Risk-Informed Land Use Planning Familiarization Material
For Pipelines and Informed Planning Alliance (PIPA)

Purpose

To meet the requirements of the Pipeline Safety Improvement Act (PSIA) of 2002, PHMSA contracted with the Transportation Research Board (TRB) to conduct a study of land use practices, zoning ordinances, and preservation of environmental resources with regard to pipeline rights-of-way and their maintenance. As a result of this study, TRB Special Report 281, PHMSA/OPS formed the Pipelines and Informed Planning Alliance (PIPA) to develop risk-informed land use guidance for application by stakeholders. This paper summarizes the concepts of risk and risk management strategies, the risk characterization practices in the pipeline industry, the TRB recommendations for risk-informed land use guidance, and the role of risk in land use decision-making near transmission pipelines.

Concepts of Risk and Risk Management Strategies

What is risk?

Risk is a concept used to characterize the magnitude of negative consequences and the likelihood of the consequences occurring. The mathematical expression for risk is:

Risk = Likelihood x Consequence

As described in the TRB report, sound risk assessment practice attempts to answer the following questions:

- What can go wrong?
- How likely is it?
- What are the consequences?

Because of the complexity of precise calculation of risk, the results of the risk assessment process are often termed "risk insights," which are often used to *inform* decision making by operators and regulators.

Terms related to risk assessment that can lead to confusion include "hazard" and "threat". *Hazard* means a material or condition that could produce an adverse health or safety impact (e.g., natural gas in a pipeline under pressure) and *threat* means a physical process that could cause the hazard to produce such an effect (e.g., severe corrosion of the pipeline, careless excavation that could damage the pipeline).

What are the elements of risk management?

Risk management process involves the following elements:

- *Identify* threats to the pipeline system and pipeline locations where failure would have the greatest consequences,
- *Assess* and quantify risks
  - Assemble data about the pipeline system susceptibility to the threats,
  - Integrate data in a risk model,
- *Evaluate* results to make and implement risk-informed decisions
  - Rank pipeline segments by risk,
- *Mitigate risk* - Identify, evaluate and implement additional prevention and mitigation measures to reduce risk,
- *Monitor* the effectiveness and modify the risk management process as needed.

To learn more about risk management, Ctrl click here>>>

Why is risk a useful metric?

Operators of transmission pipelines must comply with regulatory requirements developed to assure that the pipelines are maintained and operated safely. Over the last sixty plus years, improvements have been made in pipe materials, fabrication and installation techniques, and post-installation operating and maintenance practices. These diverse pipeline systems have varied susceptibility to threats to their integrity which at times lead operators to employ practices in excess of the regulations. As a result of Integrity Management regulations for transmission pipelines, operators collect extensive data about the characteristics of the pipe, the environment near the pipe, historical practices and the concentration of people near the pipeline. Combining the data collection process and institutional knowledge, an operator knows the system and can develop an objective method to determine how and where to focus enhanced practices and which practices are the most effective. Risk is the best, perhaps only, metric to enable an operator to consolidate information on the pipeline characteristics in support of decisions on allocating resources to address recognized diverse safety issues on its system.

The Risk Characterization Practices in the Pipeline Industry

What do we know about the causes of pipeline failure - What are the implications to land use near pipelines?

Threats considered "beyond the operator's control" include third party excavation damage and damage from natural force (e.g., wind, rain, floods, lightening, and earth movement). Together they make up the largest category of incidents (the term used to describe reportable events for gas transmission pipelines) and accidents (the term used to describe reportable events for liquid transmission pipelines). Threats within the operator's control also can contribute significantly to the occurrence of reportable events. If only incidents and accidents *leading to fatalities* are considered over the period from 2000 to 2005, excavation damage contributes 62.5% to hazardous liquid accidents and 50.0% to gas incidents.

2000- 2005 Percent of Transmission Pipeline Events by Threat

Threat	Gas Transmission Pipelines Incidents	Liquid Transmission Pipelines Accidents
Excavation Damage	19.3	**14.8**
Natural Force Damage	16.1	**7.1**
Corrosion	23.0	**26.9**
Human Error	2.3	**5.4**
Material Failure	20.4	**27.9**
All Other Causes	18.9	**17.8**

Land use planning near pipelines can influence the amount of third party excavation damage. Increased land use near a pipeline can adversely impact the safety of the pipeline.

