Not All Pipes Age Alike: Let Smart Data Models Pick the Next Repair

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Problem Statement

Sugar Land's CIP planning relies on separate hydraulic and asset management models, leading to suboptimal investments. This project integrates both models, enabling data-driven decisions that optimize costs, extend infrastructure life, and enhance service reliability.

Integrated Asset Management System (IAMS) and Degradation Function

To address this, the Integrated Asset Management System (IAMS) provides a risk-based framework to prioritize infrastructure maintenance and optimize budget planning by standardizing failure probability across linear and point assets.

Degradation Function for Linear Assets

- Aging & External Conditions: Water mains degrade over time due to material wear and environmental factors.
- Data-Driven Modeling: IAMS uses historical break data fitted to an exponential regression model to predict deterioration.
- Cross-Asset Comparison: Converts degradation into a failure density function, allowing for standardized risk assessment.
- Segmented Risk Analysis:
  - Breaks assets into homogeneous sections (e.g., 1,000-ft segments).
  - Uses a Bernoulli process to estimate component-level failure probability, making linear asset risk comparable to point assets.

Cross-Asset Reliability

- Life-Cycle Assessment: Condition ratings (1–5) estimate effective asset age for point assets like pumps & lift stations.
- Failure Probability Modeling:
  - Uses condition scores, Estimated Useful Life (EUL), and a 20% Coefficient of Variation (CoV).
  - Applies a Weibull conditional reliability function to model age-dependent failure risks.
- Cross-Asset Optimization: IAMS standardizes failure probabilities across asset types, enabling data-driven budget allocation and minimized infrastructure risk.

Hydraulic Impact Factor (HIF)

IAMS optimizes asset prioritization but lacks hydraulic context, crucial for system performance. To bridge this gap, the Hydraulic Impact Factor (HIF) integrates pressure, velocity, water age, and headloss gradient into decision-making. HIF identifies high-risk areas by penalizing deviations from optimal conditions, ensuring smarter infrastructure investments and greater system reliability.

$$HIF = (0.35 \times PENALTY_{PRESSURE}) + (0.30 \times PENALTY_{VELOCITY}) + (0.20 \times PENALTY_{HEADLOSS}) + (0.15 \times PENALTY_{AGE})$$

$$PENALTY_{PRESSURE} = \frac{(40 - P)}{40}$$

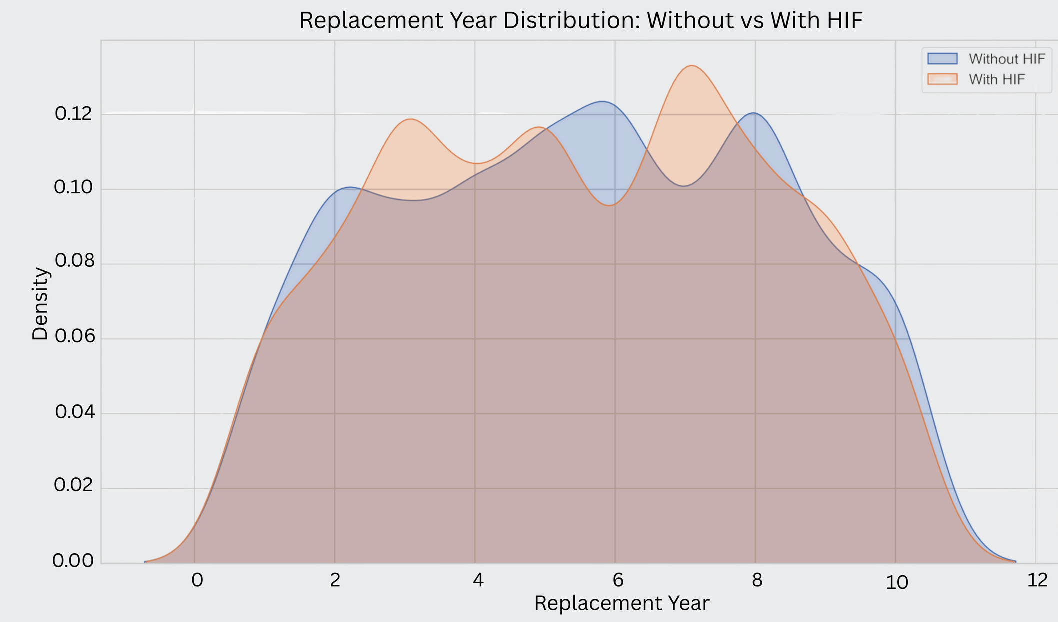
$$PENALTY_{PRESSURE} = \frac{(P - 60)}{60}$$

