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Technology Development Considerations for Pipeline Geohazard Management

2023 PHMSA R&D Forum

Outline

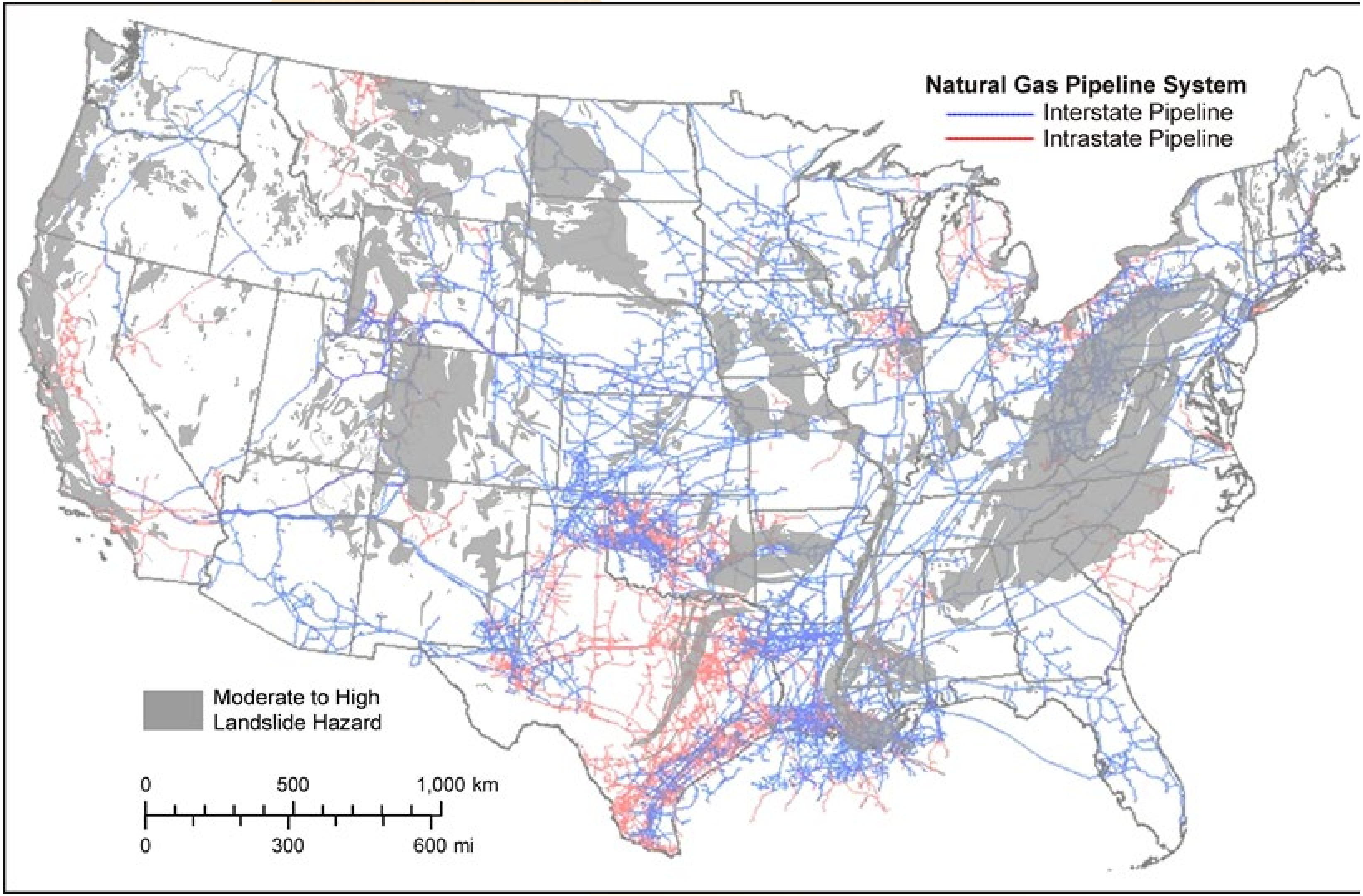
1. **Pipeline Geohazard Management**
   - Introducing machine learning
2. **Technology Development Avenues**
3. **Acknowledging Collegiate Input**

