

## Lessons Learned in Pipeline Risk Assessment

By W. Kent Muhlbauer, P.E.

The safety of pipelines relative to other modes of transportation is generally not in question—by most measures, moving products by pipeline is safer than by alternate means. Yet even as pipelines claim a superior safety record, catastrophic failures are a real possibility. With an aging infrastructure, ever encroaching population areas, and increasing economic pressures, the perceived, if not actual, risk of pipeline failure is increasing. Pipeline safety probably can and should be improved. (An irony of spending too much on pipeline safety is that in so doing, public risk may be increased as business is forced to less safe modes of transportation). As the second law of thermodynamics implies, we must continue to inject “energy” into a process in order to offset the natural tendency towards “disorder” (increasing entropy). This injected “energy,” the activities of people and machines, is being allocated to specific aspects of pipeline operations everyday. Is it being spent in the most optimum way?

The ability to predict pipeline failures would obviously be a great advantage in reducing risk. Unfortunately, this is not an easy thing to do. Time and energy has been spent in gathering and analyzing historical data towards this end. Historical data however has two inherent weaknesses. First, it is only useful in predicting the future for a very similar and constant set of conditions. This is difficult to find in the real world. Second, rare-event data, such as pipeline accidents, paints, at best, only a very fuzzy picture—statistically valid sample sizes are rare. While we should not work without this data, we must also recognize that it only provides a piece of the puzzle.

It is perhaps useful to view a pipeline system, including its operating environment, as a complex entity with behavior similar to that seen in complex or chaotic systems. As such, we recognize that, as one possible outcome of the process of pipelining, the risk of pipeline failure is sensitive to immeasurable or unknowable initial conditions. Therefore our risk efforts are often NOT attempts to predict how many failures will occur or where the next failure will occur. Rather, the efforts are designed to systematically and objectively capture everything we know and use it to make better decisions.

Recognizing the inherent differences in pipelines, we are hopefully building a decision-support tool to capture significant differences, boiled down to a level of “practical certainty.” “Practical certainty” means that we know we have an answer that may well be exactly wrong *tomorrow*, but it reflects our best available information *today*. It is useful enough for us to make decisions with because it better combines all of our knowledge (and uncertainties) into a decision framework.

### Formal vs. Informal Risk Management

While formal pipeline risk management is growing in popularity among pipeline operators, it is important to note that these pipeline operators have always practiced risk management. Every time a decision is made to spend resources in a certain way, a risk management decision has been made. This informal approach to risk management has served us well, as is evidenced by the very good safety record of pipelines versus other modes of transportation. An informal approach

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to risk management can have the further advantages of being simple, easy to comprehend and to communicate, and being the product of expert engineering consensus built upon solid experience.

However, an informal approach to risk management does not hold up well to close scrutiny, since the process is often poorly documented and not structured to ensure objectivity and consistency of decision-making. Expanding public concerns over human safety and environmental protection have contributed significantly to raising the visibility of risk management. Although the pipeline safety record is good, the violent intensity and dramatic consequences of some accidents, an aging pipeline infrastructure, and the continued urbanization of formerly rural areas has increased perceived, if not actual, risks. Historical (Informal) risk management, therefore has these pluses and minuses:

### **Advantages:**

- Simple/intuitive
- Consensus is often sought
- Utilizes experience and engineering judgment
- Somewhat successful, based upon pipeline safety record

### **Reasons to Change:**

- More at stake from mistakes
- Inefficiencies/subjectivities
- Lack of consistency and continuity in a changing workforce
- Need to better consider complicated risk factors and their interactions

The last few years have witnessed the introduction of more formalized risk programs and studies, as well as an increasing number of private pipeline risk management ventures. The general conclusion seems to be a recommendation to move the industry towards such formal risk management programs.

## **Lessons Learned in Establishing a Risk Assessment Program**

As the primary ingredient in a risk management system, a risk assessment process or model must first be established. This is no small undertaking. Having played a role in building pipeline risk management systems for many varied situations for a number of years, the author offers some insights gained. Of course, each situation is unique and any rules-of-thumb are necessarily general and subject to many exceptions-to-the-rule. They also to some degree reflect a personal preference, but nonetheless are offered here as “food for thought” for those embarking on such programs.

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The general lessons-learned are as follows:

1. Work from general to specific,
2. Think ‘organic,’
3. Avoid complexity,
4. Use computers wisely,
5. Build the program as you would build a new pipeline, and
6. Study your results.

