No Fault Found, Retest OK, Cannot Duplicate or Fault Not Found? – Towards a standardised taxonomy

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Abstract
There is a phenomenon which exists in complex engineered systems, most notably those which are electrical or electronic which is the inability to diagnose faults reported during operation. This includes difficulties in detecting the same reported symptoms with standard testing, the inability to correctly localise the suspected fault and the failure to diagnose the problem which has resulted in maintenance work. However an inconsistent terminology is used in connection with this phenomenon within both scientific communities and industry. It has become evident that ambiguity, misuse and misunderstanding have directly compounded the issue. The purpose of this paper is to work towards standardisation of the taxonomy surrounding the phenomena popularly termed No Fault Found, Retest Okay, Cannot Duplicate or Fault Not Found amongst many others. This includes discussion on how consistent terminology is essential to the experts within organisation committees and, to the larger group of users, who do not have specialised knowledge of the field.

Keywords: No Fault Found, Through-life Engineering, maintenance, operational effectiveness

1 INTRODUCTION

Since the advent of electronic systems, engineers have seen increasing the reliability and maintenance effectiveness of the technology in use as a paramount objective in through-life engineering capability (Phillips *et al,* 2011, Simpson and Sheppard, 1992). Traditionally, approaches to reliability have been focused on system/subsystem/component levels as a purely technical issue, which are dealt with once the product specifications are outside of the pre-defined parameters (Qi *et al* 2008). However, increasing system complexities have now appreciated separate types of reliability issues, which are not dependent on technical specifications or performance, but are related to business process and human factors (Wu, 2011, Vichare *et al,* 2007)

Understanding system reliability from technical and non-technical perspectives has become the focal point in research when considering faults which cannot be correctly diagnosed or even detected under standard maintenance testing. This is commonly termed No Fault Found (NFF) amongst a multitude of other similar terms with Fault Not Found (FNF) Retest Okay (RTOK) or Cannot Duplicate (CND) to name a few of the more common. This difference in terminology is found to differ across industries, organisations and even individual maintenance lines, which often undermines the many reasons ranging from simple faults in electronics, to the way in which the organisational structure is setup. There is also a feeling beginning to be expressed that the actual term which is used, and the increased inconsistency, is undermining attempts to help solve these problems.

The aim of this paper is to provide the basis to move towards formal research discussion and investigation into the need for standardisation to help reduce the occurrence and impact of NFF/RTOK/CND/FNF, in particular the promotion of a common taxonomy within the subject area.

2 THE PROBLEM

In order to address the scale of the problem we need to become familiar with a sequence of events which result in what we will describe in this paper as a **'diagnostic failure'** (often reported as No Fault Found or a similar descriptive term). This sequence begins during operational service when a Built-In-Test (BIT) fails or the operator reports the possibility of an error. Independent functionality tests will then be ordered on the suspect Line replaceable Unit (LRU) at *1st* line maintenance to look to verify the fault/failure, if it cannot be repeated a failure to diagnose the problem will be recorded. If the functionality tests fail, then further off-line tests within the maintenance shop/depth will be used to diagnose the system fault to a group of Shop Replaceable Units (SRUs) that are suspected of being the source of the LRU failure. Depending upon the accuracy of the diagnosis at this level, ideally only one SRU will be called out; less precise diagnostics may call out two, three or more SRUs. The called out SRU(s) are then sent back to the

