SYSTEM WIDE RISK-BASED PIPELINE INTEGRITY PROGRAM AT TRANSCANADA

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ABSTRACT

TransCanada is meeting the challenges of enhanced pipeline safety and reliability in a competitive environment by combining new technologies in an innovative way to help manage risk. TransCanada is building on existing capabilities with development of a new pipeline risk assessment system to identify and prioritize segments on the 38,000 km system that will require particular attention for condition monitoring and mitigation. The system wide risk-based system incorporates a data storage and maintenance asset, tools for risk analysis, as well as tools to view, summarize and learn from the data, including a geographical information system. First use of the new system occurred in 1999.

INTRODUCTION

TransCanada is positioning itself to meet the challenges of continued safe, reliable and competitive service in a changing gas transmission market in Canada. Change is pervasive in the energy industry today and for TransCanada it relates to a maturing infrastructure, increasing public and regulatory expectations and two recent developments: the introduction of competition into the gas transmission industry in the Western Canadian Sedimentary Basin, and the merger between NOVA Gas Transmission and TCPL in 1998. The ultimate challenge is to continue to meet service expectations, illustrated in Figure 1, while also managing the balance sheet. These apparently opposing needs have caused the company to re-examine its historical integrity analysis practices and to implement innovative technologies to assist the decision-makers.

Integrity management at TransCanada comprises a balance of both risk based and traditional approaches. The latter treating topics not immediately amenable to a risk-based treatment. For example, code compliance issues, routine maintenance tasks, and the development and implementation of condition monitoring programs.

The merged TransCanada consists of a network of 38,000 km of pipelines spanning five provinces from British Columbia to Quebec. The network services gas producing customers from over 900 receipt points and delivers gas to Local Distribution Companies (LDCs) and major industrial users downstream. The system crosses crown and private lands, the latter consisting of some 21,000 land owners. Other stakeholders include approximately 43,000 residences and industrial sites within 750 m of the pipeline across the five provinces. In addition to the foregoing, and as a consequence of the merger, TransCanada finds itself governed by two distinct regulators.

Management of risk under these conditions, therefore, requires a detailed knowledge of the pipeline network at a fine level of detail, its condition, the potential failure causes, as well as the relative proximity of the pipeline to features or structures on the land from gas receipt to delivery. Management of risk also requires a rational, defensible, and system wide basis for prioritization, decision making, and integrity program development.

It is fundamental to the methodology that it be able to address the entire pipeline system and not only areas associated with high consequence or areas with predicted high failure frequencies. As part of the analysis process, the pipeline system is dynamically segmented according to changing attributes along its length and risk assessments are carried out on a meter by meter basis, all of which results in literally millions of iterative calculations. Clearly, system-wide integrity management on such a pipeline system requires dealing with vast amounts of information and an automated risk analysis capability.

TransCanada has a fifteen year history of developing and using risk management and is recognized in the industry as a leader in development of philosophies and methodologies for failure frequency and consequence estimation. This experience was applied, for example, in the joint industry project involved with designing the PIRAMID risk assessment tool (Pipeline Risk Analysis for Maintenance and Integrity Decisions. Detail development by C-FER Technologies Inc) Notwithstanding the fact that TransCanada's current pipeline risk management tool (PRIME, Pipeline Risk and Integrity Management Enabler) continues to evolve, it is considered that the current state of development of the technique is sufficiently advanced that quantitative methods can be usefully implemented.

The solution to the integrity challenge, therefore, was to develop an integrated risk based integrity decision enabling process that includes a suite of tools and methodologies to store and maintain large quantities of pipeline facility and other data, failure frequency and consequence models, decision models, and feedback measures of performance, Figure 2. This paper highlights some of the challenges addressed during the development and implementation of system wide risk management and describes the enhanced risk assessment capacity of the tool used. The paper also presents an outline of the methodology and models used to assess system wide risks and describes how this assessment supports integrity decisions.