What decisions do existing integrity management regulations require operators to make using a characterization of pipeline risk?

The Integrity Management regulations require pipeline operators to develop and maintain a program that assesses pipeline risk and uses risk information as part of the effort to ensure pipeline integrity and to protect high-consequence areas (HCAs) adjacent to pipelines. Provisions of these rules include:

- Establishing risk-based schedules to conduct integrity assessments on highest risk segments first.
- Evaluating segment risks to identify the interval for periodic integrity assessment (with maximum intervals prescribed in the regulations).
- Integration of information that can impact the risk to a pipeline's integrity and the consequences of pipeline failure.
- Performing risk analyses of pipeline segments to evaluate the need for additional preventive and mitigative actions to protect HCAs. The analysis of the effectiveness of the additional actions requires assessment of the magnitude and nature of risks along different pipeline segments and the effect of the actions on risk.
- Evaluating the need (in Hazardous Liquid Systems) for Emergency Flow Restriction Devices (EFRDs) and enhanced Leak Detection Systems.

The concept of "Class Locations" is another example of how population densities and surrounding land uses are incorporated in some existing pipeline safety regulations. 49 CFR 192.5 defines area classifications on the basis of population density in the vicinity of a natural gas pipeline and specifies more conservative operating constraints as human population density increases.

Each of these Class Locations has requirements on the depth of cover of the pipe, and the maximum stress level it is allowed to operate. In practice, operators periodically survey their pipelines to identify areas where new development has occurred, and determine whether the development has produced a change in the class location. Where a change in class location has occurred, the operator either lowers the pressure in the pipe to meet the required stress level, or replaces the pipe with thicker pipe.

What approaches do operators use in characterizing pipeline risk?

Pipeline operators currently employ four basic types of risk analysis models in order to evaluate and rank pipeline segments.

All models require location specific pipe characteristic data related to the threats to be collected. This typically includes the design, operation, and maintenance variables that are thought to affect the likelihood of failure. Data is also collected about variables that reflect conditions surrounding the line (e.g., population density, or sensitive environmental resources) that relate to the potential consequences of failure of a segment.

In quantitative models, algorithms using this data are used to estimate risk. Other models are qualitative and use company expert opinion. Models may incorporate both.

Most models provide a relative measure of risk (how the risk of different segments compare) rather than an actual quantitative measure. They are used to determine which pipeline segment poses the highest risk. The numerical representation of risk from a relative model at one company does not correspond to the same degree of risk at another company. A relative risk model does not estimate actual risk such as the annual risk of death to an individual residing near the pipeline.

Index Models

Index models are quantitative tools and provide operator specific, relative risk ranking. They are the most frequently used risk models.

Operator specific numerical scores are assigned to the model variables based on the known pipeline characteristic data. These numerical scores are then combined according to a subjective assessment of their importance using weighting factors and an index or score is calculated. The scores characterizing the relative likelihood of a failure are combined with those relating to consequences to arrive at a score representing the relative risk by each section.

Risk Estimation Models

Risk estimation models are quantitative methods that use the characteristics of sections of the pipeline and the surrounding area to derive an estimate of the actual risk for each pipe segment. In risk estimation models, the likelihood is estimated as the expected probability of failure along the segment over a year’s time. Consequences are estimated in categories such as economic loss, fatalities, and/or residual spill volume after clean-up (as an indicator of long term environmental damage). Risks associated with each threat for a section are calculated as the product of the likelihood of a failure and the expected consequences from that failure. The total risk for each section is estimated as the sum of risks from individual threats over all threats and subsections. The model output is an actual measure of risk.

Scenario-Based Approaches

Scenario models are qualitative and use an inductive approach to develop accident sequences (or scenarios). A particular occurrence or initiating event that has the potential to result in a leak or failure is assumed, and possible scenarios that could evolve are then developed. Scenario approaches allow the time-sequencing of events and accident progression following a pipeline failure to be clearly described; index models do not.

