MAKING REMAINING LIFE PREDICTIONS FOR POWER CABLES USING RELIABILITY ANALYSES

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How significant is the pipe network?

- ~ 75% of the budget of building and operating either a water or a wastewater utility is in pipe networks
- The motto of 21st century is: doing more with less
- I live what I preach: airfare and hotel for 3 nights total $ 453.17

Seeing Ahead

When asked of Wayne Gretzky about his most important advice to younger players he answered “really simple; always skate to where the puck is likely to be.”

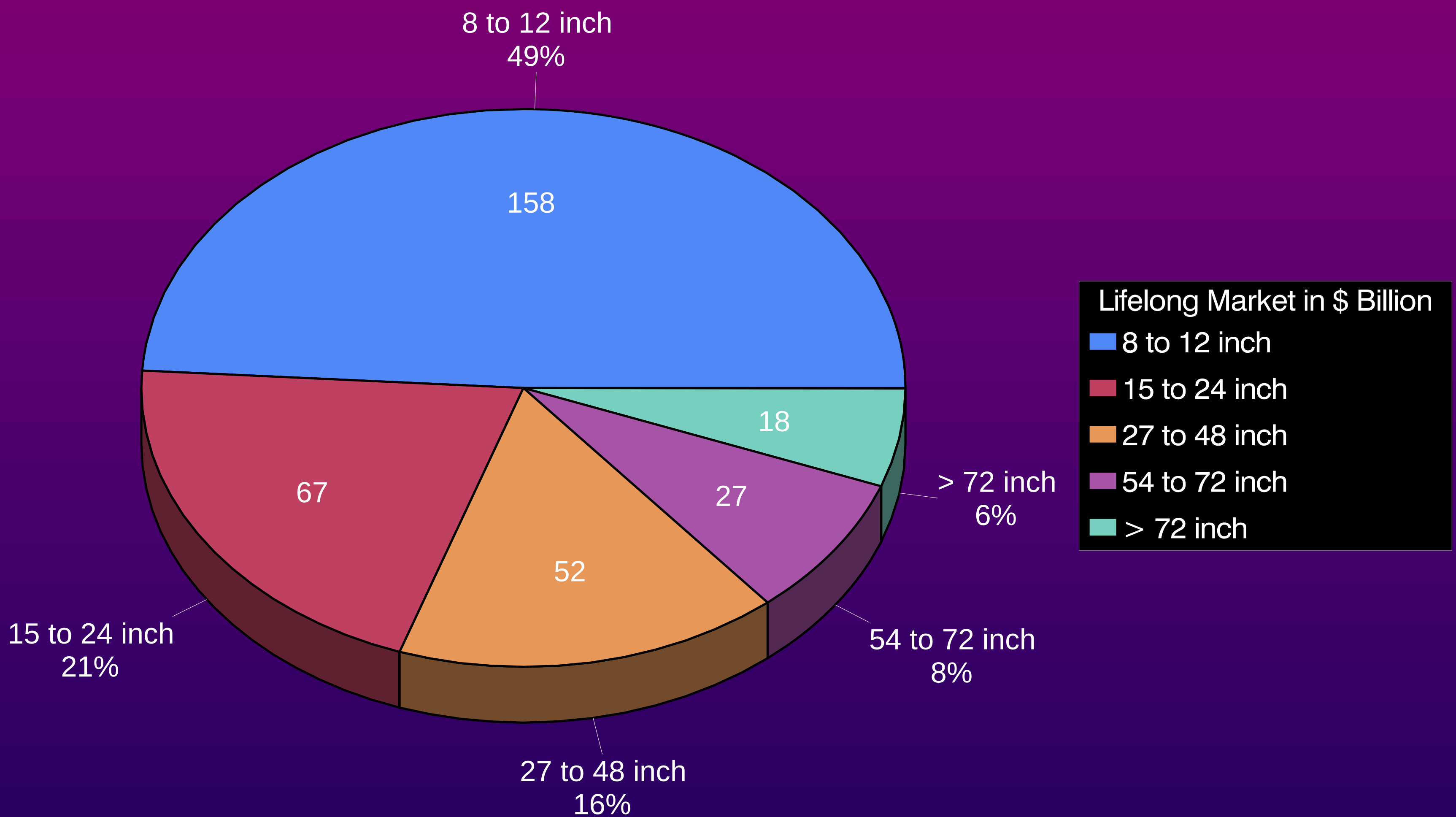
Buried Assets in America

Type	Km
Sanitary sewers	1,500,000
Storm drains	800,000
Combined sewers	200,000
Potable waterlines	1,600,000
Natural gas lines	1,800,000
Petroleum pipelines	500,000
Irrigation pipelines	300,000
Industrial waste lines	900,000
Total	~ 8,000,000