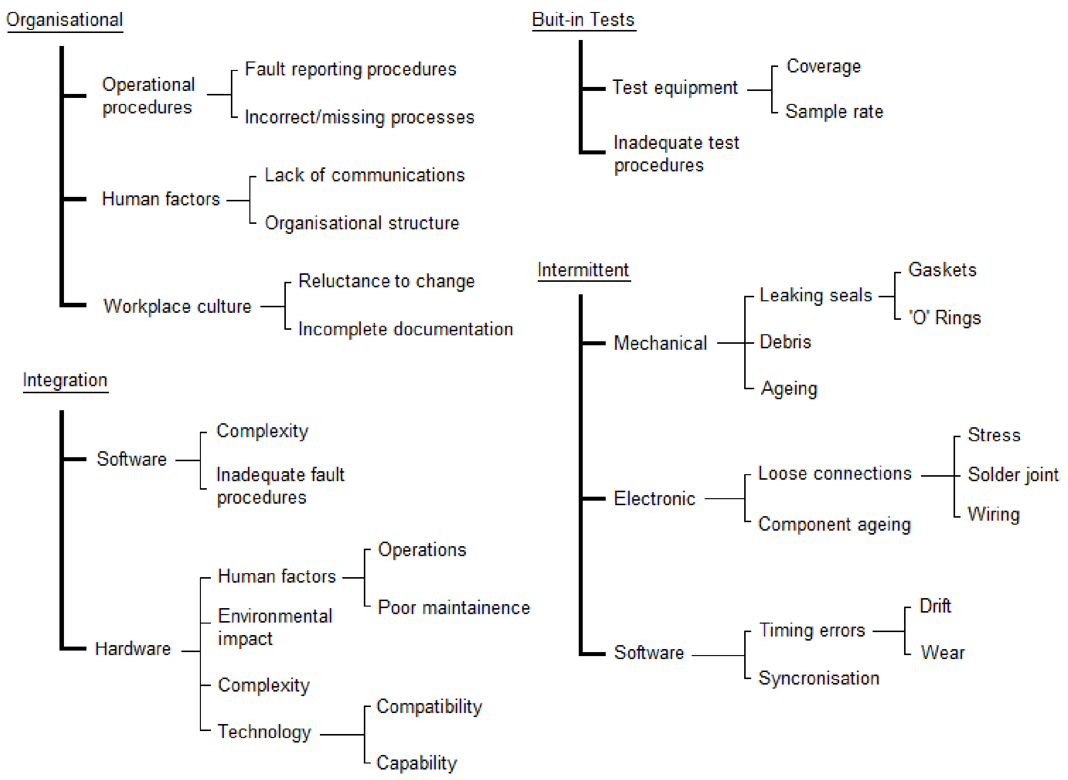

Figure 1. Various No-Fault Found causes/events

depot for functional testing using Automatic Test Equipment (ATE). If the SRU passes at this stage a diagnostic failure will be recorded. There are then two possible scenarios, either the SRU may be healthy and falsely replaced, or it is probably faulty and the diagnostic testing is inadequate (Ungar, 2007).

Such scenarios will evidently have a negative impact on system requirements, which at the top level may include safety, dependability, availability as well as negative implications for Whole Life Cycle (WLC) costs. All major industries which operate complex engineered systems (in particular those which are electrical or electronic) suffer from such failures within the diagnostic process as described. These industries, which a small selection, include military/civil aerospace, automotive, energy and consumer electronics.

3 OCCURRENCE OF DIAGNOSTIC FAILURE

It is clear that a great many of the diagnostic failure events which are of interest occur in avionics, electrical and electro-mechanical, but initial research shows that mechanical systems also give rise to similar difficulties but are far less known. Figure 1 captures and presents a non-exhaustive list of instances found in literature that classify events/factors as NFF (or with a similar terminology variant).

In Electronics systems, loose connections probably cover most of the faults that have been published as NFF (Jones and Hayes, 2001, Line and Krishnan, 2007). Some of the more common and well known include poor solder joints, faulty electrical components, damaged PCBs and problems with internal wiring. In addition, electronic failures are not considered as static (or random) events, but a process of mechanical and material changes. These changes will not always lead to a loss of operation for the system, even though their components are out of specification. This is because electronics have an inherent self-compensating aspect which makes the task of diagnostics difficult. In addition to this self-compensation, degradation of failure modes will manifest differently depending upon the operating environment and may offset one another depending on circuit configuration (Line and Krishnan 2007). There are several generic causes of faults and failures within electronic systems (Pecht *et al*, 2001):

- Interconnect failures (including connectors)
- System design (electrical and mechanical)
- Excessive environment (temperature, moisture, chemicals, mechanical stresses)
- User handling