In a scenario-based approach, probabilities are qualitatively estimated for the initiating event and each of the successive events in the scenario to derive likelihood estimates for the scenario. Consequences are qualitatively estimated to reflect the conditions resulting from the sequence of events in the scenario. The numbers of scenarios that are produced depend on the level of detail employed in the model.

Scenario-based approaches employ the same type of data as index and risk estimation models but the data are typically used in conjunction with a group evaluation process, rather than a model algorithm. The result is a relative risk ranking of pipeline segments.

Subject Matter Expert Approaches

Similar to scenario-based approaches, subject matter expert (SME) approaches utilize a panel of senior level personnel having in depth knowledge of the pipeline system to identify various threats to pipeline integrity and the associated consequences in high consequence areas from pipeline operations. The SME process may also be used to provide inputs to one of the other types of risk assessments.

For the SME approach to be effective, these “expert individuals” must represent the major areas of pipeline activities such as operations, engineering, cathodic protection, and assessment/testing. To be effective, this method requires that data related to pipeline integrity and the potential consequences of failure be readily available to support characterization of the identified threats and consequences. A process to rank the threats according to the collective judgment of the panel is followed and a basis for the judgment is documented. The result is a relative risk ranking of pipeline segments.

What do operators know about the range of impact (consequences) of potential ruptures in their pipelines?

In the case of hazardous liquid pipelines, the regulations require operators to identify the pipe segments that “can affect” pre-established high consequence areas (HCAs). These pre-established areas include populated areas, areas unusually sensitive to environmental damage and commercially navigable waterways. In most cases, operators have performed "can affect" analysis that takes into account at a minimum: a spectrum of leak sizes, their detection capability, their ability to mitigate the effects of spills, and the terrain between the pipeline and the HCA.

In the case of gas pipelines, operators are required by the integrity management regulation to evaluate their entire pipeline to determine which segments, if they were to rupture, would impact areas having prescribed population characteristics. The extent of impact of a pipeline rupture is described by an equation that determines the "potential impact circle". While a circle is used to estimate the range of impact of a pipeline rupture, the actual observed burn area is typically elliptical, and the application of the circle in identifying HCAs is defined to address this difference.

The integrity management regulation requires changes in land use to trigger a reevaluation of potential HCA's. This ensures that pipelines near new high impact locations are incorporated into an operator's integrity management program.

How does a gas pipeline fail and what is the potential impact?

The impact of a gas pipeline failure is influenced by the length, depth and type of defect and whether the pipeline fails by puncture or rupture. It is dependent on the pipe diameter, wall thickness, material properties and the operating pressure. At failure, the surrounding soil will be expelled leaving a crater. A mushroom shaped cap is formed which increases in height above the release point and is fed by the gas jet and entrained air from the plume which follows. In addition to entrained air the release can also result in entrainment of ejected soil into the cap and plume. Eventually the cap will disperse and a plume will remain.

Ignition can occur at any time during the release. If ignition occurs immediately after rupture, a fireball will result. The fireball typically lasts for up to thirty seconds and then the gas burns as a large flame. There will not be a fireball if the release does not ignite shortly after rupture. Depending on the failure mode, the gas can be released with a wide range of different speeds and directions.

The levels of thermal radiation vary with time after rupture and with distance from the release point. People can become casualties as a result of receiving large doses of thermal radiation, and buildings can be ignited by thermal radiation directly from the fire or from secondary fires (e.g. from burning vegetation). A number of different criteria can be used for predicting casualties which should also take account of the distance from the pipeline and the availability of shelter.

The calculated consequence distances (potential impact circle) represent the distance beyond which people would be expected to escape to safety and the distance up to which houses would be predicted to catch fire. These calculations take account of the time-dependent nature of the event, and the variations due to the effects of parameters that cannot be known in advance of the event, such as the prevailing weather conditions or the crater source conditions, and range from a few meters for vertical puncture releases to distances up to several hundred meters for rupture releases, depending on the initial pressure assumed.

How does a liquid pipeline fail and what is the potential impact?

