Electronic Product Failures – A Case Study

Sensors, Prognostics & Risk Avoidance

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Introduction.

The value of Prognostics and Health Management ("PHM")[1] is best understood by looking at what happens when PHM is not utilized. In the growing field of PHM, the mistakes of others often provide us with valuable real world lessons that should fuel greater development, understanding and use of PHM. The science of PHM should play an ever increasing role in the management of commercial risk associated with new product development. Taking liberty with George Santayana's famous quote: *"Those who cannot remember the past are condemned to repeat it,"* a student of PHM might say, "*Those who ignore PHM are condemned to fix the failure rather than prevent it."*

Many years ago, a significant failure occurred in graphics processing units (GPU) sold by Nvidia. The problems caused hundreds of millions of dollars of loss, not to mention losses associated with reputation, market and executive and engineering time and resources. Those problems may have been avoided with effective deployment of PHM.

At least $300 million is the cost of trying to fix the many problems caused by Nvidia's defective GPU's. As consumers began observing and reporting failures in their computers to companies like Hewlett-Packard, Asus, Toshiba, Dell, and others, the absence of effective PHM programs caused delay in understanding

[1] "Prognostics and Health Management (PHM) is a cutting-edge integrated technology, which takes knowledge, information and data [1,2] of system performance, control, operation and maintenance as input to: i) detect the initiation of anomalies, ii) isolate/diagnose the occurring failures, iii) predict the health state of the system in the future and estimate its remaining useful life to dynamically support the maintenance decisions [3,4]." Yang Hu, Xuewen Miao, Yong Si, Ershun Pan, Enrico Zio*, Prognostics and health management: A review from the perspectives of design, development and decision*, Reliability Engineering & System Safety, Volume 217, 2022, 108063, ISSN 0951-8320, https://doi.org/10.1016/j.ress.2021.108063.

the problems, the failure mechanisms, the root cause and the available corrective actions. These delays resulted in continued production and sale of defective units, ineffective solutions, consumer and securities lawsuits, and dramatically increased costs. As the American saying goes, *"An ounce of prevention is worth a pound of cure."*

Is There Value In What We Do?

"Smaller and faster" is a common phrase used to describe the electronics industry's race to develop the next generation device that will capture the imagination of consumers in a wide variety of markets – smart phones, notebook computers, video game consoles. Compressed product development cycles often result in less than robust testing and qualification of key components, systems and the products themselves. Against this backdrop, the supply chain funnels an increasing volume of diverse components and systems – often with differing specifications and builds – into a narrow ODM market. A development process on this path will inevitably yield a growing number of failures like that experienced by Nvidia and, consequently, its OEM partners.

Expanded development and use of PHM tools will help to identify at an earlier stage of product deployment those deviations from normal operating conditions that are most likely to lead to failures. The early gathering and analysis of these data are certain to speed the understanding of potential failure mechanisms which, in turn, will enable more rapid and effective corrective actions during the manufacturing process, as well as after the product has entered the stream of commerce. Expanded use of PHM carries with it the very real prospect that every stage of a product's life cycle will fit within an all-encompassing cycle of failure prediction, prevention and continuous product improvement.

As PHM enables us to create an environment in which product failure is more rapidly predicted and prevented, we will increasingly be able to manage the costs and damage associated with epidemic failures. As we look at the enormous damage brought about by Nvidia's GPU problems, the business community should applaud and support your efforts to develop an ever increasing arsenal of PHM tools and methods.

Nvidia's GPU Problems.

Our knowledge of Nvidia's GPU problems can be gathered from a variety of publicly available sources, as well as our own experience with similar large-scale

failures. These sources include Nvidia's own filings with the U.S. Securities & Exchange Commission ("SEC"), filings with the U.S. District Courts handling a variety of claims stemming from the GPU failures, as well as to a lesser degree on-line consumer complaints and reporting by interested journalists.

At least 24 Nvidia chips are alleged to be defective. The accused chips can be found in many models of computers (mostly notebooks) manufactured by at least 3 ODM's for at least 8 OEM's. Nvidia has reported that due to a "weak die/packaging material set" the affected chips tend to fail. It has been reported that the failure mode is cracked bumps. The root cause of the cracked bumps has been subject to much discussion and debate, which continues to this date.

This much is clear, however. In early 2007, consumers began reporting problems with their computers to OEM's. By June 2007, OEM's were discussing the problems with Nvidia and at least one ODM. By this stage, attorneys were engaged, and an outside consultant was hired, to help determine the root cause of the problem. Finally, on July 2, 2008, Nvidia stated in a filing with the SEC, that "it would take a $150 to $200 million charge against the cost of revenue to cover anticipated customer warranty, repair, return, replacement and other consequential costs and expenses arising from a weak die/packaging material set in certain versions of our previous generation MCP and GPU products . . . ." ODM's had continued to manufacture, and OEM's had continued to sell, computers with Nvidia MCP's and GPU's during this lengthy and ongoing failure analysis process.