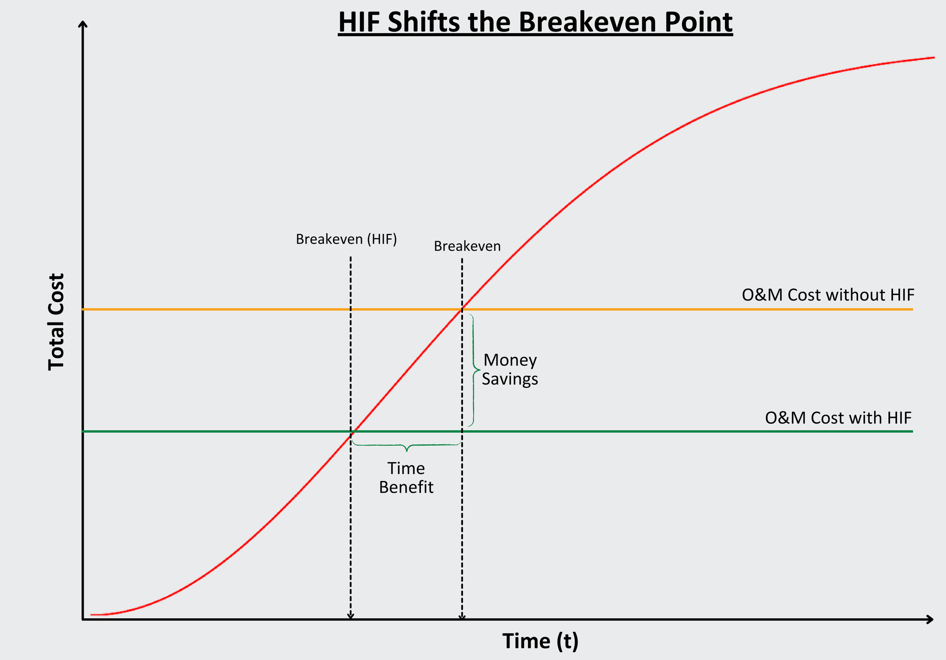
$$PENALTY_{VELOCITY} = \frac{(2 - V)}{2}$$

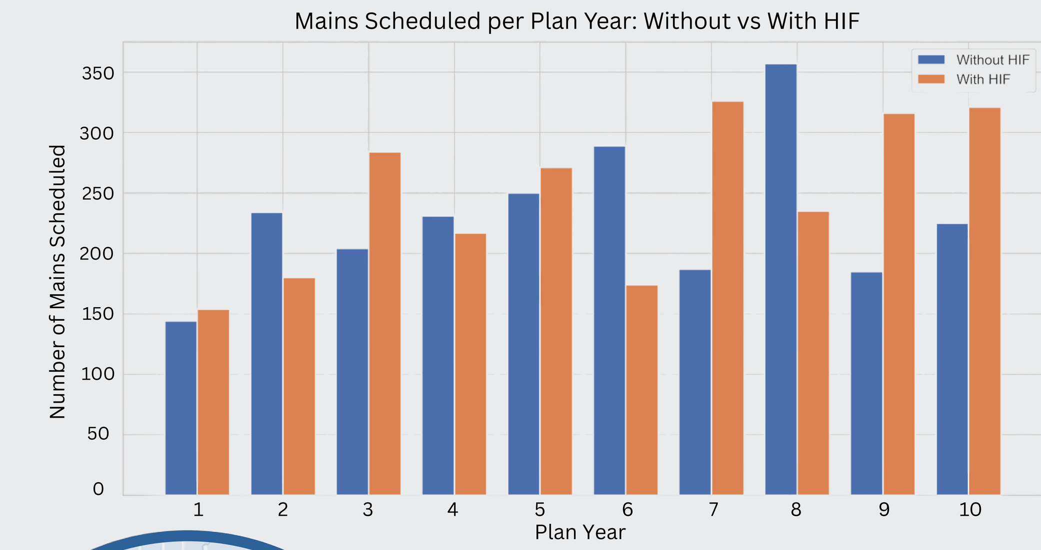
$$PENALTY_{VELOCITY} = \frac{(V - 5)}{5}$$

