MAPPING OF THE CAUSE / CONTRIBUTING FACTORS AS CITED IN PHMSA'S KEYSTONE ACCIDENT REPORT TO HUMAN FACTOR RELATED ISSUES

<table>
<tr><th>7. Findings and Contributing Factors</th><th>Error Shaping Factors</th><th>Involved Decision Makers</th></tr>
<tr><td>PHMSA has determined the failure was caused by bending stress from soil loading on the pipeline which concentrated at the girth weld containing LOF defects on the fitting assembly TAG 98. Cracks initiated due to the applied bending stress, and they grew in service due to cyclic fatigue.

The following factors contributed to the failure:
• Inadequate quality control of original fitting manufacture resulted in a fitting replacement program prior to the pipeline being placed in service.
• At the location of the failure, the fitting replacement program was executed in a manner which allowed excessive bending stress to be applied to TAG 98 fitting assembly and caused excessive ovality of the assembly.
• The back fill process during the TAG 98 replacement was not adequately inspected to assure proper compaction.
• The replacement fitting assembly TAG 98 contained welding defects which were exacerbated by an inadequate wall thickness taper transition design that concentrated applied stress at the girth weld.
• Counterboring with tapers is preferred in TC's welding procedure for transition welds exceeding 0.100 inches but was not used.
• The TAG 98 ovality investigation in 2013 did not consider the integrity threat associated with the bending stress that caused it.
• Removal of the TAG 98 fitting assembly to mitigate the ovality present in 2013 was declined in favor of ILI tool modification.
• The fitting assembly TAG 98 design, wall thickness taper transition and ovality decreased the probability that girth weld defects in the assembly could be reliably identified through ILI.
• IMU data post construction was not gathered to establish a baseline pipeline position to be compared to future IMU data collections.
• Bends and wall thickness transitions affect the accuracy of in-line inspections.</td><td>• Does not see the risk or mistakenly believes the risk is insignificant or justified
• Behavior is often the norm within groups
• Risk monitor does not alarm – mistakenly believes the choice is safe
• Does not consciously disregard what is known to be a substantial and unjustifiable risk.</td><td>• Individual
• Group
• Corporate
• Industry</td></tr>
</table>

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PHMSA has determined the failure was caused by bending stress from soil loading on the pipeline which concentrated at the girth weld containing LOF defects on the fitting assembly TAG 98. Cracks initiated due to the applied bending stress, and they grew in service due to cyclic fatigue.	• Does not see the risk or mistakenly believes the risk is insignificant or justified • Behavior is often the norm within groups • Risk monitor does not alarm – mistakenly believes the choice is safe • Does not consciously disregard what is known to be a substantial and unjustifiable risk.	• Individual • Group • Corporate • Industry
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The graphic on the next page attempts to flowchart PHMSA's various findings adding in "barriers" that an operator will cite as the means by which they control or mitigate the risk of for instance a mechanical defect causing a failure, as often seen in Bow Tie analyses. The color green is frequently used to depict a barrier. In the graphic rather than shade the entire barrier green, only a portion of each of the barriers is shaded green to depict the barrier being less than 100% effective.

Modeling the loss of effectiveness of barriers whether due to the form and nature of the actual written code, standard or instruction, training, time or changes in an organization, etc. is not something I have seen applied in the pipeline industry risk modeling efforts. While a number of techniques have been developed for assessing and modeling Human Factor errors, such as Human Error Assessment and Reduction Technique (HEART), Human Error Root Cause Analysis, A Technique for Human Error Analysis (ATHENA), etc. these techniques dig deep into a particular issue or task. Assessing and modeling the various human factor or human error issues that per PHMSA's recent report, contributed to the Keystone failure requires a more wholistic approach across a wide spectrum of at any one time would likely be considered disparate issues. However with the advances being made in AI, it is perhaps, now, feasible to start developing the models to tackle such a complex task.

