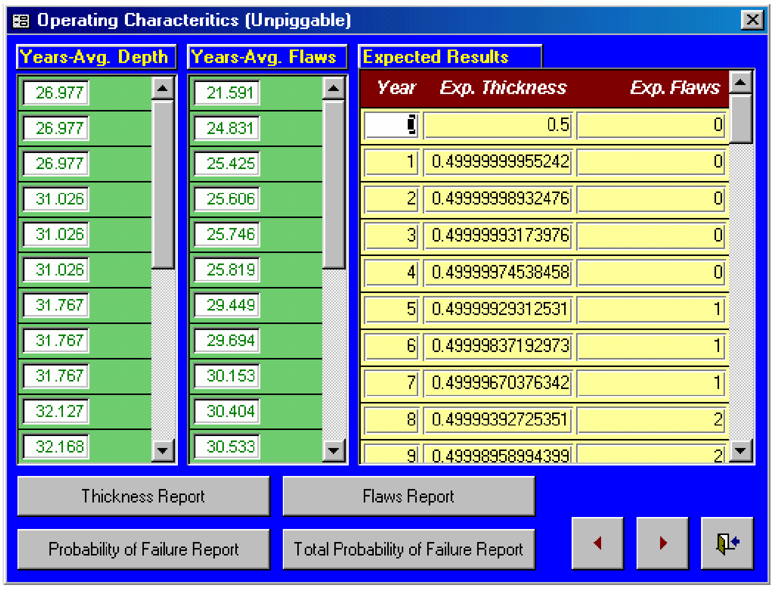



**Figure 11:** Form used to review the results of calculations performed by the database, according to the search criteria specified in the "Search Criteria" form.

The various reports that are capable of being produced are a thickness report, flaws report, probability of failure report and a total probability of failure report.