### Work from General to Specific

Get the big picture first. This means **get an overview assessment done for the whole system rather than getting every detail for only a portion of the system**. This has two advantages:

1. No matter how strongly the project is begun, things may change before project completion. If an interruption does occur, at least a general assessment has been done and some useful information has been generated.
2. There are strong psychological benefits to having ‘results’ (even if very preliminary — caution is needed here) early in the process. This provides incentives to refine and improve preliminary results. So, having the entire system evaluated to a preliminary level gives timely feedback and hopefully encourages further work.

It is easy to move quickly through the entire system by limiting the number of risk variables to include. Use only a critical few, such as population density, type of product, operating pressure, perhaps incident experience, and a few others. The model is then later ‘beefed up’ by adding the variables that were not used in the first pass. Use readily available information whenever possible.

### Think Organic

Imagine that the risk assessment process and even the model itself are living, breathing entities. They will grow and change over time. There is the fruit—the valuable answers that are used to directly improve decision-making. The ideal process will continuously produce ready-to-eat fruit, easy to ‘pick’ and use without any more processing. There is also the roots —the behind-the-scenes techniques and knowledge which creates the fruit. To ensure the fruit, the roots must be properly cared for. Feed and strengthen the roots by using HAZOPS, statistical analysis, FEMA, event trees, fault trees, and other specific risk tools occasionally. Such tools provide the underpinnings for the risk model. Allow for expansion: there will be new inspection data; new inspection techniques; new statistical data sets to help determine weightings; missed risk indicators; new operating disciplines, etc. Plan for the most flexible environment possible. Make changes easy to incorporate. Anticipate that regardless of where the program begins and what the initial focus was, eventually, all company personnel might be visiting and ‘picking the fruit’ provided by this process.

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### **Avoid Complexity**

Every single component of the risk model should yield more benefits than the cost it adds in terms of complexity and data-gathering efforts. Challenge every component of the risk model for its ability to genuinely improve the risk knowledge at a reasonable cost. For example:

- Don't include river "total dissolved solids" numbers unless "total dissolved solids" is a useful risk variable.
- Don't use more significant digits than is justified.
- Don't use exponential notation numbers if a relative scale can be appropriately used.
- Don't duplicate existing databases—instead access them whenever possible. Duplicate data repositories will eventually lead to data inconsistencies.
- Don't use special factors that are only designed to change numerical scales. These tend to add more confusion than their benefit in creating easy-to-use numbers.
- Don't add levels of calculations to the model. For example, don't multiply initial point scales by category factors and then again by category weightings and then again by adjustment factors, etc.
- Keep it simple. The advantages of a simpler point evaluation scale will quickly be lost when you try to manipulate data and find that one point here means something quite different than one point over there.
- Don't overestimate the accuracy of your results, especially in presentations and formal documentation. Remember the high degree of uncertainty associated with this type of effort.

### **Use Computers Wisely**

Too much reliance on computers is probably more dangerous than too little. In the former, knowledge and insight can be obscured and even convoluted. In the latter, the chief danger is that there are inefficiencies—an undesirable, but not critical event. Regardless of potential misuse however, computers can greatly increase the strength of the risk assessment process and no modern program is complete without extensive use of them. The modern software environment is such that information is easily moved between applications. In the early stages of a project, the computer should serve chiefly as a data repository. Then, in subsequent stages, it should house the algorithm—how the raw information such as wall thickness, population density, soil type, etc. is turned into risk information. In later stages of the project, data analysis and display routines should be available. And finally, computer routines to ensure ease and consistency of data entry; model tweaking; and generation of required output should be available.

Software use in risk modeling should always follow program development—not lead it.

- Early stage: use pencil and paper or simple graphics software to sketch out preliminary designs of the risk assessment system. Also use project management tools if desired, to plan the project.

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- Intermediate stages: use software environments which can store, sort, and filter moderate amounts of data and generate new values from arithmetic and logical (if-then-else) combinations of inputted data. Choices include modern spreadsheets and desktop databases.
- Later stages: Provide for larger quantity data entry, manipulation, query, display, etc. in a long-term, secure and user-friendly environment. If spatial linking of information is desired, consider migrating to Geographical Information Systems (GIS) platforms. If multi-user access is desired, consider robust database environments.

### Build the Program as You Would Build a New Pipeline

A useful way to view this process is a direct analogy with new pipeline construction. In either case, a certain discipline is required. As with new construction, failures in risk modeling occur through inappropriate expectations and poor planning, while success happens through thoughtful planning and management.