Definition of Geohazards

- “Geohazard” normally refers to a phenomenon in the physical environment such as a landslide, flood, earthquake or volcanic eruption that can occur naturally and can threaten man-made structures
- In the context of pipelines, “geohazard” refers to a wider range of environmental loads and effects, some of which are triggered by pipeline installation and/or operations
- Taken together, a working definition would be:

“Natural hazards of a geotechnical, geological, hydrological, or tectonic origin that represent potential threats to the pipeline, right-of-way and/or ditch, including hazards induced by pipeline installation and/or operation.”

Mapping US Pipeline Landslide Geohazards



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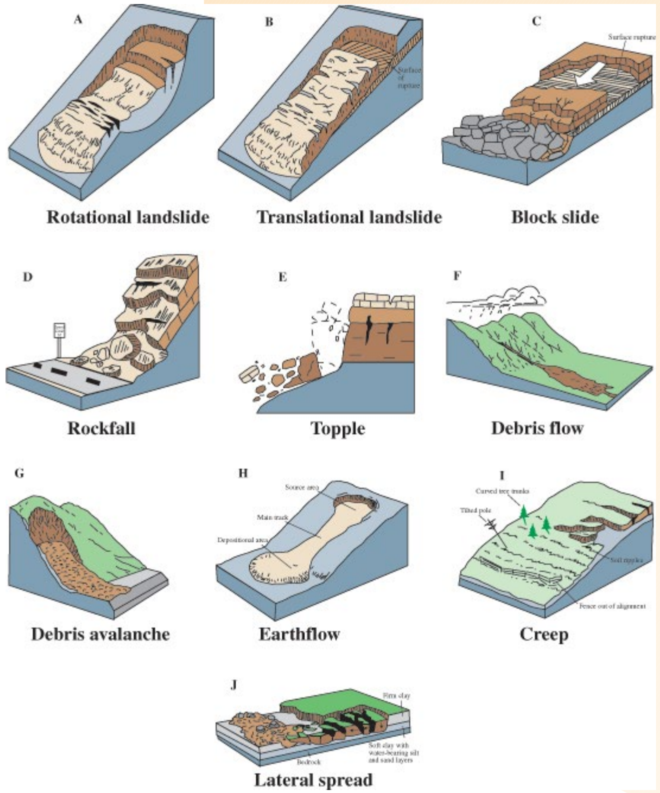
Landslide Types and Velocities



Class	Description	Typical velocity	Proposed annual displacement criteria (m)	Proposed mean annual displacement (m)
7	Extremely rapid	>5 m/sec		
6	Very rapid	>3 m/min		
5	Rapid	>1.8 m/hr		
4+	Moderate	>13 m/month	>16	64
3	Slow	>1.6 m/yr	>1.6	6.4
2b	Very slow	>160 mm/yr	>0.16	0.64
2a	Very slow	>16 mm/yr	>0.016	0.064
1	Extremely slow	<16 mm/yr	>0.0016	0.005
0	Dormant	0 mm/yr	<0.0016	0

