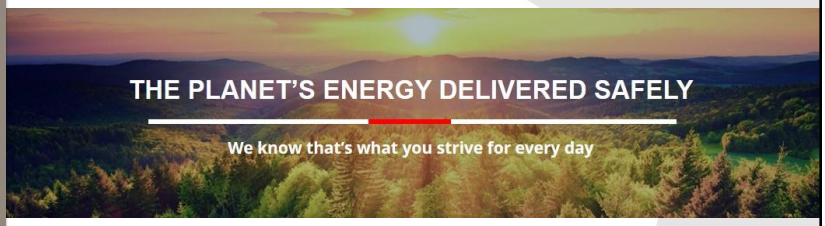
Dynamic Risk




# Operationalization of Mechanical Damage Assessment Technology

**Patrick H. Vieth**

**PHMSA Research & Development Forum**
**September 12, 2018**

## Areas of Discussion

- Why?
  - Find critical defects
  - Avoid unnecessary excavations
  - High reliability
- Background
  - Significant amount of industry research has been completed over the past decade
  - ~ 99% of excavations are stable

Dynamic Risk

## PHMSA Reportable Incident Data..

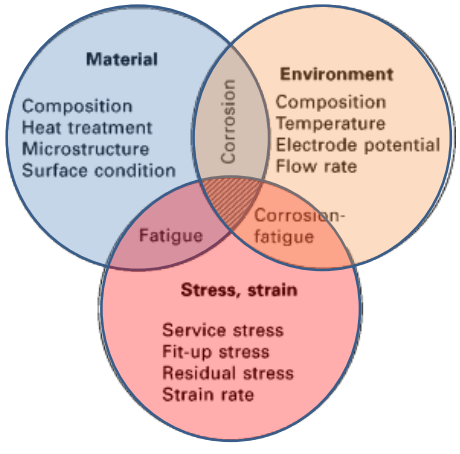
- 2010 to Present

| | Natural Gas | | | Hazardous Liquid | | |
|---|---|---|---|---|---|---|
| **ILI Survey -->** | | Yes | No | | Yes | No |
| EXCAVATION DAMAGE BY OPERATOR (FIRST PARTY) | 5 | | | 1 | | |
| EXCAVATION DAMAGE BY OPERATOR'S CONTRACTOR (SECOND PARTY) | 18 | | | 34 | | |
| EXCAVATION DAMAGE BY THIRD PARTY | 94 | | | 69 | | |
| PREVIOUS DAMAGE DUE TO EXCAVATION ACTIVITY | **15** | **4** | **11** | **16** | **13** | **2** |
| | 132 | | | 120 | | |
| Narrative References "Rock" (Pipe or Weld only) | 4 | | | 5 | | |

Dynamic Risk

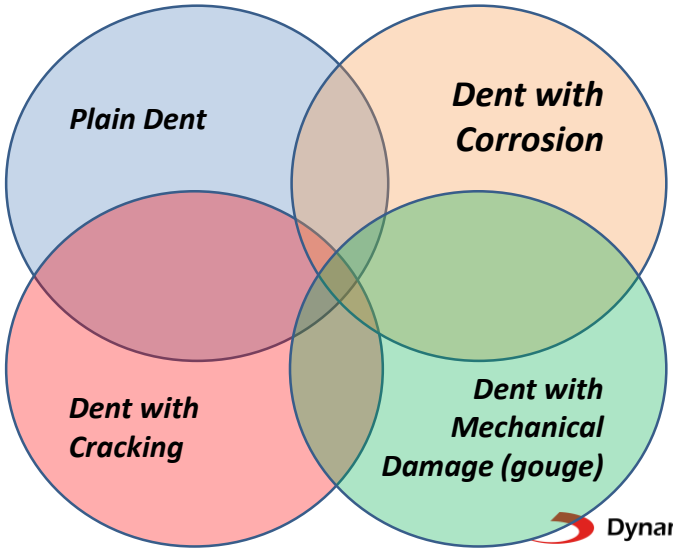
## Now pipelines, SCC has 3 attributes

- Dr. R.N. Parkins
- 9th Symposium on Line Pipe Research (circa 1996)