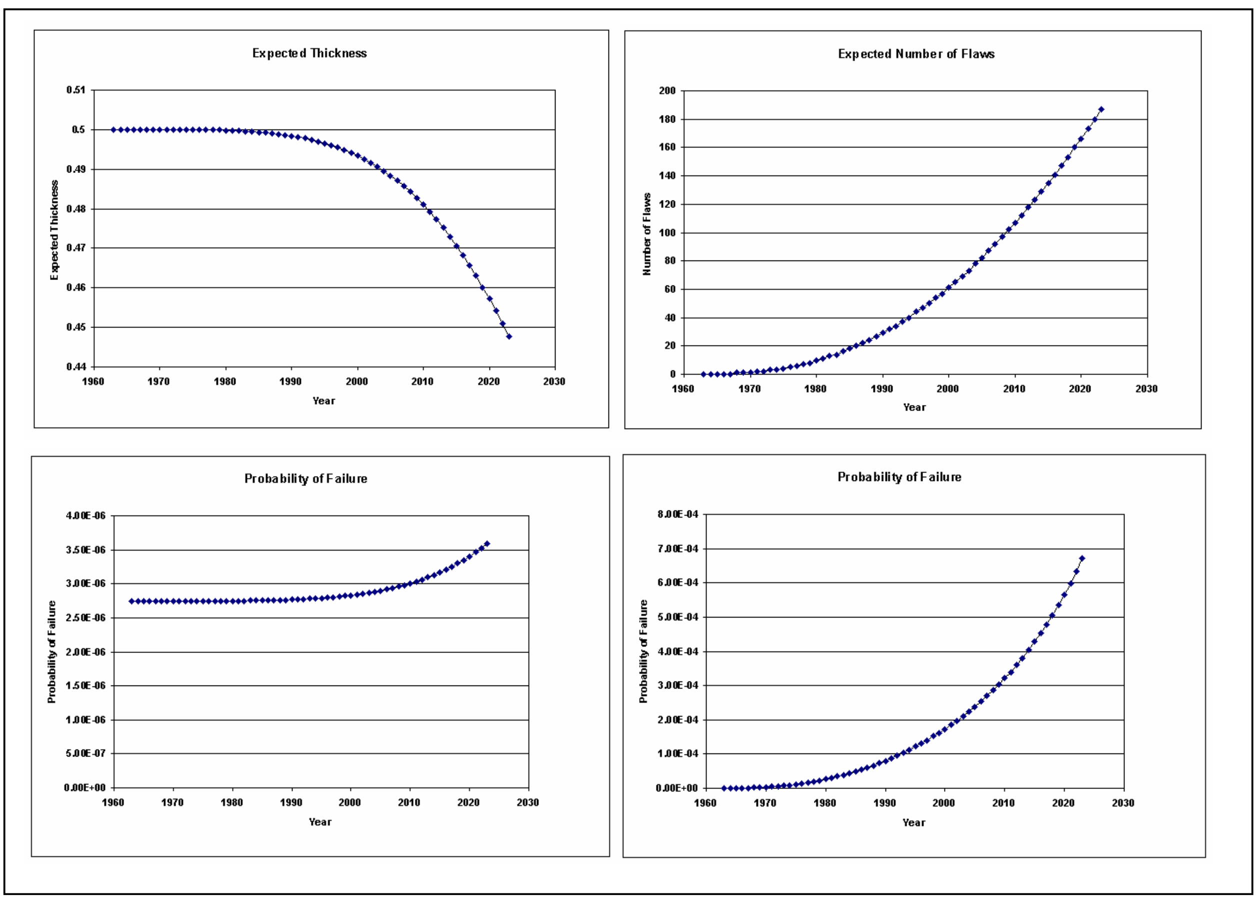



**Figure 12:** Various reports produced by the pipeline inspection, maintenance and performance information system.

Figure 12 shows the results of the various reports for a specific case. The difference between the two probability of failure reports is that the total probability of failure represents the probability of failure when all 6 to 12 inch flaws are accounted for. The simple probability of failure on the other hand is only dependent upon the reduced thickness of the pipeline. The total probability of failure represents the probability of failure per mile of pipeline. If the data is grouped according to some other criteria than per mile, than the new grouping controls the probability of failure.

The second type of analysis that can be performed is that of qualitative analysis. To run a qualitative analysis the "Qualitative Analysis" button is activated. The corresponding form that appears is the Qualitative Analysis form. See Figure 13. With the qualitative analysis only several criteria like the type of steel, percent head loss, and percent length where the analysis is taking place needs to be specified. For further information on this analysis the reader is referred to the Spring 98 PIMPIS report.

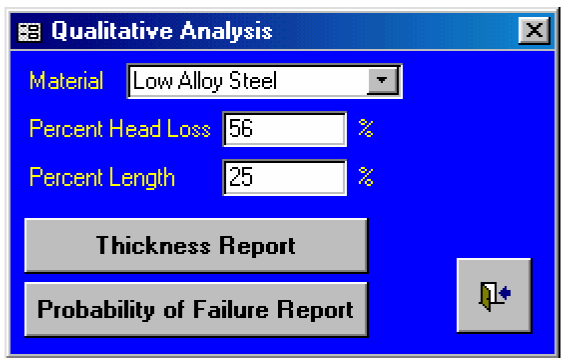



**Figure 13:** Qualitative analysis form.

After performing the qualitative analysis, the results shown in Figure 14 are obtained.

