U.S. DOT PHMSA #DTPH5615T00010

Human Centric Approach to Improve Pipeline Non-Destructive Evaluation (NDE) Performance and Reliability: Phase 1 Final Report

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September 30, 2016

Battelle
The Business of Innovation

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September 30, 2016

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Abstract

The United States of America is critically dependent on natural gas and petroleum liquids transported through pipelines. The infrastructure that currently transports these energy resources is aging, with a significant fraction over fifty years old. New pipelines are currently being planned and constructed; however, pipeline operators are planning on continued operation of the vast majority of existing pipeline mileage. Assuring the long-term integrity and security of these existing pipelines is essential.

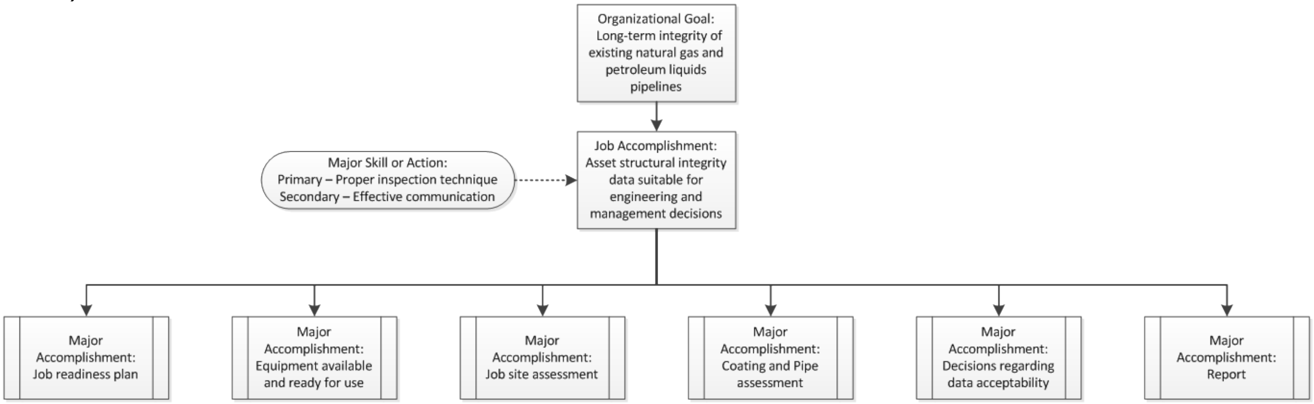
Recognizing these facts, the U.S. Department of Transportation (DOT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Office of Pipeline Safety (OPS) designed a continuing process to emphasize the importance of continuing pipeline-related Research and Development (R&D). DOT PHMSA PHP Research Announcement #DTPH5615RA00001 was issued as part of that overall effort.

Battelle entered into a Transaction Agreement, #DTPH5615T00010, “Human Centric Approach to Improve Pipeline Non-Destructive Evaluation (NDE) Performance and Reliability” to apply a phased approach to first identify major human performance shaping factors of NDE measurements and then to identify high-impact human and technology interventions to reduce identified negative influences on performance. The primary objective of this first phase effort was to extract information from designated NDE pipeline inspector accomplished performers (APs) through coordinated in-depth interviews. The secondary objective was to provide a preliminary set of recommendations for the integration of the results into one or more performance-enhancing interventions such as new training, personnel screening, motivational incentives, and/or technology enhancements, with the ultimate goal of bringing inspector novices or “non-experts” up to speed more rapidly. Phases 2 and 3 of this project will address the high-impact positive and negative influences through implementing and evaluating human (Phase 2) and technological (Phase 3) interventions that were selected to improve inspection performance across the work population.

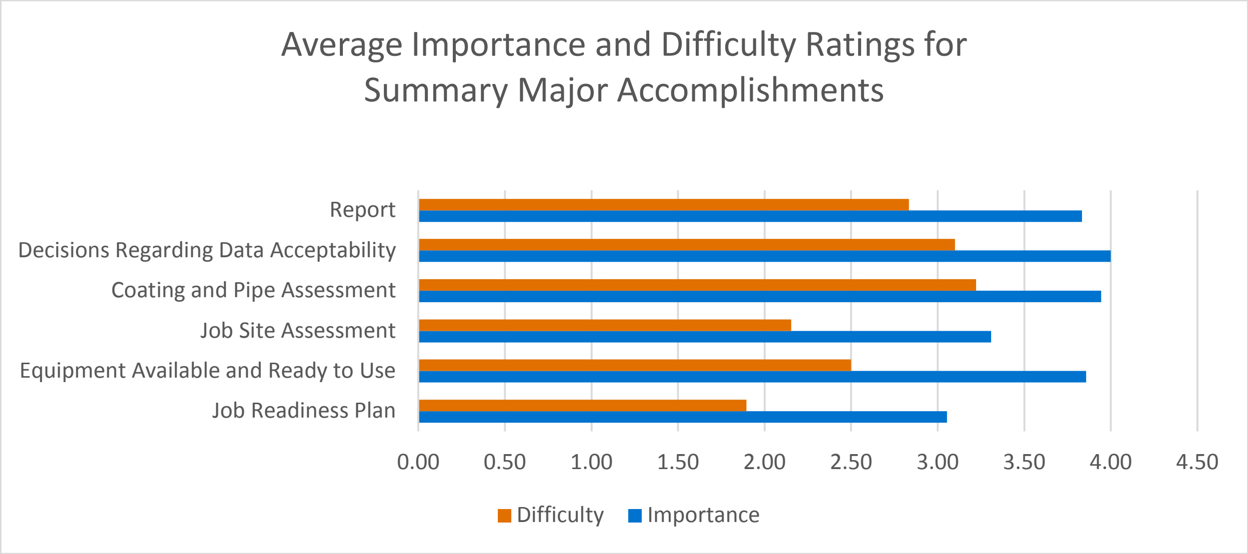
Keywords: human error, human reliability, human factors, performance shaping factors, non-destructive evaluation (NDE), non-destructive testing (NDT), performance influencing factors, error inducing factors, fuzzy cognitive models, probability of detection (POD), probability of identification (POI), receiver operating characteristics (ROC), in-service inspection, human performance, inspection performance, training.

Executive Summary

Twenty-four (24) APs from three partner organizations (Mistras Group, JENTEK, and Applus RTD) participated in extensive interviews and task observations. Interviews comprised a structured interview about the pipeline NDE inspection process and more general, open-ended questions regarding positive and negative influences on the inspection process. A subset of APs was provided a pipe sample and asked to demonstrate the inspection process as part of the interview. Analysis of the structured Human Performance Technology (HPT) data suggests a close alignment between APs regarding the overall job accomplishment of an NDE inspector and the major accomplishments associated therein (see Figure below).



Average difficulty and importance ratings (see Figure below) indicate that APs place the greatest emphasis on (1) decisions regarding data acceptability, (2) the coating and pipe assessment, and (3) production of the final report.



An analysis of the comments from the HPT process and some of the open-ended questions identified several performance shaping factors (PSFs) and positive and negative influences on the inspection process. Performance shaping factors were organized into seven (7) categories:

PSF1. Organizational
- a. Organizational structure (authority, communication channel(s))
- b. Actions by supervisors, coworkers
- c. Rewards, recognitions, benefits
- d. Team structure and communication
- e. Plant policies
- f. Feedback of results
- g. Threats (of failure, loss of job)

PSF2. Operational
- a. Procedures required
- b. Work methods
- c. Plant policies
- d. Training provided

PSF3. Work Task
- a. Work hours/breaks
- b. Work methods
- c. Task speed
- d. Task load
- e. Task frequency and repetitiveness
- f. Task complexity
- g. Work risk
- h. Monotonous work
- i. High vigilance
- j. Distractions

PSF4. Technology
- a. Availability and adequacy of equipment/tools
- b. Man-machine interface factors

PSF5. Physiological/Cognitive
- a. Long- and short-term memory
- b. Calculating requirements
- c. Interpretation requirements
- d. Stress (onset and duration)
- e. Fatigue
- f. Pain or discomfort

PSF6. Personality
- a. Intelligence
- b. Motivation and attitude
- c. Emotional state
- d. Group identification

PSF7. Environmental
- a. Temperature
- b. Humidity
- c. Air quality
- d. Lighting
- e. Noise
- f. Vibration
- g. Degree of general cleanliness
- h. Movement constriction

Positive influences suggested that APs are team oriented and value clear, concise, and accurate communication with respect to the conditions they are likely to encounter when they arrive at a job site; commonly mentioned positive influences included good team chemistry, positive feedback, management involvement, and good communication. Negative influences included workload, time pressures, and poor communication.

A high-level list of proposed interventions (tied to the top four performance shaping factor categories) for consideration is in the list below. Additional details are provided in Section 6 of this report.

- Organizational Interventions
  - Implement or improve employee recognition programs
  - Evaluate and implement improved merit-based compensation
  - Improve Client – Inspector communication
- Operational Interventions
  - Create a forum for inspectors to share “lessons learned”
  - Better utilize down time between jobs
  - Expanded training
- Work Task Interventions
  - Promote a better work life balance
- Technological Interventions

- Provide for adequate equipment upgrades

This list is not exhaustive and other interventions will be identified for potential subsequent development and evaluation in Phases 2 and 3 of this project.

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List of Acronyms

AP	Accomplished Performers
DOT	U.S. Department of Transportation
FEA	Front-end Analysis
HPT	Human Performance Technology
IDI	In-depth Interviews
NDE	Non-Destructive Evaluation
NDT	Non-destructive Testing
NTSB	National Transportation Safety Board
OPS	Office of Pipeline Safety
PHMSA	Pipeline and Hazardous Materials Safety Administration
POD	Probability of Detection
PSF	Performance Shaping Factors
R&D	Research and Development
ROC	Receiver Operating Characteristics

1. Project Background

Oil and gas remain the primary energy source around the globe, and transporting these products in an efficient and safe manner is more critical than ever. The infrastructure that transports these resources is aging, with a significant fraction of the pipelines being more than fifty years old. In 2014 alone, U.S. pipeline incidents were responsible for over $300 million in property damage, 19 fatalities, and 97 injuries.[1] Though the nation's pipeline infrastructure continues to age, these same pipelines will be relied on to operate for decades.

One critical method in monitoring and maintaining this infrastructure is via non-destructive evaluation (NDE), which may lack vital accuracy and reliability due to unintentional human error. Often pipeline operators feel that they can trust only one individual inspector. This uneasiness in NDE is warranted as human error poses a significant threat to safe and efficient pipeline operations. While human factors typically are not attributed as the sole source of pipeline incidents, they contribute substantially to incident prevalence and severity. Of high consequence pipeline accidents between 1992 and 2004, the National Transportation Safety Board (NTSB) found human factor involvement in 10 of the 13 incidents.[2]

This effort was designed to produce insight into the conduct of successful NDE inspector performance and support the mission of the Pipeline and Hazardous Materials Safety Administration (PHMSA) to ensure the long-term integrity of natural gas and liquid petroleum pipelines. The critical outputs of an inspection task and the positive and negative influences (i.e., performance shaping factors) on those outputs identified through directed in-depth interviews conducted with accomplished inspectors provide knowledge that could lead to the development of actionable interventions supporting improved inspector performance.

2. Project Objectives

The overall "Human Centric Approach to Improve Pipeline NDE Performance and Reliability" project (#DTPH5615T00010) has three objectives:

- Identify human performance shaping factors' influence on in-the-ditch NDE inspector performance
- Identify and validate high-impact human interventions to improve NDE inspector performance
- Identify and validate high-impact technology interventions to improve NDE inspector performance

Battelle proposed an investigative approach staged in three (3) phases, with each objective having a dedicated milestone for a clear go/no-go decision to enter into the subsequent phase.

Phase 1, the subject of this report, identified human factors that affect NDE inspector performance and reliability. Although human factors have been cited in various NDE studies, human factors contribution has not often been separated and rigorously addressed as a separate issue.[3] The primary objective of

[1] https://hip.phmsa.dot.gov/ analyticsSOAP/saw.dll?Portalpages Accessed March 24, 2015.

[2] http://www.phmsa.dot.gov/pv_obj_cache/pv_obj_id_751C99B2334D7A0B306F740B0559696E3B580000/filename/Control%20Room%20Management%20Human%20Factors.pdf Accessed 06 January 2016

[3] Rummel, W. D., *Human factors consideration in the assessment of nondestructive evaluation (NDE) reliability*. From Thompson, D.O.; Chimenti, D.E; p. 37-46; Plenum Press; New York, NY (USA); Conference on quantitative NDE; Santa Cruz, CA (USA); 7-12 Aug 1983.

this phase was to extract information from designated NDE inspector accomplished performers through coordinated in-depth interviews (IDIs). Analysis of the IDI content serves to identify the optimal approaches or techniques undertaken by the inspector during an NDE task that may be facilitated and transferred to other inspectors through the development and implementation of human-based and technological interventions.