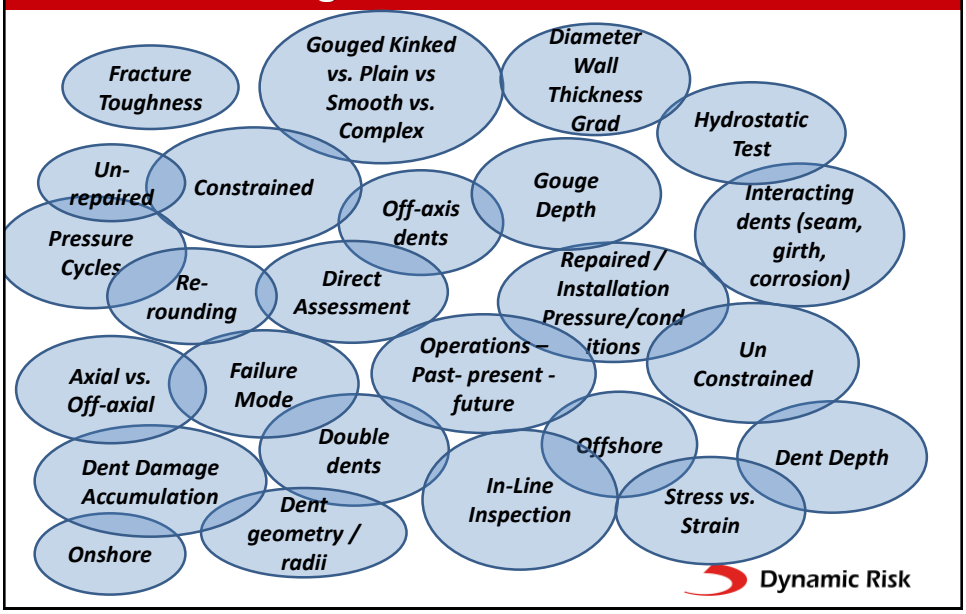



Dynamic Risk

## Dents and Damage




## Dents and Damage



## A lot of work has been done…IPC Papers…

IPC1996-1868: Techniques for Preventing Accidental Damage to Pipelines by Alain Lathon, Samir Akel
IPC1998-2033: Fatigue Curves for Damage Calculations for n Dented and Ovalled Section of the TransAiaska Pipeline System by Glen R. Stevick, James D. Hart, Bill Flanders
IPC1998-2035: Fatigue Behavior of Line Pipes Subjected to Severe Mechanical Damage by Naoto Hagiwara, Noritake Oguchi
IPC1998-2036: Investigations of Dent Rerounding Behavior by Michael J. Rosenfeld
IPC2000-188: A Pipeline Dent Assessment Model Considering Localized Effects by A. Dinovitzer, A. Bhatia, R. Walker, R. Lazor
IPC2000-206: Multiple Magnetization Level MFL for Pipeline Mechanical Damage Characterization by T A. Bubanik, J. B. Nestleroth, R. J. Davis, Harvey Haines
IPC2002-27069: An Experimental Approach to Evaluate the Resistance of Gas Pipeline to Dent and Gouge Damage by an Excavator by Gianluca Mannucci, Mauro Guagnelli, Osvaldo Vittori and Carlo Spinelli
IPC2002-27122: Basis of the New Criteria in ASME B31.8 for Prioritization and Repair of Mechanical Damage by M. J. Rosenfeld, John W. Pepper and Keith Leewis
IPC2002-27125: Reliability-Based Limit States Design for Onshore Pipelines by Maher Nessim, Tom Zimmerman, Alan Glover, Martin McLamb, Brian Rothwell and Joe Zhou
IPC2002-27142: Detection of Mechanical Damage Using the Magnetic Flux Leakage Technique by L. Clapham, Vijay Babbar, Thana Rahim and David Atherton
IPC2002-27320: A Satellite-Based Mechanical Damage Management Solution by Gregg O'Neil, Michael Besserer, Daron Moore and Louis Fanyvesi
ipc2004-000271: Detection of Mechanical Damage Using the Magnetic Flux Leakage Technique by Lynann Clapham, Vijay Babbar and James Byrne
ipc2004-000326: Integrity Analysis for Dents in Pipelines by Brian N. Leis, Thomas P. Forte and XianKui Zhu
ipc2004-000274: Quantifying the Severity of Mechanical Damage by C. R. Torres and A. P. Dean
IPC2006-10043: Understanding Magnetic Flux Leakage Signals From Dents by Lynann Clapham, Vijay Babbar and Alex Rubinshteyn
IPC2006-10101: Calculation of Strains in Dents Based on High Resolution In-Line Caliper Survey by Stanislaw A. Lukasiewicz, Jaroslaw A. Czyz, Chao Sun and Samer Adeeb
IPC2006-10138: Experimental and Numerical Modelling of Pipeline Denting by Ste´phane Hertz-Cle´mens
IPC2006-10141: A Time Dependent Model for Assessing the Significance of Mechanical Damage by Michael Martin and Robert (Bob) Andrews
IPC2006-10192: Effect of Pre-Deformation on Fatigue Crack Propagation Life of X60 Pipeline Steel by Xinwei Zhao, Jinheng Luo, Rong Wang, Maosheng Zheng and Baosheng Dong
IPC2006-10396: Evaluation of the Resistance of X120 Pipe to Mechanical Damage by Antonio Lucci, Gianluca Mannucci, Giuliano Malatesta and Nicholas E. Biery
IPC2006-10407: Management of Pipeline Dents and Mechanical Damage in Gas Pipelines by David J. Warman, Dennis Johnston, John D. Mackenzie, Steve Rapp and Bob Travers
IPC2006-10409: Probabilistic Assessment of Minor Mechanical Damage by Patrick H. Vieth, Clifford J. Maier, William V. Harper, Elden Johnson, Bhaskar Neogi, U. J. Baskurt and