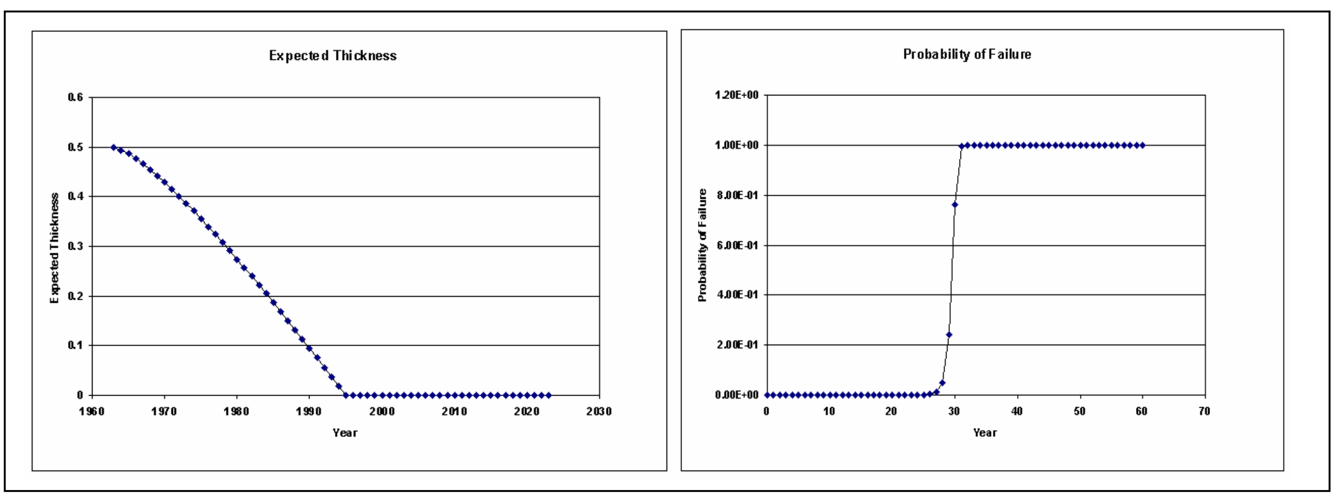



**Figure 14:** Expected thickness and probability of failure report for qualitative analysis.

The results of the analysis are case specific and apply to a certain section of an unpiggable pipeline only. For example the numbers in Figure 14 are representative of a pipeline that is constructed from a low alloy steel, has a head loss of 56% and the analysis is at 25% of the total length. It should also be noted that the probability of failure is calculated in the same manner as in the quantitative analysis except corrosion is assumed to be uniform over the total circumference of the pipeline. Therefore the number of flaws is irrelevant in this calculation.

This concludes the description portion of the database report. It must be kept in mind that this is an alfa version of the knowledge-based system for predicting the probability of failure of a pipeline. A much more comprehensive database system can be developed in the future, that incorporates other failure modes and analyzes the corrosion failure mode in an even more comprehensive manner.

## Conclusion

The purpose of any tool is to help the user perform a function that is difficult to perform. In this case, the purpose of the database is to help pipeline management personnel make better decisions when they are dealing with unpiggable pipelines. Analysis for a piggable pipeline is only dependent upon data, and therefore as long as data is available, decisions can always be backed by data. In the case of unpiggable pipelines, data is not available so two analysis methods have been developed.

The quantitative analysis is highly dependent upon piggable pipeline data, but the main aspect of this technique is to leverage existing knowledge of piggable pipelines for analyzing unpiggable pipelines. In essence this is the most accurate method of performing an analysis for unpiggable pipelines, but the data requirements are relatively high. The analysis requires a minimum number of piggable pipeline records to be available and for these records to be similar to the unpiggable one. Searches can be limited or expanded depending upon how many search criteria are chosen, but the key is that the user has the option to choose. This flexibility in the analysis enables the user to perform either a very comprehensive analysis or a watered down analysis.

The qualitative analysis on the other hand is only dependent upon the data about the physical and operating characteristics of the unpiggable pipeline. The main portion of this analysis is dependent upon the corrosion prediction method used, and therefore the majority of potential error is rooted in this equation. The key however is that with time the equation can be refined and therefore made more accurate. It is recommended that before the system is implemented test be performed to validate the accuracy of the corrosion loss prediction equation.

If the analysis can be refined to a point where the confidence in the risk assessment due to corrosion is high, focus can be shifted to analyzing other failure mechanisms associated with pipelines. To complete the analysis, the final step is to perform a consequence analysis due to failure. For this last step, every pipeline will be unique but the factors associated with consequences need to be defined and the most influential ones highlighted.

Finally the risk assessment can be combined with the consequence assessment, and the expected cost of failure can be calculated to help owners manage their pipelines. The analysis system can also be made robust enough to handle maintenance schedules, and to analyze the pipelines in real time. The key to performing all the tasks listed above is decomposing the problem into its major components, and developing a solution that is practical and simple to implement.

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