The failure mechanisms within a mechanical system are widely regarded as having less of an effect upon the rate of NFF occurrences than those which are present within electrical systems. The causes of failure in mechanical systems are similar to those in electrical systems, such as ageing, poor maintenance, incorrect installation or usage. The difference however is that it is much easier to predict the effect upon the systems operation with mechanical failures. As a result this allows inspection criteria to be developed during the design phases. It should be noted that as with many electrical failures, mechanical failures can be intermittent in nature and only occurring under specific operating conditions. Some of the more common mechanical failures which are of interest but receive a lot less attention then the electrical failures which contribute to diagnostic failure are:

- Broken seals and leaks: Leaks from broken seals will affect the operation of items which include engines, gearboxes, control actuators and hydraulic systems. The nature of seal design is that they are often designed to slightly 'weep'. This is a good example of the need for maintenance personnel to be familiar with the system and hence be aware of what constitutes acceptable leakage in order to avoid unnecessary removals.

- Degradation of pneumatic and hydraulic pipes: Degradation within pipes often occurs due to corrosion or fretting against other components or structures. The nature of pneumatic/hydraulic systems is that under pressure they may develop small leaks. These minor leaks may result in an alarm to the operator indicating failure, resulting in the unwarranted shut down of the system, when no equipment malfunction has actually occurred.

- Backlash in mechanical systems: One area where backlash can cause significant concern is within actuation systems, particularly those used for aircraft control surfaces. It is possible that with excessive wear in actuator couplings, position sensors may indicate incorrect operation, including asymmetric settings, which are difficult to isolate from a maintenance perspective.

It is clear that a great deal of NFF occur in avionics, electrical and electro-mechanical systems, however research discussions have also revealed that software is also a key contributor to the problem. This includes processing delays, discrepancies between software testing procedures, timing errors, lack of appropriate training, or perhaps a poorly written program code (Mariani *et al*, 2011).

4 A MULTITUDE OF TERMS

What rapidly becomes evident when reviewing the associated literature, coupled with discussions with industrial organisations, is that there are no standards in place to ensure correct identification, reporting and mitigation of these problems. To date no published academic literature has been found by the authors of this paper which specifically raises/deals the issue how the disparity between terminology and definitions affects the ability to deal with the issue of diagnostic failures. This is despite the earliest real call for this standardisation has been found in Simpson *et al.* (1987) where research into testability attributes of electronic equipment, specifically to mitigate NFF – but this has not yet been achieved across all test/maintenance levels. Early research in the EPSRC Centre for Innovative Manufacturing in Through-life Engineering Services shows that one of the major drivers and influences on the cultural impacts contributing to the inability to diagnose a reported fault is this lack of standardisation, clarity and inappropriate usage of taxonomies. Figure 2 shows the results of a recent survey conducted by Copernicus Technology Ltd into the causes and perceptions of NFF in the aerospace industry responded to by approximately 120 aerospace organisations. The results show that approximately half of the respondents refer to it as No Fault Found but the other half refers to it as a variety of other terms.

There was of course a degree of variation observed within this survey depending on sector for example in the airworthiness/QCI/regulatory sector the use of No Fault Found reduced to 38% whilst 'Cannot Duplicate' and 'Unable to reproduce Fault' both increased to 21%. The highest percentage of respondents referring to 'No Fault Found' was in the production/design/R&D sector (52%) and in the maintenance sector (62%).

Despite such variations, fundamentally all these terms are frequently assumed to be being applied to identical events where the attempts to answer the question of why the unit has ended up in the maintenance process has failed. The diversity in the terms used to describe this event highlights that manufacturers, suppliers and operators are more than aware that there is a problem and acknowledge the existence of the phenomena throughout the whole-life cycle of the product.