Phase 2 is dedicated to identifying and developing valuable human-based interventions (e.g., training, personnel selection, incentives) to eliminate or otherwise reduce detrimental human factors that hinder NDE performance and reliability.

Phase 3 is dedicated to identifying and developing high-value technology interventions. To be run in parallel with the human interventions in Phase 2. Phase 3 will examine how improved equipment could aid the reliability of existing techniques or how novel inspection technologies can make inspection inherently more reliable.

3. Project Report Scope

This project report presents the approach, analysis activities, and a summary of results and recommendations from a series of in-depth interviews conducted during Phase 1 of the project.

4. Technical and Management Approach

“Human Performance Technology (HPT) is a field of practice that has evolved largely as a result of the experience, reflection, and conceptualization of professional practitioners striving to improve human performance in the workplace.”[4]

The HPT process formed the basis of the technical approach to data collection for this Phase 1 effort. HPT-based programs focus on accomplishment-based human development and management, whereas other approaches may only target training. The process of analyzing, designing, developing, implementing and evaluating activities that influence human behavior puts job aids, selection, motivation, environmental, and technology factors into play when they may provide the greatest potential for performance improvement.

As a methodology, HPT focuses on the outputs produced by top accomplished performers (APs) and builds upon these outputs to create strategies for disseminating expertise across the work population. In short, it relies less on how something is done in principal and more on the empirical evidence of how activities are actually accomplished by current exemplar performers (i.e., those individuals that have been identified as the most effective at completing their job within an organizational system).

A Front-end Analysis (FEA) of a given role—in this case, pipeline inspectors conducting NDE—reveals the single core pretest “Job Accomplishment.” The key element of this identification of the job accomplishment is being able to identify all the individuals who hold the role against a given standard. Generally speaking, the results of the whole peer group can be placed into a normal distribution, and the individuals in the far right of the curve represent “star performers;” where the majority of the group will

[4] Stolovitch, H. D., & Keeps, E. J. (1992). What is human performance technology? In H. Stolovitch & E. Keeps (Eds.) *Handbook of Human Performance Technology* (p. 3). San Francisco, CA: Jossey-Bass, Inc.

hover around the middle, the far right outliers have worked out a way to achieve more and better results (see Figure 1).

Figure 1. Representative Distribution of Normal and Exemplar Performers in a Workforce.

Through a combination of interviews and analysis, a picture is built of the key — or “Major Accomplishments” — achieved by these star performers, which allow them to create better overall Job Accomplishment results. A primary aspect of this work is the fact that the information being collected is contextually strong; that is, these APs have worked out how to complete a process within the context of the existing system, which means that the procedures being captured will be highly likely to produce successful input that increases the value of subsequent interventions.

The following sections describe the HPT process undertaken for project coordination and subsequent AP knowledge elicitation through the execution of FEA IDIs through four steps:

- Project Alignment
- Literature Review
- Knowledge Elicitation
- Data Compilation and Analysis

Because the HPT process is output driven and the content of that output comprises feedback gained from the IDIs conducted with APs, the results that are reported herein are a direct synopsis of the accomplishments, recommendations, and comments received.

4.1 Project Alignment

The project alignment effort comprised the development of a detailed Production of Effort Implementation Plan and the execution of a kickoff meeting with the project team on 9 October 2015 to review, discuss, and agree upon; the project roles, objectives, and timeline; as well as to identify sources of existing data, determine the precise project scope, and review the proposed analysis methods.

4.2 Literature Review

A review of the published NDE literature was conducted primarily to facilitate the researcher’s understanding of the basic NDE history and processes as well as to generate ideas for the development of IDI questions.

A representative, though not exhaustive, list of keywords used to conduct the NDE HF literature search is provided in the list below. Secondary searches were also conducted for literature cited in reviewed documents.

- Error inducing factors
- Human error
- Human factors
- Human performance
- Human reliability
- In-service inspection
- Inspection performance
- Non-destructive evaluation (NDE)
- Non-destructive testing (NDT)
- Performance influencing factors
- Performance shaping factors
- Pipeline inspection
- Probability of Detection (POD)
- Probability of Identification (POI)
- Receiver Operating Characteristics (ROC)
- Training

Approximately 200 citations/abstracts were reviewed from open sources such as web-searches, the Battelle Library search engines, engineering literature/peer review sources, proceedings, etc. Sixty (60) full-text articles were identified and acquired for further review.

The literature review revealed a number of performance shaping factor (PSF) listings as well as summaries of studies conducted to determine their influence on NDE inspector performance. Resources identified in Appendix D led to the preliminary identification of performance shaping factors, skills, and characteristics among NDE inspectors.

The literature tends to broadly categorize and order the influence of PSF on NDE reliability from most salient to least as:

1) Organizational characteristics

2) Inspection procedures/training

3) Individual characteristics

4) Technology

5) Working (environmental) conditions

6) Group/team dynamics

Higher reliability standards are believed to have been achieved with increased use of automation. However, human inspectors, and thus human performance shaping factors, still play an important role throughout the inspection process. Increasingly, factors related to organizational structure, inter-personal/inter-organizational communication, training, and procedure content are being investigated to determine their influence on effective NDE.

Little data or research on the influence of working (environmental) conditions and even less on the influence of group/team dynamics was found. Technology no doubt affects performance, but also presents its own set of problems that come with automation. Organizational characteristics, inspection procedures/training, and individual operator/inspector characteristics are seemingly the focus of much of the more current research.

4.3 Knowledge Elicitation

Accomplished NDE performers—indeed, experts in any profession—are often unable to explicitly describe the skills and knowledge that makes them exceptional. Instead, it requires observations and formally structured interviews with APs to identify the mental models, heuristics, and overall task knowledge of the best inspectors.

This stage of the HPT process comprised identifying appropriate APs, planning the data collection methods and developing the corresponding forms, and conducting the IDIs.

4.3.1 HPT Front-end Analysis Process

The HPT process relied upon the structured interview of APs or exemplars. These are inspectors who are effective in conducting NDE resulting in accurate and credible inspection results (i.e., the inspection results in the production of accurate data suitable for subsequent engineering analysis). Interviewing APs allows the procedures, techniques, and insights used by the best inspectors to be incorporated into human performance enhancements.

The method of analysis began with the identification of the NDE operational goal – in this case, maintaining the long-term integrity of natural gas and liquid petroleum pipelines. APs were interviewed to identify what accomplishments (i.e., valuable outputs) are necessary to achieve the goal and, in turn, what critical skills and behavior (i.e., actions) are implemented to produce the outputs (Figure 2).

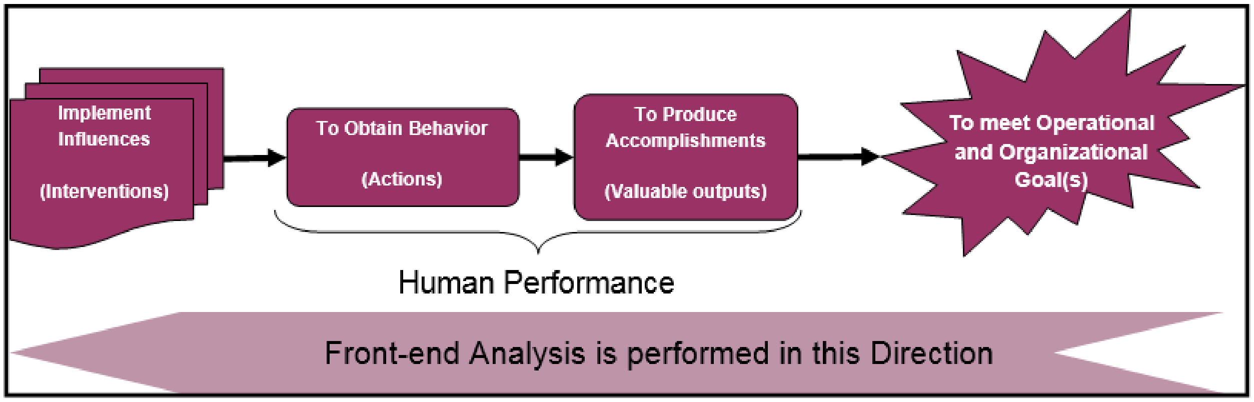

Figure 2. HPT Front-end Analysis Flow.

Performance criteria, importance, and difficulty data were captured with respect to the accomplishments. An analysis of the data captured leads to the identification of likely performance-enhancing interventions.

4.3.2 Accomplished Performer Recruiting

Accomplished performers were recruited by soliciting input from the partner organizations on the Battelle project team (Mistras Group, Inc., JENTEK Sensors, Inc., and Applus RTD USA, Inc.). Mistras identified APs in Magnetic Particle Testing (MPI/MT), X-Radiograph inspection (X-ray), and Ultrasonic Testing (UT) weld inspection. Applus identified APs in Inverse Wave Field Extrapolation (IWEX). JENTEK identified APs in Meandering Winding Magnetometer (MWM) Eddy Current Sensors.

Rather than collecting performance metrics and independently identifying APs, Battelle relied on the partners to provide their best inspectors. Battelle asked that the partners provide the names of inspectors that consistently produce quality data and that they would trust with the most difficult inspections. This was the most expedient way to identify potential participants within the project phase timelines. This approach, however, does not provide a metric that can be applied objectively across inspectors, and therefore relies on the objectivity of the nominating organizations.

Nominated inspectors were contacted, asked whether they were willing to participate, and provided the letter of introduction found in Appendix A.

4.3.3 Interview Flow and Content

AP interviews generally lasted 3 to 4 hours. The interviews were divided into three sections: [1] an introductory brief to the project was provided by the investigators, followed by [2] the structured interview to capture accomplishment data, and then [3] a guided discussion targeted to open-ended questions such as those found in Appendix B.

Audio recordings of the interviews were captured from all inspectors for reference during the analysis process. In addition, seven (7) inspectors were provided one or more pipe samples to allow them to demonstrate their inspection technique(s) to the investigators. Two inspectors from JENTEK, two inspectors of Applus RTD and three inspectors from Mistras conducted inspections on two pipe samples. All seven inspectors were able to identify the seam crack anomalies in the various pipe samples. This hands-on demonstration was video recorded and was useful to allow the APs to clarify their job tasks, as well as for investigators to understand the nuances of an inspection task that are not easily captured through the interview process alone.

The job accomplishment (i.e., the output of value that best summarizes the main intent of the inspection activity), major accomplishments, and supporting data were elicited from the interviewee during the structured data collection. The investigators asked the inspector what was the “primary output” of a successful NDE inspection to elicit the job accomplishment. If necessary, the investigators offered clarifying examples from other domains; for instance, “profit is the job accomplishment of a sales person.” After eliciting the job accomplishment, investigators asked the inspector what the most important critical skill is to achieving the job accomplishment.

Investigators elicited the major accomplishments from inspectors after collecting the job accomplishment data. Investigators asked inspectors to start from receipt of notification of a new inspection job (e.g., work order, traveler) and identify the outputs that lead to the production of the job accomplishment and a successful inspection. Inspectors would then describe their workflow and accomplishments. If necessary, the investigators provided clarifying examples of major accomplishments from other domains; for instance, “a signed contract is a major accomplishment for a sales person.” Collection of the major accomplishments concluded when the inspector indicated that data reporting was complete and subsequent engineering or management analysis would begin. The inspectors were explicitly asked to define the end of the inspection task/workflow.

After collecting the major accomplishments, investigators asked inspectors additional questions about each of their identified major accomplishments. These questions included “How important is this major accomplishment?” and “How difficult is it to achieve this major accomplishment?” If necessary, clarifications were provided to reinforce that these questions were in reference to the NDE inspection process and how the major accomplishments support the job accomplishment.

Investigators also asked inspectors about interactions and time spent on each major accomplishment. Interaction refers to whether the inspector was working primarily with other inspectors, clients, other support personnel (e.g., engineers or abatement crews), equipment, or materials. Time spent refers to the percentage of time an inspector may spend on each major accomplishment, compared to the overall inspection process.

After completing the structured data collection, investigators engaged inspectors in a conversation regarding several open-ended questions. The questions included “What are positive influences on your performance?” “What are negative influences on your performance?” and “What are common mistakes that new and novice inspectors make?” The conversation also provided the inspector an opportunity to revisit any comments made during the structured interview that were not job- or major-accomplishment specific, such as references to motivational and career development interventions that may facilitate performance.

Investigators reviewed the data captured following each interview and iterated any questions or unclear comments with the AP in follow-up emails and phone calls to ensure there were no gaps and that each comment was captured and recorded as the AP intended.