HISTORY

Both NOVA Gas Transmission and TransCanada PipeLines (TCPL) incorporated risk assessment in their pipeline integrity program optimization. The present system, PRIME, incorporates and builds on this previous work, extending the capability of the methodology to detailed system wide risk assessment. The objectives remain the same. That is:

- to maintain a high level of safety,
- to concentrate integrity effort on areas of higher risk,
- to optimize integrity programs, and
- to maintain system reliability and availability

The recent completion of accelerated integrity programs at TransCanada provides a secure base from which to introduce the risk based integrity methodology described in the paper and meet the company's objectives in a budget constrained environment. In this environment, TransCanada must leverage off its considerable existing investment in gas transmission infrastructure by maintaining responsible operating expenditures.

PROGRAM OBJECTIVES

The integrity programs in TransCanada were designed explicitly to address company corporate objectives with regard to safety, value enhancement, changing business model, commitment to health safety and environment (HS&E), community relations, and customer service, and the management of maintenance and integrity issues.

Value is enhanced (as will be shown) through the selection of projects that provide the highest return, that is, the highest present expected value of risk reduction versus project cost. Risk-based prioritizaton/optimization is the tool chosen to change our business model by re-evaluation and re-prioritizing our pipeline integrity management projects to develop prudent expenditures while balancing pipeline safety and system reliability with shareholder, customer, and regulatory expectations. As will also be shown, HS&E, Community Relations, and Customer Service together with Regulatory and Financial impact comprise the major consequence groups addressed by the risk assessment.

OUTLINE OF THE METHODOLOGY

The basis of the methodology conforms to the CSA guidelines for risk management[1]. In common with all large-scale risk assessment projects, the program is highly data-intensive. The majority of the development costs were, in fact, incurred in the collection and collation of data. Examples of managed data categories are as follows

Pipe Characteristics	Individual Structures
Casings	Public Assembly Areas
Coatings	Environmental Areas
Buoyancy Weights	Public Perception Areas
Soils	Mechanical Damage
Crossings	Constants
Valves	Structure Probabilities
Failure Frequencies	Area Probabilities
Consequences	Pipe Ignition Probabilities
Risks	Hydrostatic Test
Throughput	Inline Inspection
Volumes	Digs
Meter Stations	Repairs
Compressor Stations	Incidents

Essentially, data are read from the database and used by the failure frequency and consequence models and the output of these models are then combined, as described below, to give risks per unit length of the pipeline. The risks are then used in a decision model to determine the optimum integrity program and information from this program is fed back into the database and the failure frequency models to continually improve and refine the process.

The programs driven by the methodology generally comprise the following:

- Inline inspections
- Hydrostatic re-tests,
- Investigative digs,
- Large-scale recoating,
- Pipe replacements,
- Class upgrades, and
- Geotechnical monitoring and remediation

RISK OPTIMIZATION

Risk is a measure of expected future exposure or expenditure and therefore should be controlled in order to minimize the total costs associated with integrity programs. It should be noted that TransCanada uses a constrained optimization approach to control risks. That is to say that before the optimization process is begun, specific constraints not directly related to optimization are applied to the process. In principal almost any number of constraints could be applied, but whereas TransCanada may choose to increase the range of constraints in future to address changing conditions, it now restricts itself to imposing explicitly only a safety constraint.

Once this constraint has been applied the optimization process proceeds by calculating the present value of the risk reduction for each candidate integrity project over the expected benefit horizon and dividing it by the cost of the project to give the Risk Value Ratio (RVR).

The projects are then ordered by ascending RVR in an array of accumulated expected risk reduction benefit versus accumulated program cost, as illustrated in Figure 3. As a first cut at overall integrity program definition, those individual projects that have an RVR greater than one are proposed and added to those that are required by the safety constraint.

The balance of the decision process is described in more detail below under System Architecture.

The following definition of risk is adopted for each hazard:

$$Risk = F_F \times \sum (C_F \times P_C) \qquad (1)$$

where:

F_F is the frequency of failure;

C_F is the expected consequences of the failure;

P_C is the probability of consequences given the failure

The Hazards currently addressed are:

- Internal Corrosion
- Stress Corrosion Cracking (SCC)
- Mechanical Damage
- Geotechnical Loads

For each of these a susceptibility model has been formulated that predicts the expected annual failure frequencies as functions of appropriate parameters such as pipe parameters, coating, soil, rainfall, etc.