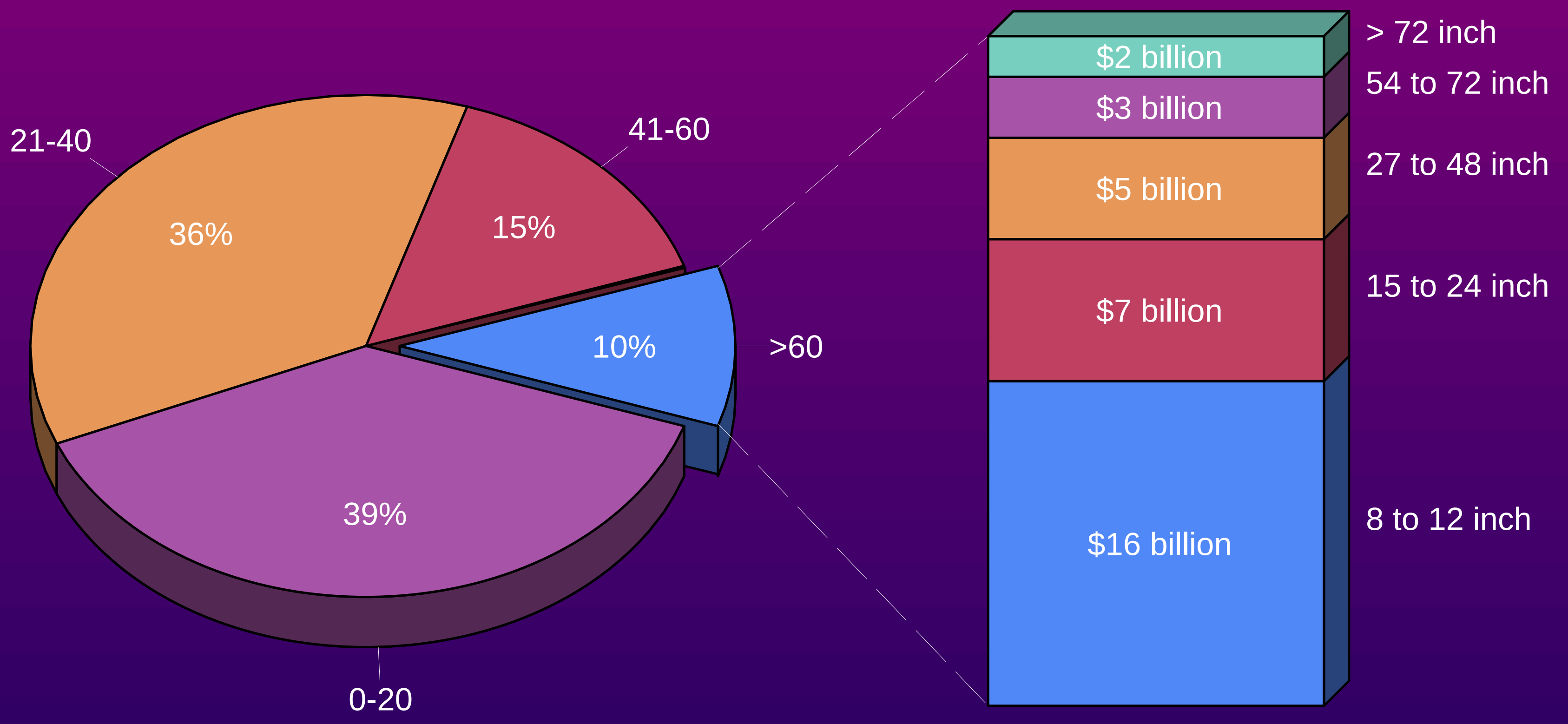
Cables for Power and Communications

Other countries have similar assets.