4.4 Data Compilation and Analysis

Job accomplishments captured during the interviews were summarized into a single job accomplishment. Major accomplishments captured during the interviews were categorized into summary major accomplishments that support the job accomplishment outcome. These summary major accomplishments represent common themes across AP responses. Importance and difficulty ratings captured for the individual major accomplishments are reported herein at the summary accomplishment level.

Responses to open-ended questions and comments elicited over the course of the interviews were extracted from the interview notes and added to a comments list. An analysis of these items revealed that topics varied widely, but that in general, the items fell into three categories:

1) Traits of expert inspectors

2) Skills APs must possess

3) Interventions that would help facilitate inspector performance

Investigators then sorted the comments into these categories and grouped related items in each category to aid comprehension of the content. The complete lists of inspector traits and inspector skills are shown in Appendix C. The suggested interventions are discussed in *Section 6, Conclusions and Recommendations*.

5. Results

5.1 Accomplished Performer Demographics

Twenty-four (24) AP interviews were conducted from March 2016 through August 2016. The number of APs participating from each partner is shown in Table 1 below. The majority of interviews were focused on Mistras Group as their project role was to represent traditional, fully-commercial in-the-ditch NDE. Applus RTD and JENTEK represented newer, upcoming NDE technologies.

Table 1. Number of APs Interviewed.

Partner Organization	No. of APs Interviewed
Mistras Group	20
Applus RTD	2

JENTEK	2

Relevant AP demographics are shown in Table 2 below. Of the inspectors with college degrees, approximately half had a degree in an engineering field (e.g. electrical, mechanical, computer).

Table 2. AP Demographics.

Demographic	Results (N=24)
Age	Average = 34 years old (range 20 – 49 years)
Years of Experience	Average = 7.5 years (range 1 – 16 years)
Education Level	
High School	10
Some College	3
College Degree	11*

*All Applus RTD and JENTEK APs are included in this number, suggesting that upcoming NDE technologies may require highly educated operators.

Interviewees were NDT Level II and III inspectors or technical specialists with experience across the various inspection techniques of interest for this effort (e.g., visual, liquid penetrant, magnetic particle, phased array, ultrasonic). Interviewees had in-the-ditch and/or in-the-shop pipeline inspection experience; with some also citing experience in refinery/above ground storage environments.

5.2 Accomplishment Data

The overall inspector job accomplishment and contributing summary major accomplishments are presented in Figure 3 below.

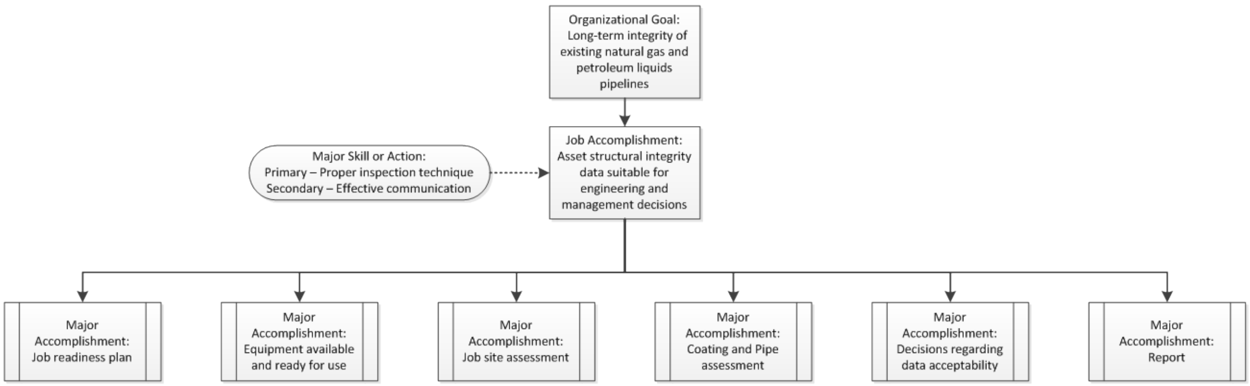

Figure 3. Job and Major Accomplishment Hierarchy.

5.2.1 Job Accomplishment and Major Contributing Skills

The overall job accomplishment (i.e., the output of value that best summarizes the main intent of the inspection activity) was "Asset structural integrity data suitable for engineering and management decisions." All twenty-four (24) APs provided a similar job accomplishment. The accomplishment includes concepts such as “accurate data that is suitable for engineering decisions,” “parts that are characterized accurately against a specification,” and “usable data used to determine the life expectancy of a particular component.” The APs described usable data as data collected with a proper inspection technique, with equipment that has been correctly calibrated, from a clean and properly prepared inspection surface.

Investigators reviewed APs’ statements regarding the major skill(s) required to successfully produce the job accomplishment. The APs most often cited “Proper inspection technique” and “Effective communication” with respect to job planning as the two major/critical skills associated with successful production of the job accomplishment. Other critical skills mentioned by APs included analyzing the data set, having above average attention to detail, and effective job planning.

5.2.2 Summary of Major Accomplishments

There are six (6) major accomplishments (i.e., sub-outputs of value that make up the overall job accomplishment).

5.2.2.1 Job Readiness Plan

This major accomplishment includes the development of a plan to gather the data needed to complete a given job. To accomplish correctly, APs interact with the client or call ahead to gather additional information about the job site that may not be included on the job traveler (a document given to the inspector by their organization containing job information). Additional activities may include confirming job scope, confirming the material under test, gathering environmental information, and gathering historical data surrounding the pipeline or specimen. APs also coordinate with their assistant as needed to read the job traveler and identify the appropriate inspection technique, the correct equipment and the appropriate calibration standards.

5.2.2.2 Equipment Available and Ready for Use

This major accomplishment includes the process of identifying and gathering the appropriate equipment for a given inspection. To accomplish correctly, APs identify the correct equipment for the inspection based on the job traveler, historical data from the test specimen, and discussion(s) with the client. Once the equipment is identified, APs ensure the equipment is functional and is calibrated correctly. Several APs also reported that they make a habit of bringing as much equipment as possible to a job site to be prepared for a variety of situations.

5.2.2.3 Job Site Assessment

This major accomplishment includes the initial process of evaluating the job site with respect to overall safety, access to the test specimen, environmental factors (weather, noise, etc.), and accuracy of the job traveler. The client (or client representative) typically escorts the inspector around the job site. During the walkthrough, APs will complete a Job Safety Analysis/Assessment (JSA), and work with on-site personnel to complete the necessary permitting to begin the job. APs will also confirm the scope of work from the job traveler by getting eyes on the test specimen for the first time. Depending on the inspection, APs would also set up safety boundaries around the inspection site during the Job Site Assessment.

5.2.2.4 Coating and Pipe Assessment

This major accomplishment includes the physical assessment of the test specimen. To accomplish correctly, APs must first conduct a visual inspection of the pipeline or test specimen. APs look over and examine the pipeline to identify any irregularities with the surface or coating of the pipe itself. APs the set up and calibrate their equipment. After set up and calibration is complete, APs use the appropriate standard to conduct the inspection. APs noted that they know they have quality data if they followed the procedures detailed in the job traveler and the inspection specification provided by their organization, used the proper inspection technique, and were detail oriented and inspected the entire specimen. The goal is to produce data that is repeatable.

5.2.2.5 Decision(s) Regarding Data Acceptability

This major accomplishment includes an inspection of the raw data to determine its acceptability. For data to be considered *Acceptable* it should be repeatable and have all faults correctly identified. To accomplish this, APs must interact with the raw data files and correctly interpreted the standards, apply background knowledge of the part and its historical data, and ensure the data assessment aligns with client requirements. If needed, APs will contact a more experienced inspector and ask their opinion about a specific anomaly. On select jobs the NDT program will have two levels of checking the results. One field review and another final review that occurs back at the office.

5.2.2.6 Report

This major accomplishment includes the final compilation of the data and the delivery of the final report to the client. To accomplish correctly, APs stressed the importance of including all relevant administrative information and technical data. APs work with quality assurance personnel from their company to ensure that the information is presented in a way that is understandable and useable for the client. APs consider a good report to contain detailed information about the scan plan, background information surrounding the test specimen, which calibrations were used, flaws that are correctly classified, and the potential causes of those flaws identified. APs also supplement their reports with photographs of the test specimen taken at various angles and at various stages of the inspection process.

5.2.3 Major Accomplishment Difficulty and Importance

APs were asked to provide an *importance* and a *difficulty* rating for each of the major accomplishments they identified during the interviews. For importance, APs were provided the following statements and asked to select one to characterize the major accomplishment output:

Table 3. Major Accomplishment Importance Job Aid.

If the output (major accomplishment) is not produced correctly, it would:	Then, note as:
Constitute a danger or intolerable hazard to health/environment; and/or would result in an intolerable loss to the organization.	4. Most Important
Seriously jeopardize the job accomplishment, but does not constitute an intolerable penalty.	3. Important
Would harm the job accomplishment, but not seriously.	2. Moderate
Would not directly affect the job accomplishment.	1. Low

APs were also asked about the things they have to do and think about when producing each major accomplishment, and then asked to estimate the difficulty of those activities using the following scale:

1. Low difficulty
2. Moderately difficult
3. Difficult

4. Most difficult

APs were provided the following guidance to facilitate their assessment of major accomplishment difficulty:

> The more a given output contains these, the more difficult it is to produce:
> - Large number of tasks
> - Requires difficult decision making
> - Requires application of rules which have exceptions
> - Requires dexterity to produce
> - Must be produced rapidly
> - Takes much experience to do well

The importance and difficulty ratings for each of the summary major accomplishments are presented in Figure 4.

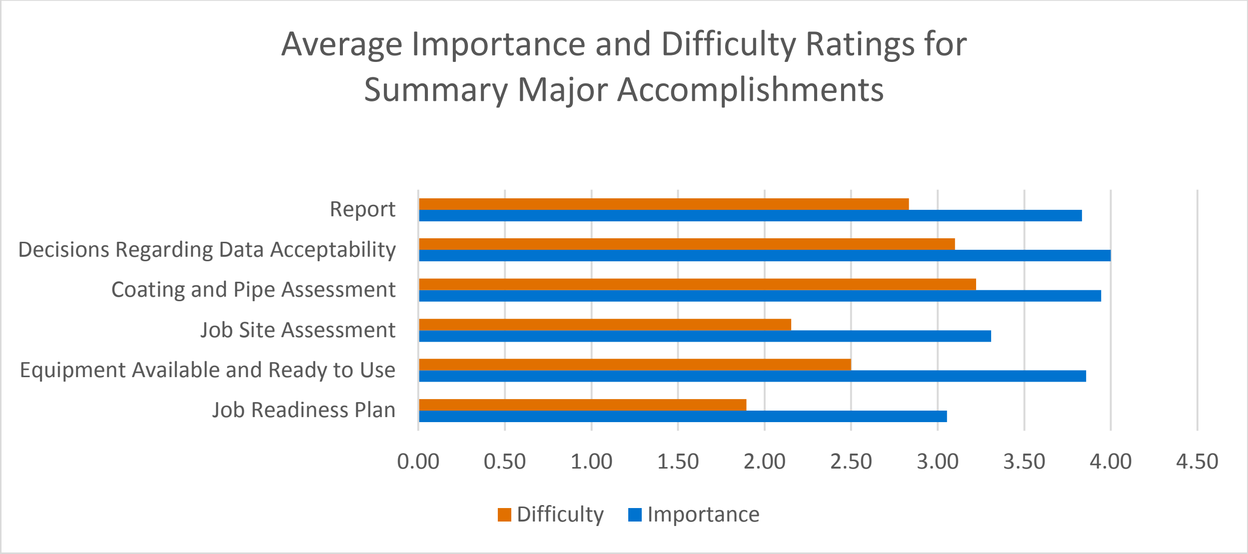

Figure 4. Importance and Difficulty Ratings for Summary Major Accomplishments.

The importance and difficulty rating data suggests that all six major accomplishments are at least “Important” and would seriously jeopardize the overall job accomplishment if not done correctly. Four of the six major accomplishments rated closer to “Most Important” and would constitute an intolerable loss or penalty if not done correctly.

Based upon the difficulty ratings of the six major accomplishments, APs appear to spend the most effort producing (1) the coating and pipe assessment, (2) decisions regarding data acceptability, and (3) the report. While still seen as important to the overall job accomplishment, APs rated the (4) equipment available and ready to use, (5) job site assessment, and (6) job readiness plan major accomplishments as less difficult to successfully produce.

In general, APs placed extra effort in the gathering and processing of inspection data. APs commented that the coating and pipe assessment is difficult due to a number of factors. Conducting the actual assessment in a way that produces quality data requires considerable skill and experience. It takes a large amount of patience and knowledge of the appropriate inspection procedure. Additionally, APs commented that they often have to conduct inspections in extreme environments. Test specimens may be located in areas that make conducting a full inspection difficult. Inspectors may have to crawl into confined spaces or conduct inspections while lying on their backs for extended periods. Extreme weather conditions may also affect the inspection process.

