221 J

Attachment A

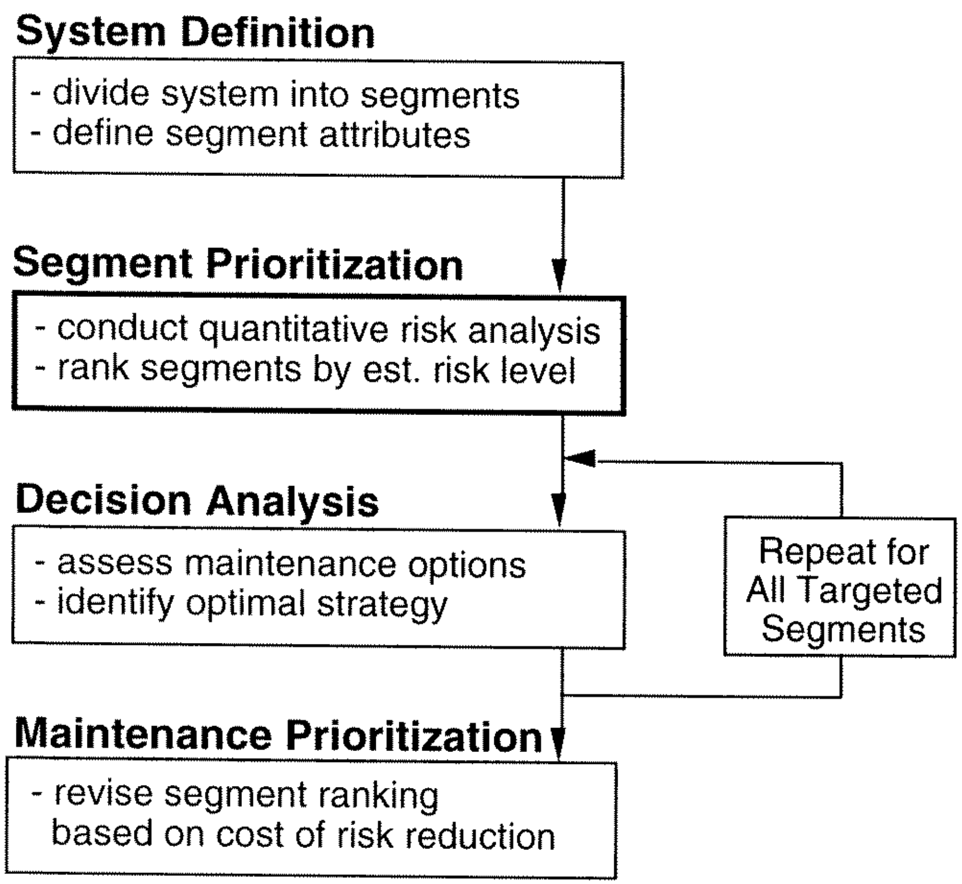
Software Updating

- **Implement modifications requested by participants**
  - **dual units** (metric or imperial)
  - **hole size specification options** (absolute vs. fraction of line diameter)

- **Implement improvements identified by C-FER**
  - **convert to 32 bit environment** (remove model size limitations)
  - **refine release rate / volume calculation algorithms**
  - **improve program calculation speed**

