FAILURE ANALYSIS 101

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It seems intuitive to most with years of troubleshooting or failure analysis experience, but it's forgotten or ignored so much it bears repeating: **a methodical process is the best way to find and solve problems**. Methodical in this case does not mean slow, it means ordered and logical, which in turn leads to improved efficiency. Too often a scattered, shotgun approach is taken, trying to patch symptoms rather than finding and resolving root cause. The following four-step process is effective regardless of the scope or field of technology and a simple real-life example will be used to illustrate the process. This process is applicable to investigations in support of litigation, although the end goal is not repair or redesign, but thorough understanding of the facts and how they impact the case.

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Recently the author resolved an issue with a foot-operated electronic control device which included a footswitch. The device would operate correctly most of the time, but occasionally when the user would step on the footswitch, the device would stop working. Sometimes it would recover on subsequent switch presses and other times it would remain unusable. When the device stopped working, the user had to quickly patch around the control device to keep the real-time process from shutting down and the user would lose the additional control this device provided.

A good problem description sets the stage for the investigation to follow

1. Describe: The process starts with an initial problem description and a gathering of all available facts. The problem description or definition needs to be thoroughly reviewed to make sure you're trying to solve the real problem and not just a symptom. The problem statement shouldn't include any presumptions or hypotheses. It's important not to skip this step as attention to details at this point can save countless hours later. Facts and data need to be reviewed to determine how they relate to the problem at hand and to make sure the facts make sense relative to each other and the problem as defined. This comparison of all available information forms the basis for the next logical step. Before proceeding, it's a good idea to give the problem definition one more quick review in light of all the data, to confirm you're trying to solve the right problem.

Organize Data and Facts. Then use Plan, Test, Review to obtain missing information

In our example problem, the problem was defined as "determine how to make the device work consistently." Notice the problem definition does not include assumptions or solutions for the problem. A problem definition such as, "determine why the footswitch is intermittent" assumes the root cause is the footswitch itself. This needs to be avoided for a good problem definition.

2. Understand: The next step is to resolve any discrepancies in the data/facts and fill in any missing information in order to get a complete picture. This is the heart of troubleshooting - and the discovery process in litigation – gaining enough knowledge about the mechanisms, components, and factors involved in a situation to fully understand how the combination could potentially create the problem or failure. This may involve running additional tests, doing additional research, making measurements or observations, or using other means to provide a detailed picture of what may be happening to cause the problem. If some guesses or hypotheses are made, they need to be confirmed or refuted through testing and/or research. The gathering of information needs to be done in a logical and orderly manner rather than attempting a shotgun of tests hoping something useful turns up. The desired information should be identified (what is it you want or need to know?) and tests should be designed to provide the desired information. Using a Plan, Test, Review approach gives a much better chance of getting useful data. Desired information should be prioritized so the most important and useful tests are started first, even if they're not the fastest ones to conduct. One caveat is that testing which must be conducted over a long period of time, such as accelerated life tests, should be started early in the process so long-term tests can run in parallel with quicker tests. This step is complete when you have enough information to know what is causing the problem, malfunction, or failure.

A review of the schematic for our example control device showed this was an all analog control, so there were no microprocessor or code hang-up problems to deal with. This left the most common problems with analog equipment: power supply issues, connector failures, intermittent shorts or opens, or component failures. Complicating the trouble-shooting was that the problem never seemed to occur when the unit was open for servicing, so it was impossible to reproduce on the bench, and trouble-shooting during real-time use was not acceptable. One condition observed was that during failure there was no output from the device, which could possibly point to a power supply problem. An indicator light continued to function, however, indicating some parts of the system still had power. This contradiction of symptoms pointed to checking the power supply circuit first (generally a good place to start anyway). The power supply circuit was traced and confirmed to be working under all possible conditions. The circuit board was visually examined and any suspect solder connections were retouched. All possible areas where something could short to the metal housing were eliminated as potential causes. All components were determined to be well within proper operating range and bench testing near electrical limits showing all electrical components to be operating properly. The unit was returned to real-time operation, but kept in one state of operation and functioned properly through multiple real-time operating cycles. Once control of operating states was attempted, however, the device failed after a few cycles. The proper functioning in steady state operation and failure during change of state narrowed the likely causes of failure to mechanically induced failure during the switching process (short or open) or a faulty footswitch. Another bench test showed the switch to be operating properly during many cycles, so the footswitch was working. All grounding to the metal housing was confirmed to be as designed, and eliminated as a possible cause. While the unit was operating on the bench, the cover was replaced and the unit failed. The cover was removed and unit operated. The cover was installed one screw at a time until the unit failed. From the location of the screws that caused the failure, it could be determined where the cover was exerting force, which turned out to be the bottom of the footswitch. The switch used side terminals, so it wasn't shorting to the cover, but slight pressure on the body of the switch moved it just enough that one of the contacts was shorting to a terminal on a nearby control potentiometer, effectively connecting an op-amp input to V+ and therefore not allowing any signals to pass. Further examination of the switch showed that the body would move slightly during operation so even if the minor interference with the bottom cover was eliminated, the body could still move enough to cause the failure.