The consequences of a liquid pipeline failure depend on the product being transported, the manner in which the pipe fails, pressure, and location. The major hazards associated with products transported by pipeline are flammability and toxicity. Just as with natural gas, petroleum liquid products are flammable and can result in fire or explosions under certain conditions. In the case of liquid releases, the area impacted can be a point some distance away from the pipeline where liquid flowed and pooled before igniting. Chemicals such as ammonia are toxic above certain airborne concentrations. Both of these types of hazards can affect the safety of personnel in the vicinity of the structural failure. A flammable vapor cloud can form after a pipeline or tank fracture and, if an ignition source is present, the cloud can detonate, or explode. In the case of a crude oil or gas pipeline failure, a toxic cloud may also develop due to the presence of hydrogen sulfide (H/sub 2/S). Even in low concentrations, inhalation of H/sub 2/S may cause physical impairment or death.

What strategies can be used to reduce risk for existing pipelines?

The pipeline safety regulations, which are closely related to various national consensus standards, are designed to require operators to carry out preventive and mitigative activities for threats to integrity which experience has shown to be important. As described above, the recent integrity management regulations require operators to rigorously assess the physical condition of pipe segments with the potential to impact high consequence areas, and to remediate defects identified during these assessments.

TRB Recommendations for Risk-Informed Land Use Planning Guidance

TRB Special Report 281, *Transmission Pipelines and Land Use: A Risk-Informed Approach*, recommendation states that risk-informed guidance should address:

1. Land use policies affecting the siting, width, and other characteristics of new pipeline corridors.
2. The range of appropriate land uses, structures, and human activities compatible with pipeline rights-of-way.
3. Setbacks and other measures that could be adopted to protect structures that are built and maintained near pipelines.
4. Model local zoning ordinances, subdivision regulations, and planning policies and model state legislation that could be adopted for land uses near pipelines.

Such a risk-informed guidance system should include three interrelated components:

1. A decision framework informed by risk analysis.
2. Guidelines based on the analysis.
3. Alternative actions that could be taken on the basis of the guidelines.

The process for developing risk-informed land use guidance should:

1. Involve the collaboration of a full range of public and private stakeholders (e.g., industry and Federal, state, and local governments);
2. Be conducted by persons with expertise in risk analysis, risk communication, land use management, and development regulation;
3. Be transparent, independent, and peer reviewed at appropriate points along the way; and
4. Incorporate learning and feedback to refine the guidance over time.

What does TRB say about the important components in risk-informed land use decisions?

A systems approach to risk management that uses quantifiable mitigation measures (such as setbacks, warning signs, and alarm and evacuation procedures) and prevention measures (such as design, inspection, and maintenance of pipelines) would likely improve pipeline safety across the nation. The TRB suggests that the methodology should involve the following principal components:

1. *A high-quality, national level risk assessment* that acknowledges various classes of pipelines, their risk profiles and the variety of conditions that exist in the field;
2. *Simple and easy-to-use decision-guiding tools* with regard to risk levels associated with various extents of setbacks, rights-of-way, and procedures involved in maintenance, inspections, and mitigation in emergencies;
3. A *management plan for implementation* that renders help to local communities according to need and incorporates feedback from use of the approach in the field;
4. A *management plan for long-term communication* of risk and input from all stakeholders, especially pipeline operators, local officials, and the public; and
5. A *management plan for integrating* all the preceding components and refining them on a continuing basis using actual experience.

Overview of the Role of Risk in Land Use Planning - Risk-Informed Decision Making and Communication

How has risk-informed land use planning near pipelines evolved and what is the current state?

Land use planning near transmission lines is a subset of land use planning near hazardous facilities which has its roots in the Seveso Directive in 1982. The best-known consequence of the Seveso disaster was an EC-wide regulatory framework for ensuring the safety of hazardous installations. Prior to the Seveso Directive there was no requirement for public information about major industrial hazards and appropriate safety measures in the event of an accident. This was the first time that the principle of "need to know" was enshrined in European Community legislation. It expanded the scope of public information and public participation in decision-making. Other results of the directive were planning for off-site emergencies and multiple aspects of industrial safety. It also equalized the burden of regulation on industry across the EC.

