A Note on Failure Mode Avoidance

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Abstract

Category

Case Study

Purpose

To enable failure mode avoidance it is necessary to understand when and why potential failure modes are created. The purpose of this paper is to understand when and why potential failure modes are created, to create a better base for failure mode avoidance.

Methodology/Approach

This paper is based on a study of ten customer related reliability problems in an automotive company. The interviews were all based on open-ended questions that facilitated the interviewees to give narrative descriptions of their views and experiences. In total 13 interviews, each between one and two hours, have been performed and secondary data has been used as a complement.

Findings

The cases analysed are all customer related problems; meaning that the failures were detected when the product had been introduced in the market. However, a majority of the failure modes were created in early development phases. Many of the failure modes that eventually occurred in customer use had their cause in the concept development and selection phase. A costly time gap seems to exist between failure mode creation and failure mode detection. The research in this study indicates that this gap could probably be minimized and faults avoided through a more proactive failure mode avoidance work.

Research Implication

This paper calls for a change of mindset in the work to improve reliability; a change from a focus on failure mode detection to failure mode avoidance. This implicates a need to frontload the product development process in terms of reliability enhancing efforts.

Originality/Value of paper

For researchers as well as practitioners in the field of reliability this paper offers an insight into current industrial practice in this area, revealing areas in which further research and development is needed. The findings of the paper will hopefully facilitate a shift in reliability practice from work on failure mode detection to work on failure mode avoidance.

Keywords

Failure Mode Avoidance, Failure Mode Detection, Reliability, Robustness

1 Introduction

Clausing (2004) define reliability failure modes as any customer-perceived deviation from ideal function of the product. Further, Clausing (2004) and Clausing and Frey (2005) outline two main causes of failure modes: lack of robustness and mistakes. Both mistakes and design decisions that lead to lack of robustness can occur during all stages of product development. In other words, associated with all product development, and all its stages, is the creation of potential failure modes.

Naturally, there are a lot of efforts made to avoid failures and failure modes. An example of such an effort is reliability engineering and its related methods (for an overview see IEC 60300-3-1 (2003)). These methods, e.g. Failure Mode and Effects Analysis (FMEA), aim at identifying potential failure modes and if necessary initiate appropriate countermeasures so that they stay potential and do not eventually become real failures. Thus, in summary reliability methods aim at preventing failures, as outlined by Clausing (2004) "reliability is failure mode avoidance."

In the preventing spirit is also an underlying assumption of reliability methods as being proactively used. Proactive is defined in Oxford English Dictionary as something "that creates or controls a situation by taking the initiative or by anticipating events (as opposed to responding to them)." In literature on quality and reliability improvement proactive work is regarded as desirable; see e.g. Clausing (1994), O'Connor (2000, 2002), Davis (2006a). However, proactive use of methods can be distinguished into two groups. The first group concerns identifying and executing a solution to a potential problem, before a fault occurs. The second group is to foresee potential failure modes and prevent the failure mode from being created. In this paper we refer to the first group as proactive and the latter as genuinely proactive. Figure 1 provides an illustration of these concepts.

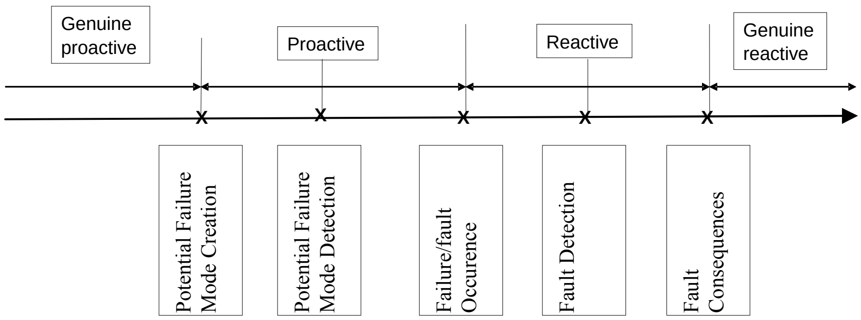

Figure 1. Categories of countermeasures related to failure/fault development. Failure Mode is the termination of the ability of an item to perform a required function, fault is the state of an item characterized by inability to perform a required function (according to nomenclature in IEC standard). Thus, failure is an event whereas fault is a state.