Prioritization of Offshore Pipeline Segments for Integrity Maintenance

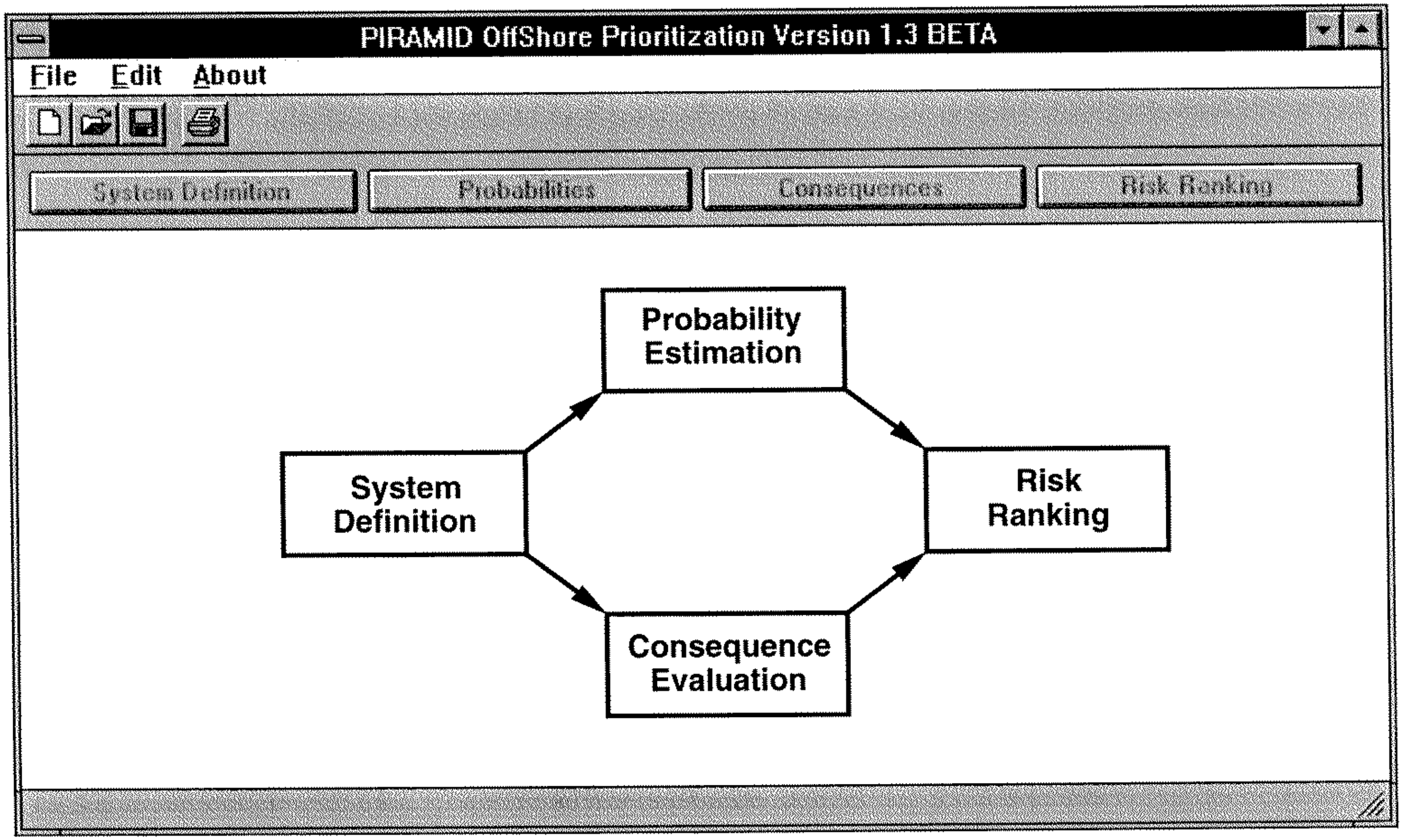
Review of Risk Methodology



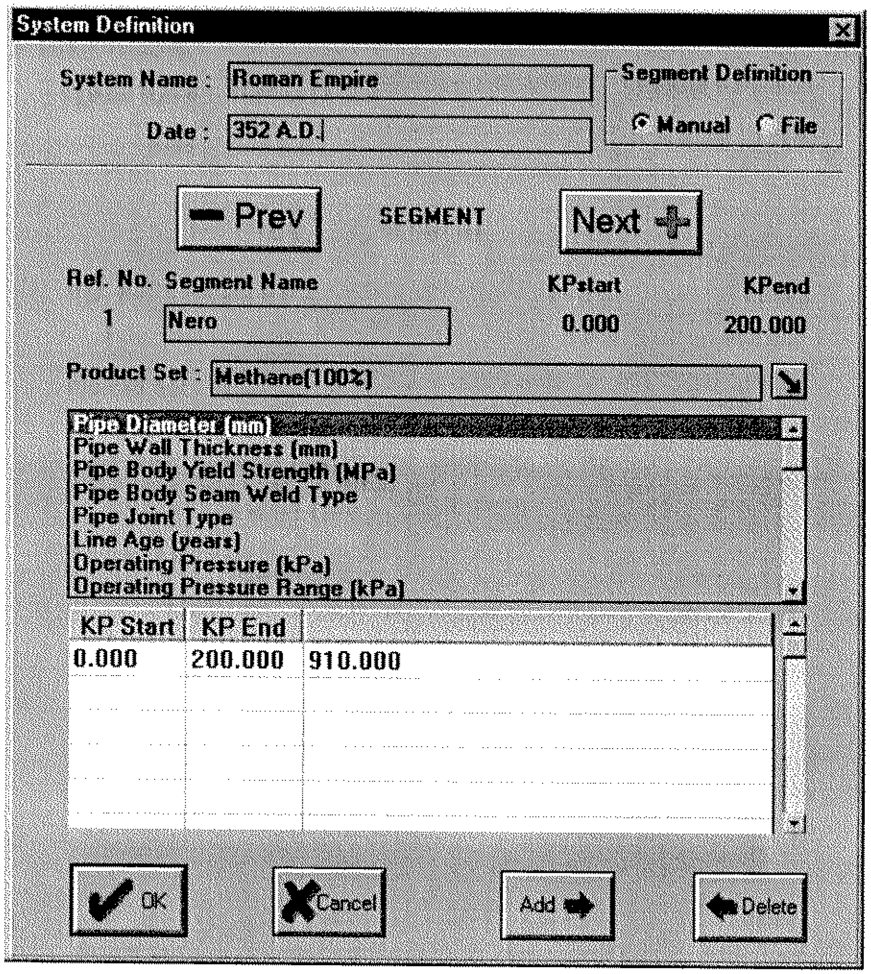
PIRAMID Offshore - Prioritization

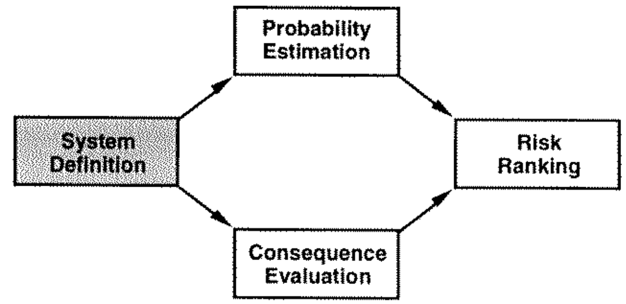
- Provides a quantitative estimate of operating risk for each segment within pipeline system
- Ranks segments by estimated level of risk
- Risk estimates:
  - linked to specific line attributes
  - failure cause specific
  - provides a combined measure of
    - » financial risk
    - » life safety risk
    - » environmental risk

Software Program - modules



System Definition



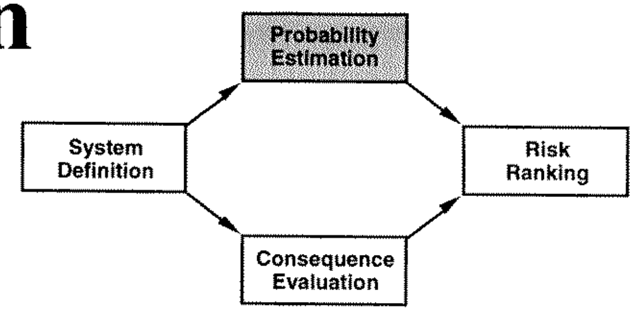


Program divides each segment into sections having consistent attribute values

Segment Attributes - Affecting Failure Probability

Onshore		Offshore
– Line diameter		
– Wall thickness		
– Yield strength		
– Joint type		
– Line age		
– Line pressure		
– Line temperature		
– Depth of cover		
– Land use type	→	– Vessel traffic density
		– Water depth range
– Soil corrosivity	→	– Enviro. corrosivity
– Coating type		
– Coating condition		
– Cathodic protection level		
– SCC potential		
– Product corrosivity		
– Ground movement potential		
– Failure potential given ground movement		

Probability Estimation



Program adjusts baseline failure rates to reflect segment attributes

Baseline Failure Rate Estimates

Failure Cause	Failure Rate (incidents/km·yr)	Relative Failure Probability by Mode		
		small leak	large leak	rupture
External Metal Loss Corrosion	0.00010000	0.85	0.10	0.05
Internal Metal Loss Corrosion	0.00044000	0.85	0.10	0.05
Mechanical Damage	0.00015000	0.25	0.50	0.25
Natural Hazard Damage	0.00008000	0.25	0.50	0.25
Ground Movement		0.20	0.40	0.40
Environmentally Induced Cracks (SCC)		0.60	0.30	0.10
Mechanically Induced Cracks (girth weld fatigue)		0.60	0.30	0.10
Other Causes	0.00016000	0.80	0.10	0.10

OK Defaults Cancel

Probability Estimation Approach

Probability of failure for a given section

$$Pf_{ijkl} = Rf_{ijkl} L\sec_{ij}$$

$$Rf_{ijkl} = Rfb_l MF_{kl} AF_{ijl}$$

Section length

Section failure probability for given mode and given cause

Adjustment factor for section and cause

Failure rate for section, mode and cause

Baseline failure rate per cause

Relative failure probability per mode

Adjustment Factor - External Corrosion

$$AF = K_{EC}\left[\frac{A}{D}(T+17.8)^{2.28}\right]F_{CE}\;F_{CP}\;F_{CT}\;F_{CC}$$

- AF: Rate adjustment factor
- K_{EC}: Scaling factor
- A: Line age
- D: Line Diameter
- T: Operating temperature
- F_{CE}: Environment corrosivity factor
- F_{CP}: Cathodic protection factor
- F_{CT}: Coating type factor
- F_{CC}: Coating condition factor