In 1999, Seveso II Directive introduced the new requirements relating to safety management systems, emergency planning, land-use planning and the reinforcement of inspections. It was aimed at prevention of major-accident hazards involving dangerous substances and at limiting their consequences if they occurred. The document, *Guidance on Land Use Planning*, was released but is not legislation. The Directive excluded but required further investigation of the transport of dangerous substances by pipelines.

Canada followed the EC's path. In the late 1980's, increasing pressure from citizens' action groups and a growing body of regulatory legislation encouraged Canadian industry to adopt a proactive approach to disaster planning. In 1991, the Major Industrial Accidents Council of Canada released a national standard on emergency planning for Canadian industry followed by land use planning for in 1995 and guidance for land use near pipelines in 2004.

While highly structured quantitative risk characterization is mandated as part of land use near hazardous facility decisions in the UK, Canada, European Union, Australia and New Zealand, virtually no similar national approaches exist in the US. Risk informed land use planning guidance specific to pipelines exists in the UK, Canada, Israel, Netherlands and the EU. Land use planning in the US is usually performed at the local level and planners generally do not require risk-based or risk-informed evaluations. They typically do not have experience evaluating risks associated siting new developments near existing hazards. The California Department of Education is an exception.

What examples exist of land use decisions related to pipeline siting and development near existing pipelines in the US?

- California Department of Education (CDE)

Support's school siting decisions, including comparison of alternative sites, when an oil (crude or refined) or natural gas pipeline is within 1500 feet of the proposed school site. The decision making process involves three sequential steps: screening analysis of candidate sites to determine whether additional analysis is needed (Stage 1); detailed estimation of the individual risk (IR) from the pipeline to a person at the boundary of a proposed site (Stage 2); more detailed analysis needed only to address factors such as diverse materials in the pipeline, the presence of multiple pipelines, or physical features that may change the nature of the risk such as the presence of storm drains (Stage 3). CDE developed a spreadsheet to estimate risk called, *Pipeline Risk Analysis Protocol Total Individual Risk (TIR) Estimating Aid*. The approach requires considerable technical expertise for CDE.

- City of Austin Ordinance on Development Near Hazardous Pipelines

This Ordinance applies to hazardous liquid pipelines 8 inches or greater in diameter. A "use requiring evacuation assistance" (list provided) is prohibited in a structure located within 500 feet of a hazardous pipeline. Exceptions are possible for certain structures between 200 and 500 feet of the pipeline and require resolution of the city Council based on a recommendation of the fire chief that the structure design provides an adequate time period for evacuation. There may not be new construction within 200 feet of a hazardous pipeline. Exceptions are possible for certain structures based on determination by the fire chief that the structure design provides a one hour period for evacuation. No placement of structures or excavation is permitted in a restricted pipeline area (within 25 feet of the hazardous pipeline) or within its easement (limited exceptions listed). A residential lot of less than one acre may not include a restricted pipeline area. A person may not place a structure or excavate within a restricted pipeline area (exceptions listed).

- Model Setback and Depth Requirements - Municipal Research & Services Center (MSRC) of WA

MSRC is a non-profit that provides research, consultation and information services to and is funded by counties, cities and districts in Washington state. This model Ordinance applies to new hazardous liquid and gas transmission pipelines. It is designed to avoid encroachment on the pipeline right-of-way, thereby reducing the likelihood of third-party damage. All new hazardous liquid and gas transmission pipelines must be buried a minimum of three feet below grade. A setback of at least 50 feet from the nearest edge of the gas transmission pipeline corridor (including right-of-way and easements) is required for general residential, commercial and industrial buildings. This setback distance must be doubled for certain educational and recreational facilities.

- Washington Utilities and Transportation Commission

These guidelines are designed to increase awareness of the need to integrate land use decisions with understanding of the pipeline right-of-way location. They apply to existing transmission pipelines only. The guidelines seem to draw heavily on the material in the Canadian Standards Association guidelines described above. The guideline proposes a Consultation Process emphasizing early communication among key stakeholders as part of any land use planning process. The Consultation Process should be undertaken for any proposed development based on the criteria established by local governments. The report tabulates nine factors that should be considered in designating the distance between a pipeline and a proposed development for which consultation should occur. The position in an earlier draft that development within 660 feet of the pipeline - called the "Consultation Zone" - should be subject to consultation was eliminated from the final draft because the extent of the zone of potential impact depends on the nine factors now enumerated.