Consequences are grouped under the following headings. The principal consequence parameters are shown in brackets:

- Safety (probability of injuries or fatalities)
- Customer Impact (energy or volumes restricted)
- Public Perception (adverse media coverage)
- Environmental (environmental change and response)
- Regulatory (intervention and investigations)
- Financial (direct and indirect costs)

In a similar way that the hazard models convert line attributes to predicted failure frequencies, the consequence models convert consequence parameters into a common measure known as severity points. This is done by means of an Integrated Risk Assessment Process matrix (IRAP), represented by Figure 4, which seeks to equate the seriousness of each level of consequence and to combine appropriate severity points for individual consequence categories into integrated scores. The company's risk profile can be customized by adjusting the relative consequence scores between the categories in the matrix. For example, the specific scoring used by TransCanada reflects a particularly high aversion to public safety risk.

The IRAP matrix, therefore, provides a process to integrate individual consequences into a single, consistent consequence score. It also allows a quantifiable method to relate risk reduction benefits to integrity program costs for the purpose of evaluating the effectiveness and benefit of projects.

Prioritizing on the basis of risk assessment promotes an environment of critical and systematic review of integrity programs. The optimization process based on risk assessment provides a safe framework with which to address the stated company objectives. It is not, of course, the only methodology available. A more traditional method based on experience and previous operating knowledge (perhaps enhanced by selective expert interviews) can be used in certain individual cases. This approach, however, does not lend itself readily to the large volumes of data and detail involved in a comprehensive risk assessment on a large and complex system such as that of TransCanada.

Another possible way to prioritize integrity is to base the prioritization purely on susceptibility, that is, to address the areas with like condition to those of previous failures, or to areas where the failure frequencies are known to be highest. However, it is widely recognized that prioritization on the basis of failure probability/frequency alone is not likely to provide the most efficient integrity program, even though reducing probability is a strong risk control measure and may be applied when the probability of failure is considered excessively high. Also, consequence alone is not enough since an approach thus based can lead to focus on highly improbable events. For these reasons TransCanada believes the most representative and useful criterion for integrity program optimization is risk since it encapsulates in a single measure all that is known about the likelihood and anticipated severity of possible incidents as well as incorporating the values of the company, employees and other stakeholders.

HAZARD FAILURE FREQUENCY MODELS

A model was developed for each of the hazards to predict frequencies per unit length of failure conditions (small leak, large leak, or rupture) as functions of input parameters appropriate to each hazard. These models were developed incorporating a mix of physical modeling and historical data. Historical data trended over appropriate time scales were also used to calibrate the failure frequencies.

Failure frequency calibration is a very important step. Each model predicts failure frequencies with some measure of uncertainty. Calibration is used to scale the results to avoid aggregating overly conservative estimates or underestimates of the frequencies while maintaining the correct proportionate dependency on parameters. This calibration also provides an integration between hazards consistent with the time scale chosen.

Outlines of each of the models are given below.

External Corrosion

The basic model parameters include coating type, macro environment (basically soil type), and drainage. Relating these to historical failure and inspection data provides an estimated annual failure frequency per meter of pipe with similar characteristics. This prediction was achieved by fitting suitable distributions to groups of features to allow extrapolation to extreme event probabilities of rupture at MOP (Maximum Operating Pressure).

Stress Corrosion Cracking

Significant stress corrosion cracking (SCC) features were classified according to pipe, coating, and soil parameters. Failure frequencies were based on actual in-service failures and failures recorded during hydrostatic re-tests. The data were taken from over 2000 investigative digs and over 200 hydrostatic re-tests on the TransCanada mainline system.