Sewer Size-Based Market Distribution



Sewer Age-Based Market Distribution



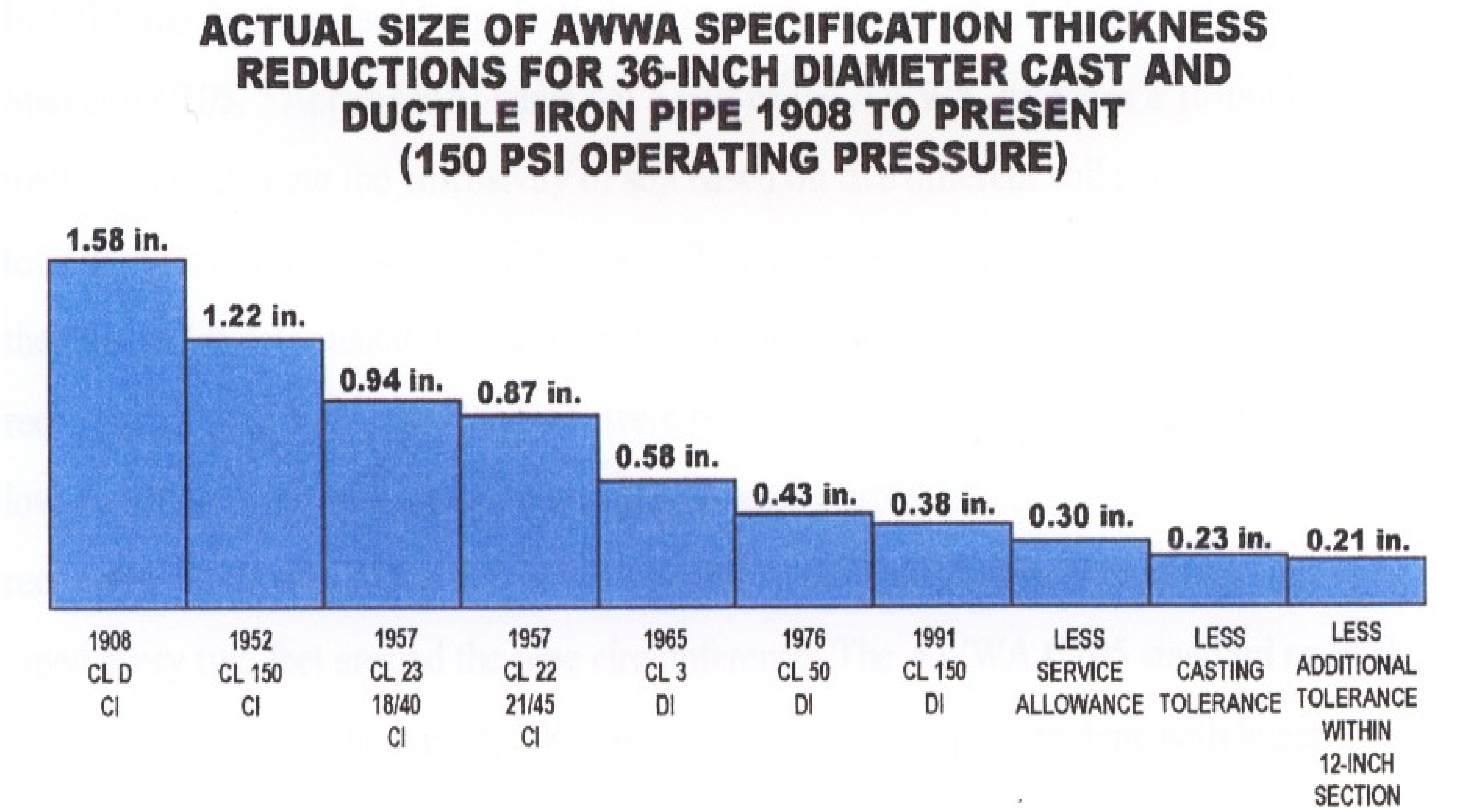
Questions asked:

What is the probability of failure of a given linear asset as a function of certain attributes?