The WUTC in Chapter 480-93-020 defines allowable distances from buildings and future buildings to gas pipelines operating at different pressures. A gas company must receive commission approval prior to operating any pipeline within 500' at 500 psig or 100' between 250-500 psig to a building. Newly constructed pipelines must adhere to these standards and their design must consider possible future development near the pipeline. If they cannot meet the requirement, they must demonstrate why an alternate route was not practical.

- Edison Township Municipal Code, Section 17.08.210

The code is prescriptive. No building or land disturbance shall be permitted within seventy-five (75) feet of any distribution, gathering or transmission line, as defined in subsection A of this section. No building or structure or part thereof which is used for the manufacturing, processing, generation or storage of corrosive, highly toxic, oxidizing, pyrophoric, water-reactive, highly combustible, flammable or explosive materials that constitute a high fire, explosion or health hazard, including loose, combustible fibers, dust and unstable material, shall be constructed within one hundred twenty-five (125) feet of any distribution, gathering or transmission line.

What does risk-informed land use planning look like?

Where structured characterization of the risks related to development exist, the typical *elements* of current risk-informed land use planning include the following:

- *Identify* hazards and screen for potential impact,
- *Assess* and quantify risks
    - More complex situations may require a quantitative assessment of actual risk (e.g., involving consideration of failure cause, failure mode, gas outflow, ignition, thermal radiation, thermal effects, risk calculations)
- *Evaluate* - Make and implement risk-informed decision,
- *Mitigate* - Include consideration of means to reduce risk (e.g., reducing amount of hazardous material, strengthening preventive or mitigative measures, strengthen emergency planning) Involve stakeholders in consultation,
- *Monitor* hazard and related risk over time.

These elements closely parallel the elements in pipeline integrity management. The risk management already performed by operators may have the potential to provide information to support risk-informed land use guidance as shown below in parentheses. However, inconsistencies in the approaches operators take to modeling risk and the prevalence of risk models that estimate relative rather than absolute risk would prevent the use of existing models to support consistent land use decisions.

- *Identify* hazards (The hazard is the failure of a natural gas or hazardous liquid transmission pipelines covered under 49 CFR 192 and 195.),
    - Screen for potential impact (Operators identify areas of potential impact area through HCA's and "can affect" pipeline segments. The criterion is based on population density but it does not require facilities be identified by other characteristic such as ability to evacuate quickly.)
- *Assess* and quantify risks (Operators currently perform a risk assessment as previously described. Most do not currently determine actual risk. Operators currently are not required to share assessment data except with OPS or state Commissions.)
    - More complex situations may require a quantitative risk criterion
- *Evaluate* - Make and implement risk-informed decision
- *Mitigate* - Including consideration of means to reduce risk (Operators currently are required to consider this as part of the IMP but there is not a target level of risk for operators to reach.)
    - Involve stakeholders in consultation (Operators currently are required to have a communications plan that follows API RP 1162. It includes information that is required to be communicated to different stakeholder groups such as information on how to respond in the event of a leak or emergency.)
- *Monitor* hazard and related risk over time (Operators are required to patrol pipelines and at least annually reassess risk.)

Here are some key observations on existing risk-informed land use planning practices:

- Limited experience exists with risk-informed land use planning specific to pipelines - both in the US and abroad,
- Most decision processes involve initial screening to determine whether more detailed risk evaluation is needed,
- Many risk screening approaches consider only the consequences not the threats,
- Some land use decisions include the option to reduce likelihood of failure - who is responsible for the cost of these preventive measures is an issue, primarily for development near existing hazardous facilities,
- Regulations require minimum distance to pipeline. If the minimum distance cannot be met, additional mitigation actions such as installing thicker walled pipe, increasing depth of cover or installing concrete barriers are required.
- The use of formal decision criteria seems to drive toward greater complexity of analysis (e.g., evaluation against individual risk criteria requires performance of quantitative risk analysis),
- Stakeholder involvement in decision process seems critical to the acceptability of land use decisions.
- Regulations that restrict land use near a hazard can impact land value and may be subject to compensation requirements depending on a court's interpretation of regulatory "takings" provision of the Fifth Amendment.