Below, the project phases of a pipeline construction are compared to a risk assessment effort.

### I. Conceptualization and Scope-Creation Phase

Pipeline: Determine the objective, the needed capacity, the delivery parameters and schedule.

Risk Assessment: Several questions to the pipeline operator may better focus the effort and direct the choice of a formal risk assessment technique:

- What data do you have?
- What is your confidence in the predictive value of the data?
- What are the resource demands (and availability) in terms of costs, man-hours, and time to set up and maintain a risk model?
- What benefits do you expect to accrue, in terms of cost savings, reduced regulatory burdens, improved public support, and operational efficiency?

Subsequent defining questions might include: What portions of your system are to be evaluated: pipeline only? Tanks? Stations? Valve sites? Mainlines? Branch lines? Distribution systems? Gathering systems? On-shore/offshore? To what level of detail? Estimate the uses for the model, then add a margin of safety because there will be unanticipated uses. Develop a schedule and set milestones to measure progress.

### II. Route Selection/ROW Acquisition

Pipeline: Determine the optimum routing and begin the process of acquiring needed ROW.

Risk Assessment: Determine the optimum location for the model and expertise: Centrally done from corporate headquarters? Field offices maintain and use information? Unlike the pipeline

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construction analogy, this aspect is readily changed at any point in the process and does not have to be finalized at this stage of the project.

### III. Design

**Pipeline:** Perform detailed design hydraulic calculations; specify equipment, control systems, and materials.

**Risk Assessment:** The heart of the risk assessment will be the model or algorithm—that component which takes raw information such as wall thickness, population density, soil type, etc. and turns it into risk information. Successful risk modeling involves a balancing between various issues:

- Identifying an exhaustive list of contributing factors vs. choosing the critical few to incorporate in a model (complex vs. simple),
- “Hard” data vs. engineering judgment (how to incorporate widely-held beliefs which do not have supporting statistical data),
- Uncertainty vs. statistics (how much reliance to place on predictive power of limited data), and
- Flexibility vs. situation-specific model (ability to use same model for variety of products, geographical locations, facility types, etc).

It is important that ALL risk variables be considered, even if only to conclude that certain variables will not be included in the final model. In fact, many variables will not be included when such variables do not add significant value but reduce the usability of the model. These “use or don’t use” decisions should be done carefully and with full understanding of the role of the variables in the risk picture. Note that many simplifying assumptions are often made, especially in complex phenomena like dispersion modeling, fire and explosion potentials, etc., in order to make the risk model easy to use and still relatively robust.

Both probability variables and consequence variables are examined in most formal risk models. This is consistent with the most widely accepted definition of risk:

$$(\text{event risk}) = (\text{event probability}) \times (\text{event consequence})$$

### IV. Material Procurement

**Pipeline:** Identify long-delivery items, prepare specifications, and determine delivery and quality control processes.

**Risk Assessment:** Identify data needs that will take the longest to obtain and begin those efforts immediately. Identify data formats and level of detail. Take steps to minimize subjectivity in data collection. Prepare data collection forms or formats and train data collectors to ensure consistency.

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### **V. Construction**

Pipeline: Determine number of construction spreads, material staging, critical path schedule, and inspection protocols.

Risk Assessment: form the data collection team(s); clearly define roles and responsibilities; create critical path schedule to ensure timely data acquisition; schedule milestones; take steps to ensure quality assurance/quality control.

### **VI. Commissioning**

Pipeline: Testing of all components, startup programs completed.

Risk Assessment: Use statistical analysis techniques to partially validate model results from a numerical basis. Perform a sensitivity analysis and some trial “what-if”s” to ensure that model results are believable and consistent.

Hopefully the risk assessment characteristics were earlier specified in the design and concept phase of the project, but here is a final place to check to ensure that:

- All failure modes are considered,
- All risk elements are considered and the most critical ones are included,
- Failure modes are considered independently as well as in aggregate,
- All available information is being appropriately utilized,
- Provisions exist for regular updates of information, including new types of data,
- Consequence factors are separable from probability factors,
- Weightings, or other methods to recognize relative importance of factors, are established,
- The rationale behind weightings is well documented and consistent,
- A sensitivity analysis has been performed,
- The model reacts appropriately to failures of any type,
- Risk elements are combined appropriately (“and” vs. “or” combinations),
- Steps are taken to ensure consistency of evaluation,
- Risk assessment results form a reasonable statistical distribution (outliers?),
- There is adequate discrimination in the measured results (signal-to-noise ratio), and
- Comparisons can be made against fixed or floating “standards” or benchmarks.