There are two possible areas of investigation which result from this disparity:

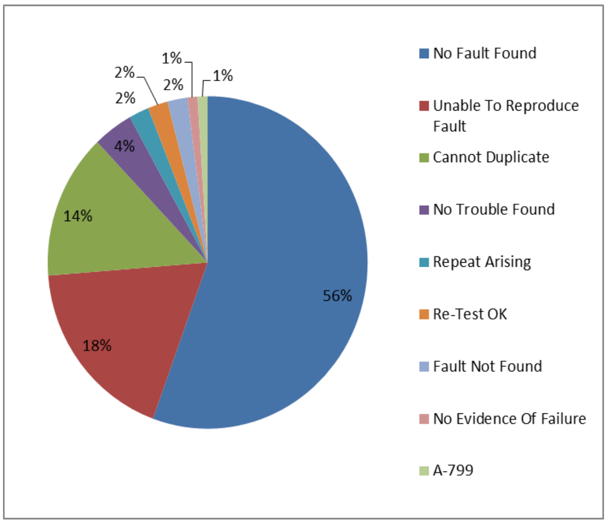

Figure 2: Results showing a disparity in terminology from a recent survey into NFF within aerospace (Huby, 2012)

1) How can a true gauge of the problem be investigated if there is no standardised term used in the maintenance history?

2) Are all of these terms accurate – do they actually describe the same event, or are there subtle differences which need to be recognised?

5 THE CONSEQUENCE OF INCONSISTENT TERMINOLOGY

Considering the first question, research by Roke (2009), which used the Harrier aircraft as a research platform perfectly, illustrated this problem. In this research, in order to gauge the size of the problem based upon 'work hours', both forward and depth domain maintenance data was independently filtered for events tagged as the LITS (Logistics Information Technology Strategy) default phrase '01 – No fault found after check/test'. The result returned an average occurrence of ~3.5% over approximately a 3 year period. This is significantly different to what the research had found in the literature which indicated an average 42% across multiple industries. What was however found was that despite LITS application users being able to populate a 'Work Carried Out (WCO)' field with a default phrase the reporting was laden with a multitude of additional maintenance actions.

In the forward domain some 13 different NFF phrases were extracted as being available for use by the LITS. There was also strong evidence that many of these events were misreported or false feedback terms such as 'fault cleared itself during investigation' were used to circumvent formalities. Expanding the database query produced an average figure of 10.5% occurrences. A significant increase on the original figure which was generated on the presumption that reporting was accurate and consistent A similar picture was seen within the depth domain where the figure leapt to ~27%. Two of the key findings of this research relating to disparity between terminologies were as follows:

1) The problem is being under reported by approximately 300%.

2) The disparity between original and tagged facts is caused by the significant miscoding of events bought on by the availability of LITS terms.

3) The output of LITS data within the forward domain is very erroneous and cannot be relied upon to provide an accurate picture of aircraft/fleet health.

It is expected that there will be a high likelihood that a very similar situation will occur in other industries such as civil aviation and within rail vehicles/infrastructure where best practice and/or past experiences may be able to be shared if an appropriate knowledge transfer platform was developed. But for now the more generalised recommendations would be to work towards:

1) Ensuring reporting is based upon a set of accepted and standardised phrases and terms in order to avoid false/misreporting and all applicable events are captured.

2) The functionality of recording systems should be simplified restricting erroneous use of terms.

6 STANDARDISING THE TAXONOMY

6.1 Why do we need standards?

Adopting standards help industries (and research) overcome technical barriers by promoting organisational success through better workflow paradigms and maintenance strategies. Since diagnosis failure is a multidisciplinary issue, establishing a formal methodology, process, criteria and practice may help reduce the consequences of such failures. However, one interesting point in the discussion is where exactly do these diagnostic failures occur within the maintenance process? Most of the definitions for these phenomena do not provide any consideration for this and therefore leads to the assumption that the level of test is unimportant. For example the following definitions can be extracted from the information provided in published research:

"No Fault Found is a reported failure that cannot be confirmed, recognised or localised during diagnosis and therefore cannot be repaired" (Roke, 2009)

"The inability to replicate field failure during repair shop test/diagnosis" (Kirkland, 2011)

"A failure that may have occurred but cannot be verified, or replicated at will, or attributed to a specific root cause, failure site, or failure mode" (Qi *et al*, 2008).