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## A lot of work has been done…IPC Papers…

IPC2006-10426: The Role of Technology in Preventing/Detecting Mechanical Damage by Mark Hereth, Keith Leewis and Rick Gailing
IPC2006-10432: Leading Practices for the Prevention of Mechanical Damage by Mark Hereth, Bernd Selig, John Zurcher, Keith Leewis and Rick Gailing
IPC2006-10454: Characterization of Mechanical Damage Through Use of the Tri-Axial Magnetic Flux Leakage Technology by Vanessa Co, Scott Ironside, Chuck Ellis and Garrett Wilkie
IPC2006-10482: Assessing the Use of Composite Materials in Repairing Mechanical Damage in Transmission Pipelines by Chris Alexander and Franz Worth
IPC2006-10513: Deterministic Assessment of Minor Mechanical Damage on Pipelines by M. J. Rosenfeld, Alan Beckett, Bhaskar Neogi, U. J. Baskurt and Elden Johnson
IPC2008-64061: Modelling of Dent and Gouges, and the Effect on the Failure Probability of Pipelines by Patricia Seevam, Chris Lyons, Phil Hopkins and Malcolm Toft
IPC2008-64278: Modelling Magnetic Flux Leakage Signals From Dents by Lynann Clapham, Vijay Babbar, Kris Marble, Alex Rubinshteyn and Mures Zarea
IPC2008-64304: Towards a New Limit State Function for Determining the Failure Pressure of a Pipeline Containing Mechanical Damage by Chas Jandu, Bob Francini, Mike Taylor and Andrew Francis
IPC2008-64345: Reduction Factors for Estimating the Probability of Failure of Mechanical Damage Due to External Interference by Andrew Cosham, Jane Haswell and Neil Jackson
IPC2008-64377: Testing of a Dual Field Magnetic Flux Leakage (MFL) Inspection Tool for Detecting and Characterizing Mechanical Damage Features by Alex Rubinshteyn, Steffen Paeper and Bruce Nestleroth
IPC2010-31245: A Synthesized Approach to Pressure Reduction for Investigating Mechanical Damage by M. J. Rosenfeld
IPC2010-31246: Effect of Geometry, Material and Pressure Variability on Strain and Stress Fields in Dented Pipelines Under Static and Cyclic Pressure Loading Using Probability Analysis by Husain Mohammed Al-Muslim and Abul Fazal M. Arif
IPC2010-31409: Investigate Performance of Current In-Line Inspection Technologies for Dents and Dent Associated With Metal Loss Damage Detection by Ming Gao and Ravi Krishnamurthy
IPC2010-31417: Mechanical Damage of Pipelines at Low Operating Pressure by Khalid A. Farrag and Robert B. Francini
IPC2010-31470: Design of Pipeline Damage for the BP X100 Operational Trial by Robert M. Andrews, James Johnson and Julie Crossley
IPC2010-31561: Evaluation of Composite Sleeve Repair in Kinked Dent in Natural Gas Pipeline by Byron G. Souza Filho, Cristiane S. Frota, Fabio M. Matsuo, Gabriel Petry and Walter Schultz Neto
IPC2010-31668: Understanding Magnetic Flux Leakage Signals From Gouges by Lynann Clapham, Vijay Babbar, Jian Dien Chen and Chris Alexander
IPC2012-90017: Integrity Assessment of API 5L X65 and X70 Pipelines With Mechanical Damages by Kyu Jung Yeom, Yong Kwang Lee, Kyu Hwan Oh, Cheol Man Kim and Woo Sik Kim
IPC2012-90244: Multiple Data Set ILI for Mechanical Damage Assessment by Chris Goller, James Simek and Jed Ludlow
IPC2012-90314: Development of a Novel Electromagnetic Quantitative Residual Stress Sensor for Characterization of Steel Pipeline Mechanical Damage by Angelique N. Lasseigne, Kamalu M. Koenig and Joshua E. Jackson
IPC2012-90427: Full Scale Cyclic Fatigue Testing of Dented Pipelines and Development of a Validated Dented Pipe Finite Element Model by Sanjay Tiku, Vlado Semiga, Aaron Dinovitzer and Geoff Vignal
IPC2012-90433: Pipeline Mechanical Damage Integrity Management Framework by Vlado Semiga, Sanjay Tiku and Aaron Dinovitzer

