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Critical review of the 'art' of forensic investigations in pavement engineering

Abstract

Forensic investigations into premature failures of pavements can be a highly structured process with a strong reliance on maths, statistics, applied science and engineering science. The art of forensic investigations include handling data gaps and uncertainty via Occams razor. Zooming in via Root Cause Analysis (RCA) techniques like the Pareto Principle is advocated to help define a problem as a first priority. Engineers tend to be lower skilled in emotional intelligence and may even tend be autistic like in their communication. The human nature exposed to confirmation and hindsight biases play into the development of own sets of truth and paradigms where inconvenient facts are banished to outlier status. The ugly truth about the short comings of tunnel like human vison and observation and frailty of memory recall all need to be accounted for. Ultimately fact based paper trials have standing in legal evaluations like arbitration and mediation.

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Emile Horak
Department of Civil Engineering, University of Pretoria, South Africa

Correspondence: Emile Horak, Department of Civil Engineering, South Africa, Email emileh@global.co.za

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Introduction

Premature failure of a flexible pavement by definition is failure of one or more forms of distress that manifest pre-maturely or during the very early part of an intended much longer design and operational life. This onset of premature distress may even happen when the actual pavement is still under construction with a significant failure rate evident already. The well-known 'bathtub curve' is often used in reliability engineering and has relevance also in pavement engineering. The reality of engineering constructs (e.g. pavements) is that there is always a constant random probability of failure. Under ideal circumstances failures due to consumption or wear out show a definite increase over time and tend to morph into an exponential function towards the end of life. The focus here is however on premature failure ("infant mortality"). This type of distress or failure has the highest probability at the start of the life cycle and rapidly (exponentially) decreases as operational pavement life proceeds. The combination of these three curves related to the types of failure creates the classical bathtub curve. It needs to be noted that observation of premature distress is at a time where information generally is still limited. This sets the scene for confusion during the early period of observation. Experience with arbitration and mediation have shown the value of fact-based paper trails versus lower valued subjective personal opinions. For that reason a deliberate effort must go into getting to objective information that has a paper trail and or is peer reviewed as a matter of priority from the onset.

Structured approach to gather contextual data

In forensic investigations into the cause of distress in flexible pavements (NHCRP 2013) a contextualised structured approach is strongly advocated starting with broad based information gathering first. This includes as-built information, normal Quality Control and Assurance (QC and QA) information coupled with a structured visual survey and analysis) before various non-destructive tests like using the Falling Weight Deflectometer (FWD). Using benchmark analysis with the easily calculated deflection bowl parameters helps to get an early indication of where the problem originates in depth of the pavement system as well as over the length and width of the pavement.[1] Other non-destructive testing like high frequency Ground Penetration Radar (GPR), normal Pavement Management System (PMS) type instrument surveys like riding quality, macro texture, rut, skid resistance, etc. are also often done. Strictly speaking using the Dynamic Cone Penetrometer (DCP) on flexible pavements with either granular or lightly cemented granular materials also classify as a non-destructive testing technique and is often used in South Africa due to its good calibration with pavements and materials tested under Accelerated Pavement Testing (APT). Lately the tendency is to use DCP penetration rates (mm/blow) and not convert to the laboratory determined California Bearing ratio (CBR) due to lack of repeatability.[2,3] After this it is normal to follow with test pits, material sampling, cutting out slabs or coring and doing a wide variety of laboratory tests.

Zooming in with specialised tests

At this stage a bewildering amount of information is often available and needs to be effectively evaluated to get to the actual cause(s). More detailed laboratory tests like X-Ray Diffraction (XRD), X-Ray Florescence (XRF), Scanning Electron Microscope (SEM), Bending Beam Rheometer (BBR), Multiple Stress Creep Recovery (MSCR) Test, Dynamic Shear Rheometer (DSR), Constant Height Repeated Simple Shear Tests (CHRSST), various types of permeability (falling head or constant head), Computed Tomography (CT) scans and modelling, etc. should normally follow once the focus of the investigation had been determined via these broader contextualization fact gathering information.

Application of the pareto principle

Various statistical analyses procedures can be applied to the data. It is however important to zoom in on the most probable causes as soon as possible to achieve some efficiency and focus in the investigation. The information can be consolidated by applying basic Root Cause Analysis (RCA) techniques. In the field of RCA.[4] The use of the Pareto Analysis is used as one of the more powerful toolsets to help address a situation where multiple related problems or a common problem with multiple possible causes are encountered. Pareto Analysis is based on the classic 80/20 rule.[5] That is, in many cases 20% of the problems cause 80% of the occurrences. Rather than attacking the causes randomly, a Pareto Analysis might show that 80% of the problems are caused by a few main causes. This gives you consolidated information and direction to know which causes to concentrate on in further more detailed analysis. It is however not always possible to do a classical Pareto analysis but the concept of cause and result or RCA are often

useful to distinguish between the mere observation of various forms of distress and to use the logic of RCA to derive a short list of the actual possible causes.

