Solving the Mystery of the Disappearing Symptom and Why it Benefits the Product Life-Cycle

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Abstract

Maintenance Technicians have been known to grow prematurely bald: when they investigate the transient fault, the symptoms have gone - only for the fault to resurface at the next operational use. This insidious problem is common in transport and infrastructure support with the cause eventually flagged as Intermittent Fault. The phenomenon has many names: No Fault Found (NFF), Cannot Duplicate, No Trouble Found, No Defect Found, Hidden Failures, False Failures. The USDoD NFF costs exceed $2B per year; figures for each commercial airliner are around $140,000 per year. Increasing down-time and wiring degradation are NFF flags and lead to multiple rework attempts, compromised safety and reductions in product life-cycles. The insight that intermittency is a symptom of degrading system integrity has led to test equipment that includes specialist Intermittent Fault Detection capability and its expanded use across the Product Life-Cycle: this test equipment fully supports product build assurance and Prognostics & Health Management (PHM). Proven case studies of aircraft wiring, avionics repair cases, product assurance testing, and PHM development are cited.

Keywords: Product Life-Cycle, Prognostics, Health Management, Intermittent Fault, Electrical Wiring, No Fault Found, Cannot Duplicate, Neural Network, Testing,

Introduction

This is about money: qualifying an item as "fit-for-purpose" is only the start; the item must perform to specification for the whole of its advertised life whilst all faults must be found and corrected. Testing is an insurance element in the money trail.

This paper will focus on the Electrical Wire Interconnection Systems [EWIS] and if an EWIS tester can qualify the cables, connectors and chassis, can find intermittent faults, can predict where the product is likely to fail and in so doing eliminate the disappearing symptom, then it will have measurably extended a product's cost-effective life-cycle.

Aim

The Aim of this paper is to solve the mystery of the disappearing symptom and, whilst doing that, extend the product life-cycle.

The Problem

In the Beginning…

In his book "Out of the Crisis", Edwards W. Deming recommended manufacturers:

> *"Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place."*

Post WWII General D. MacArthur CMH, DSC invited Deming to transform Japan industry: in 2016, it is the World's third largest economy [1].

On 17th July 1996, a TWA Boeing 747 exploded off East Moricles, New York: all 230 souls were lost when the wing centre fuel tank exploded. The fuel contents indicating system wiring loom also carried electrical power cables and the insulation around the wires had abraded conducting power into the tank which arced against the airframe [2]. Similar accidents were explained by this investigation [3] [4] and Wiring Reporting became part of a new Specification 2200 of the Air Transport Association of America (ATA) Chapter: Chapter 97 and known as Electrical Interconnection Wiring System [EWIS] [5] .

US Department of Defence has attributed some US$10B to maintaining air assets and of that, US$2B is spent finding transient or intermittent faults. Further, avionic systems have been proven to demonstrate more than 40% 'no fault found' rates and for the civil sector, the average estimated is some US$140,000 per aircraft per year; the same causes cost mobile phone manufacturers US$4.5 billion per annum [6] [7] [8] [9] [10].

In March 2015, Performance Standard MIL-PRF-32516 was issued to categorise intermittent fault test equipment [11]. With an EWIS categorization system and a Performance Standard, industry was able to develop appropriate test equipment and test procedures. The "disappearing symptom" had been recognised but not beaten.

Technology Driven

Getting faster, higher and doing it with less is the holy-grail. As analogue morphs into digital for almost every function, "boxes" become lighter and smaller but the connecting cabling has remained essentially the same with the parallel addition of some optical fibre conduits. Even so, the number of thinner signal wires has continued to increase. Whereas analogue circuits were tolerant of nanosecond failures, missing pulses in a gigahertz data stream can cripple a system. If the functional boxes are getting smarter, then the technology to test them, and their interconnections, must follow suit. The Wile E Coyote of fault detection is in pursuit of the Road Runner of disappearing symptoms.

The Wider Environment

Original Equipment Manufacturers hold the equipment design data, the build and all of the test results so they are privileged to provide repair and overhaul services. Often, OEMs will not release this information so poor reliability and high repair costs are tolerated until unreliable systems can be wholly replaced. Poor OEM support does not have to be tolerated.

The US Navy identified an aircraft generator to be the main cause of intermittent power failures. By testing the aircraft critical component separately using neural network methods, the US Navy has doubled the component's mean time between failure [12]: longer installed time, more availability, reduced OEM costs. A neural network tester monitored all-of-the-wires-all-of-the-time.

Hard-wired systems in boats, planes and trains require portable, self-contained, fast, reliable test methods for cables and connectors; both the tests and the results must be repeatable and able to be saved for maintenance recording purposes. There is an even larger saving to be made in the product life-cycle.

When a system fails, the easiest practice of replacing a Line Replaceable Unit (LRU) is invoked and the EWIS is neglected as a fault source. EWIS is disturbed by unplugging and re-plugging connectors to effect an LRU change and the disturbance leads to a temporary fix: the disappearing symptom. The removed LRU is shipped to the repairer: functional tests result in No Fault Found and the LRU is returned to the sender………….. with a bill. The disappearing symptom has won Round One.

