Prognostics-Based Warranties

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A warranty is a manufacturer or seller's assurance to a buyer that a product is or shall be as represented. When products do not perform as expected, the manufacturer or seller must provide a remedy, such as repairing or replacing the item, to fulfill the contract of the warranty. This is an important aspect of the purchase of a product by a customer, especially when the product has a significant cost.

A warranty provides evidence that the manufacturer cares about its customers and indicates the dependability of its product servicing and the willingness of the manufacturer to cooperate in solving possible problems [1]. Longer warranty coverage is often a tool that marketers can use to convey the seller's confidence in its product. For example, Hyundai began offering a 10-year/100,000-mile powertrain warranty in the U.S. to differentiate itself from its competitors, and ultimately increased its share in the U.S. market to 4.6% by 2010 [2][3].

Warranties can be expensive for manufacturers and their suppliers if their products fail too quickly; costs generally include providing administration, repair, and field service [4]. According to *Warranty Week Magazine*, the top 20 U.S.-based warranty providers paid over $25.5 billion in warranty claims in 2009: warranty costs were around $2,701 million for Hewlett-Packard, $1,561 million for Ford Motor Company, $780 million for General Electronic, $353 million for Microsoft, and $303 million for Apple [5]. In 2009, automotive manufacturers and their suppliers spent $11.3 billion on warranty claims in the U.S. [6]. These large costs suggest that companies are still not appropriately designing or testing for reliability. It also suggests that their warranty business practices are out of kilter.

In practice, the prediction of future warranty costs is often carried out based on historical warranty data for similar products, sales data, and warranty claims captured in the early stages of product lifetime. However, historical data for similar products will not be appropriate for new technologies and new ways of using products (for example, the use of computers has changed significantly with wireless applications). Moreover, early product life cycle warranty data may not capture complex failure trends caused by component hazard rates that change with time [7]. Other problems with warranty claims data include delays between failure occurrences and the time when claims are made [8], as well as underestimation as a result of some claims not being documented [7].

To help the customer and the provider of warranties, a new prognostics-based warranty paradigm has been in development at the Center for Advanced Life Cycle Engineering at the University of Maryland. Prognostics and health management (PHM) is an enabling discipline consisting of technologies and methods to assess the reliability of a product in its actual life cycle conditions to determine the advent of failure and mitigate system risks [9]. PHM utilizes sensing, data analysis, and interpretation of environmental, operational, and performance-related parameters to indicate a system's health status in terms of performance deviation (such as deviation of operational parameters from their expected values); physical (e.g. material, chemical, electrical) degradation; and changes in life cycle conditions (e.g. operational temperatures, humidity, vibrations) and usage duration and frequency [10]. Using this approach, PHM can help access the actual usage conditions, detect initial degradation, and estimate the remaining useful life of a product.

This paper describes the application potentials for new business models based on PHM. It is assumed that the reader has an understanding of PHM fundamentals (an overview of the approach is shown in Figure 1 and described in detail in reference [11]).

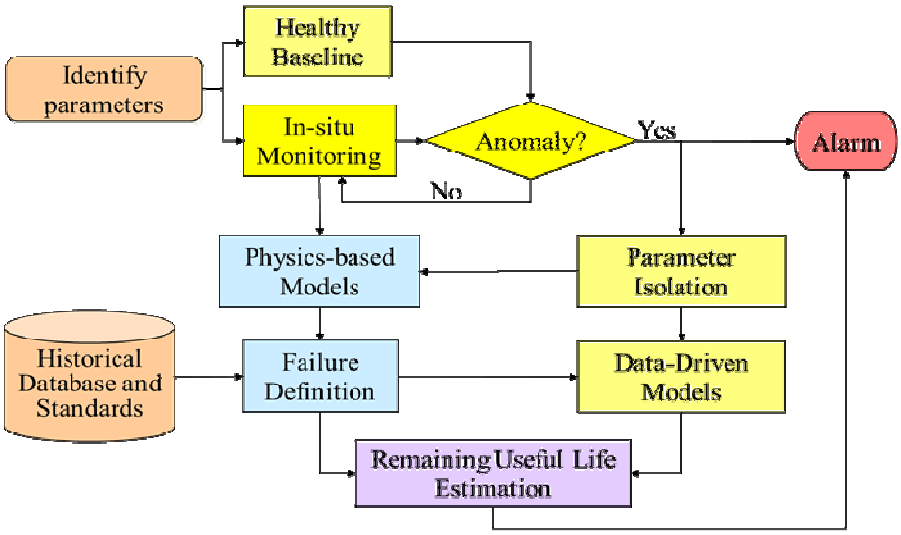

Figure 1. Health monitoring and fusion prognostics

Changing the Warranty Paradigm

Most warranty service is performed after the occurrence of failure. A PHM-based warranty philosophy shifts the warranty from a reactive paradigm to a proactive "warranty service prior to failure" paradigm.