### **VII. Project Completion**

Pipeline: Finalize manuals, complete training, ensure maintenance protocols are in place, and turn system over to operations.

Risk Assessment: Carefully document the risk assessment process and all sub-processes, especially the detailed workings of the algorithm or central model.



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Set up administrative processes to support on-going program (see also *Think Organic*). Refer to DOT Risk Management Demonstration Program control documents for details on aspects of a good administrative program, including:

- Assigning responsibilities,
- Measuring improvement,
- Re-visiting processes,
- Management of change,
- Etc.

### Study the Results

This might seem obvious, but it is surprising how many really don't appreciate what they have available after completing a thorough risk assessment. Remember that your final risk numbers should be completely meaningful in a practical, real-world sense. They should represent everything you know about that piece of pipe (or other system component)—all your years of experience, all the statistical data you can gather, all your gut feelings, all your sophisticated engineering calculations. If you can't really believe your numbers, something is wrong with the model. When, through careful evaluation and much experience, you can really believe the numbers, you will find many ways to use them that you perhaps did not foresee. They can:

- Design an operating discipline;
- Assist in route selection;
- Optimize spending;
- Strengthen project evaluation;
- Determine project prioritization;
- Determine resource allocation;
- Ensure regulatory compliance;
- Etc.

### A Measuring Tool

In creating a risk assessment system, you have in effect created a measurement tool. As with any measurement tool, it must have a suitable "signal -to-noise ratio." This means that the "noise," the amount of uncertainty in the measurement (due to numerous causes) must be low enough so that the "signal," the risk value of interest can be read. In the case of pipeline risk, some sources of "noise" that must be dealt with include:

- Varying static conditions along a pipeline and between compared pipelines—different soils, vegetation, temperatures, pipe materials, pipe sizes, operating practices, etc.
- Varying dynamic conditions—activities of people, presence of people, weather events, stress conditions, soil moisture content, etc.
- High level of uncertainty associated with the modeling of phenomena such as dispersion and explosion.



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- Small amounts of statistical data from which to predict event frequencies.
- Large numbers of variables that can contribute to risk changes and which are often confounded with each other.

These and other considerations limit the ability of the risk assessment tool to distinguish real changes in risk level from changes that do not necessarily contribute to risk. We should be careful not to think we can find a 2% change in risk with a tool that is only sensitive to +/- 10%.

This is similar to the “accuracy” of the model, but involves additional considerations that surround the high level of uncertainty associated with risk management. However, it would not be reasonable to assume that this tool cannot be continuously improved. Improvement opportunities should be constantly sought.

### Moving into Risk Management

In some sense, we have near-complete control of the risk. We can spend nothing on preventing accidents or we can spend enormous sums of money over-designing facilities, employing an army of inspectors, and routinely shutting down lines for preventive maintenance and replacement. Pragmatically, operators spending too little on preventing accidents will be out of business from regulatory intervention or from the cost of accidents. On the other hand, if an operator spends too much on accident prevention, he can be driven out of business by the competition—even if, perhaps, that competition has more accidents!

Risk management, to a large extent, revolves around the central process of making choices in the design and day-to-day operations of a pipeline system. Many of these choices are mandated by regulations whereas others are economically (budget) constrained. By assigning a cost to pipeline accidents (a sometimes difficult and controversial thing to do) and including this in the cost of operations, the optimum balance point is the lowest cost of operations.

No operator will ever have all of the relevant information he needs to guarantee safe operations. There will always be an element of the unknown. Managers must control the “right” risks with limited resources, as there will always be limits on the amount of time, manpower, or money to apply to a risk situation. Managers must weigh their decisions carefully in light of what is known and unknown. The deliverable most requested after risk assessment is therefore a “resource allocation model.” In such a model, the output of the risk assessment would play a key role in evaluating the benefits of any project or activity. The user would in essence be performing “what-if” scenarios to see the risk level which results after any proposed action.

### Conclusion

The value of a pipeline risk assessment/risk management system lies in its ability to provide useful decision-support information at a reasonable cost. As the most complex aspect of the system creation, the risk assessment portion is best developed in a systematic process, just as any large project should be. Since formal risk assessment programs are relatively new, there are few clear roadmaps to follow and many opportunities for missteps. As with other projects, failures

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occur through inappropriate expectations and poor planning, while the most successful projects happen through thoughtful planning and management.

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