First Signs of Trouble.

At the same time consumers began reporting problems to OEM's, the consumers turned to internet postings and complaint boards to express their frustration with the slow or inadequate responses they received. The reported problems and complaints included: no video, unexpected shut-downs, excessive heat, random characters, failure to reboot, vertical or horizontal lines, inability to recognize available wireless connection, no power, failure of LED lights, and multiple images. Many of the problems were intermittent and could not be repeated on warranty returns.

Due to the variety of reported problems, and the apparent delay by the OEM's in focusing their attention on Nvidia, it appears that it took the OEM's several months to understand the failure mechanism that produced the reported

symptoms. During this time, and even later, there was either insufficient data to permit corrective action, or a desire by the OEM's to simply push past their consumers' warranty expirations and hope for the best. In any event, the lack of a mechanism with which to obtain accurate real time data (*i.e.,* no PHM) contributed to this delayed understanding, which in turn led to continued production and supply of computers with defective Nvidia chips.

The Learning Curve.

By the middle of 2007, it appears that H-P was taking the lead in the investigation of the growing field failures of computers that had incorporated Nvidia's GPU's. A joint defense team (formed to deal with the impending avalanche of lawsuits) apparently comprised of H-P / Nvidia / Quanta began consulting with outside experts to understand the root cause of the failures. From mid-2007 through mid-2008, and beyond, the group was involved in many, many series of tests, experiments and analyses of the affected GPU's, boards and systems. Later, the joint defense team appears to have also included Pegatron in its ongoing failure analysis efforts. The wide-ranging post-problem analyses yielded no conclusive root cause determination.

Ultimately, when Nvidia reported these material events in its July 2, 2008 SEC filing (as well as later filings), it was at least publicly stating that it could not determine a root cause. According to Nvidia, "while we have not been able to determine a root cause for these failures, testing suggests a weak material set of die/package combination, system thermal management designs, and customer use patterns are contributing factors." Thus, at least publicly, Nvidia was blaming its suppliers, customers and consumers for the failures. However, as events would unfold, Nvidia would pay millions of dollars to its customers – the OEM's – to support their extended warranty programs and other efforts to deal with the ongoing failures.

Had the ODM's and OEM's recognized the value of PHM, and incorporated it into their products, it is likely that deviations from normal operating conditions would have been identified early during the deployment of the affected GPU's and MCP's. Instead, the market was flooded with products that presented consumers with varied and intermittent failure symptoms that required months (years) to understand.

Who & What Is Affected.

The solder bump cracking in Nvidia's GPU's has affected numerous OEM's and ODM's. From what we can discern from court filings, internet postings and investigative journalists, the affected companies include virtually every computer ODM and OEM. In the U.S. class action lawsuit consumers brought against Nvidia, the consumers' attorneys say that the affected Nvidia chips include at least 24 models of 9 different GPU's and MCP's.

The bulk of the affected computers appear to be notebooks, although consumers have reported some desktop failures. This appears to be related at least in part to the differing thermal management issues associated with notebooks versus desktops.

The Missed PHM Opportunity.

This single epidemic failure event involving Nvidia's GPU's and MCP's should reveal PHM's exceptional value. Without PHM, Nvidia, the ODM's, and OEM's were left to wade through delayed, sparse, and inconsistent consumer data. There could be no uniform standard for collection of this hodgepodge of consumer data, which made any application of PHM algorithms and other tools equally impossible. Months went by without anyone - from component supplier to OEM – being able to understand that patterns existed within the data, and that those patterns were the early warning signs of a growing wave of failures about to crash upon them. Of course, the scope of the problem continued to rise as the defective products continued to make their way into the stream of commerce during this period of delayed realization.

The Consequences.

As of early December 2009, Nvidia has announced that it has or will incur costs of approximately $300 million simply to deal with satisfying the demands of its customers – the OEM's. It has already entered into settlement agreements with many of its customers whereby it undoubtedly has agreed to bear the financial burden of extended warranties and other customer support services. These costs do not appear to reflect the costs it will incur in dealing with consumer litigation against it, consumer litigation against its customers, or its shareholders' class action stemming from its alleged extreme delay in reporting this fiasco to the public. Although it is impossible to say for certain, the ultimate cost of these problems could grow significantly once all the litigation has been resolved.

Delayed Announcement – Securities Class Action.

Nvidia's first public announcement that it had a problem with its GPU's came on July 2, 2008 when it filed a Form 8-K with the SEC reporting that it would take a charge of $150 – 200 million dollars as a result of the problem GPU's. The share price of Nvidia's stock dropped dramatically on that news. As one might imagine, Nvidia's shareholders were not pleased.