Adjustment Factor - Mechanical Damage

Scale factor

$$AF = \frac{K_{MD}}{D^{0.72}} F_{MA} F_{MD} F_{MC}$$

Rate adjustment factor

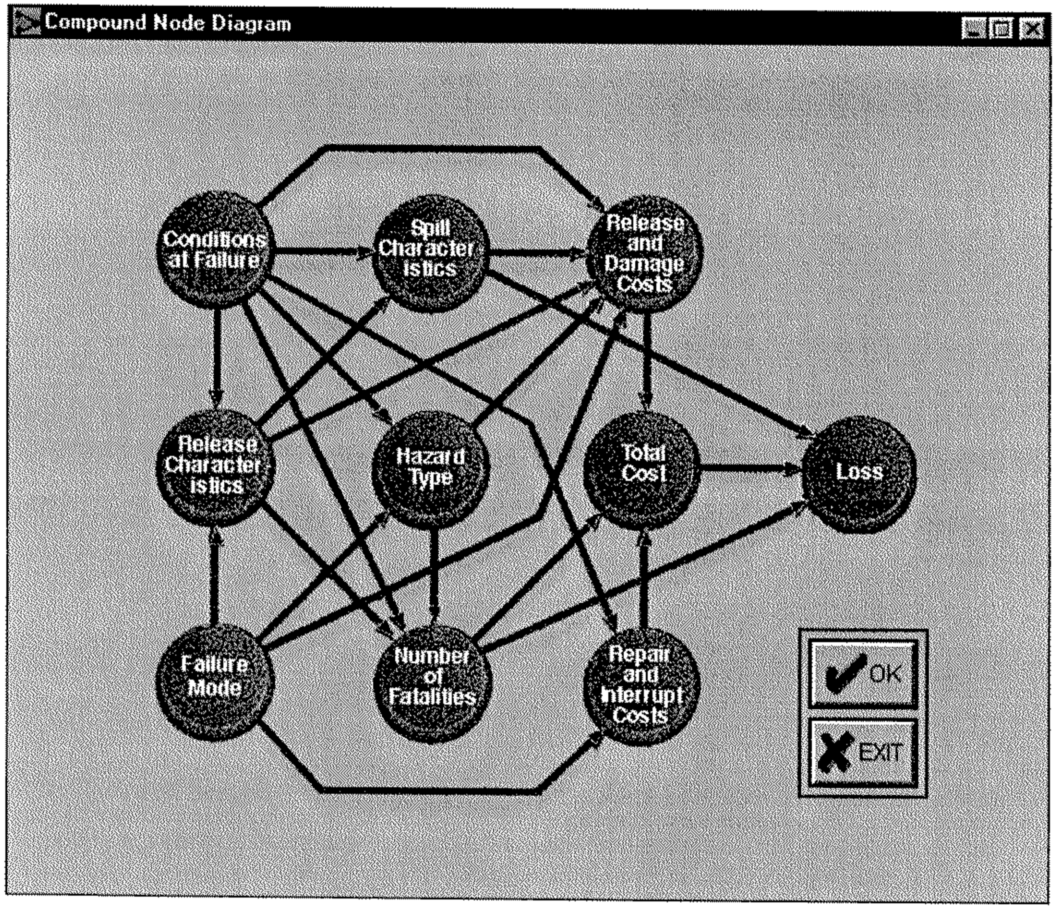
Line diameter

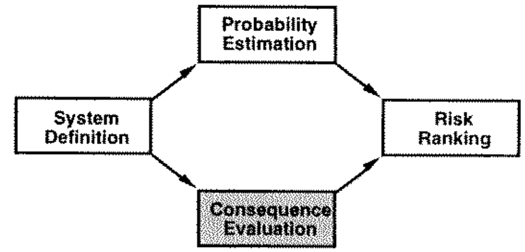
Traffic density factor factor

Water depth factor

Soil cover factor

Consequence Evaluation

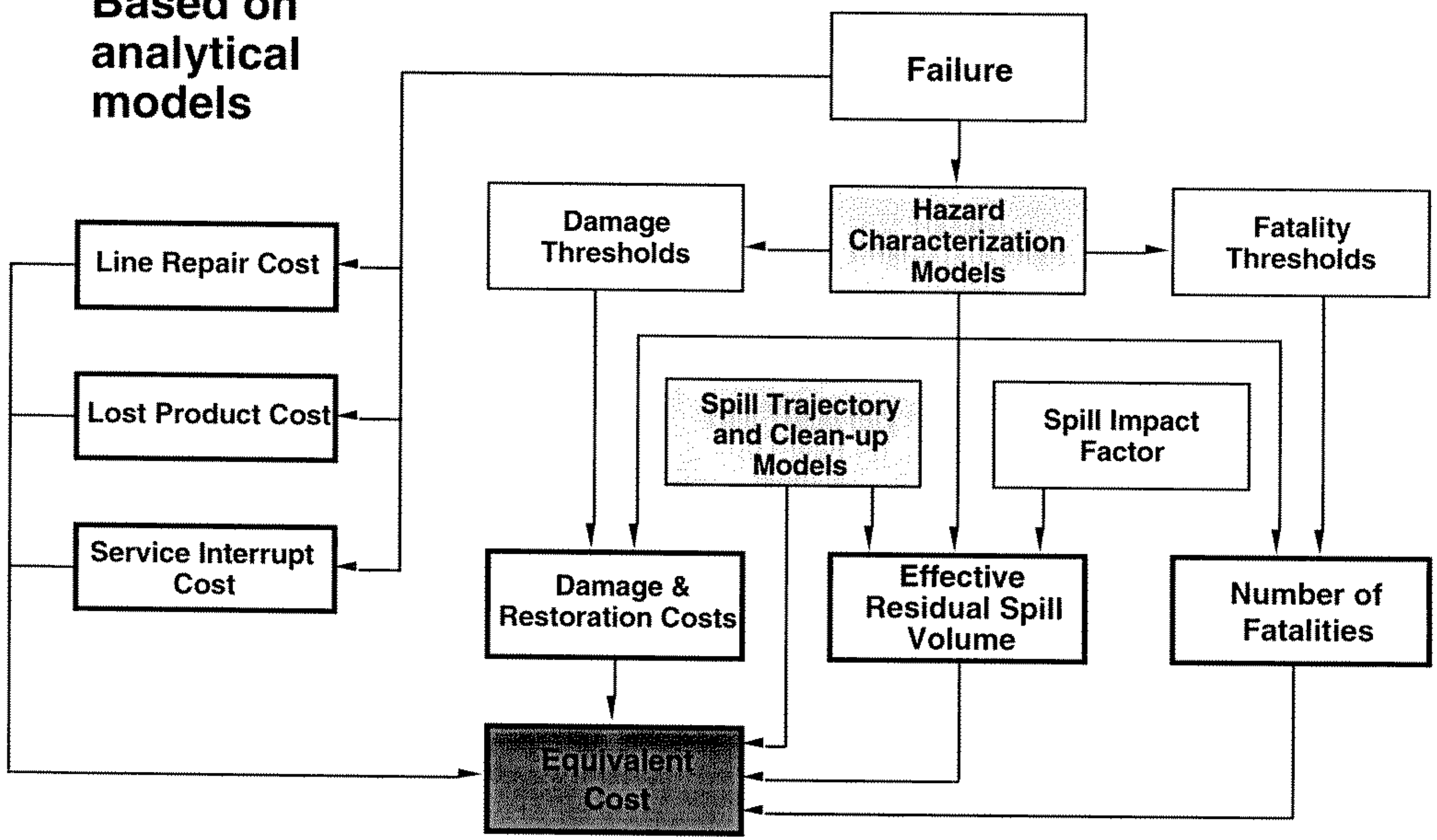




Program estimates loss components based on segment attributes

Consequence Evaluation Approach

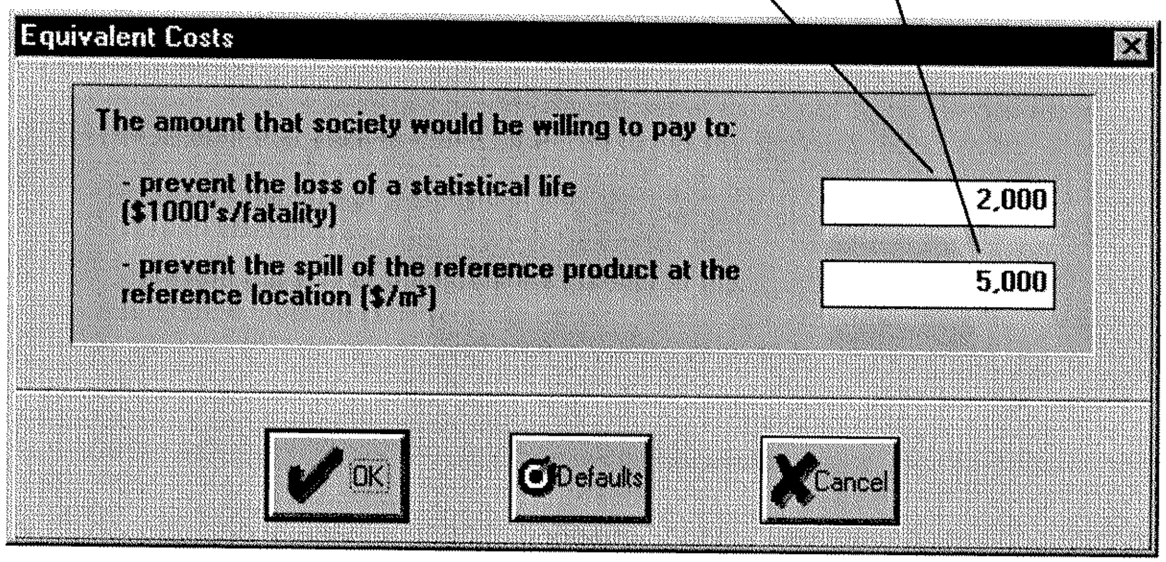
Based on analytical models



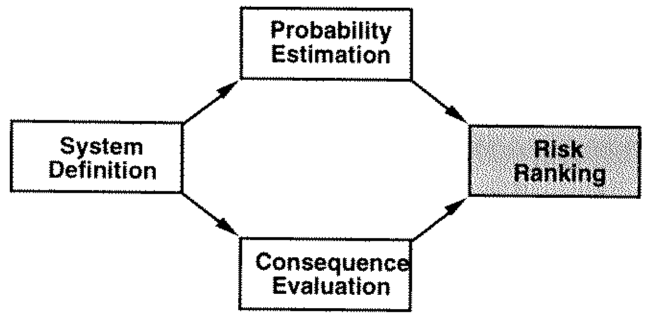
Consequence Evaluation - Loss Estimate

Total loss — Cost — Number of fatalities — Equivalent spill volume

$$Loss_{ijk} = \bar{c}_{ijk} + \alpha_n \bar{n}_{ijk} + \alpha_v \bar{v}_{ijk}$$



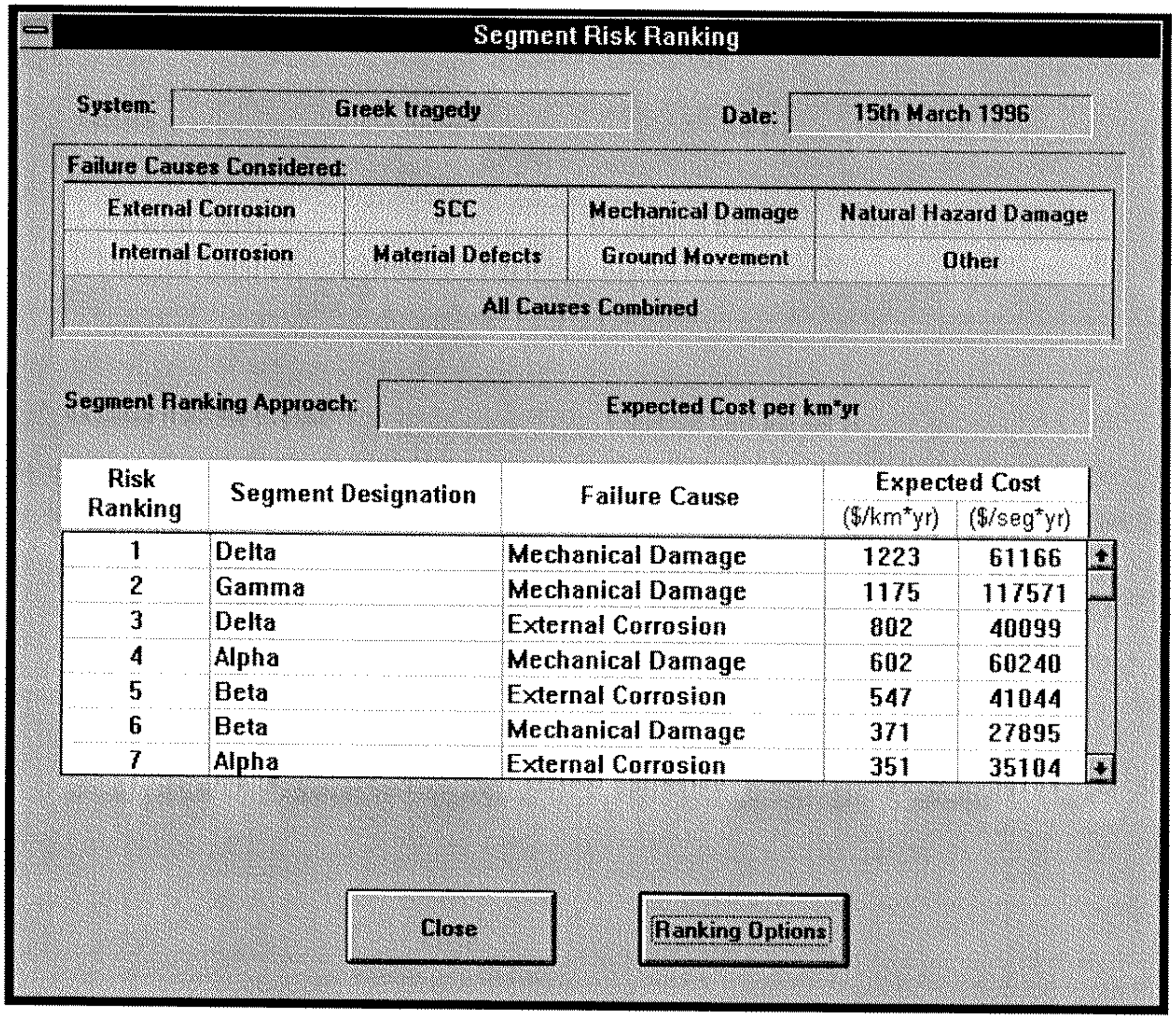
Risk Ranking



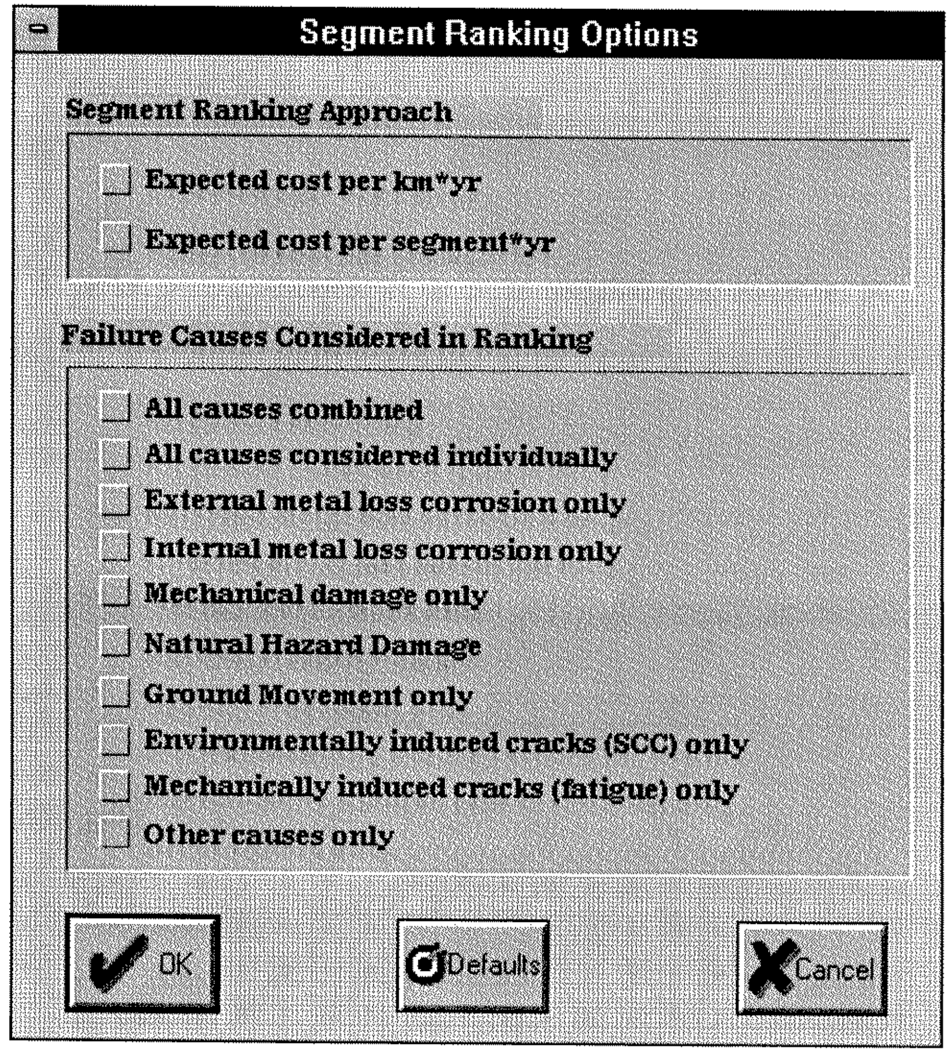
Calculate total risk = Expected loss

$$ExpLoss = Pf \cdot Loss$$

Risk Ranking Output



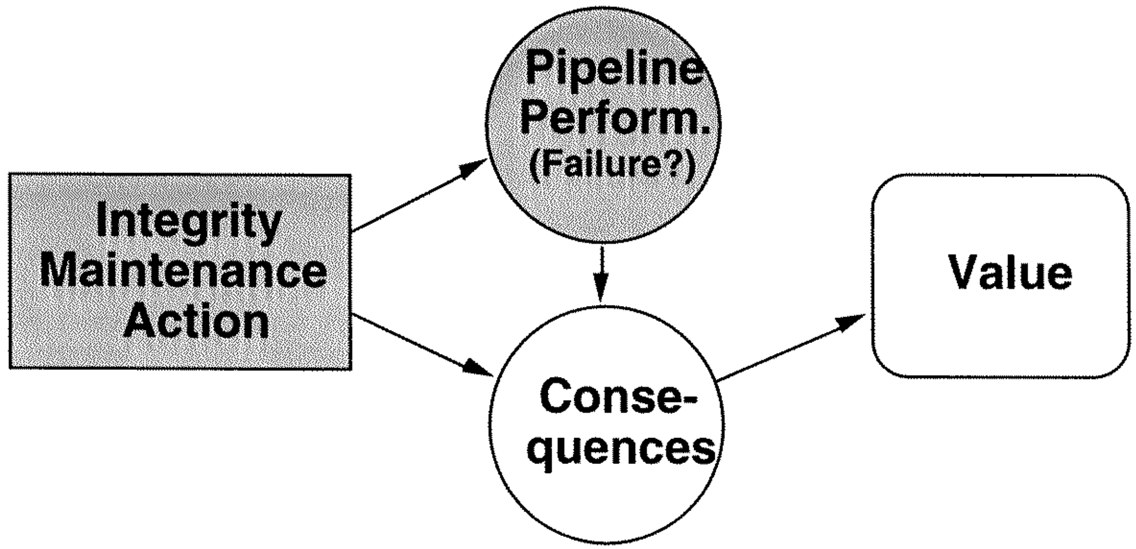
Risk Ranking Options



Optimization of Metal Loss Corrosion Maintenance

- Objectives
  - Develop models to
    - » Calculate probability of failure due to corrosion
    - » Quantify impact of maintenance on failure probability
  - Incorporate models into PIRAMID to make corrosion maintenance optimization decisions