- type of material
- type of function
- age distribution of the asset
- type of environment
- break history
- predominant failure mechanisms

How do we allocate future funding to get the most optimum return from the current assets?

Declining Wall Thickness



DIPRA's survey on cast iron pipe

- 611 cities with cast iron longer than 100 years
- 22 cities with cast iron longer than 150 years

Average Age of Our Sewers

< 50 years

Just returned from China: her engineers and contractors will NOT execute infrastructure projects our way.

When ASCE writes: Much of the estimated 800,000 miles of water delivery pipeline in the U.S. is old, well past its service life and prone to leaks and breaks. Surely we will have over 300,000 major breaks this year - nothing to do with age. Taj Mahal built in 1660 seems to be as good as new.

Cable Failure Analysis Panel
ICC Spring 2007, Orlando, USA

- "Field Aged Cable Failure Analysis for Making Repair, Replace or Restore Decisions" Ray Bristol – Hendrix Wire & Cable

- "Analysis of Cable Failures"
Margaret Jasek – Public Service of New Mexico

- "Solid Dielectric Cable Failure Analysis at Consolidated Edison Co of NY"
Thomas Campbell – Consolidated Edison

- "Distribution Cable Failure Analysis at Hydro Quebec"
Serge Pelissou, Jacques Cote – Hydro-Quebec

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- "Medium Voltage Cable Failure Analysis Experience at NEETRAC"
Thomas Champion – NEETRAC

- "Field Failure Samples – Charcoal or Diamonds"
Mark Walton – General Cable Corporation