Geotechnical

Geotechnical hazards incorporated in the system wide risk assessment are classified as either River Scour or Slope Movement. At present, only the latter is treated explicitly. The model incorporates:

- a rainfall-ground movement sub-model,
- advanced pipe-soil interaction factors that relates calculated slope movement to strains induced in the pipeline, and
- a limit strain criterion that predicts failure frequencies based on the above

Mechanical Damage

The rupture calculation methodology is based on the Mechanical Damage model developed from Pipeline Research Committee International (PRCI) research projects related to reliability based methods for the prevention of mechanical damage[3]. The contact and failure frequencies are derived from models incorporating knowledge of population density, land use, depth of cover, public awareness, pipe characteristics, inspection frequencies, and markers and signage

CONSEQUENCE MODELS

Life Safety

Radii defined by piloted ignition of wooden structures and 1% lethality are calculated and associated probability of casualties estimated for a given rupture. This consequence dimension is calculated using the PipeSafe[2] model based on potential release rate (mode, pressure, diameter), probability of ignition given a rupture, structure occupancy / area population density, location relative to pipe (inner zone/radius, outer zone/radius), and exposure condition (indoor versus outdoor). These estimates are then aggregated on a meter by meter basis taking into account the interaction with local structures and populations. This process also calculates the structural damage due to pipe failure.

It should be noted that relative to other consequences the life safety consequence receives the highest weighting and influence in the program decision process.

Customer Impact

The impact to the customer of an event such as a pipeline rupture is potential loss of service. The principal components of the model used in PRIME to calculate this impact are:

- average throughput gas volume,
- availability of alternative flow paths,
- criticality of service to receipt/delivery points, and
- duration of outage

Public Perception

Public Perception is what might be described as a "lag consequence". As a rule, public outrage does not affect the company's operation with the same immediacy as do Public Safety or Customer Impact consequences. However, the company considers it important in that it can ultimately lead to regulatory intervention and negative impact on the future expansion and/or operation of the system. The model comprises the following components:

- ignition/ no ignition
- developed/ undeveloped area
- typical/ sensitized populations involved

Environmental

The severity levels incorporated in the consequence integration matrix range from Incident Occurrence to Critical Environmental Impact. The environmental impact model estimates the impact a pipeline failure will have on the local environment adjacent to the pipeline. For the purposes of calculation, the entire pipeline system was first classified by expert interview as either low, medium, or high environmental sensitivity. The matrix severity levels were then scaled accordingly.

Regulatory

The severity levels incorporated in the consequence integration matrix range from Reportable Incident to Public Enquiry. The consequence model associated with Regulatory Impact is similar to that of Public Perception. The final weighting given to Regulatory in the IRAP matrix reflects TransCanada's aversion to regulatory intervention both from the perspective of corporate responsibility and the physical effort required on the part of the company in the event of, for example, a public enquiry. The actual costs associated with an inquiry would be treated under Financial Impact.

Financial Impact

This category includes all the direct and indirect "real dollar" costs associated with an event (e.g. a rupture). The costs include those associated with regulatory impact, cost of repair, cost to implement maximum pressure restrictions (pending re-establishing the integrity of the line), cost to restore operational confidence in the line, certain financial impacts to customers (in addition to the customer impact described earlier), land and environmental clean up.

PRIME ARCHITECTURE

Risk Assessment

The risk assessment process is achieved by feeding information on the state of the system through successive layers of information processing in which the results of one layer of processing becomes the input to the next layer. The results of each layer of calculation are retained for trace-ability and to facilitate calibration of the system. Figure 5 illustrates this process.

The results define both the total risk and the risk associated with each hazard and consequence measure for a single meter of pipe. This analysis is conducted for each meter of pipe in the system entirely through an automated software process. Automation of this task ensures that the engineering knowledge embedded in the models are applied in a consistent and repeatable manner across the system so that the risk for any given segment of the system may be compared to any other section in a quantifiable manner.

Calibration

Following risk assessment, the calibration process begins. This process, illustrated in Figure 6, consists of a feedback loop through which risk is aggregated iteratively to the section, pipeline, or system level and compared against known information on the state of the system (referred to as calibration filters). Calibration factors are created based on the difference between calculated and actual information and these are fed back into the raw data at the appropriate risk assessment level. Successive passes through this process will eventually result in convergence on risk values that best represent the current knowledge of the system.