Review of Basic Influence Diagram



Individual projects expand different nodes

Example

- Company X inspected a 50-km segment using a high resolution in-line tool
- Inspection revealed 63 external corrosion defects
- For each defect inspection provided
  - maximum axial length
  - Maximum depth

Required

- Should a more accurate inspection be carried out?
- Which defects should be repaired?
- How long to the next inspection?

Step 1 - Statistical Characterization of Defect Population

- Average defect fequency
  - Number of defects / segment length = 1.37 defects / km
- Probability distribution of defect depth
  - Lognarmal
    - » mean = 15% wt
    - » standard deviation = 5% wt
- Probability distribution of defect length
  - Lognarmal
    - » mean = 27 mm
    - » standard deviation = 17 mm

Step 2 - Calculate Safety Factor for Each Defect

$$R = 2.3C\frac{TS}{D}\left[\frac{1 - H/T}{1 - H/MT}\right]$$

R = Resistance
C = Mean model error factor
T = Wall thickness
S = Yield strength
H = Average defect depth
M = Folias factor (function of D,T,L)
L = Maximum defect length

Step 3 - Run PIRAMID

- Input
  - Line attributes
  - Defect characteristics
  - Defect growth rates
- Output
  - Another inspection? (Yes / No)
  - Repair criterion --> 1.64 safety factor
  - Time to next maintnance --> 16 years