APs also indicated that decisions regarding data acceptability could be difficult to produce correctly. Inspectors receive considerable amounts of classroom training and utilize a number of standards to assist in determining the acceptability of a data set. However, inspectors face a large number of scenarios that could not realistically be covered in training. As a result, analyzing the data and determining whether the data is acceptable requires an amount of skill that is built up through years of experience. APs with less experience described a willingness to contact more experienced inspectors to get their opinion on a given anomaly. Additionally, conversations with the client representative typically occur during this major accomplishment. Those conversations require detailed knowledge about the inspection process, the tested material, and the discovered anomalies to communicate the results to the engineer.

5.2.4 Percentage of Time Spent per Major Accomplishment

APs were asked to estimate the amount of time spent on each accomplishment. This data was used in combination with the importance and difficulty data to determine which major accomplishments require the most resources for the inspector to produce correctly. Additionally, each inspector was asked “why” each major accomplishment took that specific percentage of time. This data assisted in creating the performance shaping factors detailed in section 5.6.

The average percentage of time spent on each major accomplishment, compared to the overall inspection process, as reported by the APs is presented in Figure 5. APs closely aligned on major accomplishments, however not all APs provided the same major accomplishments, as a result not all APs provided a response to each of the major accomplishments as noted in the figure.

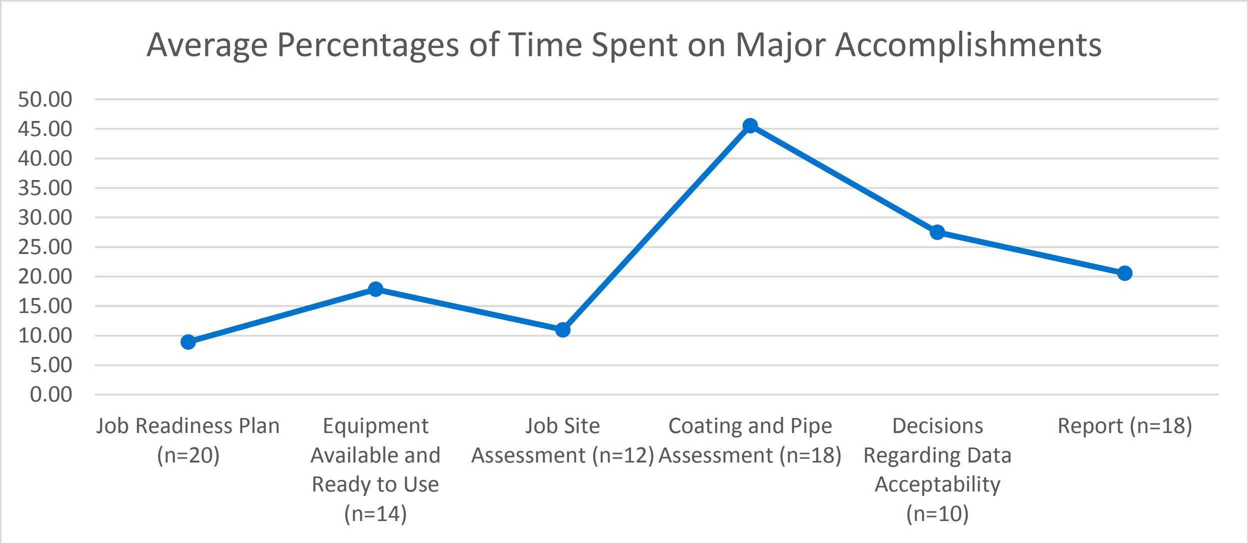

Figure 5. Average Percentage of Time Spent on each Summary Major Accomplishment.

Similar to the importance and difficulty rating data, APs indicated they spend the highest percentage of their effort/time conducting the coating a pipe assessment itself. This is followed by the time spent making decisions regarding data acceptability and subsequently reporting of the inspection results. The data suggest that APs understand and readily align their efforts and time commitment to those accomplishments deemed most important for successful job accomplishment output. Conversely, AP comments indicate that while the first three major accomplishments are important to complete correctly (see Figure 4), the tasks performed to complete these accomplishments are generally well defined and facilitated by formal checklists/job aids or by processes and procedures the AP has developed through experience. As a result, the percentage of time spent is low for these relatively routine tasks.

5.3 Positive Influences on Inspection Performance

APs were asked to detail the positive influences on inspection performance. Positive influence data assisted in identifying both performance shaping factors and potential inspection interventions.

Table 4 presents a compilation of the AP self-reported responses to the question: "*Can you identify some positive influences on your inspection performance?*" In general, these responses fall into two categories:

1. Tangible influences
2. Cultural influences

The first category includes the following influences:

- Good Communication
- Current Equipment Available for the inspection
- Proper Training
- On the Job Training
- Job Variety
- Appropriate Pay
- Modern Facilities
- New Trucks

The second category includes the following influences:

- Team Chemistry
- Positive Feedback
- Management Involvement
- Mentorship from Experienced Inspectors

Responses not grouped into one of the two categories include job-related travel, dig sheets from the job site, being well rested in advance of a job, good weather, and good client relationships.

Table 4. Positive Influences on Performance.

Positive Influences	Number of Responses
Good Communication	10
Current Equipment Available for the Inspection	9
Team Chemistry	9
On the Job Training	8
Proper Training	7
Positive Feedback	6
Management Involvement	6

Positive Influences	Number of Responses
Well Rested	3
Good Client Relationships	3
Job Variety (shop vs. field)	3
Mentorship from Experienced Inspectors	3
Appropriate Pay	2
Balanced Travel Schedule	1
Dig Sheet from the Site	1
Good Weather	1
Limited Travel	1
Modern Facilities	1
New Trucks	1

APs place a high value on effective communication between the client and the AP's management and between management and themselves. APs stated that open and accurate communication helps in establishing client expectations and allows them to do the job efficiently and correctly.

APs also placed a high value on having access to both classroom and "on the job training." APs view having access to all the training they want or need as a sign that management is interested in allowing inspectors to advance their careers.

Inspectors frequently commented on the benefits of positive feedback. APs did not express a need for an official employee recognition program, but did mention that informal recognition, such as compliments on a job well done, makes them want to continue to work when they otherwise would not want to.

5.4 Negative Influences on Inspection Performance

APs were asked to detail the negative influences on inspection performance. Negative influence data assisted in identifying both performance shaping factors and potential inspection interventions.

Table 5 presents a compilation of the AP self-reported responses to the question: "*Can you identify some negative influences on your inspection performance?*" In general, these responses fall into two categories:

1. Operational/Organizational influences
2. Influences which are an inherent part of the examiners position

The first category includes the following influences:

- Lack of Access to Proper Equipment
- Poor Communication
- Lack of Certified Inspectors
- Insufficient Training

- No Perceived Career Progression
- Bad Attitudes
- Lack of Staffing
- Low Pay
- No Job Aids
- Lack of Management Support

The second category includes the following influences:

- Poor Working Conditions
- Time Pressures
- Long Hours
- Lack of Access to the Pipe
- Too much Travel

Table 5. Negative Influences on Performance.

Negative Influences	Number of Responses
Poor Working Conditions	16
Lack of Access to Proper Equipment	14
Poor Communication	14
Time Pressure	12
Long Hours	8
Lack of Certified Inspectors	5
Insufficient Training	4
No perceived career progression	3
Access to Pipe	3
Bad Attitudes	2
Lack of Staffing	2
Low Pay	2
Too Much Travel	2
No Job Aids	1
Lack of Management Support	1

Poor working conditions were the most frequently referenced negative influence on job performance. APs reported that they have to work in a variety of environments that may have extreme temperatures (hot and cold), rain, mud, and snow. These environmental challenges make focusing on the inspection process difficult for the inspectors and generally lowers the morale of the inspection crew. The only current mitigation APs identified to assist with poor working conditions is occasionally having access to a tent to help protect the inspectors against extreme temperatures and rain.

APs reported not having access to the proper equipment and poor communication as the next two of the biggest negative influences on their performance. Inspectors reported they will often need a specific piece of equipment to complete an inspection and it will not be available to them because another inspector is using it (lack of sufficient quantity) or the equipment is not functioning (lack of sufficient maintenance). Additionally, inspectors reported that poor communication regarding the details of a job has caused them to take the wrong piece of equipment out to a job site. As a result, inspectors take as much equipment to a job as possible to accommodate any potential changes. This is cited as a significant contributing factor to the equipment shortages.

APs also reported lack of access to the pipe or test specimen as a major negative influence to the overall performance of their jobs. Many pipelines require large percentages of the inspections to be conducted with the inspector either lying on his/her back or in ergonomically challenging positions. APs commented that conducting inspections like this increases fatigue, making it difficult to collect high quality data.

5.5 Summary of Supplemental Question Responses

A series of supplemental questions were asked of the interviewees at the conclusion of the formal interview process. These questions gave the interviewees the opportunity to speak freely about topics that may not have been addressed, or addressed completely, during the structured accomplishment interview process. This also gave the investigators the opportunity to probe further on motivational, training, and personality performance shaping factors.

The supplemental questions and the interviewee response themes are presented below.

5.5.1 **Question**: With what mindset do you typically approach an inspection?

- Response Theme(s):
  - Have a positive mental attitude and keep an open mind (i.e., consider all possibilities) when coming into a new job.
  - Investigate all potential questionable areas, don't just look for what the job is about.
  - Strive to do the best that you can do with no shortcuts.
  - Have an "in charge" mindset and be accountable for the work and results.

5.5.2 **Question:** [How] has your inspection technique changed over time?

- Response Theme(s):
  - Experience allows the inspector to gain a better trained "eye" for anomalies.
  - Experience helps to build a mental "library" of the types of anomalies an inspector can expect to see.
  - Organizational skills have improved and have become better at documenting results in a more detailed fashion (i.e., clearer writing, more sketches, etc.).
  - Inspection technique becomes more optimal (i.e., more efficient with calibration and prep, better able to anticipate when a given anomaly may occur).

5.5.3 **Question:** Do you use any other checklists, job aids, etc. not previously mentioned to facilitate your performance during an inspection?

- Response Theme(s):
  - Spreadsheets can help inspectors organize and track data more efficiently. Primarily used to track items like the name of the joint, the scan number, start and end times.
  - Daily logbooks to document past experience can be helpful when faced with new jobs.
  - Checklists are made for resource coordinators to assist in getting the correct information prior

to assigning an inspector.

- Inspectors use mobile apps to assist with sizing/classification of indications, standards, inspection techniques, etc.

5.5.4 **Question:** What do you wish you had learned prior to taking this position?

- Response Theme(s):
  - Inspectors wish they were given more in-depth knowledge of why their work is important and the impact their work has on keeping people safe.
  - The importance of building good client relationships.
  - The importance of scanning technique (scan speed, contact, etc.).
  - The importance of maintaining focus and following the checklist during a long job. Junior inspectors have the tendency to cut corners (e.g. not maintaining proper scan speed, not maintaining contact with the specimen, not double checking results for repeatability etc.).

5.5.5 **Question:** What do you believe are the most important characteristics of accomplished performers?

- Response Theme(s):
  - Taking pride in the job and recognizing that the work you do is a reflection on the inspector.
  - Patience and attention to detail to perform the job correctly and to standard.
  - Have humility and do not be afraid to make mistakes and learn from them.
  - Do not be afraid to ask questions.
  - Be motivated and be a self-starter. Take as many classes as possible. Do research outside of work.
  - Have integrity to do the inspection correctly and completely and present the correct outputs.
  - Always be aware of what could happen if you are wrong and a pipe or vessel bursts.
  - Keep a positive attitude.

5.5.6 **Question:** Is there a "wish list" you might give your supervisor or organization for your job?

- Response Theme(s):
  - More hands on training would give a practical application to the information learned in the classroom. Inspectors believe the information would "sink in" more.
  - Make better use of downtime with training workshops.
  - New/Larger trucks to better carry the equipment needed for the inspection.
  - Recognize employees more. APs indicated it was rare to receive recognition for a job well done. They did not state a need for formal recognition program, but an informal "good job" would work well.
  - Updated inspection equipment. New equipment is smaller, lighter, and easier to maneuver.
  - Improved compensation, especially after gaining a new certification.
  - More flexibility with vacations. Inspectors said that they work long hours and weekends and it can be discouraging when vacation days are not approved.
  - Better communication and project planning would improve scheduling and eliminate last minute jobs.
  - Open up advanced training for anyone who wants to attend. Currently, advanced classes are invitation only.
  - Third party certification of inspectors would add credibility to the organization.
  - Create a mentorship program for junior inspectors to learn from experienced APs.
  - Training on a wider variety of technologies.
  - Conduct regular performance reviews.