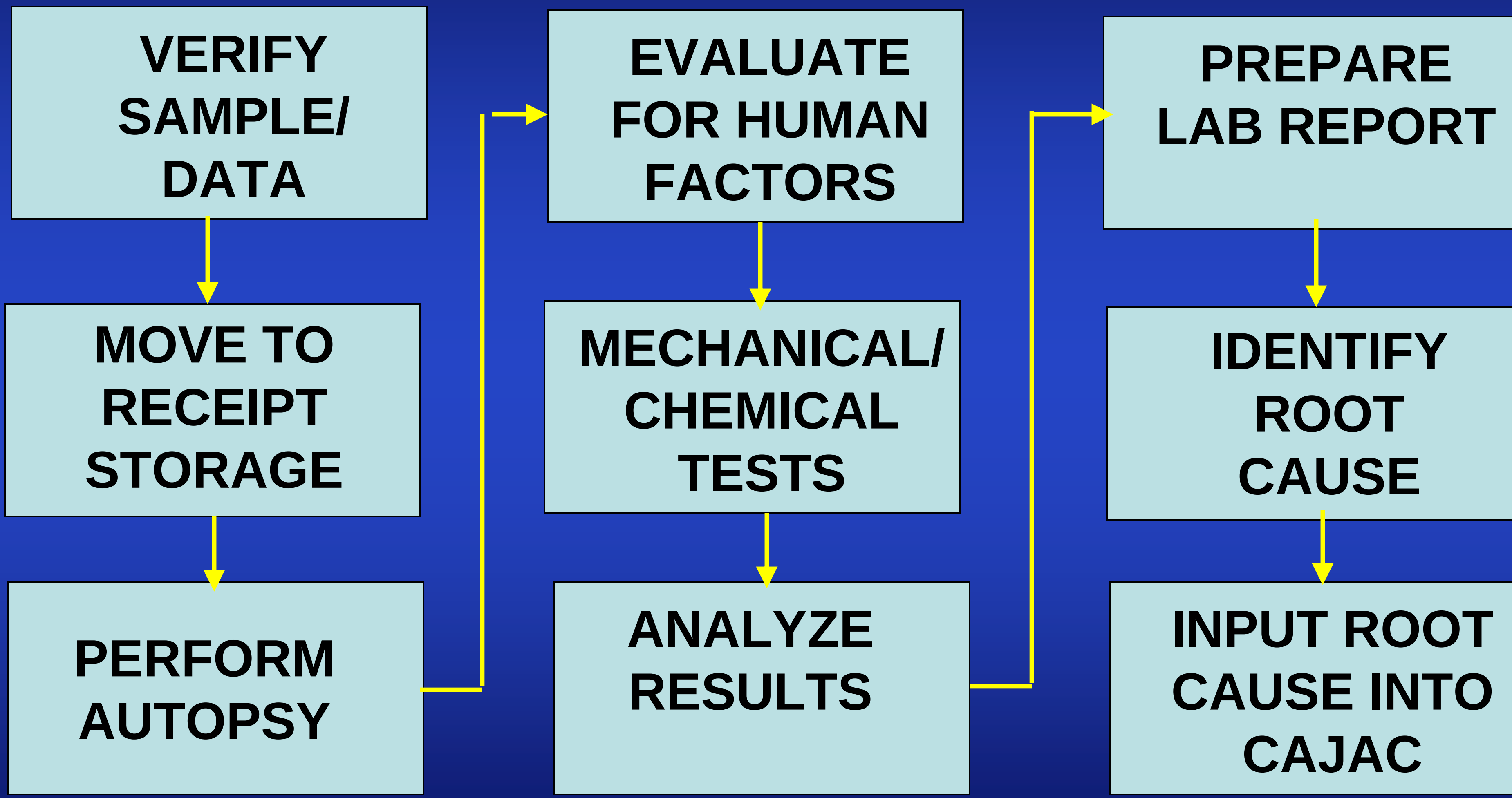
Typical Agenda

- Faulted Cable Sample Retrieval Process
- Review of Faulted Cable's History
- Cable Lab Procedure
- Visual Analysis/Autopsy
- Mechanical/Chemical Testing
- Failure Classification and Recording System
- Examples of Failure Analysis of Leaded and
- Flat Strap Neutral Solid Dielectric Cables

Source: Tom Campbell, Con Edision

Typical Cable Lab Procedure

Source: Tom Campbell of Con Edison



Typical Steps in Reliability Analyses

- Collect and organize track record data.
- Select a statistical distribution that best fits the lifetime data on hand.
- Estimate the defining parameters that fit the statistical distribution chosen to represent the lifetime data, for example using regression studies.
- Make better predictions than rules of thumb on estimates of the life's attributes:
- reliability or representative life of the cable?
- probability of failure for a chosen life span?
- which component material lasts longer?
- under what site and operating conditions?

3 Parameter Weibull PDF

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

Where β is shape parameter

η is scale parameter

γ is location parameter

t is time

f (t) is pdf

Simpler Weibull pdfs

- **The Two-Parameter Weibull Distribution**

  when the location parameter, γ is set to zero.

- **The One-Parameter Weibull Distribution**

  when the shape parameter, β is a constant

  the only unknown parameter is the scale parameter, η. Note that in the formulation of the one-parameter Weibull pdf, we assume that the shape parameter β is known *a priori* from past experience on identical or similar underground assets.

How to estimate the parameters, β, η, and γ?

- Probability plotting
- Rank regression on x
- Rank regression on y
- Maximum likelihood estimation

The most appropriate and even whether one needs a 3 parameter Weibull would be governed by the lifetime data set on hand and good engineering judgment from having done enough of these over the years.

Results from Weibull Reliability Analyses

- Reliability for a chosen life: what is the likelihood that the XLPE cable in an electric utility district will last at least 50 years?
- Probability of failure for a chosen life: what is the likelihood that the EPR cables owned by the electric utility will last 30 more years?
- Mean life: what is the average life of the city's entire underground cable asset that has certain attributes, for example, buried in low plastic clay (CL) under min 3.6 m (12 ft) of cover in slopes steeper than 6 % in areas that get more than 250 mm (10 inches) of rain per annum with a water table < 1 m (3.28 ft)?
- Failure rate: what is the rate at which the Company A's underground cables will fail during the next 25 years?
- Warranty time: what is the estimated life when the reliability of the cables installed without ducts would either match or exceed electric utility Y's minimum performance goal driven by its budget constraints?