Characteristics that are distinctive to transmission pipelines that may affect land use planning near pipelines include:

- Pipeline "site" is not localized – expecting operators to acquire broad expanse of adjacent land to prevent or constrain development is not economically realistic,
- Activity associated with land development and use can affect the safety of the pipeline (i.e., a major threat to pipeline integrity is excavation damage),
- Operator must monitor land development and use activity near pipeline to minimize risks to public safety and supply interruption,
- Operators must have access to land near pipeline to carry out maintenance activities.

What commonalities are there between risk-informed land use planning programs?

Decision Making Responsibility

With the exception of the UK, the decision to allow or restrict development is made by local officials who are able to weigh the local risks associated with development against the local benefits derived from the development. The information on which these decisions are made may come from a variety of sources and may require considerable technical sophistication. The needed analysis may be the responsibility of the land developer. Where consistent input to the decision process is desired, provisions are needed to communicate how the analysis is to be performed, and the criteria against which the results of the analysis are to be compared.

Some land use decisions made to preserve the environment (e.g., development restrictions near pristine shorelines) or to protect the community from natural disasters (e.g., restrictions to development in flood plains) can strongly impact land value and may therefore be subject to compensation requirements dictated by court interpretations of regulatory "takings" provisions of the fifth amendment.

Identify Hazards and Screen for Potential Impact

Hazards that are subject to land use restrictions vary from toxic or flammable chemicals, including natural gas and petroleum products, to natural hazards such as flooding and seismic. The discussion here is focused on restrictions related to the presence of hazardous chemicals, either in processing facilities or being transported in the vicinity of the proposed development.

- Many land use decision processes begin by conducting a simple screening for the presence and potential impact of hazards that might impact the proposed land use. The purpose of this analysis is to focus future consideration on situations where the risk is believed to be large enough either to warrant more detailed analysis, or to initiate a consultation process involving a spectrum of stakeholders in discussions intended to lead to a decision on land use (e.g., Washington Utilities and Transportation Commission). Typically this screening involves identification of the hazardous materials within some prescribed evaluation zone, and evaluating the potential for consequences if the materials were released. This screening could be as simple as determining whether an oil or natural gas pipeline is within 1500 feet of the boundary of the proposed school (California Department of Education).

Assess and Quantify Risk

For situations in which the hazard is determined to be significant, some decision processes require a more detailed assessment and quantification of risk. Both "consequence based" and the "risk based" approaches were used. Most included provisions to perform more complex analysis for more complex situations. Generally high density areas had an acceptable actual risk of 1×10^{-6} and 1×10^{-4} in low density areas for an individual. Obtaining reliable data to determine failure probability was reported as challenging. California Department of Education has a template for their rather complex analysis.

Evaluate - Make and Implement Risk-Informed Decision

Possibly involving a quantitative risk criterion (e.g., annual risk to an individual at the boundary of the development)

Mitigate

- Including consideration of means to reduce risk (e.g., reducing amount of hazardous material, strengthening preventive or mitigative measures, strengthen emergency planning)
- Involving stakeholders in consultation

Monitor Hazard and Related Risk over Time

Prescriptive programs generally provide an approval or disapproval but do not include additional actions to take to monitor the hazard. Both the EC and UK have initiatives to collect data about pipeline failures in order to improve their programs.

Links to risk-informed land base planning near transmission lines programs outside of the US:

- Canada – Land use planning for pipelines: A guideline for local authorities, developers, and pipeline operators
- Isreal - Choosing a Standard for Natural Gas Pipelines Design and Construction
- UK – Procedure for Setting Land Use Planning Zones For Major Accident Hazard Pipelines
- UK - Standard IGE/TD/1 Edition 4
- EU - Land Use Planning Policies & Good Practices

Links to QRA's examples:

- Pipeline Safety Assessment Schulte Road
- Independent Safety Review of the Corrib Gas Pipeline

Links to support material for developing the guidance program:

- Planning Public Forums: Questions to Guide Local Officials
- An Ounce of Prevention: Best Practices for Making Informed Land Use Decisions