- Create a forum for inspectors to share lessons learned and best practices.
- Add more staff to ease the travel and workload burden of current inspectors.
- Management to take a proactive approach in inspector career advancement.

5.6 Performance Shaping Factors of Interest

Factors affecting the reliability of NDE include training, experience, procedures, equipment features, working environment, and the organizational and psychological pressures that are prevalent during all inspection operations. J.D. Moré et al. proposed that human performance in NDE depends on complex interactions between the 59 PSF shown in Figure 6 below.[5]

PSF_{1} Architectural features
PSF_{2} Environmental features
PSF_{3} Temperature
PSF_{4} Humidity
PSF_{5} Air quality
PSF_{6} Lighting
PSF_{7} Noise
PSF_{8} Vibration.
PSF_{9} Degree of general cleanliness
PSF_{10} Work hours / work breaks
PSF_{11} Availability and adequacy of equipment
PSF_{12} Shift rotation
PSF_{13} Organizational structure (authority, communication channel(s))
PSF_{14} Actions by supervisors, coworkers
PSF_{15} Rewards, recognitions, benefits
PSF_{16} Motor requirements (speed, strength, precision)
PSF_{17} Control display relationships
PSF_{18} Interpretation requirements
PSF_{19} Decision making requirements
PSF_{20} Frequency and repetitiveness
PSF_{21} Complexity of task
PSF_{22} Long and short term memory
PSF_{23} Calculating Requirements
PSF_{24} Feedback of results
PSF_{25} Team structure and communication
PSF_{26} Man-machine interface factors
PSF_{27} Design of equipment
PSF_{28} Tools
PSF_{29} Procedures Required
PSF_{30} Written or oral communications
PSF_{31} Work methods
PSF_{32} Plant policies
PSF_{33} Previous training/experience
PSF_{34} State of current practice or skill
PSF_{35} Personality and intelligence variables
PSF_{36} Motivation and attitudes
PSF_{37} Emotional state
PSF_{38} Attitudes based on influence of family
PSF_{39} Group Identifications
PSF_{40} Suddenness of psychological stressor
PSF_{41} Duration of stress psychological
PSF_{42} Task speed
PSF_{43} Task load
PSF_{44} Work risk
PSF_{45} Threats (of failure, loss of job)
PSF_{46} Monotonous, degrading or meaningless work
PSF_{47} Long, uneventful vigilance
PSF_{48} Distractions (noise, glare, movement, color)
PSF_{49} Duration of stress physiologic
PSF_{50} Fatigue
PSF_{51} Pain or discomfort
PSF_{52} Hunger or thirst
PSF_{53} Temperature of operator
PSF_{54} Radiation (physiological effect)
PSF_{55} G-force extremes
PSF_{56} Movement constriction
PSF_{57} Oxygen Insufficiency
PSF_{58} Atmospheric pressure extremes
PSF_{59} Lack of physical exercise

Figure 6. J.D. Moré et al. Proposed Performance Shaping Factors.

[5] J.D. Moré, A.S. Guimaraes, G.B. Xexéo and R. Tanscheit (2007). A fuzzy approach to the evaluation of human factors in ultrasonic nondestructive examinations. *Journal of Industrial Engineering International*, Vol.3, No.5, 41-52

Using the list in Figure 6 as a baseline, and accounting for the AP input provided during the IDIs and summarized in the previous sections, an adapted summary list of the potential PSFs identified during Phase 1 of this effort, presented in order of perceived influence, is given below:

PSF1. Organizational
   a. Organizational structure (authority, communication channel(s))
   b. Actions by supervisors, coworkers
   c. Rewards, recognitions, benefits
   d. Team structure and communication
   e. Plant policies
   f. Feedback of results
   g. Threats (of failure, loss of job)

PSF2. Operational
   a. Procedures required
   b. Work methods
   c. Plant policies
   d. Training provided

PSF3. Work Task
   a. Work hours/breaks
   b. Work methods
   c. Task speed
   d. Task load
   e. Task frequency and repetitiveness
   f. Task complexity
   g. Work risk
   h. Monotonous work
   i. High vigilance
   j. Distractions

PSF4. Technology
   a. Availability and adequacy of equipment/tools
   b. Man-machine interface factors

PSF5. Physiological/Cognitive
   a. Long- and short-term memory
   b. Calculating requirements
   c. Interpretation requirements
   d. Stress (onset and duration)
   e. Fatigue
   f. Pain or discomfort

PSF6. Personality
   a. Intelligence
   b. Motivation and attitude
   c. Emotional state
   d. Group identification

PSF7. Environmental
   a. Temperature
   b. Humidity
   c. Air quality
   d. Lighting
   e. Noise
   f. Vibration
   g. Degree of general cleanliness
   h. Movement constriction

This list breaks out seven high-level performance shaping factors with a subset of those factors found in Figure 6 organized as influencing elements. The priority of influence (PSF1 - PSF7) appears generally consistent with that found in the literature, as noted in Section 4.2. However, APs interviewed for this effort tended to cite work task related factors as having a greater influence on performance than individual characteristics. Note also that while poor working conditions was most frequently cited as a negative influence on performance, it is placed last in this list as it is acknowledged that, in the majority of cases, there may be little that can be done to effectively influence those factors for increased/improved inspection performance.

6. Interventions for Consideration in Subsequent Phases

The following proposed interventions were derived from the interviews and the ensuing discussions with the APs. Some of the intervention suggestions come directly (verbatim) from the interviewees while others are compilations of several suggestions offered by the APs.

In some cases, inspectors requested updated equipment to assist in gathering data more efficiently and effectively. In others, APs were requesting a more effective method to communicate throughout the organization. APs reported that they often receive misinformation about a job that adds unnecessary complexity to the inspection process.

Many interviewed inspectors had positive things to say surrounding the training they received, especially the classroom training. However, multiple inspectors commented that “hands-on” training should be included for junior inspectors. Many inspectors believe that including “hands-on” training that is conducted in the field would help provide a practical context to the theoretical concepts taught in the classroom.

This list is not exhaustive and other interventions will be identified for potential subsequent development and evaluation in Phases 2 and 3 of this project.

6.1 Organizational Interventions

Create an employee recognition program

- Management should go out of their way to ensure inspectors know that they are doing a good job.
- Recognition can be formal (i.e. employee of the month) or informal (i.e. “pat on the back”).
- Inform inspectors when a customer is satisfied with a job.

Consider merit-based compensation

- Create a compensation strategy that awards inspectors with more certifications.
- Compensate inspectors competitively across the industry.
- Management should conduct regular performance reviews and communicate opportunities to advance to the next pay level.

Improve Client – Inspector communication

- Make job schedule available to the inspectors as early as possible to allow for better job planning.
- Create a template for management to use when bidding a job to ensure inspectors have all the relevant information.
- Include a senior inspector in the bidding process to assist with establishing scope.
- Management and sales should make it a point to visit inspection sites to have a clear picture of the inspection process.
- Encourage a respectful and open two-way communication flow.

6.2 Operational Interventions

Create a forum for inspectors to share “lessons learned”

- Offer regular in-person roundtables to discuss what works and what does not work for a given inspection scenario.
- Create a shared space (e.g. Box, Google Docs, etc.) that is accessible by all employees to share lessoned learned and best practices.
- Encourage participation from inspectors at all levels.
- Create a “log book” for inspectors to record details of specific jobs.

Better utilize down time between jobs

- Create a training plan that senior inspectors can use to teach junior inspectors
- Inspectors expressed interest in topics surrounding, client management, reporting, inspection techniques, etc.

Expand training

- Open up advanced training for anyone who wants to attend. Currently, advanced classes are invitation only.
- Certify inspectors through a third (independent) party. Third party certifications can add value to the inspector as well as the organization and give the inspector a sense of value.
- Train inspectors in advance of getting a job. Many APs called this the “build it and they will come” approach.
- Create a mentorship program for junior inspectors to learn from experienced APs. Mentorship can supplement the classroom work already conducted by the organization.
- Full time mentors can allow for working relationships to build between junior and senior inspectors and enhance the learning environment for the junior inspector. More hands on training would give a practical application to the information learned in the classroom. Inspectors believe the information would “sink in” more.

6.3 Work Task Interventions

Promote a Work Life Balance

- Allow inspectors to take earned paid time off when they request it. Inspectors said that they work long hours and weekends and it can be discouraging when vacation days are not approved.
- Training inspectors on a wider variety of technologies and techniques. APs believed having more inspectors with diverse skillsets could prevent burnout during busy periods.
- Add more staff to ease the travel and workload burden of current inspectors. Many inspectors reported that they enjoy having the ability to travel, but the long days away from their families can be draining and impact performance.

6.4 Technological Interventions

Equipment Upgrades

- Keep equipment current. New equipment is smaller, lighter, and easier to maneuver in tight spaces. This enables inspectors to get cleaner data more efficiently.
- Keep enough equipment on hand for all of the inspectors to conduct their jobs when they need to. Inspectors report not always having the equipment they need to conduct a job.
- Incorporate technologies with interfaces that present clear data, assist with analyzing data, and assist with data collection and with anomaly identification.
- Improve or develop new preparation equipment to improve access to the pipe and site working conditions with respect to extreme temperatures, rain, mud, and snow.

7. Appendices

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Appendix A: Letter of Introduction

Battelle
The Business of Innovation

February 2016

SUBJECT: Human Centric Approach to Improve Pipeline Non-Destructive Evaluation (NDE) Performance and Reliability

TO WHOM IT MAY CONCERN:

This letter serves as an introduction to the project entitled "Human Centric Approach to Improve Pipeline Non-Destructive Evaluation (NDE) Performance and Reliability." This effort is being managed under the US Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) Pipeline Safety Research and Development Program (Transation Agreement #DTPH5615T00010). Battelle Memorial Institute (Battelle) has been selected as the recipient of this transaction agreement to conduct research to:

(1) Identify and quantify *human factors' influence* on in-the-ditch NDE measurements;
(2) Identify and validate high-impact *human interventions* to improve NDE measurements; and,
(3) Identify and validate high-impact *technology interventions* to improve NDE measurements.

Battelle has selected to implement the Saba™ Peak Performance System (PPS), Human Performance Technology (HPT) Front-end Analysis (FEA) process to identify, analyze, and evaluate inspector task activities to improve overall organizational and operational performance. This method will specifically target the key NDE operational and organizational goal/output – ***Long-term integrity of existing natural gas and petroleum liquids pipelines***.

You have been identified as an "Accomplished Performer" (i.e., a highly experienced inspector) that is willing to be interviewed and observed (as applicable) to identify what accomplishments, tasks, and performance factors are necessary to achieve the goal stated above. Battelle will audio/video record the interview and take notes for subsequent analysis and reporting. Battelle will protect your privacy and the confidentiality of your feedback insofar as is protected by law. No private or personally identifiable information from the interview will be provided to your employer. All information collected will be summarized and reported without attributing specific names to the data. All records will be kept on a secure/encrypted computer and securely archived at the end of the project.

The Battelle Team appreciates your participation in this project. Should you have any questions regarding the interview and observation process, how your information will be used or stored, or any other project-related questions, you may contact David Wourms, Principal Investigator (wourmsd@battelle.org; 614.424.7263), Patrick McCormack, Researcher (mccormackp@battelle.org; 614.424.3004), or Jennifer O'Brian, Research Scientist (obrianjm@battelle.org; 614.424.6411).

/s/
David F. Wourms
Battelle, Principal Investigator

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Appendix B: Supplemental Interview Topics/Questions

- Can you identify some positive influences on your task performance (e.g., compensation, feedback)? How about negative influences (e.g., time pressure, workload)?
- What information is needed prior to being in the field?
- What sort of mindset do you approach a new job?
- Has your inspection technique changed since you started working? If so, how?
- Do you use any checklists, job aids, etc. to facilitate your performance during a pretest?
- What do you wish you had learned prior to taking this position? Said another way: Can you identify some common mistakes made by novice inspectors?
- What do you believe are the most important characteristics of accomplished performers? Said another way: What do you think makes you an accomplished performer?
- Is there a “wish list” you might give the supervisor or organization for your job?