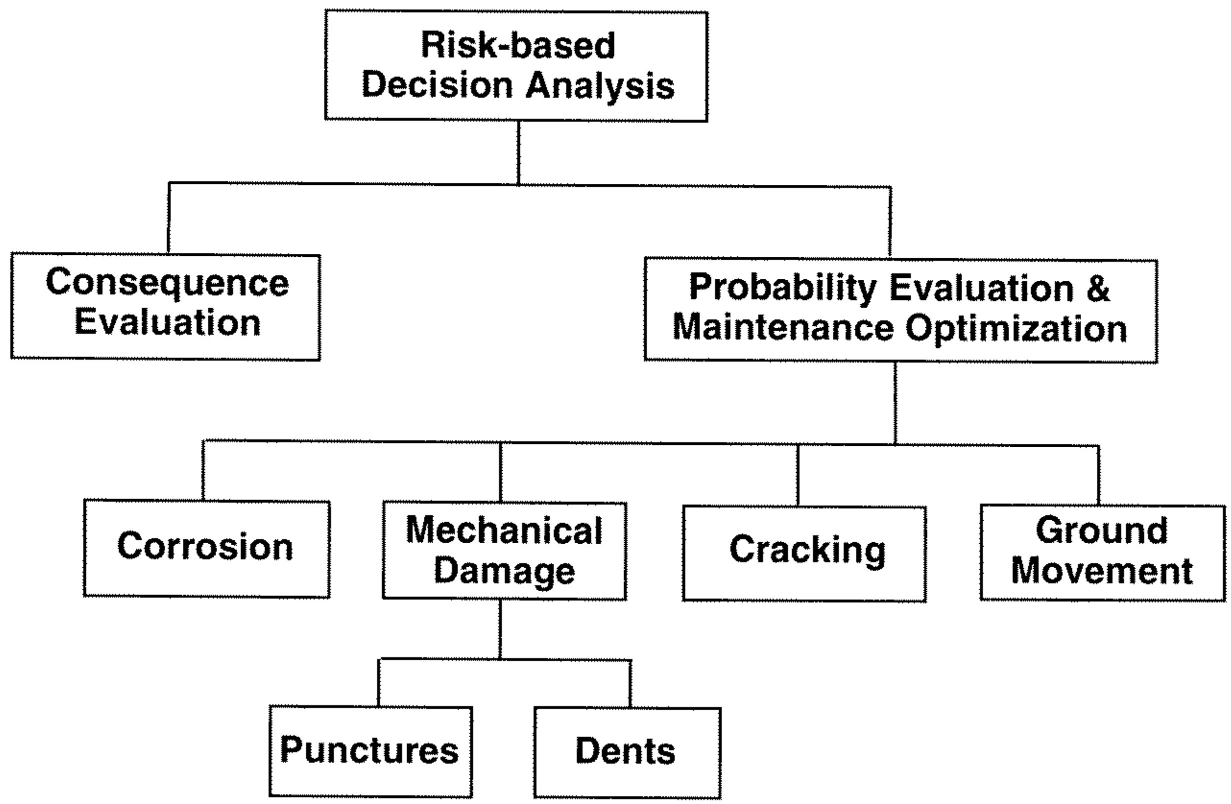
Step 4 - Implement Plan

- Repair defects with safety factor < 1.64
- Re-analyze the line in 16 years

Project Outcomes

- PIRAMID Corrosion (Beta)
  - Separate module for corrosion maintenance optimization
- Updated User Guide
- PIRAMID Technical Reference Manual 6.0

Original Development Plan



Optimization of Mechanical Damage Prevention

Project Objectives

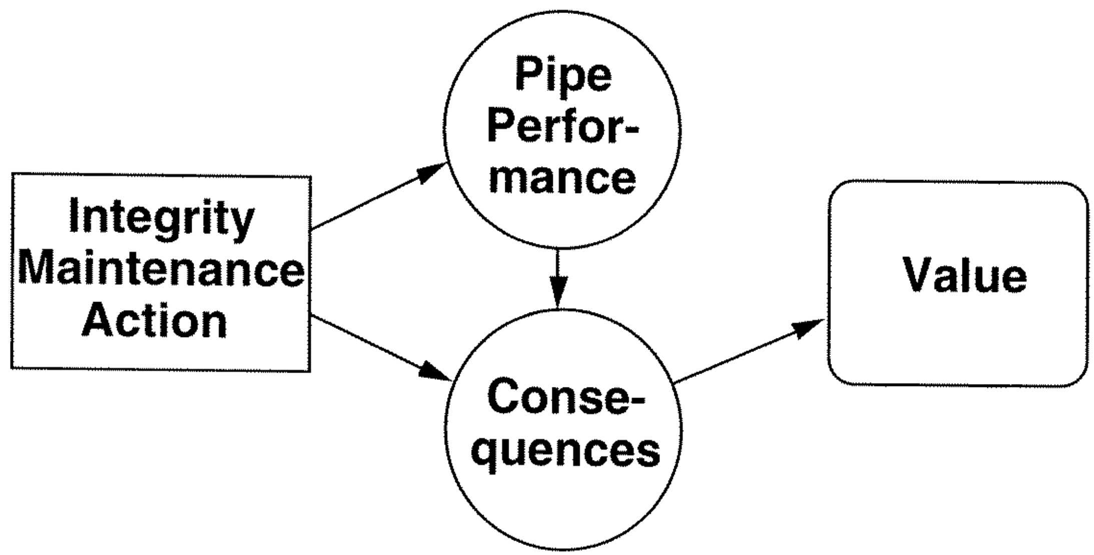
- **Develop a model for estimating probability of line failure due to mechanical interference**
  - **Model to be line specific (reflect line attributes)**
  - **Model to account for the effects of preventative maintenance activities on failure probability**

- **Integrate probability estimation model within the existing decision analysis framework**

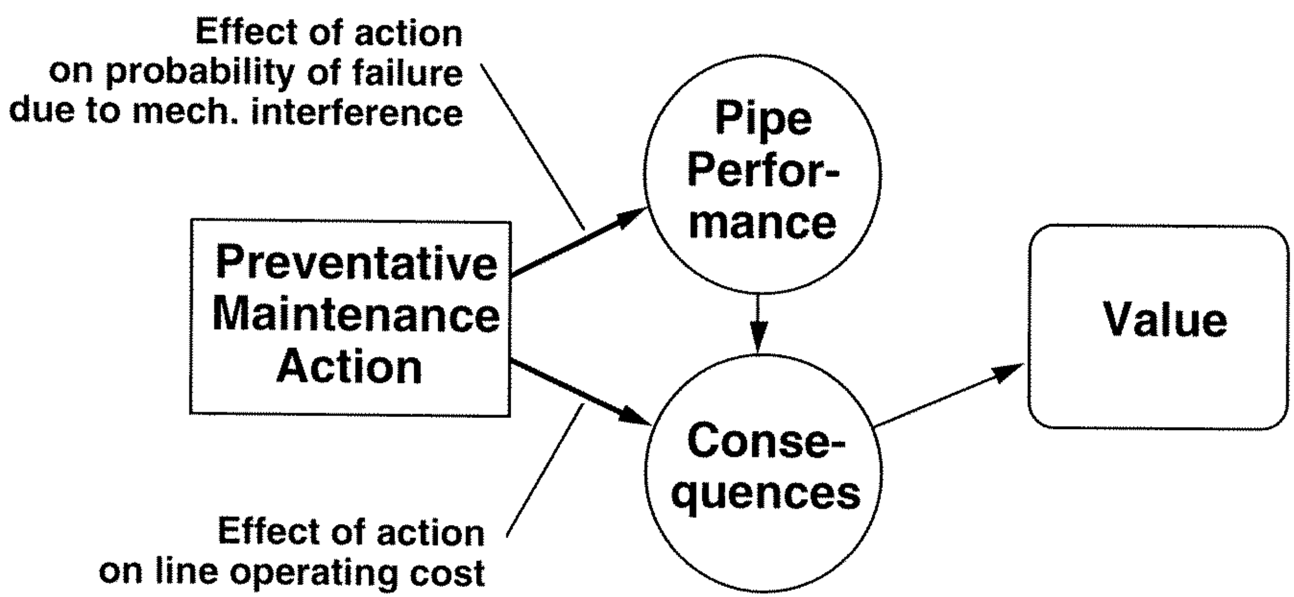
Note: model addresses immediate failures due to line puncture only, delayed failure of dents and gouges to be addressed elsewhere