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# IPC Papers…

IPC2012-90499: A Combined Approach to Characterization of Dent With Metal Loss by Rick Yahua Wang, Richard Kania, Udayasankar Arumugam and Ming Gao
IPC2012-90620: Full Scale Experimental Database of Dent and Gouge Defects to Improve Burst and Fatigue Strength Models of Pipelines by Mures Zarea, Remi Batisse, Brian Leis, Philippe Cardin and Geoff Vignal
IPC2012-90654: Review of R&D in Support of Mechanical Damage Threat Management in Onshore Transmission Pipeline Operations by Mures Zarea, Mark Piazza, Geoff Vignal, Charley Jones, Jerry Rau and Rick Wang
IPC2012-90732: Current State of Satellite-Based Right of Way Encroachment Monitoring for Mechanical Damage Prevention by Randy Nickle, Rick Pevarski, Mark Piazza, Moness Rizkalla, Richard Graham and Paul Adlakha
IPC2014-33017: Strain Localization in the Dent of a Linepipe by Jandark Oshana-Jajo, Hossein Ghaednia, Jamshid Zohreh Heydariha and Sreekanta Das
IPC2014-33413: Computational Model Based Method for Defining an Improved Criterion for Dent Fatigue Assessment by Maxime Lecchi, Stéphane Hertz Clemens, Philippe Notarianni and Magali Polo
IPC2014-33445: Mechanical Damage and Fatigue Assessment of Dented Pipelines Using FEA by W. Hanif and S. Kenny
IPC2014-33451: Application and Advancement of EMAT ILI Technologies for the Inspection of Cracks in Dents by Jeff Sutherland, Andrew Mann, Geoff Vignal, Arne Maier and Sean Keane
IPC2014-33510: Characterization of Topside Mechanical Damage by Rick Yahua Wang, Richard Kania, Udayasankar Arumugam and Ming Gao
IPC2014-33538: Experimental Investigation on Combined "Dent and Gouge" Defects on Vintage Steel Transmission Pipelines by Mures Zarea, Stephane Hertz-Clemens, Remi Batisse and Philippe Cardin
IPC2014-33618: Pipeline Mechanical Damage Excavation Process Review and Recommendations by Abdelfettah Fredj, Aaron Dinovitzer, Geoff Vignal and Sanjay Tiku
IPC2016-64040: Risk-Based Mitigation of Mechanical Damage by Fan Zhang, Guy Desjardins, Jing Ma
IPC2016-64097: MEASURING CRITICAL STRAINS IN DENT DEFECT OF OIL AND GAS PIPES by Hossein Ghaednia, Jamshid Zohrehheydariha, Jandark Oshana-Jajo, Sreekanta Das
IPC2016-64098: EFFECT OF CRACK DEPTH ON BURST STRENGTH OF X70 LINEPIPE WITH DENT-CRACK DEFECT by Hossein Ghaednia, Jamshid Zohrehheydariha, Richard Kania, rick wang, Sreekanta Das
IPC2016-64136: Assessment of In-Line Inspection Performance and Interpretation of Field Measurements for Characterization of Complex Dents by Jordan G. Stenerson, Luis Torres, Matthew J. Fowler
IPC2016-64216: Detection of Crack-related Features Within Dented Pipe Using Electromagnetic Acoustic Transduction (EMAT) Technology by Geoff Vignal, Jeffrey Sutherland, Kaitlyn Korol, Luis Torres, Stephan Tappert
IPC2016-64284: New classification approach for dents with metal loss and corrosion along the seam weld by J. Bruce Nestleroth, James Simek, Jed Ludlow
