

First insights into the human-related risks of tunnel inspection

Marija BERTOVIĆ^{1*}, Joseph GIVEN¹, Johannes LEHLEITNER¹

¹ Bundesanstalt für Materialforschung und -prüfung (BAM); Berlin, Germany

*Corresponding author, e-mail address: marija.bertovic@bam.de

Extended Abstract

Abstract

Whereas human factors (HF) in the non-destructive testing (NDT) of metallic components are a poorly investigated topic (in comparison to other industrial fields such as aviation), HF in the inspection of concrete components are even less known. Studies have shown that there is always some variability between individuals in their inspection results and that HF affect the reliability of NDT inspections. The aim of the ongoing WIPANO project is to draft a standard for a holistic reliability assessment, with concrete inspection as one case study. This includes also the HF. A human-oriented Failure Modes and Effects Analysis (FMEA) was carried out to do the following: a) identify *possible* human-related risks in tunnel inspection processes using a laser scan method (including data collection, evaluation, and assessment of tunnel damage) and b) evaluate these human-related risks as regards their possible causes, consequences and probability of occurrence – in addition with respect to existing and possible preventive measures. The results show that the causes for possible failures can lie within people, the physical environment, technology, organisation, and extra-organisational environment. Whereas current preventive measures rely mostly on the individual and quality management practices, there is potential for even larger improvement at the organisational and extra-organisational level. The FMEA results were also used to develop a quantification method to further understand the HF in tunnel inspection, which could possibly be included in the information into the overall reliability assessment. The usage of qualitative and quantitative data collected through the human-FMEA within the proposed quantification method shows promise that HF can be quantified and could offer broader understanding of HF influences on inspection in various industries.

Keywords: Human Factors, Failure Modes and Effects Analysis, FMEA, Tunnel Inspection, NDT Reliability, Quantification

1 Introduction

Human factors (HF) in non-destructive testing (NDT) have puzzled practitioners and researchers since NDT's inception. And whereas HF in NDT of metallic components are a poorly investigated topic (in comparison to other industrial fields such as aviation), HF in the inspection of concrete components are even less known. Studies have shown that there is always some variability between individuals in their inspection results and that HF affect the reliability of NDT inspections [1]–[5]. And even though those HF (*“environmental, organisational and job factors, and human and individual characteristics which influence behaviour at work in a way which can affect health and safety”*) ([6], p. 5) do not necessarily lead to negative inspection outcomes, understanding them is a vital step towards preventing possible structure-breaking failures and thereby ensuring the safety of industry, environment, and infrastructure.

NDT in civil engineering (CE) is a challenging field. From the HF perspective, the conditions under which the inspections are carried out in the field (e.g. wearing of protective equipment, heights, low temperature, running traffic, poor visibility, etc.) or during inspection and evaluation of the data (e.g. the challenging surface) could pose significant physical and cognitive demands for inspection and detection of damage. This could in turn have a large effect on people, influencing the overall reliability of the NDT process. Although research concerning



inspection of concrete structures sometimes mentions HF, e.g. in terms of addressing human error and how to avoid it by means of increased automation or improved predictive algorithms (e.g. [7]), there has not to our knowledge been any research to date focussing directly on HF in NDT of concrete structures, though the interest has been growing. Especially in the field of reliability of concrete inspection, HF are still deemed as a largely unknown but highly relevant factor that requires more attention [8], [9].

Since considerable knowledge in the field of inspection of concrete structures is missing, this study aimed to identify human-related risks in tunnel inspection with use of the laser scan method (case study) by means of human-oriented Failure Modes and Effects Analysis (Human-FMEA). Considering our efforts at writing a standard draft for the reliability assessment within the ongoing WIPANO project, the second aim was to utilise this knowledge to make the first attempts to quantify HF that could be integrated into the overall reliability assessment.

2 Identification of human factors in the inspection of concrete components

Although the laser scanning method has over 20 years history of successfully detecting structural damage, the FMEA gathered four experts to consider, besides continuous technological development, how the method could be even more improved by paying attention to human factors. During the human-FMEA, they were asked to brainstorm about *possible* errors/failures. These errors/failures were then also characterised with respect to their causes, consequences, existing and possible preventive measures in a prospective approach. At the end, a risk priority was assigned to each of the failures. The purpose of this analysis was to brainstorm and foresee possible failure, build barriers against their occurrence, and use this knowledge to understand the influencing factors on the reliability of these inspections. The results (see **Table 1**) of the risk assessment show that failures can happen at all stages of the inspection process, and they be caused by individual, environmental (physical working conditions), technological, organisational and extra-organisational factors (e.g. standards, communication between different organisations). Though the existing preventive measures, relying primarily on the individual experience and expertise and quality management practices have shown successful at preventing these possible failures so far, potential for improvement can be found at the organisational and extra-organisational level, though improved communication especially with the client, further automation, decreased pressure and open error culture (systematic learning from previous errors). The risk priority rating shows that the final assessment of the damage bears the highest risk and therefore deserves a more immediate attention.

3 First attempts at quantifying human factors using the FMEA

The FMEA results for one selected task—that of preparation—were taken further to develop the first approach to quantifying HF in NDT. For that purpose, a simple holistic method to create quantifiable data from the qualitative data was used. The quantitative data important for the analysis were the *RPN* for each *Possible Failure/Error*, while the qualitative data used were *Sub-Task*, *Aim*, *Error type*, *Cause*, *Existing preventive measures*, and *New preventive measures*. Lists of each of these considerations were created and they were brought into relation in so-called “tally-lists” that could be filled out in two ways: either by inferring the linkage of a cause to a possible error or by having the linkage ranked by either the workshop participants or by NDT experts working in that field.