"Removals of equipment from service for reasons that cannot be verified by the maintenance process (shop or elsewhere)" (ARINC Report 672, 2008)

6.2 Is a single term enough?

It should be noted that these are only a few abbreviated examples of a huge number of definitions (or descriptions) which continue to grow. The lack of a single common descriptive and standard term indicates that, even among researchers, practitioners and other experts, the phenomena is not well understood.

The majority of definitions lead to this ingrained belief that a failure during operation (such as an intermittent fault) is the actual 'No Fault Found' event, and hence leads to the majority of academic literature to classify NFF into three distinct categories: intermittent failures, integration faults and Built In Test Equipment (BITE) failures. On the contrary, the authors of this paper argue that such a practice is incorrect as these are primarily the root causes which begin a sequence of events through various levels of maintenance, which blend with other factors such as organisational/behavioural/cultural and technical abilities to result in the final outcome of NFF. These factors should be defined as separate to the root causes and should be considered as the **'drivers towards diagnostic failure'**. Below is a small sample outlining this distinction between root causes (the faults which lead to an alarm and hence maintenance action) the root cause source (the location of the fault within the equipment), drivers (the influencing factors leading to diagnostic failure):

Root causes (faults)

- Intermittency
- BIT/BITE
- Integration and software faults
- Operator error
- Poor design
- Design defects
- False alarm

Root cause sources

- Connectors
- Cables
- Chasis (LRU)
- Components

Drivers towards diagnostic failure

- Lack of communication
- Inadequate test coverage or performance measures
- Lack of information on the operating environment
- Incorrect fault reporting
- Discrepancies in test procedures
- Wrong process or test equipment
- Inadequate/missing process

It is believed then that a true definition and standardised terminology should be developed to reflect that we are not talking about simply a generic fault that cannot be reproduced – but is the result of a sequence of interlinking events, at different levels beginning with the root cause fault, but ultimately being *driven* to a diagnostic failure through a multitude of integrated issues.

In fact, there is some evidence within the literature that this is being recognised. There is a level of ambiguity in the literature where often at 1st line the event is labelled Cannot Duplicate (CND) and within the depth maintenance the event is often labelled as Re-test Okay (RTOK). The distinction between Cannot Duplicate (CND) and RTOK is that CND occurs at the same level of maintenance where the fault was reported and RTOK occurs at subsequent levels of maintenance (Ungar and Kirkland, 2008). This difference in terminology is found to differ across industries, organisations and even individual maintenance lines.

This idea is captured in the definition and explanation as provided by Soderholm (2007). This is illustrated in Figure 3 which recognises that the level of test is important.

"At any test level, a fault may be recognized and localized to a unit. However, when the unit is tested at a subsequent test level, the recognition or localization of the fault may be unsuccessful".

"This situation can occur for a number of reasons. One possibility is that having correctly recognized, and appropriately localized the fault at the preceding level, attempts to replicate the test results at the subsequent level are unsuccessful. Another possibility is the fault being incorrectly recognized or localized at the preceding level".

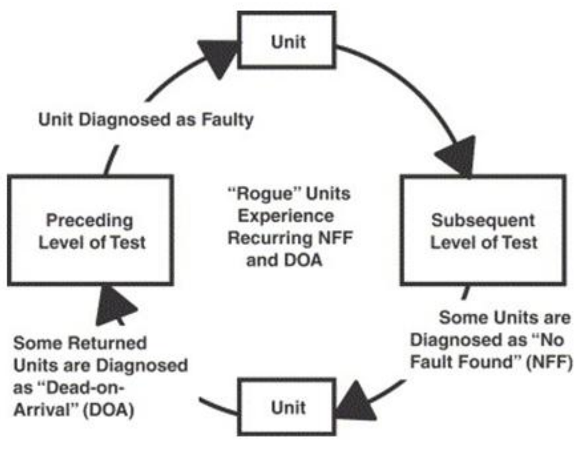

Figure 3: The phenomena described as NFF (Soderholm 2007)

This explanation recognises that the level of test is an important focal point. In relation to this point Ungar (2007) provides the following definitions taken from a set of defined terminology as part of model guidelines for 'Design for Testability (DfT)'.