For repairable products, knowledge of incipient degradation or deviation provides warrantors with an opportunity to forecast repair tasks to prevent further product deterioration, field failures, and system downtime. It is estimated that $35 billion could be saved per year in the U.S. alone if forecasted maintenance was employed [12]. The prediction of remaining useful life can be used to conduct maintenance and logistics planning to reach an optimized warranty decision. For example, a wind farm can conduct maintenance of multiple turbines at one time during low-wind times of the year based on the predicted remaining useful life.

PHM can also be incorporated into a non-repairable consumer product so that the customer can prepare accordingly prior to the occurrence of a failure to reduce losses from product downtime. The preparation for the occurrence of failure may include contacting the manufacturer for service, backing up data from the device, or using resources to temporarily replace the product. Furthermore, PHM diagnostics can be used to identify means to "control" product degradation and avoid losses in system functionality. Thus, a PHM-based warranty is able to increase customer satisfaction and retain customer loyalty. In addition, the manufacturer can track the customer's usage of their product to have early information about the performance of their product, which can be used for further business decision-making.

Warranty Returns with No Identified Defect

No fault found (NFF)—also known as trouble not identified (TNI), no trouble found (NTF), cannot duplicate (CND), or re-test OK (RTO)—occurs when a failure is reported, but cannot be verified, replicated at will, or attributed to a specific failure site, mode, or mechanism [13]. Warranty returns can be excessively high if the rate of NFF determinations is too high [13][14]. For example, Pecht et al. [15] found that NFF observations on electronics in avionics systems can be as high as 70%, and can result in removal of items that may not have failed, but may be relevant to a suspected failure. Some of the NFF problems arise because the field failures often exhibit intermittent behavior and thus are hard to replicate, often due to a lack of information about the actual usage conditions. Delays in understanding these failures can lead to continued production and sale of defective products, ineffective solutions, increased warranty costs, and lawsuits.

Devices that are reported as NFF during the first troubleshooting session are often returned again later with the same NFF symptoms or a permanent mode of failure. Mechanics tend to replace everything that may cause the problem in order to avoid sequential failures and save testing time. However, this often leads to perfectly good units being removed, which results in costly expenditures under warranty. For example, in an investigation of NFF in a cruise control module, Kimseng et al. [16] concluded that the test conditions of the manufacturer were not representative of the actual usage conditions. PHM collects real-time environmental, operational, and performance-related data, which allows technicians to understand and reproduce field usage conditions in testing. Moreover, PHM can provide online fault detection, as well as prediction of failures. It is possible, through data-driven PHM approaches, to notice sudden changes in system parameters [11].

PHM Enabled: Extended Warranties

Manufacturers, insurance companies, and third party administrators are providing consumers with extended warranties (service contracts) for a prolonged period at an extra cost to reduce consumers' risk of product failures after the base warranty coverage. For example, the designed life of a wind turbine is 20 years; however, most wind turbines carry only a two- to five-year standard warranty. The maintenance cost will be a large expenditure to the operator or owner after the OEM's warranty expired. Similarly, the average life of a vehicle is over 13 years (145,000 miles) [17], but auto manufacturers offer much shorter warranties. The expected life of a cell phone or a laptop may be three to five years, but most manufacturers provide only a one-year warranty for each. Thus, there is a huge service contract market for extended warranty providers. According to *Warranty Week*'s estimation, the revenue of the 109 extended vehicle warranty providers in the U.S. in 2010 was over $11 billion at the contract sales level [18]. Ford [19] sees longer warranties as a competitive advantage for the company; it believes that customers look at warranties when they make purchasing decisions.

The pricing of an extended warranty typically depends on the original price of the product and the coverage and length of the contract. However, the actual product reliability will depend on the inherent defect populations within the product population as well as the life cycle that the product was subjected to, which will result in different costs to the extended warranty provider. PHM enables the supplier and the customer to determine the health status and remaining useful life of a product. This information could be used to determine reasonable costs to the customer based on the health condition of the product, and provide a risk assessment for the service contractor. For example, if the product has used extensive useful life on some expensive components, it may be reasonable for the contractor to charge more for offering an extended warranty. However, the contractor may be able to reduce costs (e.g. volume buys of spare components) if certain warranty problems can be forecasted.

Lifetime Warranties

With PHM technologies integrated into a product, there will be opportunities for manufacturers to promote lifetime warranties, so long as the product is maintained appropriately. The maintenance may in fact require the replacement of certain components in the system and can be thought of in a similar way as replacing the oil in a car. The remaining useful life estimated from PHM can be used to determine the end of life of the components. As a result, PHM is able to create failure-free, always available, or failure-under-control systems through anomaly detection and advance warning of failure.