Additional Results from Weibull Reliability Analyses

- Plot of probability of failure over time
- Plot of reliability over time
- Plot of probability density distribution
- Plot of failure rate with time
- Confidence levels go with the predictions

Case History 1: Using Weibull Reliability Analyses

- City of over 1,000,000 inhabitants using 40 billion gallons per annum. Summer demand is about 220 million gallons per day.

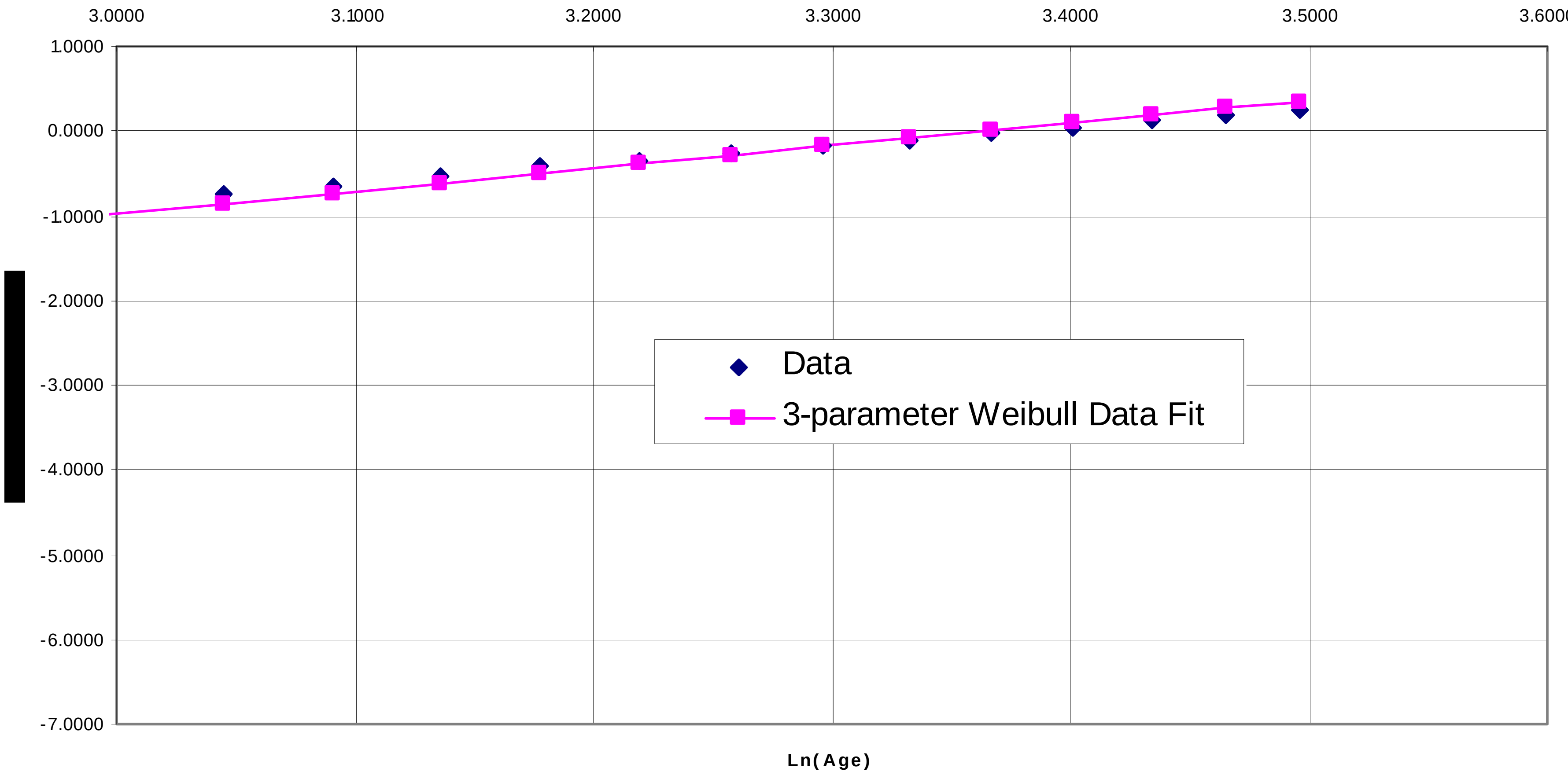
- Did a comprehensive assessment of all 3 transmission pipelines bringing 100% of treated water into the city: structural, geotechnical, hydraulic, seismic, corrosion, and was able to squeeze more out of these to delay capex of over $ 320 million on a 4th pipeline.