Thompson, Liu and Hollaway (1999) state that reliability analyses tend to be applied in the detailed design stage in order to verify the reliability of the product. The emphasis on verification gives rise to a thinking of reliability efforts applied in a reactive manner. Davis (2006a) also state that many failure modes are detected well after the drawings have been issued. He further states that "at this stage, failure modes are easy to find, but they are hard to fix because the latitude to take the proper counter-measure is severely restricted."

To enable a genuinely proactive work it is necessary to understand when and why potential failure modes are created. As expressed in Davis (2006a) the focus of reliability efforts should be "directing the actual failure modes themselves (the *how* and *why* of things failed), rather than the consequences of the failures after they have escaped into the field". The purpose of this paper is to understand when and why potential failure modes are created, to create a better base for failure mode avoidance.

2 Method

This study is based on interviews with persons involved in product development at Research and Development (R&D) departments at a company in the automotive area. The interviews were all based on open-ended questions that facilitated the interviewees to give narrative descriptions of their experiences (Silverman, 2001). Cases selected as subjects for interviews were development assignments that had been pointed out as causes to customer related concerns. The cases were all selected from one specific development project that shared several system solutions with other brands within the same company group. This means that the investigation was not strictly limited to product development at the company investigated but also includes its collaborators like other brands within its company group as well as suppliers.

At the company there is a special follow up fleet of early production vehicles for new projects, where all customer related concerns are reported by the drivers. The follow-up vehicles are normal production cars, i.e. no prototype vehicles, and the drivers are employees who use the cars in their daily life but have a special assignment to report all types of experiences of the car. Here, experiences can refer to any type of problem, experienced or even ideas or fears of things that might go wrong. The idea is that the concerns shall represent viewpoints of customers in general.

Connected to the follow up fleet is a special workshop that is used for all maintenance, problem analysis and repairs of the follow up vehicles. The information from the workshop activities is stored together with the customer related concern. If any corrective action on the car model is required, the concern will also be registered in a problem follow up system used at R&D.

The problem follow up system was used to select cases to study and to identify interviewees. More precisely, ten customer related reliability concerns, registered in the system, were studied. Technical information on the concerns were provided by the vehicle follow up system whereas the problem follow up system made it possible to find interviewees. Referring to Figure 1 above, these concerns were all identified through "fault detection", i.e. the failure had occurred and it is worth noting that by selecting concerns in this way the study only covers problems that were detected in late phases of product development.

The ten concerns were selected on the basis of being reliability related problems in areas interesting for the company. The cases were also selected in such a way that all main areas of the vehicle were covered, i.e. powertrain, chassis, electrical and body and trim. For each of the cases at least one interview has been performed. In total 13 interviews, each between one and two hours, have been performed. During this study no interviews were held outside the company under study, e.g. with suppliers. Although the intention of the study was to get the interviewees personal view of what had occurred, this has to be kept in mind when the result is analyzed, evaluated and interpreted. In some cases additional information from other sources was used as a complement, e.g. internal communication that had taken place when the fault was detected.

3 Results

Since all the problems selected for this study had been detected in a late stage of product development, none of them belong solely to the "foresee and prevent" category. However, as will be discussed below, many of the problems had a possibility to be prevented before they occurred.

3.1 Detection of Failure Modes

As already mentioned, the cases studied have been chosen from a database containing various concerns with cars from serial production. Thus it is by the selection process per se given that the failures or concerns have been detected in connection to, or after, start of production. However, the empirical study reveals that there are cases in which prerequisites for proactive work existed, but this possibility was neglected. In other words people working with the product had knowledge of a potential failure mode and ideas of how to prevent a failure, but by various reasons the preventive work was hindered.

In one case a component was bought from another automotive company mainly selling their products in a different geographical region. The component was not adapted for varying fuel quality; the fuel in certain regions could cause a failure of the component. Technical experts in the company knew about the potential failures and advocated that further investigations were necessary. However, they felt that the decision makers did not want to listen to their concerns as the contract for this component was already signed. The failure later occurred and corrective actions had to be taken after start of production.

Another similar example concerns a disturbing sound from a component that was detected in the development phases. In this case one reason not to take corrective actions in a preventive mode was time limitations. In other cases, the pressure of short development time limited the number of tests of various user conditions. Thus the concerns slipped through the development process and were not formally detected, i.e. registered in the problem follow up system, until after delivery of the cars.