Upon learning that Nvidia had known that there was a problem with its GPU's for more than a year, Nvidia's shareholders became infuriated and filed a class action lawsuit on September 9, 2008 naming as defendants Nvidia, its President and CEO, Jen-Hsun Huang, and its Chief Financial Officer, Marvin Burkett. That lawsuit, filed in the U.S. District Court for the Northern District of California, is still pending.

The securities class action is rather dramatic evidence of the cost of delayed understanding of a problem. If the Nvidia GPU problem had been identified earlier, perhaps Nvidia would have been able to make a public disclosure sooner and avoid the securities litigation. Effective use of PHM is the key to this early identification of data anomalies and understanding of the problems likely to ensue. Without these tools, the delay in gathering, analyzing and understanding the data will invariably lead to increased cost and loss.

Massive Field Failures & Band Aid "Solutions" – Consumer Class Action.

Nvidia, the ODM's, and the OEM's have not announced the number of computers affected by the Nvidia GPU's, but it is safe to assume that the number is massive. The volume of complaints posted on OEM websites, internet blogs and complaint boards, as well as those reported in the press, all attest to the pervasive nature of this industry-wide problem. When the consumer complaints began to flood the OEM's, they reacted slowly and inadequately. This simply fueled the surge in consumer litigation.

In late 2008 and early 2009, approximately 10 consumer class actions were filed in courts around the U.S. alleging that various OEM's, as well as Nvidia, breached statutory consumer warranties, and are liable under theories of strict liability, negligence and unfair competition. The U.S. District Court handling the consumer class action recently upheld the adequacy of these claims against Nvidia, even though Nvidia never dealt directly with the consumers bringing the

litigation. In sum, the Court held that a consumer may sue a component supplier directly!

The OEM's and Nvidia have long sought to deflect the consumer litigation by arguing that even if they knew that computers containing Nvidia's GPU's were likely to fail prematurely, the consumers' remedies were limited to the terms of the OEM's warranties. Thus, the OEM's have argued that if the failures occurred more than one year from purchase, that was simply too bad. This approach may well have prompted the OEM's to ignore or minimize the problem for as long as they did.

In November 2007, at the latest, several OEM's made BIOS updates available on their websites that caused the computer's fan to run constantly. Perhaps cynically, the OEM's expected that the BIOS update would provide enough "life extension" to push the affected computers beyond the one-year warranty they had provided to their customers. In any event, this "band-aid" approach to the problem was ineffective and unsatisfactory. The consumer complaints continued, as did the litigation, which was eventually consolidated before a single U.S. District Court Judge, the same Judge hearing the securities litigation arising from Nvidia's delayed reporting of the GPU problem.

OEM Extended Warranty Expenses.

As it became clearer that the scope of the Nvidia GPU problem was enormous, and that a simple BIOS update would not satisfy their customers' concerns, the OEM's began extending the term of their warranties. Naturally, they looked to Nvidia to pay all associated costs – reportedly tens of millions of dollars for many OEM's.

One after another, Nvidia began settling the claims that were being asserted against it by its customers – the OEM's. Written settlement agreements were executed and it may fairly be presumed that Nvidia agreed to provide the financial resources necessary to handle customer product returns, motherboard replacements, and associated costs. Although these settlement agreements are not publicly available, the Court has recently ordered Nvidia to produce copies of the agreements to the consumers' attorneys so that they can evaluate the efficacy of the remedies being offered to consumers.

While Nvidia is funding the OEM's extended warranties and related expenses, the OEM's will certainly suffer uncompensated damages and lingering doubt

about their products. The scope and duration of customer dissatisfaction and consequent loss of market share that the OEM's and Nvidia have suffered cannot be cured quickly, or with money. However, early detection, if not prevention, of product defects through PHM promises a "remedy" whose time might well have come.

Conclusion.

Without PHM, we are generally left to gather performance limited data only after a defect or failure has already manifested itself on a large scale. The delay between product deployment and the start of data gathering creates a gap through which more and more defective product flows into the stream of commerce. This delay results not only in greater remedial costs, but also in more significant loss of goodwill and market share. At its extreme, the delay has a negative impact on failure analysis and root cause determination, which can lead to slow public reporting and investor litigation.

These problems are not without a solution. PHM enables the immediate and large-scale gathering and analysis of performance data. With appropriate PHM tools employed to identify patterns in the data that might suggest possible defects, we may be able to take corrective actions early so that large volumes of defective products never enter the marketplace. Had effective PHM been utilized by those involved in the Nvidia GPU problem, it is not difficult to imagine that the resulting damages would be but a fraction of the $300 million lost so far.

PHM promises enormous benefit to manage and reduce risk of loss from product defect and failure. The challenge is to help business see this potential. Perhaps the carnage wrought by the Nvidia GPU problems will bring the value of PHM into greater focus.