Cannot Duplicate (CND): a faulty unit, whose faulty behaviour cannot be repeated consistently within the same level for repair

Retest OK (RTOK): the passing of the Replaceable Unit (RU) test, which at the previous level was determined to be faulty. A RTOK could sometimes be referred to as No Fault Found.

The key point to note here is that the distinguishing characteristic between an RTOK and a CND is that RTOKs can only be determined after a subsequent level of repair, CNDs happen within the same level of repair. Taking the definition provided by Soderholm (2007) RTOK would be the same as NFF, but CND would be a separate and distinct from NFF. This would however indicate that at either the 2^{nd}, 3^{rd} to the n^{th} level of repair the term RTOK or NFF or something entirely different will be recorded – but where then is the distinction? Is it even necessary to provide a coherent terminology through the maintenance levels – or does one term do the job for 2^{nd}, 3^{rd} or the n^{th} line?

Ungar (2007) illustrating that a RTOK situation is a 2^{nd} order problem inherited from a previous maintenance level *(L-1)* the term should be labelled $RTOK_{L-1}$. However, as illustrated that CND and RTOK refer to two different events it may be that at even deeper maintenance lines there requires a distinction in terminology to capture the fact that at each testing level the drivers (reasons) for the diagnostic failure resulting in RTOK/NFF may be different. For example, maybe at 2^{nd} level the drivers which resulted in the RTOK occurred because there was an inadequate outdated troubleshooting guide but then at 3^{rd} level these drivers were different and it was the test equipment lacked the necessary test sensitivity.

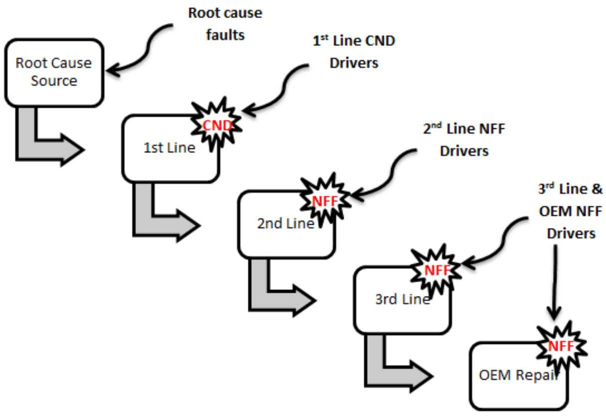

Figure 4: The repair process

Understanding what is actually meant by terms such as those in Figure 2 in the same way as the coherent descriptions for RTOK and CND will provide insights into whether a single common term should be championed as a default – or whether multiple terms should be used depending on the circumstances of occurrence (such as the maintenance level, or even based on the suspected driver as illustrated in Figure 4).

7 HAS THE TERM 'NO FAULT FOUND' ENGRAINED A CULTURE OF ACCEPTANCE?

There is in order to start a cultural change there is a definite need for standardisation and in some cases an overhaul of the terminology used for NFF. Senior UK industrial engineers representing the UK aerospace industry have expressed their belief that the term NFF (which is the most frequent term in use) quite possible provides a hindrance to reducing those cases labelled as NFF. If the result of a test is described as No Fault Found what does this really mean and how is it perceived in the mind-set of the test engineer? Firstly, we should consider the two main outcomes of a resulting NFF:

1) There has been no evidence of faults during testing so the unit can be certified as serviceable as there probably never was a fault.

2) There has been no evidence of faults during testing but the test coverage may be inadequate so it is best to replace the unit just to be on the safe side.