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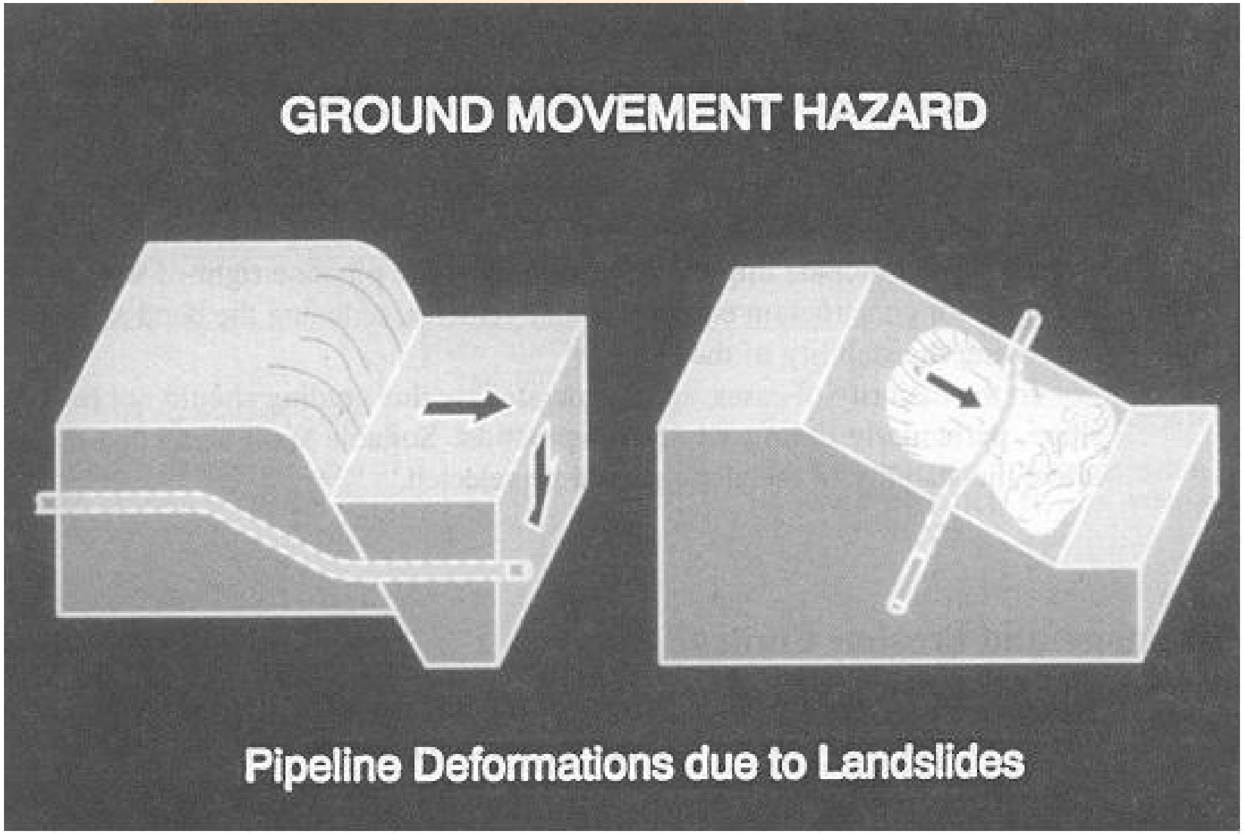
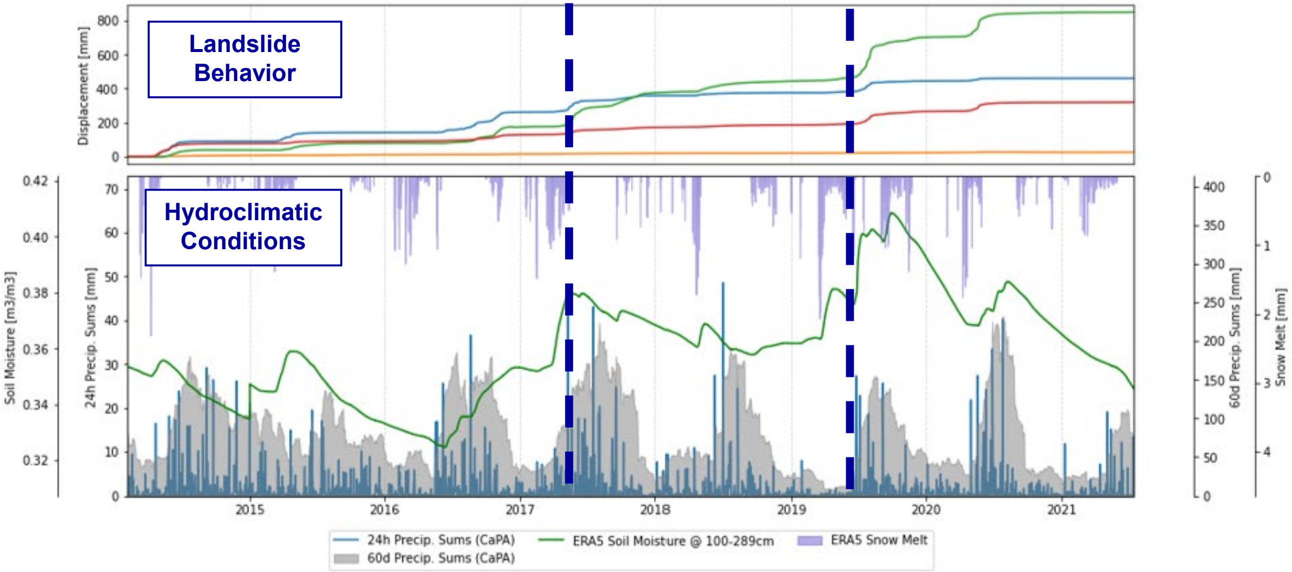
Ground Movement Hazard to Pipelines