Decision Analysis

Once the risk analysis has been calibrated, the decision analysis process begins. Decision Analysis is used to identify and quantify the benefits of doing integrity work.

Through decision analysis, risk is summed over the length of pipe over which an integrity project, such as in-line inspection or hydrostatic testing, will have a risk reduction benefit. Various project options are created; some of which may entirely or partially overlap the same length of pipe. Projects with a RVR>1 are selected as potential candidates for inclusion in an integrity program. An example is offered to clarify the process in this situation.

Where one or more candidate projects address the same risk for a given length of pipe, combination RVRs are calculated to determine the remaining incremental value of performing additional work on the area, Figure 7. For example, if one candidate project (with an initial RVR>1) is to conduct an MFL in-line inspection over 100 km and another project involves hydrostatic testing a subset of that length (also with an RVR>1), then combination RVR are needed to determine which, if not both, projects should go ahead. For the ILI project, an RVR is calculated assuming that the hydrotest has already taken place (and the associated corrosion risk has already been reduced for the test section but is still unmitigated for the remainder of the run). For the hydrostatic testing project, an RVR is calculated taking into consideration that the corrosion risk has already been mitigated through testing but that other risks (such as SCC) have not been addressed. If both of these combination RVRs are greater than 1, then both projects are maintained as candidates. If only one retains an RVR greater than 1, then that project is put forth as the optimal candidate. If neither project retains an RVR greater than one, then the project with the highest initial RVR becomes the optimal candidate.

Program options are then developed over a multi-year period to cover the list of candidate projects. Factors such as implementation issues, system usage, increases in risk due to time dependant causes, and residual risk exposure is taken into consideration when developing a long-range plan. The plan with the greatest program level RVR is considered to be the optimal choice. Additionally, the system is evaluated against acceptable levels of safety risk and, if these levels are exceeded, then projects are chosen to reduce the risk to acceptable level, regardless of the RVR and added to the plan.

CONCLUSIONS

A highly structured, quantitative, risk-based methodology had been developed to optimize pipeline integrity programs. The capability, known as PRIME, incorporates detailed, spatially referenced pipeline, environmental and stakeholder information and models to estimate the expected frequency of pipeline failure, potential consequences and risk. The analysis is conducted along the entire 38,000-km length of the pipeline network on a meter-by-meter basis. Risk output is assessed in terms of project costs and benefits to arrive at an optimized and balanced risk-based program.

REFERENCES

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The Authors

Robert Sutherby is a pipeline integrity specialist with twenty years of experience in metallurgical failure investigation, and corrosion and stress corrosion cracking technology development and management. He is past chairman of the Canadian Energy Pipeline Association (CEPA) SCC Working Group and is current Emphasis Area Chairman for SCC on the Line Pipe Research Committee of the Pipeline Research Council International (PRCI). Robert has been with TransCanada since 1989 and holds an M.Sc. in Metallurgical Engineering and is a Professional Engineer.

Louis Fenyvesi is a technologist whose background covers a number of areas in the Information Management and Communications fields. His experience is concentrated in the areas of technical writing, statistical analysis, data management, and risk management. For the past 2 years, Louis has been working on the development and support of TransCanada's PRIME system. Louis has been with TransCanada since 1995.

Iain Colquhoun has over 30 years experience in pipeline, mechanical, and structural engineering. Experience includes: pipeline integrity management, risk evaluation and rehabilitation of pipelines; technical support; business analysis and facilitation; design and analysis of pipelines and components (including detailed strength and integrity evaluations and design under seismic and other extreme loadings); failure analysis of components; design of industrial, transportation, and off-shore structures. Iain holds a Ph.D. in Mechanical Engineering and is a Professional Engineer.

Moness Rizkalla, M.Eng., P.Eng., is a civil engineer with 20 years experience. His professional background spans the fields of geotechnical engineering, pipeline design and construction, pipeline integrity, risk management, technology development and organizational leadership. Until recently, he was the Manager of TransCanada's Pipeline Integrity-Risk Management group and Chairman of the PRCI's Design, Construction and Integrity Committee. Mr. Rizkalla is currently involved in launching a pipeline integrity service provision organization focusing on the management of mechanical damage and ground movement hazards.