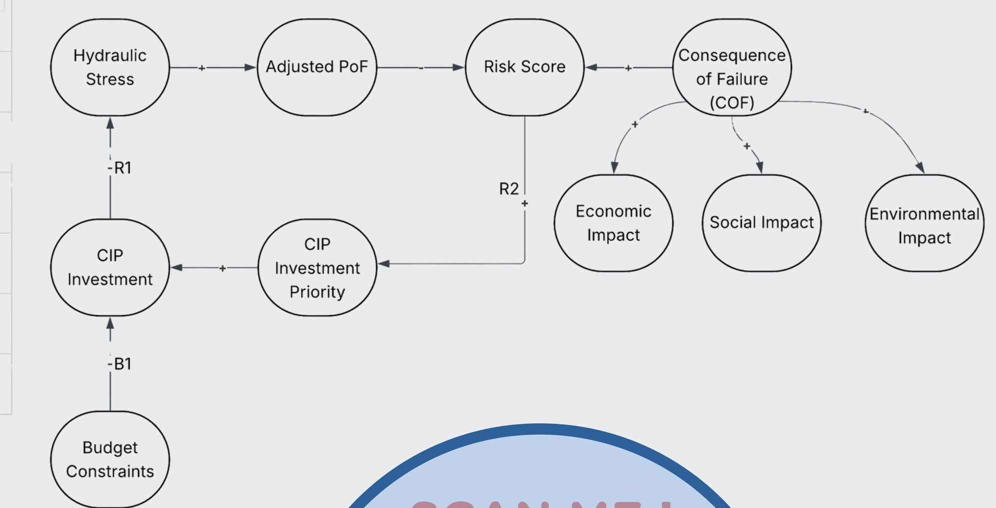
$$PENALTY_{HEADLOSS} = \frac{(H - 5)}{5}$$