Quantifying Drivers for Landslide Activity Change



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EXPONENTIALLY

- growing computer power to train mL algorithms
- increasing data coverage and supporting analytical and integrating tools provide options for increased mapping and characterization of geohazard settings and triggering mechanisms

Machine Learning - Conceptual Scope

- Introduce mL to advance pipeline geohazard management SoP from regularly updated “Static” (snapshot in time) assessments to “Dynamic” near-real predictive assessments
- May focus initially on the more common geohazards (with higher profile stakeholder impacts): slope instability, debris flow and water crossing related

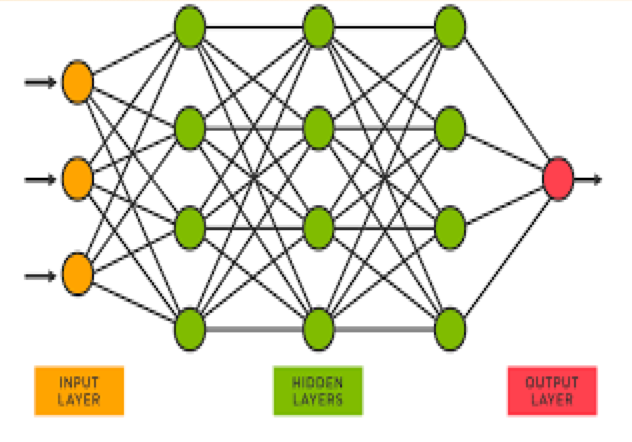
Machine Learning - Conceptual Overview

Supervised mL Behavior Relationship Algorithm Training…

Geotechnical, Geological Hydrotechnical & Displacement

Pipeline Properties

Geometric, Topographic



Machine Learning

Triggering Mechanisms

Pipeline Response

Technology Development – Proposed Approach

Adopt, adapt and customize technology developments from other sectors into the pipeline industry

Evaluate emerging products and services

Advance current analytical methods

Collaborate with major institutional stakeholders beyond the industry

Collaborate within the industry to de-risk technology development and/or reduce costs of implementation where practical and appropriate

Technology Development Avenues

Ground Displacement Monitoring

- Demonstrate/apply advances in satellite-based monitoring
- Demonstrate/apply advances in airborne and drone-based monitoring
- Demonstrate/apply the integration of various monitoring technologies

Triggering Mechanisms

- Develop/demonstrate the integration of environmental data
- Assess and demonstrate connecting to technology-based climate disaster response organizations such as FloodBase