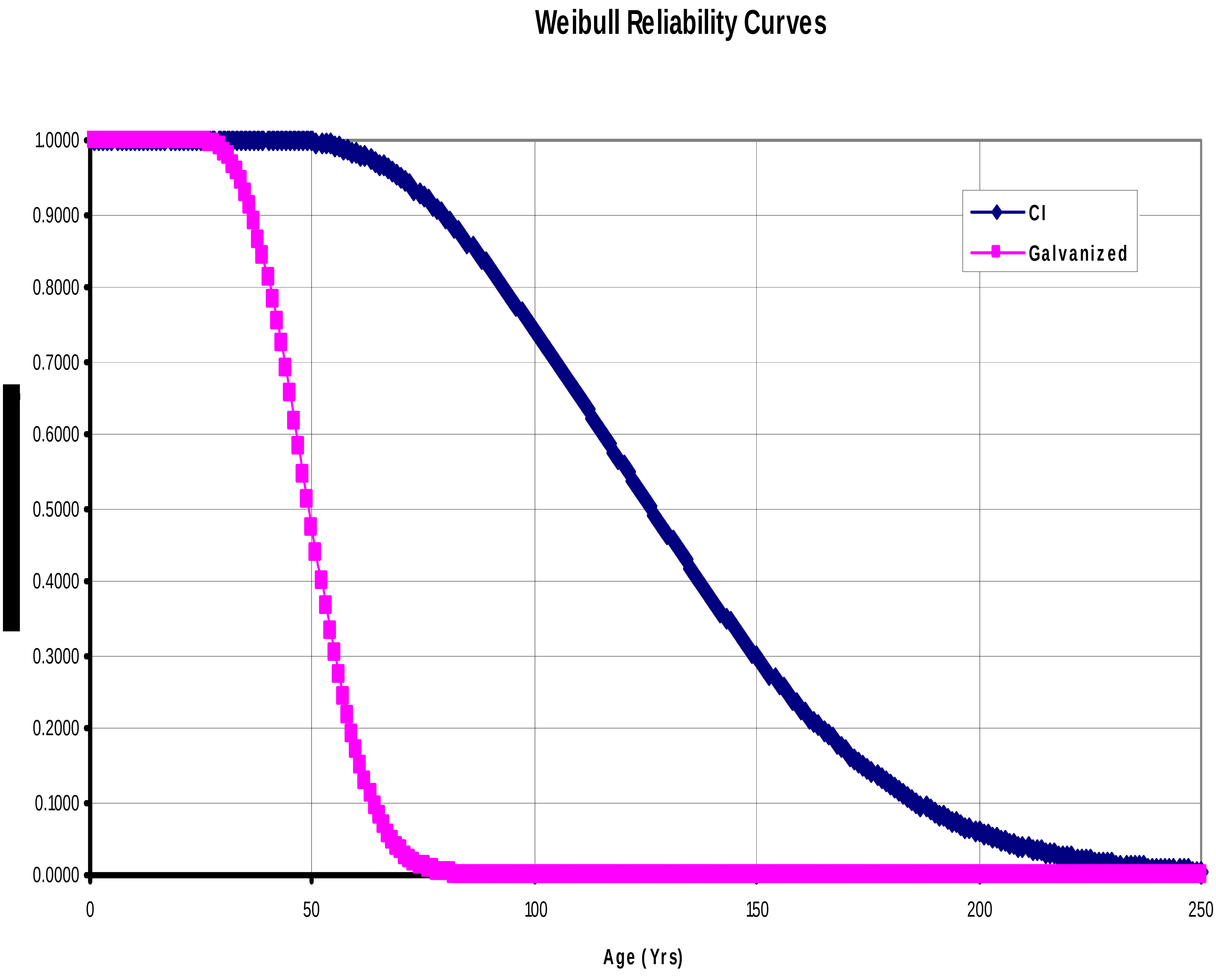
- 2,100 miles(3,360 km) of pipe form their distribution system assets with 6,200 breaks over 1977-2002 with pipes going back to 1890s.