IPC2016-64470: On the Use of Surrogate Models in Reliability-Based Analysis of Dented Pipes by Doug Langer, Muntaseer Kainat, Samer Adeeb, Sherif Hassanien
IPC2016-64490: Evaluating Dents with Metal Loss Using Finite Element Analysis by David Kemp, Joseph Bratton, Justin Gossard, Shane Finneran, Steven J. Polasik
IPC2016-64530: Improved Pipeline Dent Integrity Management by Amin Eshraghi, Luis Torres, Mark Piazza, Sanjay Tiku, Vlad Semiga
IPC2016-64548: Study of a Plastic Strain Limit Damage Criterion for Pipeline Mechanical Damage Using FEA and Full Scale Denting Tests by Ming Gao, Ravi Krishnamurthy, Richard Kania, rick wang, Udayasankar Arumguam
IPC2016-64680: Finite Element Modeling and Quantification of Mechanical Damage Severity in Pipelines by Brian Leis, Xian-Kui Zhu

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# PHMSA Research…

DTRS56-02-T-0002, Mechanical Damage Inspection Using MFL Technology
DTRS56-04-T-0009, Mechanical Damage at Welds
DTRS56-04-T-0006, Effectiveness of Prevention Methods for Excavation Damage
DTPH56-05-T-0001, Understanding Magnetic Flux Leakage (MFL) Signals from Mechanical Damage in Pipelines
DTRS7-06-C-10004, In-Line Nondestructive Inspection of Mechanical Defects in Pipelines with Shear Horizontal Wave EMAT
DTPH56-06-T-000016, Development of Dual Field MFL Inspection Technology to Detect Mechanical Damage
DTPH56-06-T-000016, Investigate Fundamentals and Performance Improvements of Current In-Line Inspection Technologies for Mechanical Damage Detection
DTPH56-06-X-000029, Mechanical Properties and Crack Behavior in Line Pipe Steels
DTPH56-08-T-000011, Structural Significance of Mechanical Damage
DTPH56-08-T-000023, Validation for Flaw Acceptance of Mechanical Damage to Low Stress Natural Gas Pipelines
DTRT57-09-C-10046, Digital Imaging of Pipeline Mechanical Damage and Residual Stress
DTPH56-10-T-000009, MWM-Array Characterization of Mechanical Damage and Corrosion
DTPH56-10-T-000013, Dent Fatigue Life Assessment - Development of Tools for Assessing the Severity and Life of Dent Features
DTRS56-04-T-0009, Mechanical Damage at Welds
DTRS56-04-T-0006, Effectiveness of Prevention Methods for Excavation Damage
DTRS56-04-T-0007, Infrasonic frequency seismic sensor system for preventing third party damage to gas pipelines
DTPH56-05-T-0001, Understanding Magnetic Flux Leakage (MFL) Signals from Mechanical Damage in Pipelines
DTPH56-06-T-000016, Investigate Fundamentals and Performance Improvements of Current In-Line Inspection Technologies for Mechanical Damage Detection
DTPH56-06-X-000029, Mechanical Properties and Crack Behavior in Line Pipe Steels
DTPH56-08-T-000011, Structural Significance of Mechanical Damage
DTPH56-10-T-000013, Dent Fatigue Life Assessment - Development of Tools for Assessing the Severity and Life of Dent Features