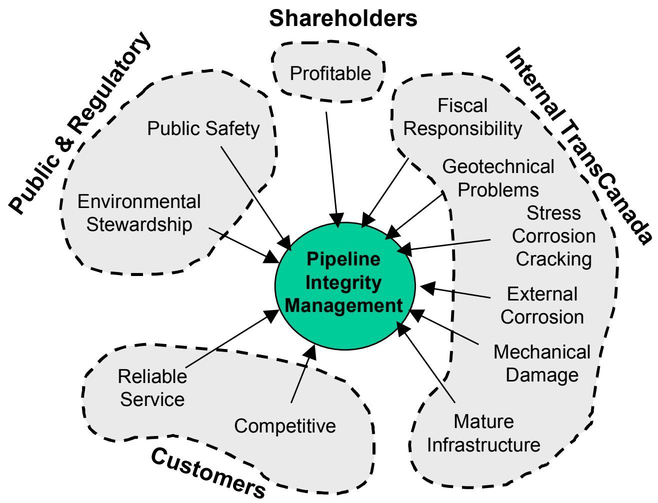

Figure 1: Pipeline Integrity is being challenged by multiple stakeholders to be responsive to needs.

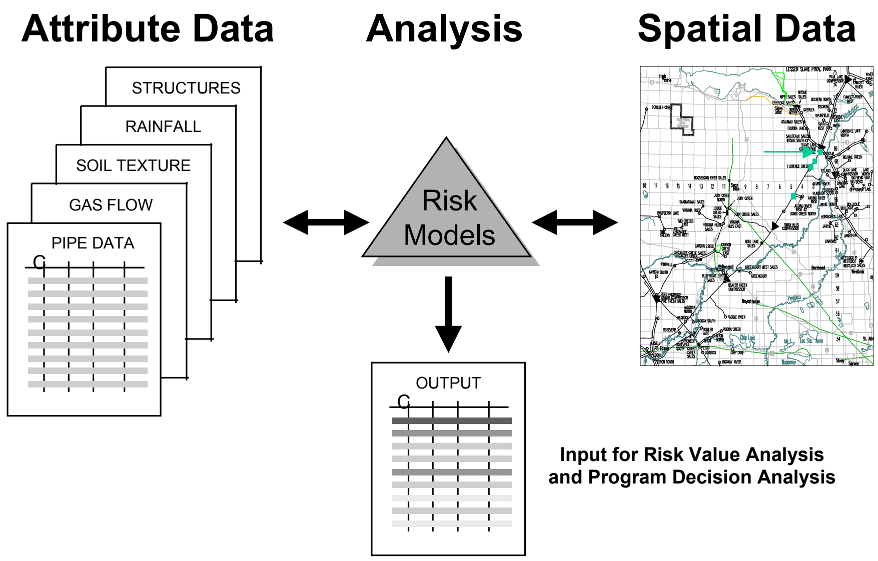

Figure 2: PRIME contains detailed attribute data supporting failure frequency and consequence models providing quantitative risk assessments, by pipeline segment, as input to the integrity program development process.