Appendix C: Inspector Identified Traits and Skills

- Must be honest with coworkers if you are having trouble working with someone.
- Must be efficient and not lazy on the job.
- Must be detail oriented.
- Must understand that your work represents you. Use that as a motivator to take pride in your work.
- Make yourself available to help others.
- Go above and beyond to get your job done well.
- Be patient.
- Be prepared for not just your job but unexpected problems that might arise during the actual job.
- Must be humble. Be willing to admit that you made a mistake.
- Don't be afraid to ask questions if you need help.
- Be polite and kind to other people.
- Must be computer literate.
- Must be able to make decisions under pressure.
- While on the job, keep in mind the people you are trying to keep safe with this work.
- Make sure work is being done compared to the standard.
- Work on getting job done efficiently and correctly.
- Must have strong interpersonal skill.
- Do more prep work so you are better prepared for the actual job.
- Have common sense when making decisions.
- Having leadership skills is a benefit.
- Have the desire to learn.
- Be encouraged to keep learning.
- Must strive to meet deadlines.
- Get as much experience as you can.
- Know how to keep your ego in check.
- Understand fundamentals of the job so you know why it is important.
- Must have knowledge about proper inspection techniques.
- Must have the courage to criticize.
- Motivate yourself before a job by thinking about what will go wrong if inspection is incorrect.
- Be driven to learn more about your job through personal research.
- Use training as a stepping stool to improving your work.
- Don't leave a job half done. If you notice something that was missed from the inspection while you are still onsite, go back and finish the job.
- Make sure report that client receives is complete with all information that was collected.
- Network whenever you can.
- Seek advice from mentors and more experienced employees.
- Earn customers trust and respect through doing a good job on the field.
- Have a positive attitude for each job that you get.
- Follow proper procedures when on the job.
- Put personal integrity in high regards so that it allows you to do the job not just for the money but because of the satisfaction of helping people.
- Be goal driven.

- Must have experience and be open minded.
- Must be aware of client's expectations.
- Must have good communication skills for communicating with client and your organization.
- If you are a lead inspector don't just get the job done with an assistant, use the opportunity as a training experience for the assistant.
- Be self-motivated and willing to learn new things even if you are considered experienced.
- Don't dwell on mistakes, learn from them and continue to have faith in your abilities.
- Complete training in areas besides what you regularly do to increase experience and become a well-rounded inspector.
- Must remain informed about the industry by reading latest discoveries and areas of development.

Appendix D: Document Reference List

This appendix contains the bibliographic listing and abstracts or excerpts from the most relevant literature search results as determined by the investigator team.

Ordering Documents

Most of the documents identified in this search can be obtained on-line, through local resources, such as city, university, or company libraries, or through inter-library loan programs sponsored by these libraries. However, some of these documents may be available only through special organizations or commercial document vendors.

Document References

Bertovic, M. (2015). *Human Factor in Non-Destructive Testing (NDT): Risks and Challenges of Mechanised NDT*. Dissertation, 1 September 2015. Berlin: der Technischen Universität Berlin.

The overall aim of the work presented in this dissertation was to explore for the first time the risks associated with mechanized NDT and find ways of mitigating their effects on the inspection performance. Hence, the objectives were to (1) identify and analyze potential risks in mechanized NDT, (2) devise measures against them, (3) critically address the preventive measures with respect to new potential risks, and (4) suggest ways for the implementation of the preventive measures.

To address the first two objectives a risk assessment in form of a Failure Modes and Effects Analysis (FMEA) was conducted (Study 1). This analysis revealed potential for failure during both the acquisition and evaluation of NDT data that could be assigned to human, technology, and organization. Since the existing preventive measures are insufficient to defend the system from identified failures, new preventive measures were suggested. The conclusion of the study was that those preventive measures need to be carefully considered with respect to *new* potential risks, before they can be implemented, thus serving as a starting point for further empirical studies.

To address the final two objectives, two preventive measures, i.e. human redundancy and the use of automated aids in the evaluation of NDT data, were critically assessed with regard to potential downfalls arising from the social interaction between redundant individuals and the belief in the high reliability of automated aids.

The second study was concerned with the potential withdrawal of effort in sequential redundant teams when working collectively as opposed to working alone, when independence between the two redundant individuals is not present. The results revealed that the first redundant inspector, led to believe someone else will conduct the same task afterwards, invested the same amount of effort as when working alone. The redundant checker was not affected by the information about the superior experience of his predecessor and—instead of expected withdrawal of effort—exhibited better performance in the task. Both results were in contradiction to the hypotheses, the explanations for which can be found in the social loafing and social compensation effects and in the methodological limitations.

The third study examined inappropriate use of the aid measured in terms of (a) agreement with the errors of the aid in connection to the frequency of verifying its results and in terms of (b) the overall performance in the task. The results showed that the information about the high reliability of the aid did not affect the perception of that aid's performance and, hence, no differences in the actual use of the aid were to be expected. However, the participants did not use the aid appropriately: They misused it, i.e. agreed with the errors committed by the aid and disused it, i.e. disagreed with the correct information provided by the aid, thereby reducing the overall reliability of the aid in terms of sizing ability. Whereas aid's misuse could be assigned to low propensity to take risks and reduced verification behavior because of a bias towards automation, the disuse was assigned to the possible misunderstanding of the task.

The results of these studies raised the awareness that methods used to increase reliability and safety, such as automation and human redundancy, can backfire if their implementation is not carefully considered with respect to new potential risks arising from the interaction between individuals and complex systems. In an attempt to minimize this risk, suggestions for their implementation in the NDT practice were provided.

Aldrin, J. C., et al., (2006). *Probabilistic Risk Assessment: Impact of Human Factors on Nondestructive Evaluation and sensor Degradation on Structural Health Monitoring* (Preprint) (AFRL-ML-WP-TP-2006-493). Wright-Patterson Air Force Base, OH: Air Force Materiel Command

Managing human factors in nondestructive evaluation is critical to maintain inspection reliability. Reliability of structural health monitoring systems is particularly sensitive to sensor degradation over time. To investigate the impact of these issues, probabilistic models for risk assessment and cost-benefits analysis have been developed. Quantitative studies are presented evaluating the effects of variations in probability of detections associated with human factors, plus in-situ sensor degradation on life cycle measures such as cost and probability of failure.

McCallum, M. & Richard, C. (2003). *Understanding human factors and operational risk in the control room.* (Paper presented at the 2003 API Pipeline Conference, Houston, Texas, April 29-30, 2003.) Seattle, WA: Battelle Seattle Research Centers.

Human factors play a critical role in the safe, reliable, and cost-effective operation of pipelines, as they do in all other safety-critical industry operations. However, in contrast to most other safety-critical industries, human factors are relatively unexplored in pipeline operations. This situation provides the pipeline industry an opportunity to leverage past human factors analyses in related industries and to define cost-effective improvements in controller-system integration.

McGrath, B. (2008). *Programme for the assessment of NDT in industry.* Prepared by Serco Assurance for the Health and Safety Executive 2008. Research Report RR617. Serco Assurance, Thomson House, Burchwood Park, Risley, Warrington, Cheshire WA3 6GA.

The project comprised of an investigation into the human factors aspects of the manual ultrasonic task and an assessment of the organization of NDT and the NDT process (initially referred to as QA Assessment). Following a data gathering exercise which is reported in Appendix 2, experimental work was performed with the twin objectives of investigating the operators' decision making processes and the correlation of ultrasonic performance with the operators' scores on ability tests and a number of personality scales.

The assessment of the organization of NDT was conducted through eliciting information from operators and NDT vendor companies and reviews of previous reliability studies and other initiatives to improve NDT reliability.

The conclusions derived from the work are as follows:

1. The PANI 3 data revealed that operator performance on the test pieces was related to their scores on one of the ability measures and two of the personality scales measured in the project. Better operators' performance was associated with higher scores on the test of Mechanical Comprehension and lower scores on the personality scales measuring Original Thinking and Cautiousness. The relationship between these ability and personality measures, and ultrasonic inspection performance, was stronger than that found between ultrasonic inspection performance and the number of years of experience that an operator had in undertaking manual ultrasonic inspections.
2. The PANI 3 test pieces were challenging but the ultrasonic results obtained from the 40 operators who participated were similar to those observed in previous PANI and other round robin exercises:
    - All defects in the test pieces used in PANI 3 were detectable using the applied procedure.
    - All defects were detected by at least 40% of the operators who inspected for them.
    - Average detection frequencies for each test piece varied from 58% to 67%.
    - The average circumferential positioning error over all defects for each operator ranged from 0mm to 28mm.
    - The average length error was +1.3mm and the average standard deviation for operators reporting two of more defects was 12mm. The external circumference of all three test pieces was 688mm.
    - The number of false calls overall was 16 with 2 operators reporting 2 and no operators reporting a higher number.
3. In a theoretical examination, the operators in PANI 3 demonstrated a good understanding of the basic principles of ultrasonic inspection as used every time an inspection is done. Their comprehension and knowledge of important but less frequently used features of ultrasonic inspection was less good.
4. De-briefing the operators following their inspection of the test pieces revealed a number of important conclusions based on discriminating between closely located defect and geometric echoes:
    - The operators were easily able to describe why they had determined that certain signals were from geometrical features of the test piece rather than defects.
    - The operators were less able to explain why they had reported indications as arising from defects. Knowledge of how ultrasonics interacts with defects was not used to assist the decision-making process in many cases. Their reasoning processes were not well defined and they frequently came to a decision before all relevant information had been acquired.
5. Observation of the trials and analysis of video recordings highlighted that for the best performance, operators should be able to:
    - Understand the implications of the geometry for the inspection. This requires that operators be given training in the understanding of ultrasound / reflector interaction.
    - Apply the procedure in a systematic way. This requires that the procedure needs to be written in a way which specifies the decision making steps. It is worth noting that current certification arrangements are not dependent on operators being able to correctly characterize defects.
6. The output from the operator's workshop showed that an operator's ideal inspection process is one where:
    - The preparation for the inspection in terms of access, safety and plant surface condition is performed by the client or NDT organization, as appropriate, in advance.
    - Suitable documentation including risk assessments, inspection procedures, standards, acceptance standards, access and cleaning requirements, drawings and photos and equipment inventory are provided.
    - Adequate time is allowed for the inspection. This allows the operator to concentrate simply on carrying out the inspection. The NDT organization should ensure that the operator is aware of the extent of his responsibilities.

7. Feedback from contributors to the project indicated that an organizational culture can predominate in which inspection is regarded simply as a statutory or contractual necessity rather than as a valuable process which can help avoid plant failures. This can lead to problems with lack of information, inadequate preparation, poor access and working conditions, unreasonable time pressures and poor remuneration. Also, operators are aware of, and influenced by, the pressure to report a clean bill of health considering the costs and time delays to the operation of plant if a defect is found.

These conclusions lead to the following recommendations from the project:

1. NDT organizations and operators should consider the use of ability and personality tests for:
   - Selecting new trainee ultrasonic operators.
   - Tailoring training courses to meet individual's specific needs for development.
   - Developing procedures at a suitable level of detail to support operators when undertaking assessments.
   - Identifying skills that should be developed as part of ultrasonic operator initial and refresher training.
2. Where relevant to an operator's role, his/her training should be expanded to include:
   - A better understanding of how ultrasound interacts with defects and how to use this knowledge.
   - A knowledge of how observed ultrasonic signals arise from different potential sources of reflection and how to make a characterization decision based on this information.
   - A grounding in the preparation requirements regarding administration, documentation, equipment and site support needed as a basis for a successful inspection. These requirements must be met prior to going to site to carry out the work.
   - A clear awareness of the roles and responsibilities in the inspection process.
3. Inspection procedures should be written in a way which promotes their systematic application.
4. Apart from carrying out the inspection itself, the role of operators in an inspection should be limited to verifying the adequacy of the arrangements for safety, access and plant condition. The preparation for the inspection and the provision of an adequate and appropriate inspection procedure is the responsibility of the client and/or NDT organization as appropriate.
5. All organizations should promote a culture in which NDT is valued as a key input to the safe and cost-effective operation of plant. Organizations must provide or facilitate the necessary preparation of and on-site facilities for inspection and in particular they must allow adequate time for the inspection to be completed safely, accurately and reliably.

Kumar, S. & Mahto, D. (2013). Recent trends in industrial and other engineering applications of non destructive testing: A review. *International Journal of Scientific & Engineering Research*, *Volume 4*, *Issue 9*, pp. 183-195.

This paper presents the reviews of different works in the area of NDT and tries to find out latest developments and trends available in industries and other fields in order to minimize the total equipment cost, minimize damages and maximize the safety of machines, structures and materials.

Todorov, E. & Spencer, R. (2013). Computer modeling solves practical problems in NDE. *Advanced Materials & Processes (October 2013)*, *Vol 171*, *No 10*, pp. 18-21.

Modeling and simulation offer an economical alternative to costly and time consuming trial-and-error optimization practices often used in nondestructive examination (NDE) and inspection.