Solutions must target root cause, not the symptoms

3. Design: Once the root cause is known, the next step is designing a solution to the problem. In some cases this is obvious, such as replacing a worn out part to make a machine function properly again. Other times, however, the solution is much more complex, especially if the root cause is a combination of factors that are not easy to control. One thing that experienced engineers do is dig beyond failed components or systems to search for an underlying root cause. For example, replacing a torn belt may immediately fix an operational issue, but it's important to know why the belt failed. If it failed due to normal wear and tear, then the failure is expected and could be prevented by routine maintenance. If the failure was premature, however, it points to a deeper-rooted problem which needs to be identified – a poor quality component (the belt), improper installation, a more serious wear issue in the machine (such as ball bearings), or partial failure of another component (possibly a cracked or chipped pulley). Knowing the root cause enables the engineer to provide a lasting solution that prevents recurrence of the problem or failure and heads off other possible impending failures related to the same cause. This may mean a return to Step 1 or Step 2 above with a new problem description and new focus to the investigation.

Investigation must uncover enough detail to fully support root cause conclusions

This detailed deep dig is very important in litigation cases. Stopping at the high level immediate or obvious symptom means the litigant doesn't have all the information about what really went wrong. A thorough investigation is necessary to demonstrate that any subsequent testimony is based on sufficient facts or data and that the testimony is the product of reliable principles and methods.

In our example case, the root cause involved a few areas that needed to be addressed: (a) interference between the switch body and the cover should be eliminated, (b) chance of shorting between the switch contacts and the potentiometer contacts should be eliminated, and (c) movement of the switch body should be controlled, if possible. Item (a) was resolved by changing the mounting depth of the switch using the threaded shaft and dual mounting nuts on the switch. By allowing the footswitch to stick up a little higher, a clearance of 3mm was added between the switch body and the cover, with no effect on the operator. Item (b) was fixed by moving the wire attached to the potentiometer terminal to another angle, adding heatshrink tubing, and rotating the position of the potentiometer body. This provided a 5 mm space between the switch contact and the now insulated potentiometer contact. Item (c) was traced to the switch itself and corrected using a replacement switch with a solidly affixed body.

Validation of root cause and solutions demonstrates results are legitimate

4. Validate: The final step is validation of the solution and conclusions. Again the amount of work and time required depends on the complexity of the situation, the cost of the operation, the cost of failures (including down time), any regulatory requirements, and the novelty of the solution. Validation testing goes beyond functional testing to make sure the system works again. Proper testing must also determine that the solution has not adversely affected other parts of the system, confirm that the solution works in all possible operating conditions, and provide the operating limits of the solution.

The validation step is also extremely important for litigation. If conclusions reached in Steps 1-3 are easily to validate through additional

Validation greatly strengthens an expert's testimony

testing, that testing should be performed as evidence that the conclusions are fully supported. This is especially true in cases where the facts indicate the failure involved contributory factors that may be counterintuitive or of remote possibility. Without the support of validation testing, the expert is left to testify based on a hypothesis. No matter how plausible the hypothesis, the expert is exposed to challenge if the hypothesis could have been validated through testing, but no validation was done.

Validation in our example proved relatively simple since operation was so thoroughly checked during diagnosis and the root cause clearly identified. It was important, however, to test that the solution(s) did not introduce new problems. The wire connection to the potentiometer was double-checked after being moved, including a visual inspection of the solder joint prior to heatshrinking and electrical testing afterward. The clearance around all the potentiometer terminals was checked. This was important because a 90 degree rotation either direction, for example, would have caused an interference with the housing or cover and introduced new problems. The operation of the replacement footswitch, as well as inspection of the solder connections to the new switch were confirmed during validation on the bench. Real-time operational testing was also performed with the device performing many cycles without problems. The device has since returned to full operation with no problems.

Four Steps:

1. Describe
2. Understand
3. Design
4. Validate

The four-step process outlined above provides a framework for solving problems. The key to effective application of this process is the removal of assumptions in each step. All assumptions need to be confirmed or eliminated by validation through research or testing. This ensures decisions are driven by facts not feelings. Intuition helps a good engineer know where to look, but it's not a substitute for the facts. When hunches or intuition are wrong, many hours may be wasted trying to fix the wrong problem, running tests that are irrelevant, or trying solutions that don't work. By using the process above and making decisions based on the facts and data from each step, real solutions can be found in the most efficient manner.

As mentioned, the failure analysis approach described above is broadly applicable and the concepts can be extrapolated to provide a structure for technical investigations involved in litigation cases. When applied to litigation, the goal in some cases may not be complete exploration of root cause per se; it may be sufficient to verify that there was a failure and that the failure led to some other event. In some cases, the goal may be

For litigation, Step 1- Describe may be used to focus the efforts relative to the technical issues of the case.

The 4-step process may be repeated to investigate different aspects of the case

the assignment of fault related to a failure and how the fault contributed to the failure, including subsequent events.

To use the process in a litigation related investigation, the problem statement in Step 1 should be modified to properly reflect the perspective from which the problem will be approached. For example, if the control device described above operated a mission-critical system and the failure of the control device resulted in significant damage to a manufacturing system, there may be multiple questions that need to be answered:

a) Did the control device actually fail (permanent failure or intermittent failure) or was it the system the device controlled?

b) If the control device failed, what are the most likely reasons and was the failure a cause or effect of the system failure?

c) Were error recovery and protection systems designed into the manufacturing system and did those systems work or did they fail as well?

d) Were any failures a result of operator abuse or faulty installation?

e) Should the system designer have anticipated this type of failure and resulting damage to the manufacturing system?

f) Were there indications that this failure could occur or might be imminent?

The list could continue on, but the important thing to recognize is that answers to each of these questions may require an investigation structured according to the method proposed above, with accompanying problem description and gathering of facts. Fact analysis, hypotheses, research, and testing might all be used to answer any particular question. Once there is enough information to reach a viable conclusion, whenever possible, the conclusion should be validated through objective, scientific testing.

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