Table 1: Summary of the Human-FMEA

Tasks	Possible risks	Causes	Consequences	Preventive measures
Preparation	On-site conditions not known, not suitable, not considered. Boundary conditions not considered. Unsuitable or non-optimal measuring system selected	PEOPLE Human error, e.g. forgetting, mixing up, memory slips, concentration, overlooking, miscalculating, misinterpreting Rule violations	SAFETY THREAT Need to improvise Critical damage overlooked Wrong assessment Accident	EXISTING Know-how and the experience of the personnel Experience exchange Availability of experienced personnel Internal communication Redundancy (“4-eye” principle) Check lists System check Quality management practices Documentation
	Scanning	Lack of or insufficient system check in the office Operating errors (forgetting to start measurement; setting the wrong configuration; driving too fast or incorrectly; no space for the date, etc.) No full coverage of the tunnel Technical failure of the measuring system (failure) Lack of or insufficient quality check	TECHNOLOGY Inappropriate choice, malfunction, broken or poorly designed equipment Ergonomics Programming errors Software design PHYSICAL ENVIRONMENT Distractions from driving cars or trains Temperature, wind, height, geometry of the tunnel, etc.	
Evaluation		Scaling error	ORGANISATION Unclear criteria	FUTURE Open communication with the owner / customer, More available time to carry out the inspection, the necessary checks and to visit the site to complete the data Flexible and adaptable error catalogue in consultation with the client Additional checklists Extra measuring system (in case of malfunction or failure) Targeted training of the personnel Being able to influence the design of the software Further automation (automated crack detection, alarms) Less pressure from the owner not to discover any damage Open error culture (the ability to report and learn from mistakes)
Visual inspection	Misinterpretation of the damage Damage overlooked	Insufficient supervision Missing or insufficient documentation, high pressure		
Mapping (Software)	Problems with the operation of the software	EXTRA ORGANISATIONAL FACTORS Communication and cooperation between several organisations Suboptimal or distracting working conditions Pressure		
Assessment	Incorrect assessment Lack of justification for the assessment Deviating assessment compared to the pre-inspection Missing assessment			

The next stage is to allocate the named human errors to a *hidden layer* of human factors. The tally lists are integral to the hidden layer because it is here that one error can be allocated to several factors. This procedure resulted in creating quantitative maps such as that shown in **Figure 1**. This made it possible not only to quantify the human factors within the scope of *Summaries according to chosen theories*, but also to trace back (left to right) within the maps, in order to find the contributory *Hidden layer factors* and *Errors* and their relative weighted importance for the final interpretations.

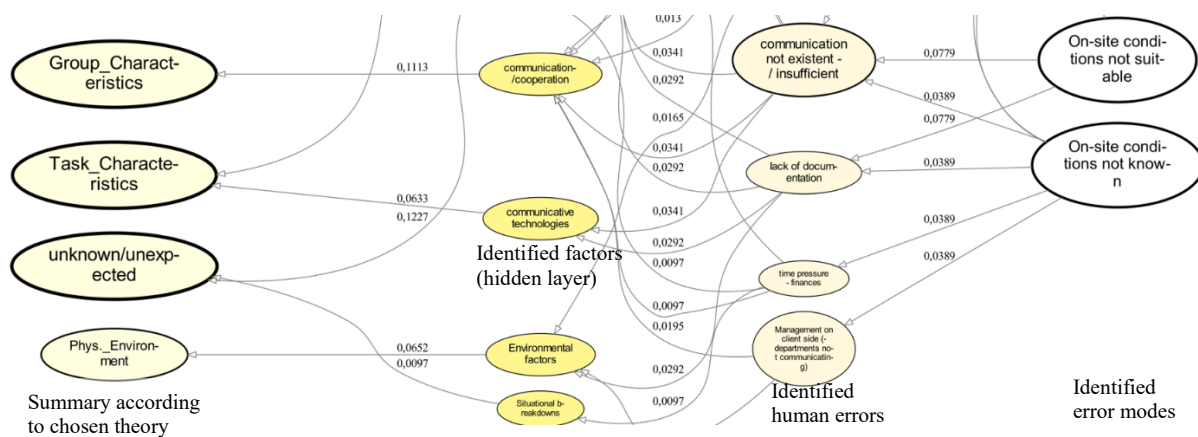


Figure 1 Detail of Assignment of *Errors* to Factors

While it is important to note that this quantitative component is still under development, we believe it shows promise. The approach used here works on the basis that context is everything. In performing a human FMEA, we enter into real contexts of real errors in specific tasks and workplaces. By quantifying the qualitative results within the given context, we have seen that value can be added to qualitative findings. Indeed, the quantifications did inform the qualitative evaluations. But beyond mere magnitudes to validate the FMEA, the quantification also serves practical qualitative purposes in this context, such as mediating the true nature of the distinctions between models. It offers not only a reporting method but could potentially become a real basis for a strategic decision template, offering a format which can address organisational (or other less quantifiable) errors through the hidden layer factors, while also drawing on the context of the errors themselves. The quantitative maps do not simply quantify. They also show possible error sources in a traceable form. We see this method as the first in a series of steps to create a system of quantification that could be used in reliability assessment methods such as POD while retaining the important qualitative aspects required for any holistic study of human behaviour.

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