If modeling tools are used in the NDE development and evaluation process, the potential benefits are numerous. Chief among these are time and cost savings. Modeling can significantly reduce the time required to optimize procedures used to inspect structures with complex geometries, especially where NDE technique performance is unknown. Significant cost savings may result from reducing the number of experimental specimens and mock-ups needed for technique and procedure validation, completely eliminating these in certain cases. Increased inspection reliability and repeatability, fast interpretation of NDE field data, and fewer repairs are additional benefits. Finally, the ability to measure electromagnetic properties via modeling may enable new possibilities for materials characterization.

Enkvist, J., Edland, A., & Svenson, O. (2000). *Operator performance in non-destructive testing: A study of operator performance in a performance test* (SKI Report 00:26). Swedish Nuclear Power Inspectorate (SKI), Stockholm, Sweden.

In the process industries there is a need of inspecting the integrity of critical components without disrupting the process. Such in-service inspections are typically performed with non-destructive testing (NDT). In NDT the task of the operator is to (based on diagnostic information) decide if the component can remain in service or not. The present study looks at the performance in NDT. The aim is to improve performance, in the long run, by exploring the operators' decision strategies and other underlying factors and to this way find out what makes some operators more successful than others. Sixteen operators performed manual ultrasonic inspections of four test pieces with the aim to detect (implanted) cracks. In addition to these performance demonstration tests (PDT), the operators performed independent ability tests and filled out questionnaires. The results show that operators who trust their gut feeling more than the procedure (when the two come to different results) and that at the same time have a positive attitude towards the procedure have a higher PDT performance. These results indicate the need for operators to be motivated and confident when performing NDT. It was also found that the operators who performed better rated more decision criteria higher in the detection phase than the operators who performed worse. For characterizing it was the other way around. Also, the operators who performed better used more time, both detecting and characterizing, than the operators who performed worse.

***Swedish Human Factors Study of NDE (TP-114671)*: EPRI NDE Center, Charlotte, NC: 1999.**

EPRI has been studying the relationship between human factors and NDE for several years. As a result of those studies EPRI has developed a software program that predicts the success of NDE personnel in successfully passing a performance demonstration.

Previous studies have shown that it is effective. It does this by dynamically measuring the combination of five aptitudes critical to successful NDE task related performance. These aptitudes are general cognitive ability, abstract reasoning, spatial visualization, pattern recognition, and stress tolerance…. Validation studies showed that the test was highly reliable, correlated with other measures of these key aptitudes, and was predictive of the job performance of ultrasonic nondestructive testing operators. These results indicated that the DIAT [Dynamic Inspection Aptitude Test] can be used with confidence for the early identification of individuals who will benefit most from training and experience on ultrasonic nondestructive testing tasks, and who will be most likely to meet operator qualification standards.

Spanner, J. C. *Human factors impact on NDE reliability*. Pacific Northwest Laboratory, Richland WA. Report supported by US NRC under Contract DC-AC06-76RL0 1830, NRC FIN B2883 and B2983.

This paper describes a feasibility study that was conducted as Phase I of this overall program. The objectives of this study were as follows:

- Identify and characterize the human factors aspects of the ultrasonic testing/inservice inspection (UT/ISI) process,
- Develop a model for the UT/ISI man-machine system,
- Examine methods for measuring and analyzing NDT performance, and
- Acquire and evaluate human factors data during a mini-round robin (MRR) test of UT effectiveness in detecting intergranular stress corrosion cracking (IGSCC) in piping specimens
- Human factors aspects of the ultrasonic testing process

Factors affecting the reliability of NDT include training, experience, procedures, equipment features, working environment, and the psychological pressures that are prevalent during all inspection operations. While the impact of human factors on NDT reliability has now been recognized, the variables influencing the performance of the NDT process have not yet be systematically studied.

Based on our work to date, the training variables appear to exert the greatest influence on technician performance (positive, negative, or both); hence, the training variables merit primary consideration. Research finding strongly suggest that the type of training most likely to improve performance is “hands-on” training using actual component specimens (prompt cueing and feedback should also be provided to the student). Significantly, there are no requirements for periodic training in the NDT field, and very little occurs except when upgrading from Level I to Level II. A parametric pilot study is needed to assess the value of periodic (e.g., annual) training (both hands-on and classroom).

The limited research available on procedural variables shows that better procedures could improve NDT performance, and this aspect definitely warrants more study. Time-on-task and the length of the work day also appear to influence performance. It is important to determine whether, and to what extent, a technician’s performance changes during the course of a shift.

Many of the task variables can also be adjusted to improve NDT system performance. Some equipment appears easier to use because of differences in the amount of signal processing that is done and because of a sharper display image. The layout and labeling of controls and displays should be evaluated, as well as signal processing and screen image clarity effects.

Environmental variables can also impact human performance. Environmental variables include heat, humidity, lighting, protective clothing, cramped and awkward working conditions, fatigue, and radiation exposure. Since adverse environmental conditions have a negative impact on performance, systematic study of the environmental variables to measure the magnitudes of their effect on performance is warranted.

Rummel, W.D. *Human factors considerations in the assessment of nondestructive evaluation (NDE) reliability*. Martin Marietta Aerospace, Denver Aerospace.

The overall performance level for an NDE operation is dependent on the NDE material, equipment, processes (methodology) and human skills applied to the operation. It is important to understand and consider human factors elements and contributions to NDE applications in the improvement of applications, in the design and validation new applications, in automating portions of task performance, and in the development of modeling tools for the prediction of task performance for existing and new applications.

Although human factors variables have been cited in various NDE capabilities studies, the human factors contribution has not often been separated and rigorously addressed as a separate issue (due, in part, to the difficulties in isolating the human contribution from other NDE operations variables)…. This paper explores consideration of some classical methods for potential application to the characterization of human factors in NDE performance.

The most frequent cause for unreliable NDE performance that has been observed by the author is that of improper NDE engineering. In many cases, the NDE method selected is incorrect or was not qualified and controlled to the level necessary to obtain the required discrimination. In other cases, the NDE equipment, materials and processes are not controlled and do not provide discrimination to the level qualified. In short, human factors in NDE involves NDE engineers, materials and process control engineers, calibration and maintenance personnel, training personnel, supervision – and the performing operator. We have no right to expect reliable detection and discrimination by the human operator (or by an automated unit), when an NDE process has been altered up-stream of a detection opportunity. NDE reliability involves the entire NDE team and that team may be much larger than you think. The science and technology being developed and reported [in this symposium] must be incorporated as tools by the NDE team in the form of improved requirements specifications and in improved understanding of the capabilities and limitations of NDE for reliable detection and discrimination.

Moré, J. D., Guimarães, A. S., Xexéo, G. B., & Tanscheit (2007). A fuzzy approach to the evaluation of human factors in ultrasonic nondestructive examinations*. In Journal of Industrial Engineering International*, *July 2007*, *Vol. 3*, *No. 5*, 41-52.

Human factors are among the main elements affecting the reliability of nondestructive examination (NDE). In a man-machine system, human reliability is affected by many factors (performance shaping factors) whose influence on reliability cannot be easily expressed quantitatively. This paper identifies and ranks 59 performance shaping factors by using a fuzzy reasoning method and proposes a procedure to measure them. This will determine the Quality Standard (QS) for a NDE system to that human reliability in ultrasonic nondestructive examination can be qualitatively evaluated.

Bertovic, M., Fahlbruch, B., Müller, C., et al., (2012). *Human factors approach to the acquisition and evaluation of NDT data*. 18th World Conference on Nondestructive Testing, 16-20 April 2012, Durban, South Africa.

This paper gives an introduction to the field of human factors with the focus on their influence on the reliability of NDT in the nuclear energy production (in-service inspections) and final storage of highly radioactive nuclear waste. A set of methodological tools has been developed in the scope of three projects, namely: 1) a theoretical model describing potential human factors influencing manual ultrasonic inspection performance during in-service inspections in nuclear power plants; 2) a method for identifying potential human errors during acquisition and evaluation of data gathered with mechanized ultrasonic, radiographic and eddy-current systems, as well as visual testing with a remote camera (Failure Modes and Effects Analysis, FMEA); and 3) use of eye tracking methodology to optimize existing procedures and practices. The experimental results have shown that time pressure, mental workload and experience influence the quality of the inspection performance. Noticeable were influences from the organization of the working schedule, communication, procedures, supervision and demonstration task. Implementing human redundancy in critical tasks, such as defect identification, as well as using an automated aid (software) to help operators in decision making about the existence and size of defects, could lead to other kinds of problems, namely social loafing (excerpting less effort when working on tasks collectively as compared to working alone) and automation bias (uncritical reliance on the proper function of an automated system without recognizing its limitations and the possibilities of automation failure) that might affect the reliability of NDT in an undesired manner.

The motivation for addressing the human factors in the reliability of NDT first came from a number of inspections, where significant variations in the individual performance were observed, but could not be overcome by physical or engineering methods…. In order for an NDT inspection to be reliable the whole system, as well as its parts, needs to be reliable (equipment, procedure and personnel). The largest source of performance variation can be found in an operator. After all, it is the operators who interpret the signals provided by the equipment.

Szwarcman, D. M., Domech, J., Tanscheit, R., et al. (2009). *A fuzzy system for the assessment of human reliability*. IFSA-EUSFLAT 2009, pp. 102-1107

Fuzzy system decision aid development.

ISO 9712 (2012). *Non-destructive testing – Qualification and certification of NDT personnel* (ISO 9712:2012(E))

This International Standard specifies requirements for principles for the qualification and certification of personnel who perform industrial non-destructive testing (NDT).

Wall, M., Burch, S., & Lilley, J. (2009). *Human factors in POD modelling and use of trial data*. 4th European-American Workshop on Reliability of NDE –Th.5A.4

Methods are evolving to understand and take account of human and application factors in estimating POD.

These involve the use of human reliability data (PISC III, PANI), simulation models and expert judgment.

It is not currently possible to model human reliability. Therefore, it is necessary to use empirical data or data from simulations or models.

This understanding is important to improve the reliability of inspection, since POD is often adversely affected by field issues.

Improving NDT in the context of risk assessment requires a particular approach:

- Objectives of inspection – What do we need to find?
- Scope – Where do we need to look, and how?
- Sensitivity – What techniques?
- Reliability – What level of control, automation and verification is required?

By understanding the factors affecting reliability, particularly human and environmental factors, it is possible to improve the NDT procedures and methods used and the reliability.

From a human factor perspective, it is useful to differentiate between NDT techniques involving hand-to-eye coordination, such as manual UT, and methods relying on image interpretation such as radiography and automated ultrasonics. To simultaneously move a probe on a surface, whilst ensuring coupling, and observing data in real time on a screen is intrinsically a more difficult process than simply interpreting a data set.

Automated NDT methods are generally found in POD trials to be more reliable than manual methods. There is still scope for human error, for example in set-up, sensitivity setting, initial calibration of equipment, coupling conditions and interpretation of data.

Müller, C., Bertovic, M., Kanzler, D., et.al., (2014). *Assessment of the reliability of NDE: A novel insight on influencing factors on POD and human factors in an organizational context*. 11th European Conference on Non-Destructive Testing (ECNDT 2014), October 6-10, 2014 Prague, Czech Republic.

The paper will give an overview of new methodologies for evaluating the reliability of NDE systems accurately, reliably and efficiently, in accordance with the specific requirements of industrial application and taking into account the very different nature of influencing factors. Using the Modular Reliability Model the three different main influencing elements, i.e. intrinsic capability (IC), application parameters (AP) and the human factors (HF) are, in the first instance, investigated separately. The intrinsic capability stands for the pure physical-technological process of the signal detection caused by the waves or the rays from a material defect in the presence of noise (caused by the material and the devices). This intrinsic capability is the upper bound of the possible reliability. Already when measuring this intrinsic capability for thick walled components the original one-parameter POD should be extended to a multi-parameter POD, where, in addition to the defect size, a number of additional physical parameters, such as the grain size distribution (or attenuation), defect depth, and angle or surface roughness, must be considered. For real life cycle assessments, it is necessary to evaluate the signal response from real defects. The industrial application factors, e.g. coupling conditions, limited accessibility, heat and environmental vibrations, diminish reliability. The amount of reduction can be determined quantitatively, if the underlying conditions are controlled. In case they are not controlled it is necessary to count for a fluctuation in the reliability in the field anyway. The third group of important influencing factors are the human factors, which do not only cover the individual performance capability of the inspectors but also the design of the working place, the procedure, the teamwork quality, interaction with systems, the organization, and finally, the relationship between the companies involved in the inspection process and to which extend the responsible parties are aware of it. When comparing and “ideal inspection” with a “real inspection” it is worthwhile to look how the existing practices, rules and standards support reliable testing and where the “delta” is.