Decision Analysis Framework

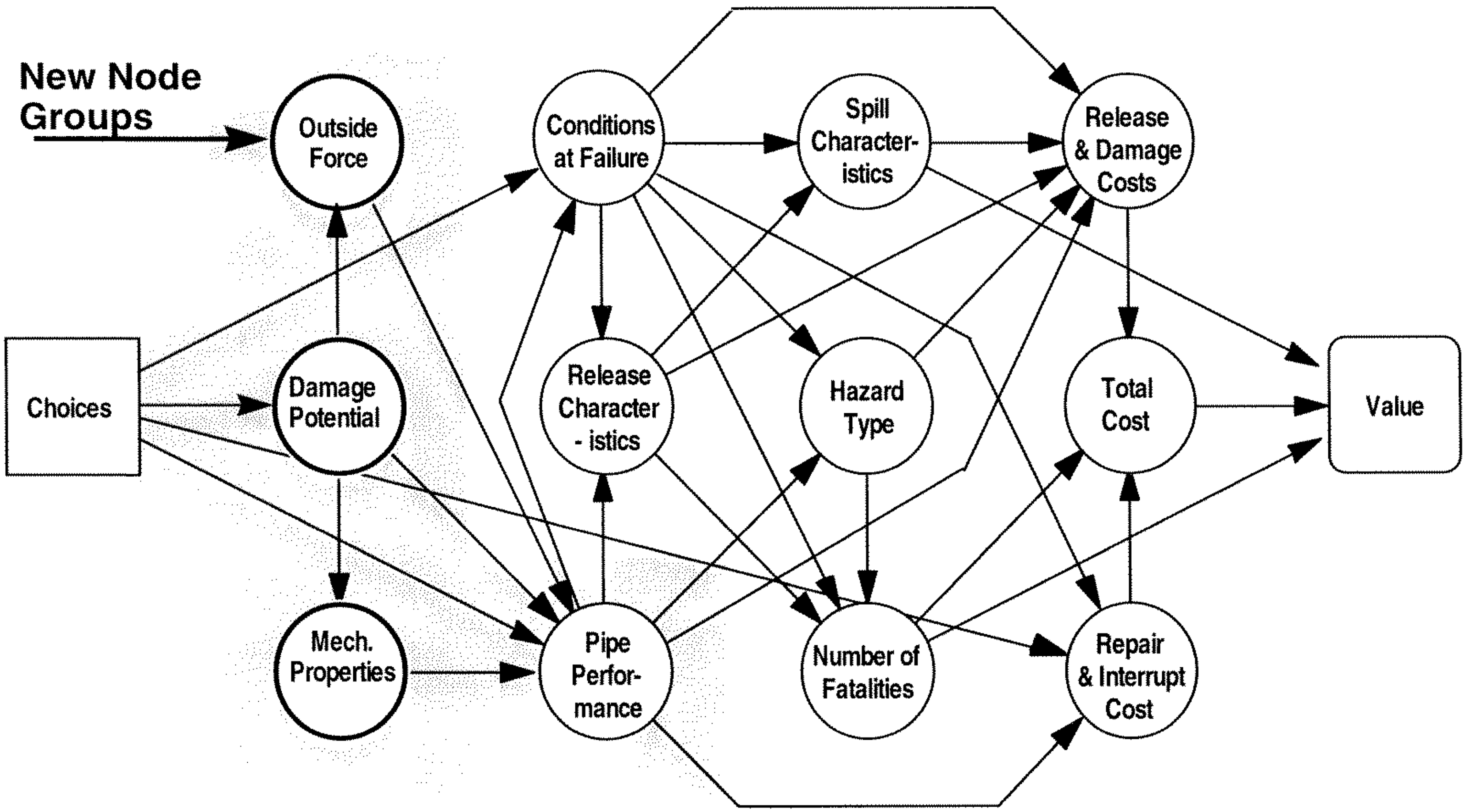
Conceptual Influence Diagram



Mechanical Damage Influence Diagram



Mechanical Damage Influence Diagram



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Choices

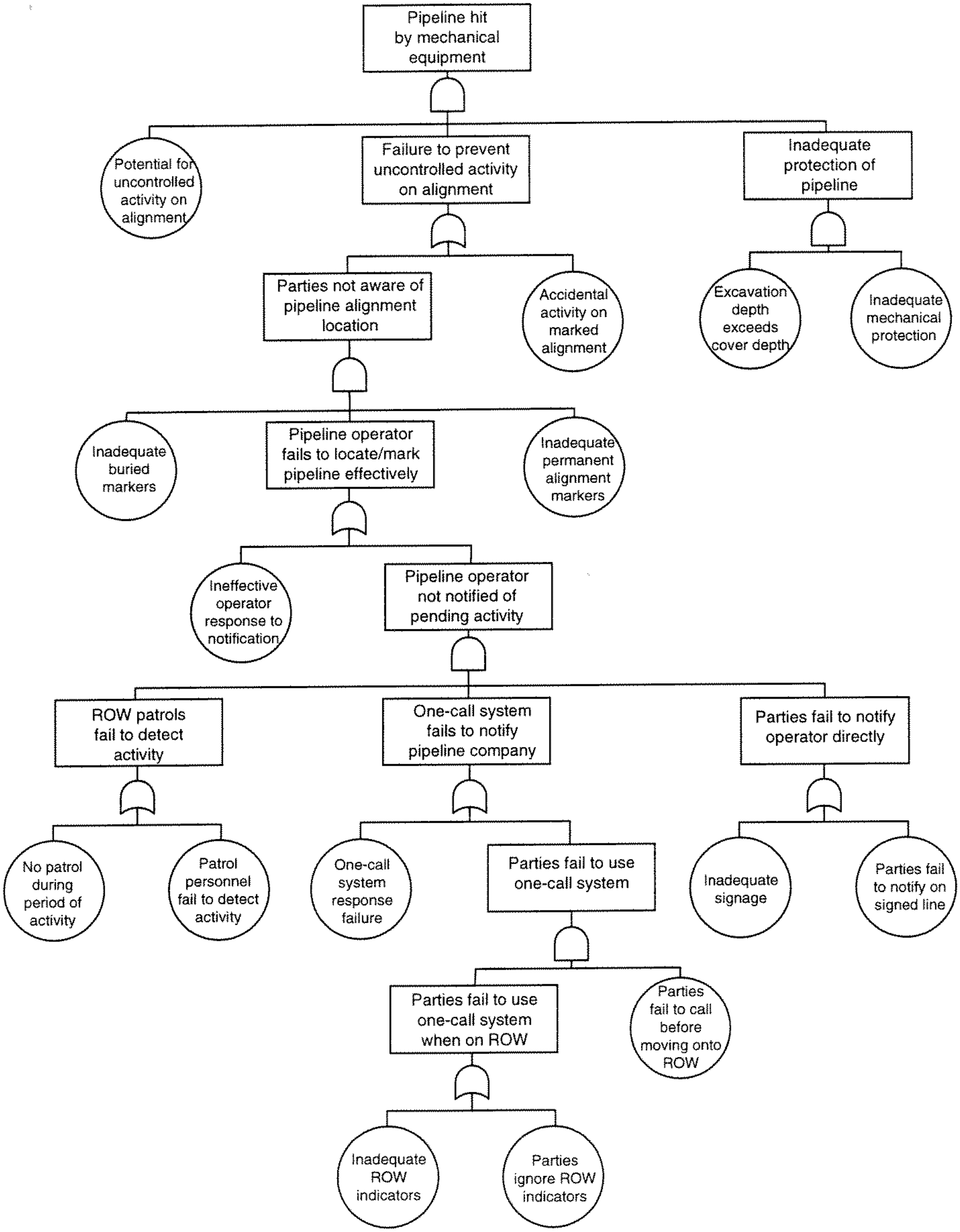
- **Preventative maintenance actions considered:**
  - Enhance: ROW condition / generic markers
Explicit pipeline signage
Notification system
  - Modify: Response to notification
ROW patrol frequency
ROW patrol method
  - Introduce: permanent alignment markers
mechanical protection
  - Increase: cover / burial depth

Damage Potential

- Estimate frequency of third party activity resulting in line impact
- Approach based on Fault Trees
  - deductive analysis identifying logical combinations of <u>basic events</u> that lead to <u>top event</u> (line impact)
  - basic event probabilities estimated from:
    - » line attributes
    - » preventative maintenance choices
  - defaults based on:
    - » **historical data** (where available)
    - » **analytical models** (where applicable)
    - » **subjective judgement** (where necessary)

Damage Potential

- Line attributes affecting damage potential
  - » *Land use type*
  - » *Crossings / Special terrain*
  - » Notification system / System response
  - » ROW condition / Generic markers
  - » Explicit Pipeline signage
  - » ROW patrol frequency / patrol method
  - » Permanent above-ground alignment markers
  - » Buried alignment markers
  - » Mechanical protection
  - » Cover / burial depth



Fault tree for mechanical interference

Outside Force

- Characterize magnitude and uncertainty associated with line impact force
- Approach involves specification of PDFs of impact force for different land use types
- Default model assumes that maximum impact force is proportional to equipment weight
  - PDF of impact force developed from PDF of North American excavator equipment weights

Mechanical Properties

- **Characterize the magnitude and uncertainty of**
  - **pipe body yield strength** (affects puncture resistance)
  - **pipe body notch toughness** (affects leak vs. rupture)
- **Approach involves specification of PDFs of F_Y and C_V for different steel grades**
- **Defaults based on specified material properties with historical data used to establish**
  - **probability distribution type**
  - **mean-to-specified ratio**
  - **coefficient of variation**

Pipe Performance

- **Estimate the probability of line failure,** P_F

$$P_F = P_{F|I} P_I$$

where $P_{F|I}$ **= probability of failure given impact**
P_I **= probability of line impact** (per yr)