Managing the uncertainty of data gaps and greyness

One of the problems often encountered is the greyness of the data and gaps in the data. Often assumptions are needed to complete the picture and this may cause additional uncertainty. In such cases Occams Razor should be used as this logic principle underlies all scientific modelling and theory building. The likes of Newton and Einstein used this logic principle to address uncertainty in developing a hypothesis or to develop a new theory with limited initial data. Occam's razor is based on a logical principle developed by the mediaeval philosopher William of Occam (or Ockham). By definition.[6] Occam's Razor is *a scientific and philosophical rule that entities should not be multiplied unnecessarily which is interpreted as requiring that the simplest of competing theories be preferred to the more complex or that explanations of unknown phenomena be sought first in terms of known quantities*. The principle in short states that *one should not make more assumptions than the minimum needed.* This principle is also often called the Principle of Parsimony and in short it translates to *it is a problem-solving principle that essentially states that the simplest solution tends to be the correct one, in essence the KISS principle (Keep It Simple, Stupid).* This rule is lifted out as a guiding principle with forensic analysis for the reasons of greyness of the data mentioned before and the pressure and human response to grasp at "*alternative*" facts not properly documented, peer reviewed or vetted. Such alternative truths are not necessary as dubious as typical outrageous Trumpian facts, but rather 'convenient information' to fit a preconceived story.

Fallibility of the human (engineer)

This brings us to some less pleasant and lesser known realities of the human mind. Like an instrument the human mind also needs to be calibrated. On a philosophical note it is noted the human reaction to premature failure is understandably stressful with high emotional content. The human element is often the more difficult aspect to manage in such circumstances. Engineers are not renowned for their emotional intelligence and this often results in virtually autistic communication.[7] The result is the communication around the event is often handled under the guise of applying 'pure' science and mathematics under the pretence or misguided understanding that it implies absolute truth and impartiality. The reality is that engineers are human and they are often unaware of their natural affinity for confirmation and hindsight biases.[8] The average engineer (human being) is often unaware of the influence and impact of such human biases and may confuse their own set of rules as the only truth. It often develops into a personal law due to such natural occurring biases and because the human mind has the strange ability to ignore certain facts that do not fit personal experience and associated set of truths that develop over time.[8] also cast doubt over visual observations and memory of humans. Memory is clearly not as crystal clear as people would like to profess to have. It certainly need not be extreme memory loss due to Altsheimer's disease to influence actual truth of events. The most shocking is however the acknowledgement of the limitations of human visual observation. "*The human vision is such our actual field of vision at any one moment is extremely limited. Outside our casual awareness, our eyes compensate for this limitation by rapidly darting around to numerous points of focus. Our brains also fill in gaps by showing us what "should be there" or "probably" are there".* This fact is recognised in the courts in the USA where much less weight is attached to eye witness accounts due to such aspects as visual focus and filling in the gaps. There is also recognition by the courts that the power of suggestion and proven imperfect memory often lead to even witnesses unknowingly developing facts to fit a story line suggested.[8] This places a damper on reliance of personal memory and observations. The maxim experienced in court proceedings is that if it was not recorded with a paper trail it also tends not to stand up in court well.

Paradigms and a need to get a shift

This selective fact assimilation was described by Kuhn based on observations in the scientific and research environment. He originally coined the concept of paradigm (pattern of thinking) and paradigm binds which have found traction in other fields like business, planning, marketing and technology development. The pervasive impact of concept of paradigms and patterns on any human mind is best described by Harrison.[8] who quotes psychology professor Hank Davis.[9] "*Patterns are everything to us. We hunger for them. We revel in them. They are the basis of art, literature, music and much more in our lives. But a perceptual system that is so geared to wrestling patterns out of complex arrays of stimuli is bound to produce some false positives. From time to time we are going to see or hear what is not there, and those cases will seem no less compelling to us*." The real challenge is when a paradigm shift is imposed due to external circumstance changes. Such a paradigm shift exposes the 'outliers' which were unknowingly ignored as they did not fit the pattern or bias or rules of the paradigm. When these additional 'new' facts are actually incorporated a clearer view of the truth can be assembled. It is in any case the ethical approach to present all facts regarding a forensic investigation case and not just selectively ignore some facts to favour a specific client opinion.

Problem definition priority

Brightness and intelligence are often wrongly associated with someone who offers instant answers with passionate and fluent verbal reasoning. Coupled with a strong personality such persons often fall prey to this "*intelligence trap*". The actual problem is often wrongly identified or too quickly jumped to a conclusion with limited factual data.[10] This is a classical mental barrier identified in the field of creativity and innovation and critical thinking or reasoning. What is needed is often a longer process of structured information gathering and evaluation. In a sense it requires the problem context to be defined first by going wide or broad in the search before effective zooming in can be warranted. Seelig[11] states in this regard Albert Einstein is quoted as saying, "*if I had an hour to solve a problem and my life depended on the solution, I would spend the first fifty-five minutes determining the proper question to ask, for once I know the proper question, I can solve the problem in less than five minutes.*" Seelig,[11] goes further by stating " *the ability to reframe problems is an important tool for increasing your imagination because it unlocks a vast array of solutions*."

Conclusion

This short critique or overview of some of the soft issues regarding forensic investigations is exhaustive and other issues also can be added. However they are described in classical Pareto principle application fashion. Once you understand these contextual and soft issues you can get stuck into the discipline and mechanics of forensic investigations (NCHRP, 2013).

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Conflicts of interest

The author declares there is no conflict of interest.

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