Pipeline Response

- Support IMU analysis
- Advance consideration of interacting threats

Machine Learning

Cooperation with key institutional stakeholders such as NASA, USGS and PRCI

Ground Displacement Monitoring

- Several technologies (sensors) from several platforms (terrestrial, satellite and drone) may be utilized in multi-temporal/differential applications for displacement monitoring
- Selection criteria would balance: Accuracy, Resolution, Footprint, Revisit/Frequency and Affordability
- An extensive body of development work (from numerous industry sectors around the world) is ongoing and reaching the market to extend the current capabilities which should be tested in and customized for the pipeline context

Ground Displacement Monitoring Technology Selection Considerations

(Froese, PRCI REX2023)

Class	Description	Typical velocity	Proposed annual displacement criteria (m)	Proposed mean annual displacement (m)
7	Extremely rapid	>5 m/sec		
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1	Extremely slow	<16 mm/yr	>0.0016	0.005
0	Dormant	0 mm/yr	<0.0016	0

Optical/SAR Change Mapping

Lidar Change Detection

InSAR

Overlapping Levels of Detection (LoD) / Limitations Point To the Benefit of Combining Several Methods to Characterize the Ground Displacements of Interest to Pipeline Integrity Management.

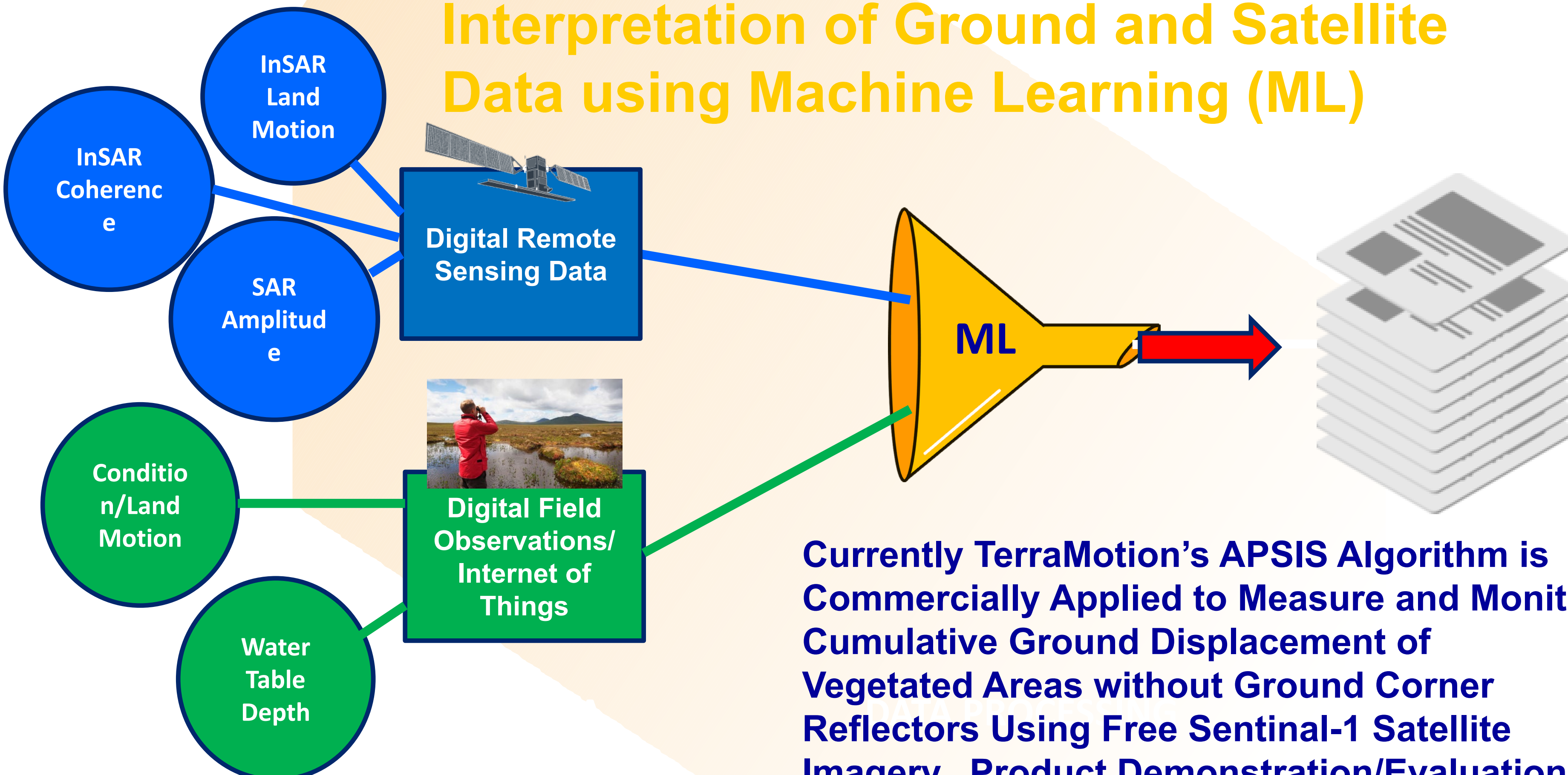
Ground Displacement Monitoring – Promising Developments