Meantime, the efficient logistic monitor flags a need to increase the number of LRUs in the support pipeline and prompts a buy: Round Two to the disappearing symptom and …………….another bill.

The same system fails on the same aircraft during the next operation because the REAL fault is still present. Intermittent faults, characterised by disappearing symptoms, will reoccur until appropriate diagnostics locate the cause. Prime equipment availability decreases and lost maintenance time increases: Round Three to the disappearing symptom and …… more bills.

When the real cause of the failure is eventuality found, only then will the recurring bills stop. To trap the disappearing symptom, ALL of the systems concerned must be diagnosed and this includes the EWIS. LRU testing demands leading-edge test equipment and an effective equivalent technology for EWIS can be found in neural network type testers.

The Fix

The Disappearing Fault Mystery

Hard or enduring faults normally occur at the end of a long line of temporary system failures. If the fault is transitory, the computer can be rebooted and the mission completed: incident forgotten. When maintenance support is at last requested, the system is fully operational and what hope has a technician got of finding the real fault? Add to this an exact simulation of the operational environment, then how does a technician precipitate the "glitch", capture its location and trace its source?

Disappearing faults demand a mind-shift in fault diagnosis strategy, one with three stages:

a. *Measurement,* which collects data to quantify and prioritise norm-driven problems;
b. *Containment,* which focuses on preventing rejections of serviceable components; and
c. *Improvement*, which introduces technology and techniques to drive up intermittent fault repair success.

The *Measurement* function captures all fault data, specifically intermittents, in standardized formats and then sorts and filters that data. Only then can testing focus on the failure area and reduce the time to find the REAL fault.

Containment of the rectification to the offending fault requires lateral thinking and comprehensive actions in a time-poor environment: it is easier to swap-a-box than it is to map and trace a faulty cable or connector. Random repair-by-exchange is a “hit and miss” approach which results in many serviceable items circulating the repair chain. One operator included an extra step, thinking laterally, to contain this waste.

Technicians who remove any LRU placed it in quarantine, marked with the prime equipment number and the removing technician’s name. If the fault reoccurred, the original LRU was reinstalled and the technician’s name added to a list for supplementary training. Whilst this reduced the consequential supply chain cost, and an un-necessary OEM test, the original fault remained. Concurrent with the introduction of this process of containment was a maintenance data analysis and an appropriate level of test and repair applied to the EWIS. Containment is a lateral approach to saving money.

Whilst *Measurement* and *Containment* use existing tools, the quantum leap of *Improvement* is made by using advanced testing tools. Synthetic neural network based testing which monitors all-of-the-wires-all-of-the-time, along with learning type functions, is capable of trapping the intermittent fault. Extrapolating the repair scenario to qualification and to prognostic testing remain the outstanding challenges.

These three principles are at the heart of eliminating faults which come and go. Can these technologies be exploited to predict impending failures and replace the offending units or systems BEFORE they fail? Firstly the testimonials of system managers who have measured, contained and improved.

Finding Things Others Miss

If the intermittent fault problem cost the US Department of Defence between US$2B and US$10B and the tools are so smart then why are they not being universally used? The will to solve the problem at trade and managerial level remains elusive as long as the underlying causes remain hidden.

Original Equipment Manufacturer monopoly and technician reticence to adopt new techniques are constraints on the ability to improve availability and reduce costs. Some have grasped the nettle, have invested and have reaped the rewards.

A Return on Investment, in dollar terms, of 28 to 1 is good; the US F-16 Attack Radar repair and overhaul programme achieved this goal. Setting aside the increased availability, the benefits of mission accomplishment and the increased reliability, the financially quantifiable Return on Investment was achieved in retaining the Attack Radar Low Power Radio Frequency Module “on-the-wing”. Immediate results were:

a. 130 LRUs with intermittent faults, being 67% of the shop throughput: All repaired.
b. 33 LRUs unrepairable for more than one year: All repaired.

c. 9 LRUs unrepairable for more than three years: All repaired.
d. 40 LRUs had open-circuit failures, 12 LRUs had short-circuit failures.
e. 7 LRUs were incorrectly wired and found through the Auto-mapping function.
f. The installed time increased from 289 to 729 average flying hours with an estimated year-on-year saving of US$1.5M.

All of the faults rectified were missed by conventional test equipment: finding things others can't.

The F-16 radar ribbon cable, carrying antenna position information, had no test set; the solution was to scrap the item and re-engineer a replacement The replacement item cost US$1600, but the crippling lead time was numbered in years. The ribbon cable was subject to neural network type testing where 74 of the 95-size sample tested had intermittent faults and the success of the repairs aborted the planned re-engineered purchase. The ribbon cable and its higher assembly were removed from the "High Notice" list.

Two mission critical and safety critical system faults on the RAF Chinook type had evaded both the Service and the Support Contractor. A portable neural-network tester was applied to targeted wiring looms and avionic chassis; system integrity faults were found in all cases. Components were replaced and quality wiring repairs effected realising increased availability and reliability paradigms; the specific neural-network testing was subsequently applied to all Chinook tail numbers at major maintenance. Once again, the faults were missed by conventional test equipment: finding things others can't.