$$PENALTY_{AGE} = \frac{(AGE - 24)}{24}$$





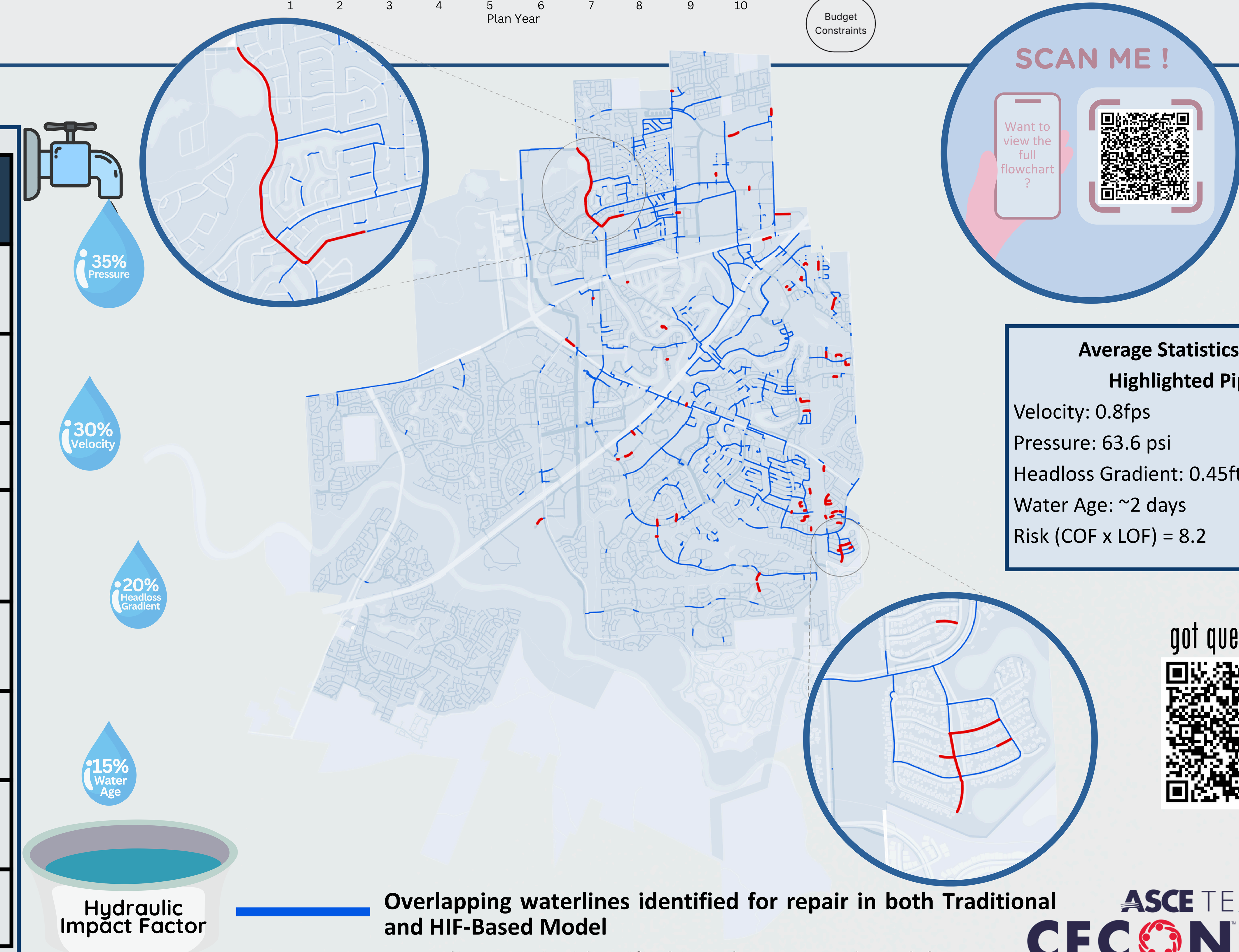




Why HIF?

Factor	Traditional Asset Model	Hydraulic Model Only	HIF-Based Model (Hydraulic + Condition + Risk)
Asset Degradation	✅ Uses past failure data but no real-time	🟨 Ignores asset condition and only models the hydraulics factors	🔄 Combines history + real-time stress
Failure Probability F(t|T)	🟨 Limited accuracy, assumeshomogeneity	❌ Lacks failure probability	✅ Dynamic F(t|T) with history, material, & stress
Capital Planning	🟨 Reactive, based on past failures	❌ No impact on budgeting	✅ Prioritizes high-risk assets
Triple Bottom Line (TBL)	🟨 Focuses mainly on financial impacts, limited social & environmental considerations	🟨 Focuses on system performance, ignores broader impact	✅ Considers financial, environmental, and social risks dynamically
Regulatory Compliance	🟨 Meets minimum standards	✅ Helps with the regulatory compliance (TCEQ , ISO, etc.)	🔄 Balances pressure, risk, & compliance
Level of Service (LoS)	🟨 Reactive—fixes failures after they happen	🟨 Improves hydraulic performance but lacks predictive capability	✅ Proactive—prevents failures through risk-based prioritization
Flexibility in Asset Management	🟨 Based on fixed replacement cycles, not real-time conditions	❌ Shows performance but does not guide replacement strategy	✅ Adapts risk scores based on operational conditions & failures
Emergency Planning	❌ No consideration for peak demand	✅ Incorporates peak demands & stressors	✅ Incorporates stressors & risks

✅ Strong / Effective Approach, 🟨 Moderate / Some Limitations, ❌ Weak / Not Applicable



Overlapping waterlines identified for repair in both Traditional and HIF-Based Model

Waterline repairs identified in only HIF-Based Model

Average Statistics of the Highlighted Pipes

Velocity: 0.8fps
Pressure: 63.6 psi
Headloss Gradient: 0.45ft/1000ft
Water Age: ~2 days
Risk (COF x LOF) = 8.2

got questions?

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