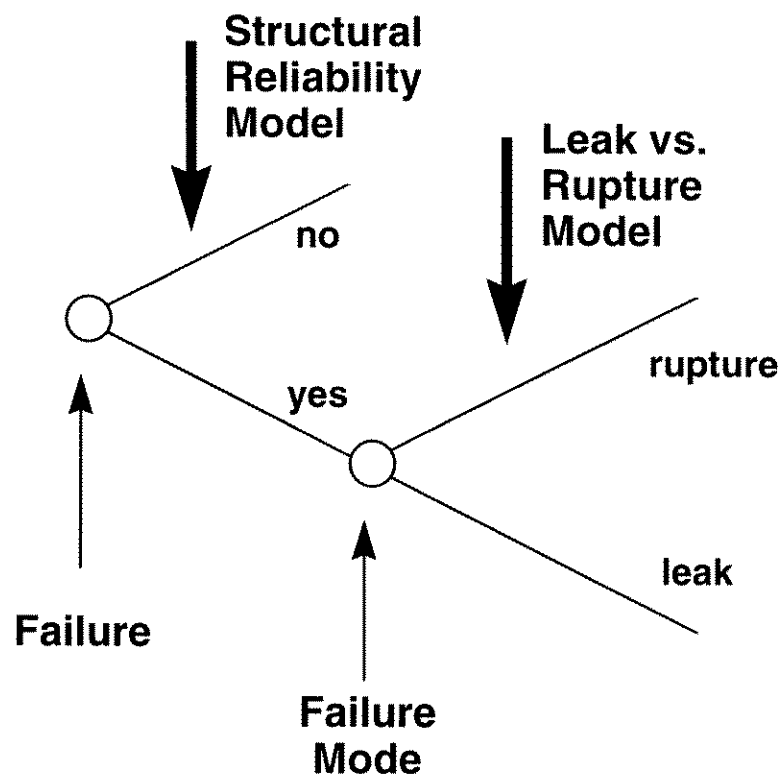
and

$$P_I = R_I L_{Seg}$$

where R_I **= rate of line impact** (per km yr)
L_{Seg} **= segment length** (km)

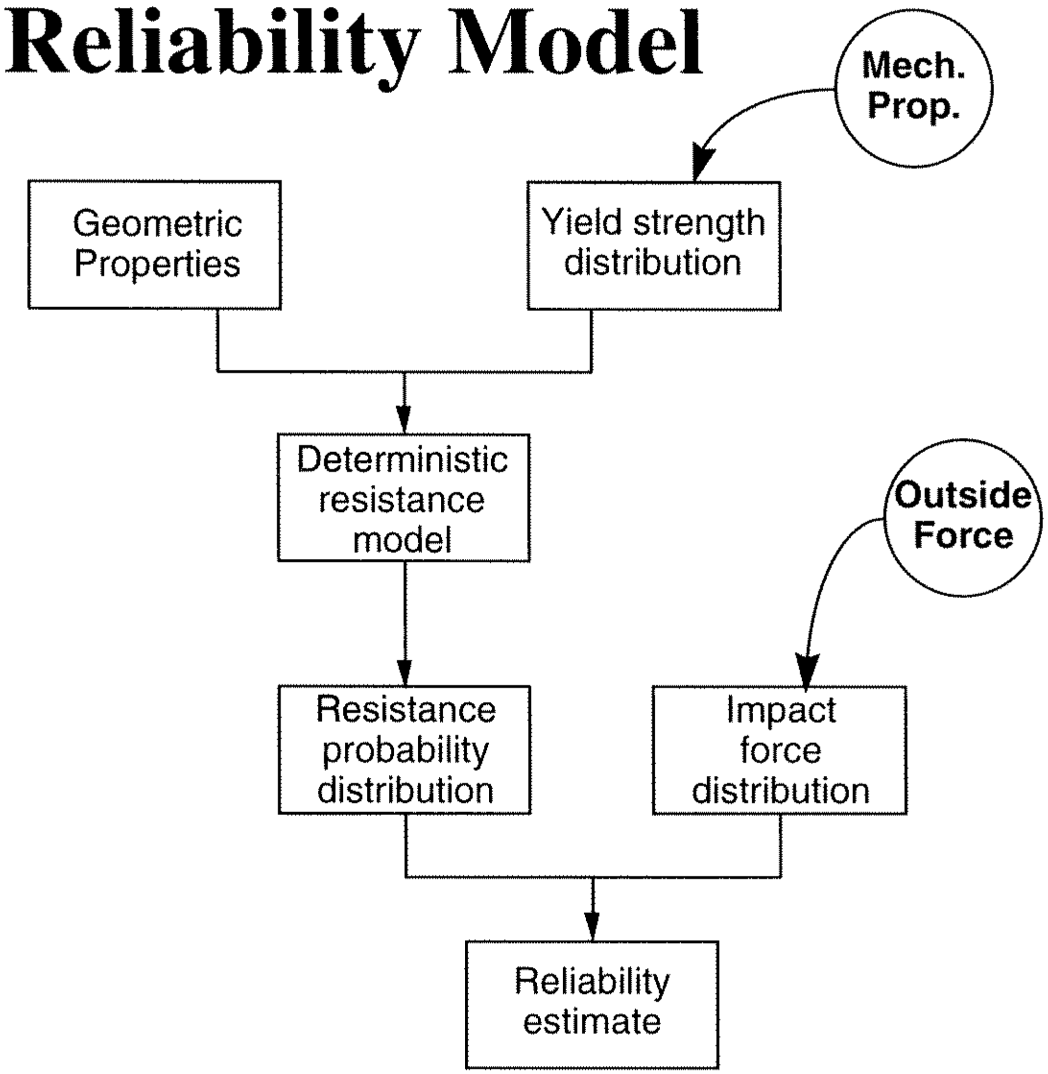
Probability of Failure Given Impact

- Estimate probability of line leak and rupture



Structural Reliability Model

- **Failure given line impact**



Deterministic Resistance Model

- **Pipe puncture resistance** (Spiekhout et al. 1987)

$$R_P = 2.3 F_Y t^2 \left[0.4 D \sqrt{\frac{D}{2t}} + L \right] \frac{1}{(D - 0.7w)}$$

where D **= line diameter**
t **= wall thickness**
F_Y **= yield strength**
L **= indentor length**
w **= indentor width**

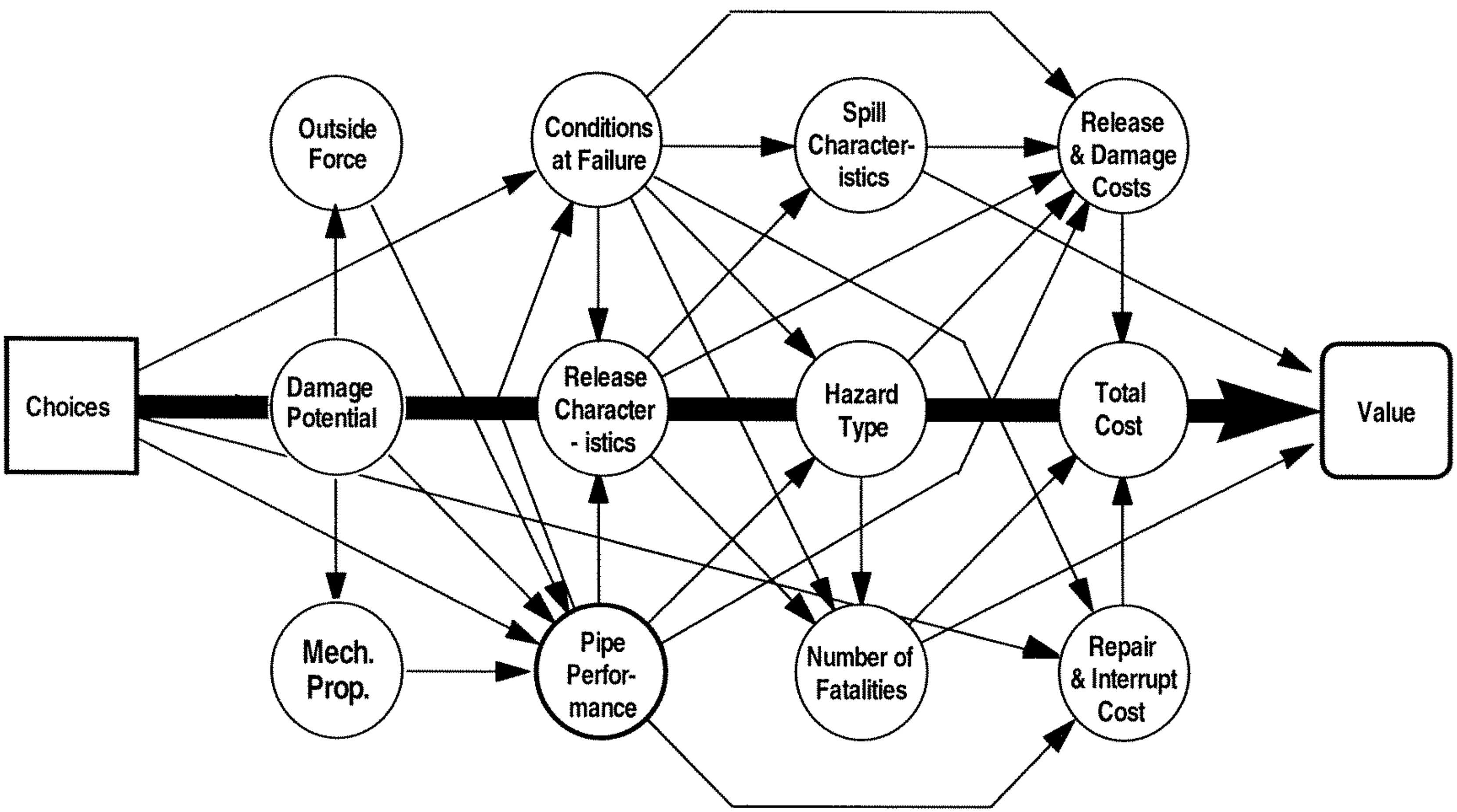
Leak vs. Rupture Model

- **Through-wall defect model** (Kiefner et al. 1973)