Retaining the helicopter theme, a US helicopter VHF/UHF communications radio was recorded as having a 45% No Fault Found repair category when it was returned to the overhaul and repair contractor. The loss of LRU availability and mission reliability were crippling operations. The application of neural network test techniques identified 57% of the items had intermittent faults whilst 75% of these items had passed all prior serviceability tests. The faults were repaired and the surety of crew communications restored.

The Tornado spear-heads the RAF bomber force and nose-wheel leg centering after take-off was intermittent. This process must be automatic and missions were aborted and aircrew confidence in their equipment suffered; ground crews replaced the whole nose undercarriage leg. Application of neural network testing to the nose undercarriage cabling identified the faulty wire along with its exact location. The repairs were effected on-aircraft whilst after-repair testing qualified the complete cabling system.

Whilst neural network testing is superior for fault rectification, by early cable and connector qualification, Electrical Wiring Interconnection Systems can be guaranteed serviceable before they leave the maintenance environment. The result is far fewer unscheduled arisings and a growth in equipment confidence.

The two-engined Tornado has a Cross-drive clutch which powers the aircraft alternator. One aircraft tail number was subject to 30 component changes and logged over 500 man hours of investigation without curing the problem. Neural network testing of the whole system traced the cause to an intermittent circuit breaker providing fluctuating power to the Cross-drive clutch. The circuit breaker was replaced, the problem solved and maintenance practices revised to test this item and the whole system at routine inspections.

Whilst available weapon systems and intelligence are vital to the war-fighter, the businessman demands his in-flight coffee. One such executive machine, with a cappuccino selection, refused to dispense anything except a “short black”. The espresso machine worked without fault during multiple ground tests but to preserve his reputation, the OEM subjected the machine to a range of vibration and climatic environmental modes and “neural network” testing. The errant operation was traced to physical “bounce” in the microprocessor mounting socket: A redesigned chip restraint was installed and the executive gets his coffee whilst the OEM continues selling espresso machines. The power of the money trail. Identifying intermittent faults and their location is one attribute of neural network testing, qualifying systems before release is another but detecting deterioration and removing the offending component before the system fails is the “holy grail” of serviceability.

Prognostic Fingerprinting™

Neural-network test equipment and advanced processing techniques can generate successive ‘Fingerprints’ to monitor the condition of avionic systems over time. Voltage, current, frequency and phase signals are processed as vectors which can be arranged as an electronic map or fingerprint. The fingerprint software procedure captures, analyses and exploits the data in multi-layered arrays. Recognising what type of processing is relevant enables the software to characterise the circuit and build a unique fingerprint. Finger-printing of electronic circuits was the subject of a previous paper [13].

Neural Network Test Equipment

Test equipment which uses neural network principles to monitor all-of-the-wires-all-of-the-time exists [14]. Racked Intermittent Fault Detection and Isolation Systems can monitor 16,384 separate test points whilst portable Ncompass-Voyager™ type units have 512 test point and included Spread-Spectrum Time Domain Reflectometers. Such systems include:

a. Advanced Intermittent Fault Finding.
b. Continuity testing, with ohmic readout to a common Node.
c. Short circuit and open circuit identification.
d. Impedance analysis both instant and over time
e. LogScope™ display of resistance changes with time.
f. AutoMap™ of all test points to directly import into test programme generation.

All systems use the same technology and have been awarded Category One status against MIL-PRF-32156 for intermittent fault testing [11].

Conclusions

Mystery surrounds the disappearing symptom in technical fault finding; intermittent faults are the Achilles Heel of serviceability. Quality must be built-in to any product rather than being inspected-in and only in the last 20 years has this been applied to EWIS: suitable wiring test standards and test equipment have not kept pace. Digital technology has made ever increasing demands on interconnection systems and test equipment technology must match or exceed that of the Unit Under Test.

Fault symptoms can disappear along with the fault but the additive costs of No Fault Found, increased LRU stocks, availability lost and, eventually sustained effort to find the true fault are cumulative cost drivers: many of which still remain hidden.

Neural network based test equipment is technology-compatible with the latest of digital devices: it monitors all of the wires all of the time, traps any "glitch" for digital display and can be mated to other extant test technologies e.g. Time Domain Reflectometry. Test regimens must include, qualification testing, fast and repeatable system testing and prognostic abilities to remove systems before they fail. Measuring critical parameters then analysing the data for trends focuses the capability onto the most likely fault area reducing the repair time.

Existing neural network test equipment has proven its worth on multiple military and civilian platforms achieving Returns on Investment of up to 28 to 1. These simplistic financial returns ignore the benefits of increased availability and the psychological benefits of increased faith in capability. These systems have an inherent prognostic capability.

Disappearing symptoms are closely aligned with their intermittent fault cousins and by detecting and correcting intermittent faults, the product life-cycle can be extended along with greater availability and reduced support costs.

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