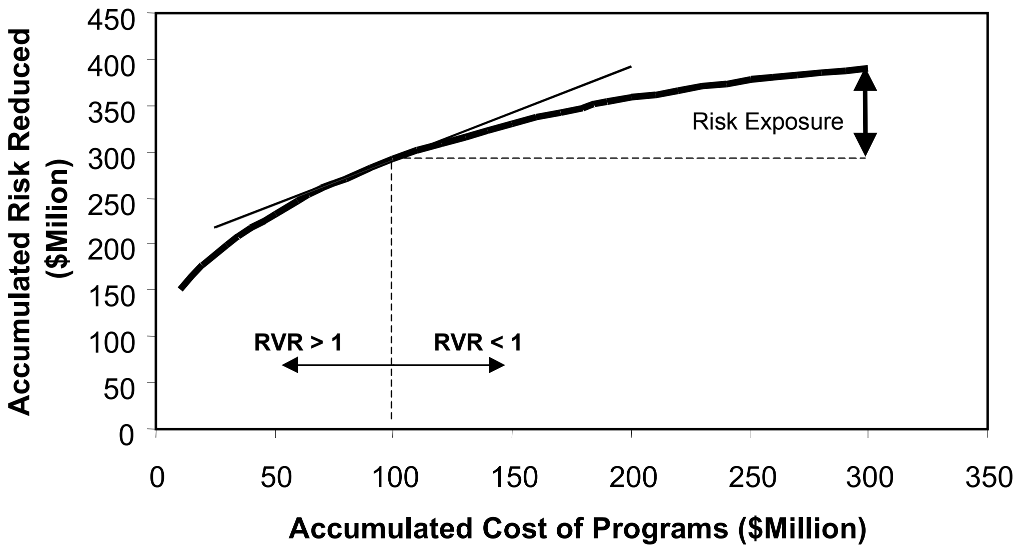

Figure 3: Use of project costs and benefits to establish an optimum program budget and residual risk exposure of actions not taken.

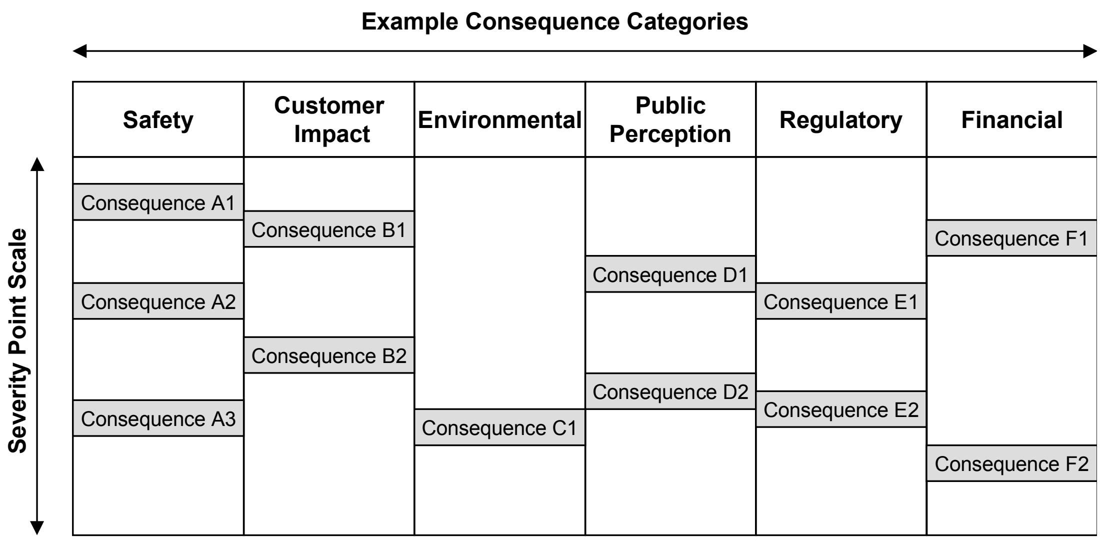

Figure 4: A representation of the Integrated Risk Assessment Process (IRAP) matrix.

