PHMSA Risk Modeling Methodologies Public Workshop

A Framework for Probability Estimation

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Why Consider Risk?

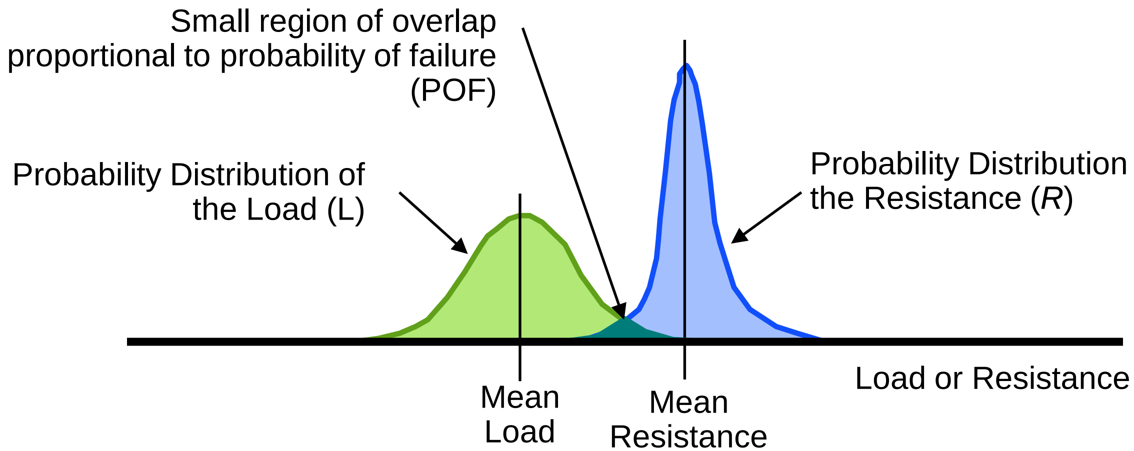
- Can provide a consistent and objective basis for assessing, managing and demonstrating pipeline performance
- Actions based on risk assessment reflect both likelihood of failure and potential consequences
- Applicable to design and integrity management
  - Focus here on application to integrity management

Available Approaches

- Qualitative vs Quantitative
  - Qualitative methods: characterize without quantifying risk
    - Suited to threat identification and risk ranking
  - Quantitative methods: objective basis for decision making
    - Suited to determining what action is required (if any) and when
- Quantitative options
  - Statistical: estimates developed from historical data
    - Not very line specific, difficult to reflect impact of maintenance
    - Best suited to model validation
  - Model based: estimated from pipeline & ROW attributes
    - Can be very line specific & reflective of maintenance actions
    - Preferred basis for decision making

Model Based Approach

- Risk = Probability x Consequence
- Models available for both risk components
  - Probability estimation models have been developed based on structural reliability methods (an established approach applied in other industries)
  - This presentation focused on probability of failure (POF) estimation



POF = P(R < L)

Central to the methodology is a formal characterization of the uncertainties inherent in both the applied load and the available resistance for each damage/deterioration mechanism (i.e. each threat)

Basis for Models - Consider the Integrity Management Process

- Management of progressive (time dependent) damage
  - Assess existing damage severity
    - Detect and size existing damage
  - Assess anticipated behavior over time
    - Estimate rate of growth and assess time for damage to become failure critical
  - Manage integrity
    - » Through periodic inspection and remediation

- Management of random (time independent) damage
  - Assess likelihood of event occurrence
    - E.g. quantify third-party hit frequency or seismic event likelihood
  - Assess anticipated pipe response to loading event
    - Quantify damage tolerance
  - Manage integrity
    - Through control of event likelihood and/or failure potential given event

Uncertainties Inherent in the Integrity Management Process

- Random variations → Loads imposed on the line
  - Internal pressure
  - Third party impact force

- Measurement uncertainty → Pipe properties & line condition
  - Joint-by-joint yield strength & fracture toughness
  - Number and size of defects
  - Defect growth rates

- Model uncertainty → Pipe behavior under loads
  - Model assumptions and approximations

