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Review

No Fault Found events in maintenance engineering Part 2: Root causes, technical developments and future research

Samir Khan [a,*], Paul Phillips [a], Chris Hockley [b], Ian Jennions [c]

[a] EPSRC Centre, School of Applied Sciences, Cranfield University, College Road, Cranfield, Bedfordshire MK43 0AL, United Kingdom
[b] Cranfield Defence and Security, Cranfield University The Mall, Shrivenham, Oxfordshire SN6 8LA, United Kingdom
[c] IVHM Centre, School of Applied Sciences, Cranfield University, University Way, Cranfield, Bedfordshire MK43 0FQ, United Kingdom

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ABSTRACT

This is the second half of a two paper series covering aspects of the no fault found (NFF) phenomenon, which is highly challenging and is becoming even more important due to increasing complexity and criticality of technical systems. Part 1 introduced the fundamental concept of unknown failures from an organizational, behavioral and cultural stand point. It also reported an industrial outlook to the problem, recent procedural standards, whilst discussing the financial implications and safety concerns. In this issue, the authors examine the technical aspects, reviewing the common causes of NFF failures in electronic, software and mechanical systems. This is followed by a survey on technological techniques actively being used to reduce the consequence of such instances. After discussing improvements in testability, the article identifies gaps in literature and points out the core areas that should be focused in the future. Special attention is paid to the recent trends on knowledge sharing and troubleshooting tools; with potential research on technical diagnosis being enumerated.

Contents

* Corresponding author. Tel.: +441234 75 0111.
E-mail address: samir.khan@theiet.org (S. Khan).

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1. Introduction

Part 1 extensively discussed the organizational complexities and challenges faced by businesses today in attempts to administer solutions to the problems caused by unidentified failures. It also described the applied method for collection and analysis of the referenced literature in detail. This was included not only to judge the validity of these papers, but also to present a statistical analysis of the academic journal publications on NFF concepts between the period 1990–2013. In addition, the authors had categorized the literature into four main areas: fault diagnostics, system design, human factors and data management, where it was noted that fault diagnostics and system design have been the main focus for NFF journal publications within the past two decades. Part 1 also focused on no fault found (NFF) standards, and how such events can cause unprecedented changes in the service performance, impact dependability and escalate safety concerns. This has long been revealed with a variety of products, within a wide range of industries [1,2,3,4]. This paper aims to elaborate on these outlooks (from Part 1), whilst examining the technical aspects for complex systems and equipment (particularly products integrated within aircraft computer systems), and how such events can have a significant effect upon the overall unit removal rate. Historically, such removals have been seen as an unavoidable nuisance [5], but this viewpoint is no longer acceptable if the unit removal rate is to be managed effectively [6,7]. Unlike those failures that result in 'Confirmed Faulty' events, the designer may have no direct influence on those aspects of the system that determine the NFF failure rate, therefore a direct mitigating action during the design phase is likely to be more difficult[1]. It can be argued that any product removal that does not exhibit a failure (during subsequent acceptance test) can be tagged as NFF. Also, for a number of these events, further investigation could conclude that the reason for the removal event was categorically caused by an external effect. None-the-less, this would still be classified as a NFF event as these external influences might be faulty sensors (or actuator), or possibly an incorrect fault isolation activity. In any case, as the device fabrication process continues to improve, failure rates of hardware components have steadily declined over the years to the point where non-hardware failures emerged as a dominant issue [9]; whereas the reduction of troubleshooting complexities and time to fix a problem seem to be the most important aspects when investigating failures of electronic systems.

In addition to the a priori discussions from Part I, this paper focuses on the following:

1. No fault found occurrences in systems.
2. Emerging resolution practices.
3. Improvements in test abilities.
4. Discussion on gaps in literature.
5. Future research directions.

The remainder of the paper is structured as follows; after identifying the common root causes for NFF in system components, the brief survey's some industry specific innovations that have been introduced in order to capture troubleshooting data. Section 4 discusses improvements in test capabilities; followed by a discussion on the identified gaps in NFF literature. Finally concluding remarks and future directions for research into testability methods, and the necessary design guidance to mitigate the problem are covered in Section 6.

[1] Although, there are specific approaches, such as 'robust design' [8], that can be used to design quality into products and processes; by minimizing the effects of the causes of variation, without eliminating the cause.

2. No fault found occurrences in systems

2.1. Electronic systems

Electronic failures are not often considered as static nor random (or pseudorandom) events, but rather the result of mechanical and material changes [9,10]. These changes seldom lead to a loss of functionality of an electronic system, even though their components maybe out of specification. This is due to the electronics having an inherent self-compensating aspect that makes the task of failure diagnostics difficult and directly contributes to a successful diagnosis. In addition, degradation of failure modes often manifest differently depending upon the operating environment that may offset components and the circuit configuration [11]. Thomas et al. [12] and Renner [13] investigated the root causes of NFF in automotive electronic systems. It was revealed that an overwhelming majority of occurrences can be traced back to poor manufacturing (i.e. soldering and Printed Circuit Board (PCB) assembly) and inherent design flaws which include violation against specifications. Vichare and Pecht [10], Qi et al. [14] and Moffat [15] have summarized some generic causes of failures within electronic systems:

1. Interconnect failures (including connectors).
2. System design (electrical and mechanical).
3. Environmental conditions (temperature, moisture, chemicals, mechanical stresses).
4. Operator handling (ergonomics, training).
5. Printed circuit Boards (PCB).
6. Ageing components and connectors.
7. Loose PCB interconnectors.
8. Disconnected solder points.
9. Damaged wiring or cabling.

A recent aerospace survey [16] has ranked intermittent faults as the major cause of NFF events, whereas built-in-test equipment (BITE) coverage and software are least likely. This is contrary to the common belief that the majority of failures are due to incompatible or competing software routines between systems [17]. Intermittency is arguably the most problematic of the NFF events due to their elusive nature, making detection by standard test equipment difficult [5]. The faulty state will often lay dormant until a component is back in operational use, where it eventually causes further unit removals unless a genuine cause is found (fault isolation). It should be emphasized that these failures are not always present during testing, which make them troublesome to isolate. This situation can result in repeated removals of the same equipment for the same symptom, with each rejection resulting in the equipment being tagged as NFF [18]. At this stage, there is a very high probability that there will be a loss of system functionality, integrity and an unacceptable compromise in safety requirements. What is clear is that even though these faults may begin as short duration low frequency occurrences, as time passes the underlying cause will increase the severity of the intermittency until eventually a hard fault appears and the functionality of the system is compromised or lost.

2.1.1. Printed circuit board interconnectors

Information published by Gibson et al. [19], claims that between 50–70% of all electronic device failures could be attributed to its interconnectors. Even though solder joints can fail by a variety of mechanisms, the device 'interface' seems to be the most