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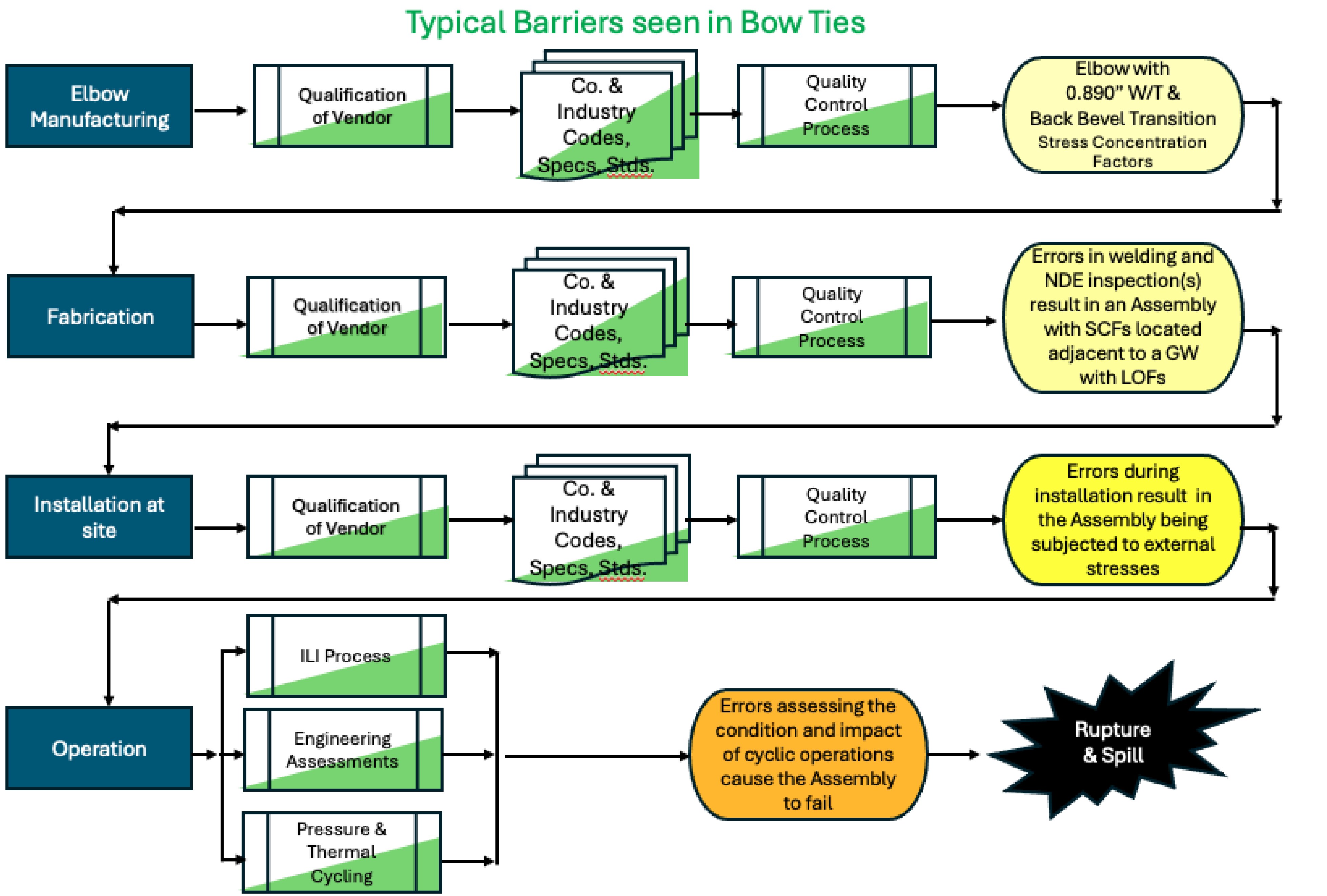

What factors impacted the effectiveness or resulted in the lapses that occurred in the various barriers?

- Quality of the standard,
- Training,
- Accepted deviations over time, etc.?

Could probabilistic risk methods model the deterioration in the various barriers and predict a failure within 10 years or XXXXX cycles of operation?