Availability is the instantaneous probability that a system or component will be available to perform its intended mission or function when called upon to do so at any point in time. PHM can mitigate failures by forecasting maintenance, so that maintenance and repairs can be scheduled when resources are accessible and repairs can be scheduled to take place low availability requirement periods, thus minimizing system downtime. When PHM technology is applied to a fleet, the overall output of the fleet can be guaranteed by prioritizing the manufacturer's maintenance resources to first work on systems that need service more urgently and allowing the manufacturer to create an optimized maintenance plan to serve multiple systems at one time to reduce the overall warranty cost. The availability-based warranty strategy is a new opportunity for businesses.

PHM also enables an effective approach for paying by service hours. For example, an airline does not purchase an engine itself. Instead, the contract guarantees the flight hours that the engine can perform and the engine company undertakes all the maintenance tasks. A manufacturer can afford this type of warranty only when it has a low-cost and efficient servicing system. In the future, there is no reason we cannot apply this to all products, including cars, computers, smart phones, and home appliances.

Incorporation of PHM into products will make manufacturers confident about prolonging their warranty periods due to increased field reliability, improved warranty service, and reduced warranty costs. A company may further offer a lifetime warranty based on PHM systems to reassure customers and differentiate itself from its competitors.

Acts of God and Humans

Not everything that goes wrong with a product falls within the scope of a warranty. Warranties often have clauses that do not cover problems caused by "acts of God," abuse, misuse, malicious destruction, ordinary wear-out, failure to follow directions, or improper maintenance (we will use the term "misuse" to cover all these items), and a warranty may state that misuse voids the warranty. However, it is often difficult to detect the differences between natural use and misuse.

An example of the assessment of warranties for misuse is the Apple iPhone. In an apparent effort to reduce warranty costs due to what they considered customer misuse, Apple placed water sensors in their phone to determine, for example, if the phone was dropped into water. If the sensors were triggered (in this case, turned red), then the Apple dealerships could deny warranty coverage, even if the owner purchased extended warranty coverage. However, Apple customers have complained that the sensors can be triggered by normal-use conditions, such as sweat from exercising, condensation in hot climates, and from holding the phone after washing dishes. Since Apple did not open the phones to determine the actual reasons for the failure of the phone (if indeed it was caused by a liquid at all), this means that they had no actual knowledge and indeed could be denying customers their rights under warranty. Prognostics-based warranties can alleviate this problem by providing diagnostic information to understand the root cause of a problem and its potential symptoms.

Warranty- and Safety-related Recalls

High failure rates under warranty can trigger a recall. Recalls can also be triggered in the case of safety-related failures. In such cases, the manufacturer may not only have to bear the direct warranty costs, but also accident costs, court fees, and losses due to damaged reputation and sales. For example, Toyota recalled approximately 2.3 million vehicles in the U.S. in January 2010 due to sticky accelerator pedals [20]. The National Highway Traffic Safety Administration (NHTSA) reported 52 deaths in accelerator-related crashes [21]. The total cost of the recall was considered to be as high as $900 million [22].

PHM has a significant advantage in situations where a wear-out failure mechanism is the cause of the recall. When an anomaly is detected, fault parameters and problematic components can be quickly located and isolated from the system to permit identification of failure root causes for the customer. Such PHM methods can enable service- and maintenance-related resolutions rather than recalls.

In the case of recalls, PHM can facilitate proactive logistics support. For example, if the prognostics solution is designed in such a way as to show where and how the product is degrading or failing, then the manufacturer and supplier can acquire the necessary equipment and supplies before the product comes in for servicing. Spare parts, equipment, and labor, if scheduled beforehand, are cheaper than if they were to be expedited.

Summary

PHM can help business warranties by resolving warranty problems, improving maintenance practices under warranty, reshaping warranty policies, and enabling warranty strategies. The field usage condition data collected from health monitoring can provide information for warranty diagnostics. PHM is capable of capturing sudden changes in systems and identifying NFF failures. PHM techniques can locate and isolate faulty structures quickly and help understand the root causes of failures. Due to the prognostic abilities of PHM, defects of products can be revealed early on to mitigate problems associated with recalls and safety issues.

Anomaly detection, advance warning of failures, and RUL prediction can enable a proactive warranty paradigm and improve the warranty decision-making process. Real-time interpretation and feedback information are used to conduct timely and effective maintenance to minimize system downtime. Prediction of RUL and future (not impending) failures is used to plan maintenance schedules and facilitate efficient logistics support. Manufacturers can also make use of the real-time conditions and RUL estimation to decide whether to perform perfect, imperfect, or minimum repair in warranty service, achieving active management of the system's health.

PHM has the potential to drive future warranty strategies for companies to increase their competitive advantage. PHM methods are able to prevent a system from degrading by isolating it from inappropriate conditions or failing parts. PHM will permit companies to offer longer warranties at lower prices, which can further enable lifetime warranties in industry. Availability-based warranties can be implemented with the adoption of PHM, which will guarantee the availability of a system or a fleet and reduce life cycle costs. Reliability evaluation through PHM will enable flexible extended warranties and bring various benefits for both warranty providers and customers.

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