A substantial number of factors that could affect the reliability of NDT methods have been identified and analyzed. Proposals for the compensation of varying human performance, according to the experts, include the implementation of human redundancy (known also as the 4-eye principle) or the semi-automation of the defect detection process. However, implementing human redundancy in critical tasks, such as defect identification, as well as using an automated aid (software) to help operators in decision making about the existence and size of defects, could lead to other kinds of problems, namely social loafing (excerpting less effort when working on tasks collectively as compared to working alone) and automation bias (uncritical reliance on the proper function of an automated system without recognizing its limitations and the possibilities of automation failure (a form of automation misuse) that might affect the reliability of NDT in an undesired manner, when not taken into account adequately.

Bertovic, M., Gaal, M., Müller, C., & Fahlbruch, B. (2009). *Investigating human factors in manual ultrasonic testing: Testing the human factor model*. 4th European-American Workshop on Reliability of NDE – Th.4.A.3/Th.4.A.4

The human factors approach relies on understanding the properties of human capability and limitations under various conditions and the application of that knowledge in designing and developing safe systems. Following the principles of MTO (Man Technology Organization) approach, emphasis should be given to the way people interact with technical as well as organizational systems

A model describing human factor influences in relation to the performance shaping factors and their effect on the manual ultrasonic inspection performance had been built and a part of it empirically tested. The experimental task involved repeated inspection of 18 flaws according to the standard procedure under no, middle and high time pressure. Stress coping strategies, mental workload of the task, stress reaction and organizational factors have been measured. The results have shown that time pressure, mental workload and experience influence the quality of the inspection performance. Organizational factors and their influence on the inspection results were rated as important by the operators.

Harris, D. H. & McCloskey, B. P. (1990). *Cognitive correlates of ultrasonic inspection performance (NP-6675; Research Project 2705-9)*. Palo Alto, CA: Electric Power Research Institute.

Ultrasonic inspection used to detect or characterize intergranular stress corrosion cracking (IGSCC) in power plan components such as pipes and nozzles can be a demanding cognitive process. This report provides a basis for improving inspection performance through the application of more-effective cognitive strategies.

During the past decade, EPRI conducted several studies to assess the capability of ultrasonic inspection for detecting and characterizing defects in the components of nuclear power plants. These studies showed that inspector performance has improved with the development of new ultrasonic techniques and training programs. Working toward the goal of further performance gains, EPRI initiated an exploratory study of human performance in nondestructive inspections and functional tests in 1988 (EPRI report NP6052). The study recommended a detailed examination and analysis of the cognitive processes involved in the performance of ultrasonic inspection.

Objectives

To determine in detail what inspectors are actually doing and thinking while performing ultrasonic inspections and to determine the correlation between cognitive processes and effective or ineffective performance.

Approach

In separate studies, researchers obtained and analyzed tape-recorded commentary from 139 inspections conducted to detect IGSCC in pipe welds and from 96 inspections conducted to estimate the extent of IGSCC in pipe welds. A total of 37 inspectors participated in the two studies. After transcribing and analyzing commentary from each inspection to identify important cognitive elements, researchers correlated the elements – individually and collectively – with performance measure obtained from the same inspections.

Results

The results provided conclusive evidence that cognitive processes are important to the success of ultrasonic inspections. Researchers identified nine cognitive elements and seven signal characteristics. The following cognitive elements were most strongly associated with successful inspections:

- Development and testing of explicit hypotheses as an integral part of the inspection process
- Avoidance of reaching a conclusion early in the inspection process, before all available information has been obtained and considered
- Application of knowledge in the form of if-then logic
- Avoidance of the arbitrary elimination of information from consideration during the process of reaching a conclusion

The results also provided conclusive evidence that a successful inspection required the use of both a combination of cognitive elements and the consideration of a combination of signal characteristics.

Harris, D.H. (1992). *Effect of decision making on ultrasonic examination performance (TR-100412; Research Project 3112-1)*. Palo Alto, CA: Electric Power Research Institute.

On the basis of previous research, an aid in the form of a checklist was developed to overcome personnel limitations in decision making during ultrasonic examinations. This study showed that examinations made with the checklist were superior to those made without it.

Background

A previous study (EPRI report NP-6675) identified elements considered important to the human information processing and decision making required in an ultrasonic examination. The elements were found to correlate with examination success – accurate detection of defects and avoidance of false reports. A panel of experts in ultrasonic inspection reviewed these findings and recommended ways in which these elements could be used to improve examination performance.

Objectives

To transform the results of previous research findings and expert recommendations into a practical decision-making strategy for ultrasonic examinations; to evaluate the impact of using this strategy on examination performance.

Approach

The results of previous research on decision making in ultrasonic examination were presented to a panel of experts in ultrasonic inspection. The panel made specific recommendations on how the results might be used to improve performance. The project team devised a checklist that promoted the use of the decision-making strategy recommended by the panel. This checklist provided a means of noting signal characteristics as they were observed during the examination and of presenting them simultaneously for decision making. The team then compared the performance of 257 ultrasonic examinations made using this aid with 250 examinations made without it. Examiners who used the aid received a one-hour training session as part of a 64-hour training course on the ultrasonic detection of intergranular stress corrosion cracking (IGSCC).

Results

The success rate for aided examinations was 25% higher than that for unaided examination.

Examinations made with the aid had a 47.1% success rate compared with a 37.6% success rate for baseline examinations conducted without the aid.

Harris, D.H. (1988). *Human performance in nondestructive inspections and functional tests (NP-6052; Research Project 2705-9)*. Palo Alto, CA: Electric Power Research Institute.

Reliable human performance is vital to inspections and tests conducted to assure the physical integrity of nuclear power plants. Recommended research should help improve human performance in eddy-current and ultrasonic inspections, in-service tests, and surveillance functional tests.

Background

The safety and effectiveness of nuclear power plants depend on many different types of inspections and tests. Prompt identification and correction of risks to plant integrity ensures plant safety and cost-effective operation. However, inadequate human performance could lead to missed defects and inaccurate reports ("false calls"), with potentially serious safety and cost consequences. The significance of human inspection and testing performance will continue to increase as plants age and their life is extended.

Objectives

To identify and describe ways to improve human performance during non-destructive inspections and functional tests.

Approach

An industry panel identified power plant inspections and tests for which human performance is critical: eddy-current inspection of steam generator tubes, ultrasonic testing (UT) inspection of pipe welds, in-service inspection of pumps and valves, and functional testing of shock suppressors. These tasks differed in type of activity, level of complexity, level of automation, and form of data generated. An investigator performed an analysis using information from industry and plant procedural reference documents, training materials, research reports and related documents, interviews with experts and job incumbents, and firsthand observation of task performance. On the basis of the analysis, he recommended approaches to improving human performance of these tasks.

Results

The study produced 11 recommendations for improving human performance in nondestructive inspections and functional tests. Two recommendations – preparing guidance documents for applying existing human factors data and principles – would not require further research. The other nine recommendations identified needed research. The report presents each recommendation in terms of the human performance issue involved, the proposed approach, and the expected benefits. The recommendations focus on:

- Preparation of written instruction
- Operator-control interface design
- UT performance data analysis, sustained UT inspection effectiveness, and enhanced automated UT scanning
- Eddy-current interpretation, display, and automatic screening and analysis
- Manual and UT detection of intergranular stress corrosion cracking in pipe welds

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Baziuk, P. A., McLeod, J.N., Calvo, R., & Rivera, S.S. (2015). Principal issues in human reliability analysis. In *Proceedings of the World Congress on Engineering, Vol II WCE 2015*, July 1-3, 2015, London, U.K.

The purpose of this article is to review the criticisms made to human reliability models. As a result of this review the observations and critiques are grouped into three main issues: (1) model's theoretical basis (including taxonomy and concept's specificity), (2) definition and use of performance shaping factors (PSF) and (3) HRA quantification. The cross-cutting aspects in the three issues suggest the use of a human abilities taxonomy based on cognitive theories and a mathematical tool that allows the quantification of vague parameters.

Performance shaping factors

Three problems are associated with performance shaping factors: (1) many methods use PSF but there is no standard set among all methods; (2) PSF aren't specifically defined which creates consistency difficulties between methods; and (3) there are few rules that govern the creation, definition and use of PSF.

Kim, J.W. & Jung, W. (2003). A taxonomy of performance influencing factors for human reliability analysis of emergency tasks. *Journal of Loss Prevention in the Process Industries 16* (2003), 479-495.

This paper introduces the process for, and the result of, the selection of performance influencing factors (PIFs) for the use in human reliability analysis (HRA) of emergency tasks in nuclear power plants. The approach taken in this study largely consist of three steps. First, a full-set PIF system is constructed from the collection and review of existing PIF taxonomies. Secondly, PIF candidates are selected from the full-set PIF system, considering the major characteristics of emergency situations and the basic criteria of PIF for use in HRA. Finally, a set of PIFs is established by structuring representative PIFs and their detailed subitems from the candidates. As a result, a set of PIFs comprised of the 11 representative PIFs and 39 subitems was developed.

Bertovic, M. & Ronneteg, U. (2014). *User-centred approach to the development of NDT instructions (SKB R-14-06)*. Stockholm: Swedish Nuclear fuel and Waste Management Co.

One of the aims of considering human factors in the reliability of non-destructive testing (NDT) for the purposes of the disposal of spent nuclear fuel – is to identify factors that can lead to errors in the completion of the NDT task and to determine how to prevent these errors. The current study is the first to examine mechanized NDT from the human factors perspective. A number of risks were identified and further analyzed. Among a number of influencing factors, the NDT inspection procedure was identified as a potential error source and, therefore, was examined in this study.

Experience and research have shown that NDT procedures and instructions, despite being written according to the requirements and by certified personnel, are not always used as foreseen and may need to be optimized.

Bertovic, M., Muller, C., Gahlbruch, B., et. al. (2013). *Holistic risk assessment and risk prevention approach to the mechanized NDT and the inspection procedure*. 5th European-American Workshop

on Reliability of NDE – Lecture 20.

The difficulty to deal with human factors in non-destructive testing (NDT) steps from their diversity and complexity – no single human or organizational factor is responsible for the entire fluctuations in the NDT performance. The typical approach to decrease the variability in the inspection results had been found in replacing manual NDT with mechanized methods. However, even though some human errors can be avoided by automating the process, there are new risks that can arise from its application and need to be further investigated. To address this problem, a combination of theoretical and practical approaches should be applied, where the source of error is not seen only in the inspector, but also in his interaction with social and technical systems, as well as the organization.

In this paper, the attention will be given to, in the opinion of the authors, two major misconceptions about human factors in NDT. First, the origin of human error will be addressed, supported by the knowledge from the field of human factors. Second, potential problems related to mechanized testing will be raised and discussed. Finally, the quality of the current NDT procedures will be addressed by presenting an ongoing study on the usability of the NDT instruction.

We will argue that a) the source of failure lies not only in the inspector, but has to be looked for, as well, in the team, technology, organization and the extra-organizational environment and that b) changing inspector's task from doing into supervising the automation can lead to new sources of errors, which need to be further considered.

Mueller, C., Bertovic, M., Pavlovic, M., et. al. (2012). *Holistically evaluating the reliability of NDE systems – Paradigm shift*. 18th World Converence on Nondestructive Testing, 16-20 April 2012, Durban, South Africa.

New methodologies for evaluating the reliability of NDE systems are discussed in accordance with the specific requirements of industrial application.

Among the influencing parameters, the human factor is of high importance. A systematic psychological approach helps to find out where the bottlenecks are and shows possibilities for improvement.

Conclusions from the project:

- It was confirmed time pressure has an effect on the quality of UT inspection
- The organizational context determines the way inspections are performed and therefore highly influences on the inspection quality.

For an improvement of the human performance attention needs to be drawn on:

- Demonstration task for training and confirmation
- Organization – good preparation
- Written procedures and protocols
- Supervision

Aju kumar, V.N., Gandhi, M.S., & Gandhi, O.P. (2015). Identification and assessment of factors influencing human reliability in maintenance using fuzzy cognitive maps. *Qual. Reliab. Engng. Int. 2015, 31,* 169-181.

Human element forms an inevitable part of maintenance activity and gets affected by a variety of interacting factors, ranging from environmental, organizational, job factors, and so on to personal characteristics, which bring in inherent variability in its reliability. Assessment of impact of these factors is, therefore, critical for human reliability estimation in maintenance. In every probabilistic risk, safety or maintenance analysis, human reliability does act as an effective aspect to assess implications of various aspects of human performance. But the main constraint with various human reliability analysis methods is in judging the important human performance influencing factors. Because of high degree of uncertainty and variability that characterizes the plant maintenance environment, it is proposed to use the soft computing technique of fuzzy cognitive maps in exploring the importance of performance shaping factors in maintenance scenario. For this purpose, the maintenance environment is modeled in terms of factors affecting human reliability using cognitive maps. The causal relationships among these factors are explored and simulations performed to quantify its effect on the human reliability. The applicability of the methodology is demonstrated through an example.