Several developments/initiatives are currently or will soon be (freely in some cases) available to benefit the pipeline industry:

- Nation-wide (USA) Airborne LiDAR Collection
- (NASA) North American Displacement Product
- (NASA & ISRO) Global L-Band InSAR Coverage
- Google and Microsoft to avail on-line access to data and analytical tool
- Landslide Early Warning and Forecasting Initiatives

Demonstrating the value-adding utility of these advances would be a highly beneficial technology development towards contributing to pipeline safety

Robust Data Integration and Interpretation of Ground and Satellite Data using Machine Learning (ML)



Currently TerraMotion's APSIS Algorithm is Commercially Applied to Measure and Monitor Cumulative Ground Displacement of Vegetated Areas without Ground Corner Reflectors Using Free Sentinal-1 Satellite Imagery. Product Demonstration/Evaluation Studies may be Considered.

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Triggering Mechanisms

The abundance of digital hydroclimatic and weather data is well suited to support developing and maintaining near-real-time "Environmental Twins" describing geohazard triggering mechanisms. Taken together with other inputs, predictive models of climate-informed pipeline response to geohazards of varying time-horizons may be developed. Technology demonstrations and development of improved modelling of triggering mechanisms would be recommended.

Assessing and adapting to the context of the pipeline industry the technology-based capabilities of organizations such as Floodbase, which consumes real-time hydrological and meteorological data in advanced modeling of potential flooding would be recommended.

Pipeline Response

IMU data is the key training data set to advance the implementation of machine learning in pipeline geohazard management. A persistent industry challenge worthy of pursuing a technology-based resolution is improving run-to-run vendor strain feature alignment reporting.

Interacting threats (i.e. several metal loss hazard mechanisims) may be caused by geohazards-induced coating disbondment and/or would aggravate the impact of the geohazard on pipeline structural capacity. Technology developments initiatives towards developing routine assessments and guidelines of the triaxial loading condition would be a recommended technology development avenue.

Machine Learning

As the pipeline industry advances the introduction of machine learning in pipeline geohazard management, it would be helpful to undertake a comparative study of different machine learning methods for landslide characterization.

Acknowledging Collegiate Input

The contributions of several industry colleagues were greatly appreciated:

- Satellite Monitoring Technologies: Corey Froese (BGC Engineering), Ken Chadder (TerraMotion) and Paul Adlakha (C-CORE).

- Airborne and Drone Monitoring Technologies: Matt Tindall (Tindall Spatial).

- IMU: Jim Hart (SSD).

- Data Integration: Jake Opdahl (Teren4d).

Thank you

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