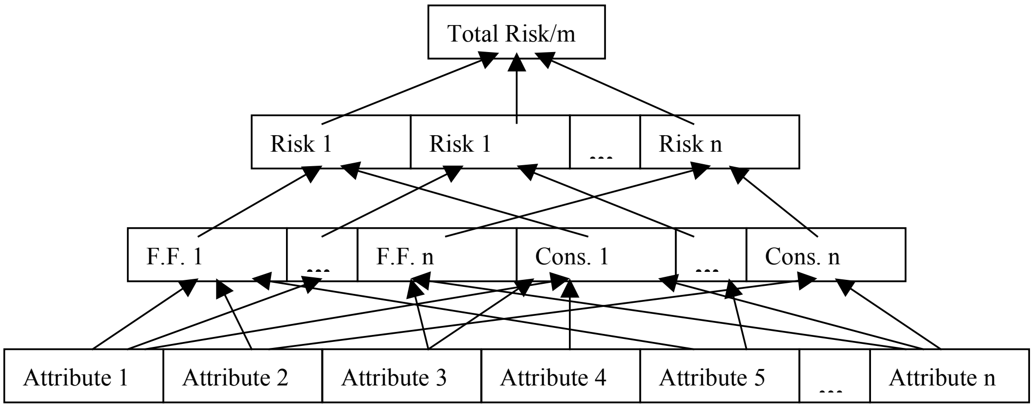

Figure 5: Hierarchical risk network from local attributes to failure frequency and consequences, discrete partial risks and integrated risk at a point.

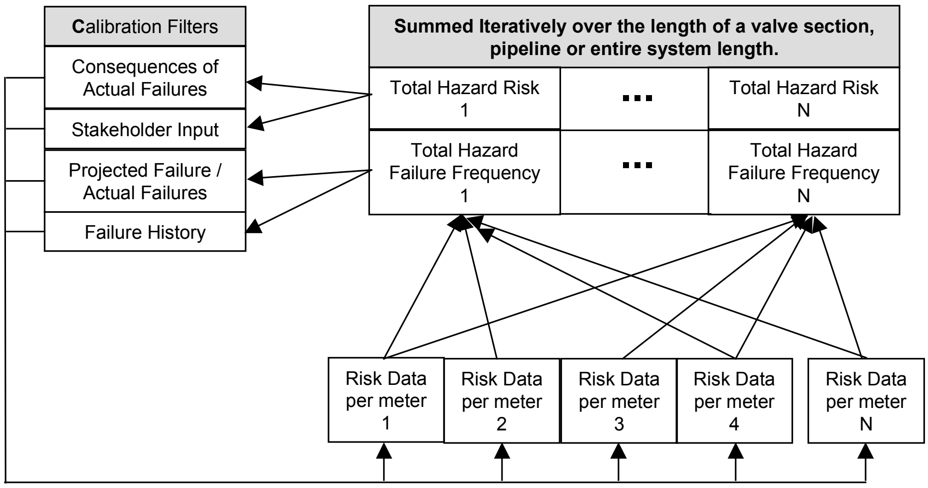

Figure 6: Risk calibration

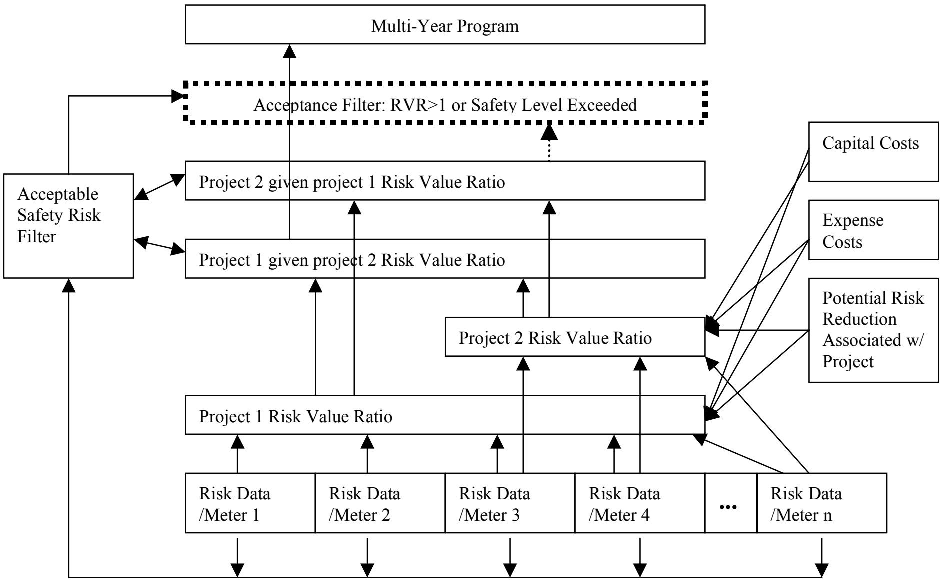

Figure 7: Maintenance program development based on risk assessment input.