- They asked for guidance to develop a better asset management program toward better allocation of their limited funds.

Sample Pipe Break Data

year	Total breaks	CI breaks	Galvanized breaks
1972	20	16	4
1973	30	24	6
1974	40	32	8
1975	50	40	10
1976	60	48	12
1977	75	60	15
1978	110	88	22
1979	110	88	22
1980	110	88	22
1981	130	104	26
1982	175	140	35
1983	275	220	55
1984	260	208	52
1985	300	240	60


3.0000
3.1000
3.2000
3.3000
3.4000
3.5000
3.6000
1.0000
0.0000
-1.0000
-2.0000
-3.0000
-4.0000
-5.0000
-6.0000
-7.0000
[redacted]
Data
3-parameter Weibull Data Fit
Ln(Age)


Weibull Reliability Curves
1.0000
0.9000
0.8000
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
0
50
100
150
200
250
Age (Yrs)
CI
Galvanized

Case History 2: **Using Normal Probability Density Functions**

- Results of NDT on ductile iron wall thickness along the alignment varied
- Depth of cover varied
- Live load varied
- Internal pressure varied
- Trench condition varied

Each of these were represented by normal pdf and factors of safety for 66 %, 90%, and 99% confidence levels were predicted for

- external load induced deflection
- external load induced bending stress
- internal pressure induced hoop tension

to determine which portions of the alignment need to be replaced how soon.

Case History 3: Using Normal Probability Density Functions

- PCCP design wall thickness, coating, core, etc. varied
- Depth of cover varied
- Live load varied
- Internal pressure varied
- Level of wall thickness loss due to H2S attack varied
- Wraps of prestress wires varied

Each of these were represented by normal pdf and AWWA C-304 design checks for 66 %, 90%, and 99% confidence levels were made.

An asset management program based on the results and:

- Proximity to the river and the level of damage it might engender.
- amount of concrete core loss due to corrosion
- relative aggressiveness of native soils
- surge potential and the working pressure
- intensity of soil and live loads
- relative accessibility to the force main

Seeing Ahead

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Seeing Ahead by Looking Back

History is the witness of the times, the light of truth, the life of memory, the witness of life.

Marcus Tullius Cicero

106 to 43 BC

Conclusions for Civil Engineers at WEFTEC

- We need to look outside the box on how we could improve the delivery to our clients.
- For example, if we were ever asked to run the oil business, we would put airlines, power plants, trucks, trains, cars, heating, all on jet fuel. This is what we have done with water for over 100 years and we have not been listening to our public.
- It's bad time, we embrace wide-spread dual water lines or supply brown water for point of use treatment.
- Engineering tools for asset management also need to account for past failure records, variability in material properties, construction practices, loads, O&M, etc.
- IBM ramping up from 2,000 to 105,000 engineers in the next 2 years in Bangalore, India makes a statement: IBM needs to staff their projects with people who could think cannot be found in America.
- We need to spend more on empowering our engineers with adequate knowledge before they undertake more work on pipe networks and less on golfing, tickets for foot ball games, lavish gifts, campaign donations, lobbying firms,.....

Conclusions

- We need to look outside the box on how we could improve the delivery to our clients.
- We cannot expect a better outcome, if we keep doing the same thing year after year. STOP email chatter to hang yourselves early in the lawsuits. Drinking fountain chat is better. Ask always "why am I doing what I am doing and can I survive the 6 O'clock news test?"
- Engineering tools for asset management also need to account for past failure records, variability in material properties, construction practices, loads, O&M, etc.
- The 3 case histories presented today using either Weibull or Normal pdfs is a step forward in the use of reliability analyses in underground asset management.
- The challenges Cable engineers face on better use of limited O&M and Capex funds are no different than what pipeline engineers face every day. The pressure to do more with less is on all of us.
- Cable engineers have been doing such a great job of cable failure analysis and what I showed you today will allow you to go very far with the enormous amount of data you have been collecting from your usual failure analyses.
- We cannot solve complex asset management problems using simple tools.