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# PRCI Research…

PHMSA Full Scale Testing of Interactive Features for Improved Models(MD-4-11)
Sleeve Removal and Full-Characterization of Features(MD-1P)
Comparison of Results from Residual Stress / Strain Measurement Techniques Based on Variations in Magnetic Permeability(MD-1O)
Full-Scale Testing of Real Mechanical Damage Features Using Recovered Pipe(MD-1N)
Selection and Management of Mechanical Damage Test Samples from Field Removal(MD-1L)
Creation of Dent and Gouge Defects for Inspection Technology Evaluation and Repair - Vintage Steels Without and With Cracks - Extension of MD-4-6 Project or DOT Project(MD-1-10)
Contributions to the "Allowable Strain Limits for Dents" - Dents with Cracks and Gouges(MD-1-8)
Assessment of Delayed Failure for Mechanical Damage Under Constant Pressure(MD-4-8)
Full-Scale Experimental Validation of Mechanical Damage Assessment Models(MD-4-1)
Improved Model for Predicting the Burst Pressure of Dent + Gouge Damage(MD-4-3)
Improved Model for Predicting the Time/Cycle Dependent Behavior of Dent + Gouge Damage(MD-4-4)
Acoustic Source Level and Signature Measurement of Pipeline Scratches and Gouges(MD-4-5)
Full-scale Experimental Validation of Mechanical Damage Assessment Models - Extension of MD-4-1(MD-4-6)
Full-scale Experimental Validation of Mechanical Damage Assessment Models - Options MD-1(MD-4-7)
DOT PROJECT: Ultrasonic Measurements of Strains in Pipelines(MD-1-6)
DOT PROJECT: Understanding Magnetic Flux Leakage Signals from Mechanical Damage in Pipelines(MD-1-3)
Field Testing and Verification of Existing Tool Capabilities for Mechanical Damage Detection and Characterization(MD-1-4)
Full-Scale Demonstration of the Interaction of Dents with Localized Corrosion Defects(MD-4-2)
PROGRAM: Structural Significance of Mechanical Damage(MD-4)
Inventory of Types of Mechanical Damage Experienced by Gas and Oil Pipelines(MD-2-1)
Model for Predicting the Likelihood and Severity of Newly Created Damage - MD-2-2 Year 2 Funds(MD-2-2)
DOT PROJECT: Dual Field Magnetic Flux Leakage Inspection Technology to Detect and Characterize Mechanical Damage(MD-1-1)
DOT PROJECT: Performance Characteristics of Current In-Line Inspection Technologies for Mechanical Damage Detection(MD-1-2)
PROGRAM: Mechanical Damage Inspection and Characterization(MD-1)
Creation of Dent and Gouge Defects Associated with Cracks - Modern Steels(MD-1-11)
Advanced Material Characterization of Dent and Gouge Samples for Improved Strain Evaluation & Implementing Damage Mechanics Modeling(MD-4-12)
Neutron Diffraction Measurements of Residual Strain Associated with Dents and Gouges in Pipelines(MD-1-9)
Guidelines for Safe Inspection and Repair of Mechanical Damage Defects(MD-5)
Evaluate Time-based Criteria to Repair Mechanical Damage(MD-4-13)
Fatigue Screening and Life Assessment of Pipelines, Dents, and Dents Interacting with Welds(MD-4-9)
Dent Integrity Management and Modeling - Shallow Dents with Limited Corrosion and Shallow Restrained Dents(MD-4-14)
Full Scale Testing of Interactive Dent Features for Improved Models(MD-4-15)
Performance Evaluation of ILI Systems for Detecting and Discriminating Metal Loss, Cracks and Gouges in Geometric Anomalies(MD-1-13)
Assessing Crack Growth Rates In Dents(MD-1Q)
New Multi-Year Project: Remaining Life Model and Assessment Tool for Dents and Gouges(MD-4-16)