Rupture if $$C_V < \frac{2A_C}{3\pi E} c\sigma_F^2 \ln\sec\left[\frac{\pi}{2}\frac{M_T}{\sigma_F}\frac{PR}{t}\right]$$

where C_v = **Charpy plateau energy** (for shear area = A_c)
c = **flaw length** (related to assumed indentor size)
σ_F = **flow stress** = F_Y + 70 MPa
M_T = **Folias factor** = f(R, t, *and* c)
P = **operating pressure**
R = **pipe radius**
t = **pipe wall thickness**

Mechanical Damage Influence Diagram



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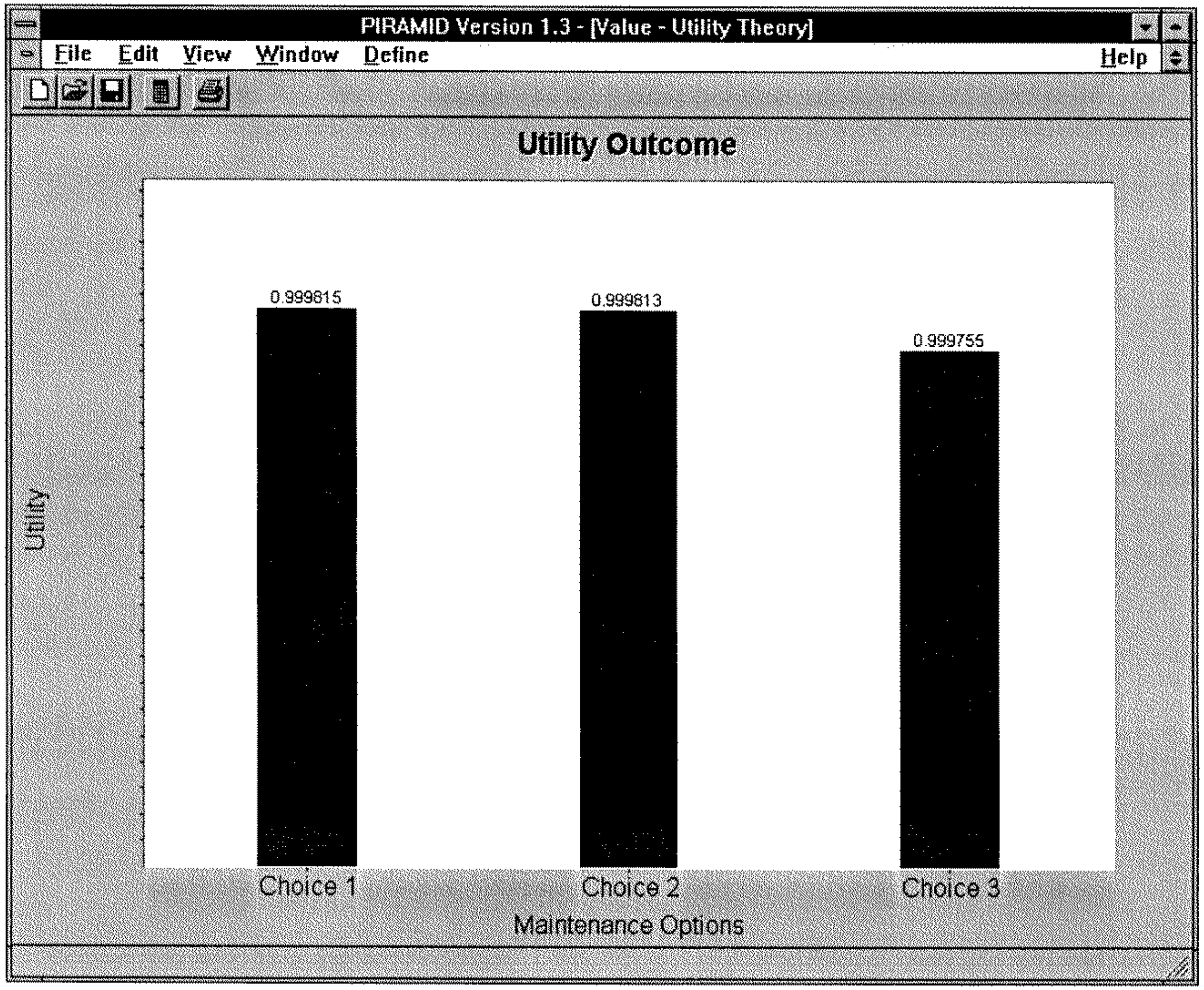
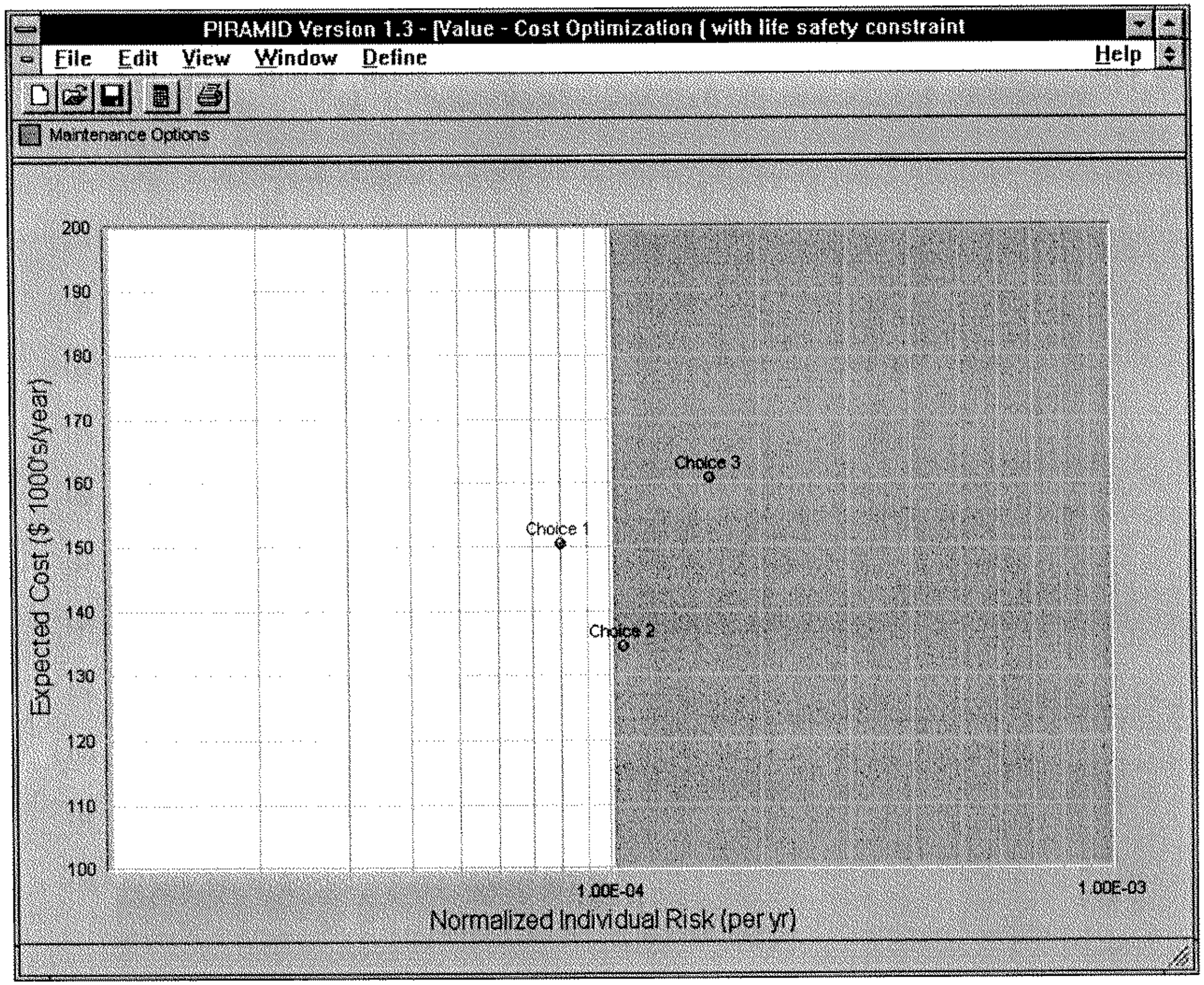
Choice Evaluation - Utility Theory



Choice Evaluation - Cost Optimization



Financial Report

Project	Budget $1000	Spent ($1000)	Spent (%)	Comp. (%)
PIRAMID Updating	85	82	96	95
Offshore Prioritization	60	56	93	90
Mechanical Damage	170	62	36	50
Corrosion (Phase II)	85	107	126	85
Management & Marketing	45	51	113	90
Contingency	36	5	16	30
Total	*481*	*363*	*75%*	*72%*