Probability Estimation

Time-dependent damage

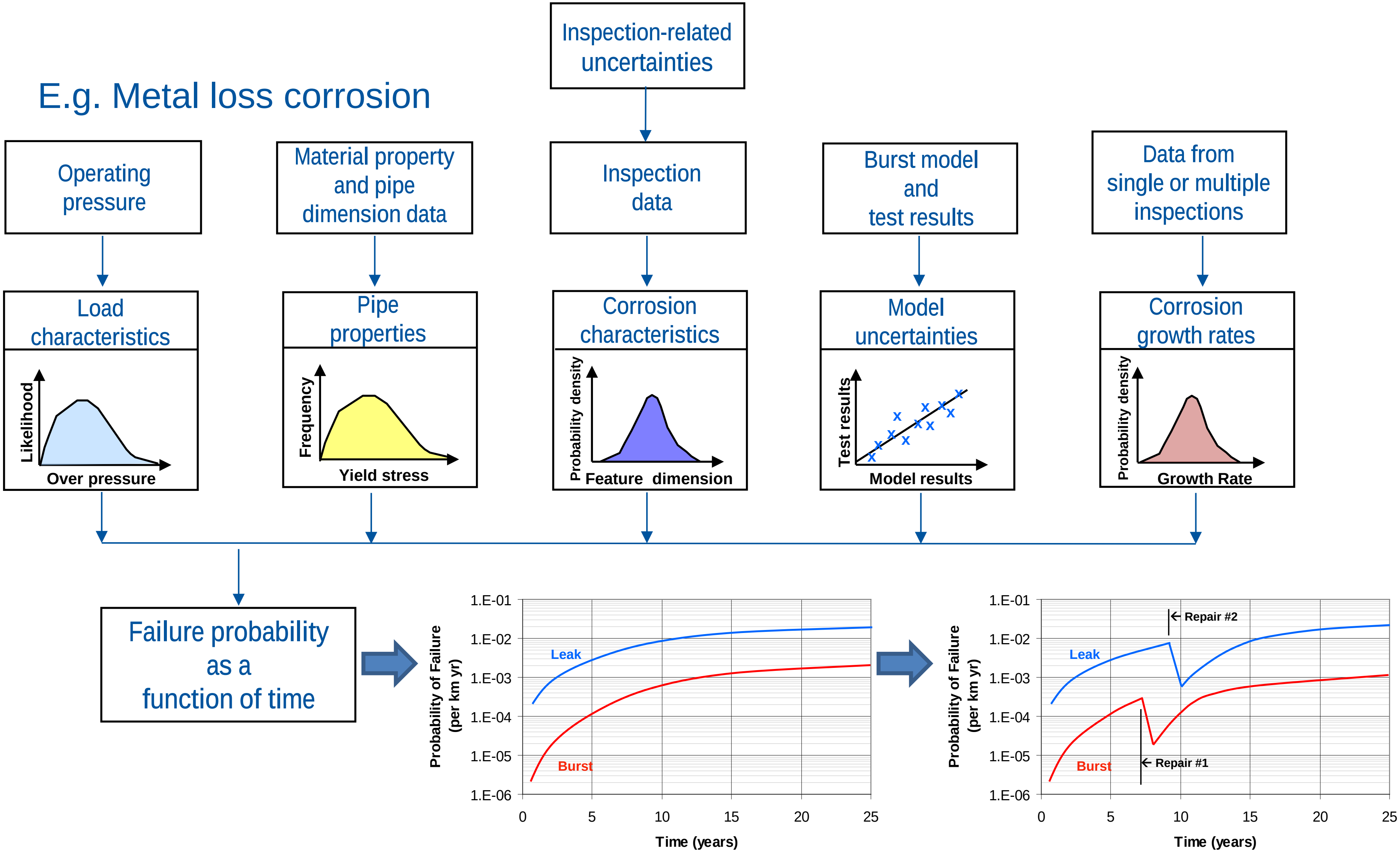
(e.g. corrosion, cracks, or progressive ground movement)

Failure rate (per mi-yr) = No. defects (per mi) x POF per defect (per yr)

- Considerations in developing failure rate estimate (e.g. corrosion)
  - Characterization of defect population
    - Assumed actual number of features and feature sizes reflects the probability of detection and sizing accuracy of inspection method
  - Probability of failure over time ← structural reliability model
    - Failure projections reflects uncertainty in defect growth rates, variability in pipe properties, and accuracy of the failure prediction model
- Ability to reflect the impact of maintenance (e.g. corrosion)
  - Effects of defect remediation, re-inspection interval and/or modified operating pressure are directly reflected in probability estimates

Failure Probability Estimation

E.g. Metal loss corrosion



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Probability Estimation

Time-independent damage

(e.g. third-party damage or sudden ground movement)

Failure rate (per mi-yr) = No. events (per mi-yr) x POF per event

- Considerations in developing failure rate estimate (e.g. 3rd party dmg)
  - Event occurrence frequency ← fault tree model
    - Likelihood of excavation activity (given land use) and effectiveness of damage prevention measures (e.g. signage, ROW condition, one-call system, patrol frequency, burial depth, mechanical protection) are reflected in estimate
  - Failure given event ← structural reliability model
    - Failure given hit can reflect uncertainty on damage caused by event, variability in pipe properties, and accuracy of failure prediction model
- Ability to reflect impact of maintenance (e.g. 3rd party dmg)
  - Effect of changes in damage prevention measures and/or modified operating pressure are directly reflected in probability estimates

Probability Estimation Based on Structural Reliability Models

- Feasibility
  - Structural reliability methods and models for specific pipeline integrity threats have been under development for more than 20 years (JIPs & PRCI → Reliability Based Design and Assessment, RBDA)
  - Many models in public domain, some in Annex O of CSA Z662
- Validity
  - Model development activities have included calibration/validation exercises wherein a suite of models were used to hindcast historical failure rates for the existing North American transmission pipeline network – agreement shown to be good

Probability Estimation Based on Structural Reliability Models

- Benefits
  - Sound basis for line-specific, threat-specific probability estimates
  - Framework for consideration of significant sources of uncertainty
  - Can reflect maintenance actions & damage prevention measures

- Implementation considerations
  - Models require significant development effort
    - Incentive to leverage previous work and/or standardize
  - Data requirements not insignificant
    - This data is the basis for objective estimates of failure probability, worth the effort to collect and interpret