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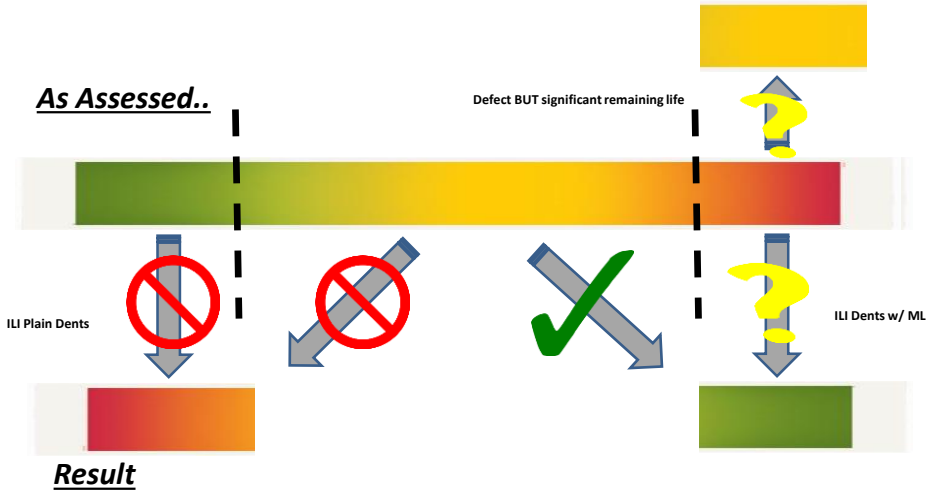
# Overview of Research..

- 66 IPC Papers related to dents and mechanical damage
- 35 PRCI Projects
- 21 PHMSA Projects

| Integrity Assessment | ECA/FFP | Direct Examination | Validation/ Calibration | P&M | Program | Research |
|---|---|---|---|---|---|---|
| 30 | 42 | 7 | 21 | 9 | 7 | 6 |

## A continuum of assessment…




Dynamic Risk

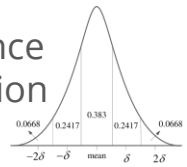
## What are the priorities?

1. Safety during excavation (e.g., rock removal)
2. Via in-line inspection, confirm dents with no damage with high reliability
3. Validated non-destructive examination for defect assessment and on-going ILI validation
4. In-line inspection analysis of features within dents and guidelines for response
5. ECA and FFS Guidelines and Acceptance Criteria
6. Repair Criteria
7. Repair Methods

Dynamic Risk

## So, the questions are…

- What is the ability to fully utilize research and practice beyond prescriptive guidelines?
- Is there an ability to develop reliability models and to establish acceptance limits?
- Can or should more refined consequence assessment be considered in the decision process?
- Even though certain defects are confirmed, can the remaining useful life be relied upon (it's not binary)?




Dynamic Risk

## What are the gaps?

- Transition from construction to operations
- Reliability approach as opposed to current deterministic approach
- Recognition that most operators (and industry) don't have qualified resources to support complex program
- Characterization of features within a deformation (via ILI) with high reliability
- Prescriptive guidelines and regulations can not fully consider all factors

Dynamic Risk

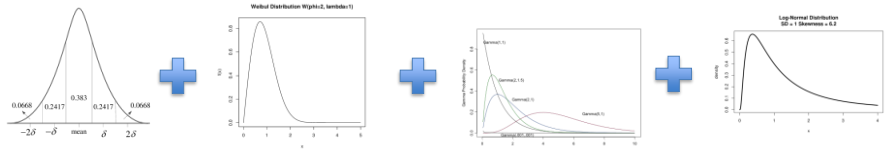
## PHMSA R&D Forum

*Thank you!*

*It's time to hear from you!*

Dynamic Risk

## Reliability Modeling Schematic..




*In-Line Inspection*

*Fracture Toughness*

*Off-axis dents*

*Interacting dents (seam, girth, corrosion)*

Dynamic Risk