This is the current practice, one way or another there will be a repeat NFF event – either because a faulty unit re-enters service or the wrong unit has been replaced. It needs to be acknowledged that the NFF phenomenon is not a single event – it is a sequence of events which begin with a warning or alarm (detected fault) on board the main equipment. Resulting in a series of actions at various maintenance levels until finally a decision is made to add the NFF label and perform one of the two actions above. These two actions however are missing the key point in solving the problem – something has occurred to result in that final decision - this is the root cause – the initial fault, whether that is intermittency, a false alarm, over sensitive BIT thresholds or systems integration problems, has not been identified. This fits with a popular definition of the NFF phenomena (Cockram and Huby, 2009):

"A reported fault for which the root cause cannot be found – in other words a diagnostic failure"

So to eradicate NFF (or reduce it consequences) it is essential to identify how that root causes blend with the various drivers earlier identified and encourage engineers/technicians to look more closely at why they have failed to diagnose the problem. So with this in mind, senior industrial engineers representing the UK aerospace industry to approach the NFF research team in the EPSRC Centre for Innovative Manufacturing in Through-life Engineering Services to assess potential cultural impacts of describing the issue as a **Fault Not Found (FNF)** which offers a statement telling you the problem has not been fixed! Rather than NFF which suggests an attitude of resignation and that there was probably no fault there anyway. FNF suggests that we must still do something to solve a problem and there is an acceptance that something must be done. Adoption of more positive descriptors may help in culturally shifting the workforce to change from the general reactive mentality to a much more proactive approach in dealing with NFF.

However, in order to be objective we also need to recognise that not all industry sectors agree with this aerospace stance. A leading international construction vehicle manufacturer disagrees with the need for this and has claimed that changing and adopting a universal name will not change anything. The problem is still the same:

"We used the term 'Trouble Not Identified' for a while years ago. We got that term from automotive. It just confused people. The culture of acceptance is driven from a lack of understanding of the real drivers of NFF"

What is interesting about this statement is the idea that there is a lack of understanding on ***"…..the real drivers of NFF"***. This supports what is being seen in the literature with over simplified descriptive terms, attempts to classify the root cause as NFF rather than recognising it as an element in a chain of events which are influenced by organisational behaviour and culture as well as processes and procedures. These are the drivers which need to be understood and it is believed by the author that standardising taxonomy, unifying definitions, championing the correct terminology and creating a high level of coherency are essential to push forward the understanding of these driving factors.

8 CONCLUSION

The phenomenon which is the subject of this paper has been, and is in industry, commonly classified as a 'diagnostic failure'. This however indicates a closed-loop system with identifiable symptom → failure → decision relations; identifying and road mapping this relationship will be a key challenge in improving diagnostic success. This will require a complete fundamental understanding of the phenomena including clear distinctions between root cause faults, root cause sources and the influencing factors (drivers) covering the entire maintenance process.

What has become clear is that the lack of standards in this area results in different terms being used to describe the same events in the maintenance records. This obfuscates the scale of the problem – a common term would provide meaningful statistics on the problem allowing it to be easily identified.

There is also a clash of opinions between different industries over just how necessary the adoption of a standard terminology/taxonomy is. It appears to be favoured within the aerospace sector where they have evidently recognised that human factors are a core driver towards diagnostic failure. Current research within the EPSRC Centre for Through-life Engineering Services will certainly be keeping an open mind on this as it is recognised that different industries have different needs and differing practices. Even though there is almost certainly good practice in mitigating these events which is not being shared, one universal solution is unlikely, and what has not worked in one industry may be just what another industry needs.

9 ACRONYMS USED FOR NFF VARIANTS

Below is a non-exhaustive list of acronyms often associated with the No-Fault Found phenomenon:

NFF – No-Fault Found
TNI – Trouble Not Identified
NTF – No Trouble Found
NPF – No Problem Found
FNF – Fault Not Found
NAD – No Apparent Defect (or Damage)
NEOF – No Evidence of Failure
NFA – No Fault Apparent
CNRF – Can Not Reproduce Fault
CND – Can Not Duplicate
NDF – No Defect Found
FCDI – Fault Cleared During Investigation
NFI – No Fault Indicated
RTOK – Re-Test OK
CNF – Cause Not Found
NFI – No Fault Indications
NPR – No Problems Reported
UTRF – Unable To Reproduce (or Replicate) Fault
RA – Repeat Arising

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