3.2 Failure Mode Creation

Looking at the creation of failure modes it is important to be aware of that one problem might have many interacting causes, created at different times. In the interviews the interviewees have given their perspective of the creation of failure modes, often focusing on what they consider to be the main cause. Based on the interviewees' statements, four phases in which failure modes are created has been identified (see Figure 2 for a graphical overview of these phases).

Several causes are connected to the *concept development and selection* phase. The actual problem was often not visible at this stage but occurred in later phases e.g. a selection of a concept that could not work under exceptional conditions of use. Examples are insufficient capacity of drainage systems or components too sensitive to variation in fuel quality on different markets. In some cases problems occurred due to selection of components with a lower reliability performance; components that had to be chosen as a consequence of the system solution selected. For example a selected sealing system required a specific type of seal, once in use the test customers discovered that this type of seal gave rise to unacceptable levels of disturbing sounds under certain circumstances.

The second phase where failure modes are created is during the detailed design, the *system and component design* phase. These problems were caused by failure modes/mechanisms that are often known to the engineers. However, the systems are complex and it is difficult to keep control of all factors influencing the system. Examples are problems related to the climate control system or the comfort of the brake system. In one of the cases studied the possible failure modes of a system were known to the engineers and taken care of in their design. However the system they designed was affected by many other components and during the product development process another design team had problem with their component and changed it accordingly. This change in turn gave rise to the failure mode affecting the system studied.

A third phase of failure mode creation is related to changed properties of components when they are transformed from prototype parts into production parts, thus this is a cause related to the *process design* phase. Parts produced in the serial production processes showed a higher degree of variation in e.g. dimensions than the prototype parts. Examples are a component in the climate system that was out of specification once in production, and problems with geometry that caused air leakage.

In some of the cases unexpected problems occurred at *start of production* that caused parts and components to be out of specifications. This was a fourth phase where problems were created.

3.3 Views on Failure Mode Avoidance

During the interviews the interviewees were encourage to come up with proposals on how the failure mode could have been avoided. These proposals can also be looked upon as a way to gain knowledge on possible causes of the failure modes.

A number of failure modes arose because robustness properties were not considered during concept development and selection, e.g. variation in market conditions were not taken into consideration when selecting components for an engine. Other examples are difficulties, during the system and component design phase, to identify how sensitive a design solution is to noise factors. Another type of variation is piece-to-piece variation for parts produced by a serial production process; this type of variation has contributed to create the failure modes in some of the cases studied.

Proposed preventive actions related to the failure modes discussed above, focused on a need to strengthen the awareness of variation and robustness. The interviewees suggested a more frequent use of robustness studies in due time, both theoretical and practical, and to include more variation and robustness consideration in testing activities. However, a limit to the use of robustness studies is stated to be insufficient data on reliability and robustness that could be used to guide engineering decisions.

One source to the creation of failure modes is when a component or system, for some reason, has to be redesigned during late stages of product development. Those situations are often characterised by time pressure, which limits the time accessible for verification and testing. In one of the cases studied a corrective action to a minor audio problem was not totally verified because of lack of time, and a new failure mode connected to the corrective action was created but not detected until after production start. Actions proposed to prevent lead-time related concerns was to assure that the development process allows for redesigns, and to assure that redesigns are tested and verified in the same manner as the original design.

Many of the studied designs are made by suppliers and failure modes are created because of insufficient interaction between the supplier and the company. An example is that the original agreement is strictly followed by the supplier although indications of a failure mode called for a new approach. Another example is when a component suddenly does not fulfil the specification because it had been changed relative the prototype parts that previously had been tested and approved.

Actions proposed for the supplier interaction concerns are to increase the openness on technical issues like the requirements or expectations on a certain type of component, on the technical bases for choosing a concept, as well as ensuring flexibility to react and initiate countermeasures if something unexpected occurs during the development.

4 Analysis

As stated in the introduction the purpose of this paper is to understand when and why potential failure modes are created. As a starting point for the analysis of our data Figure 2 graphically illustrates the interviewees' views on failure mode creation. The point of failure mode creation is related to phases in the development process and the thickness of the lines gives a rough indication of the number of causes represented by the line.

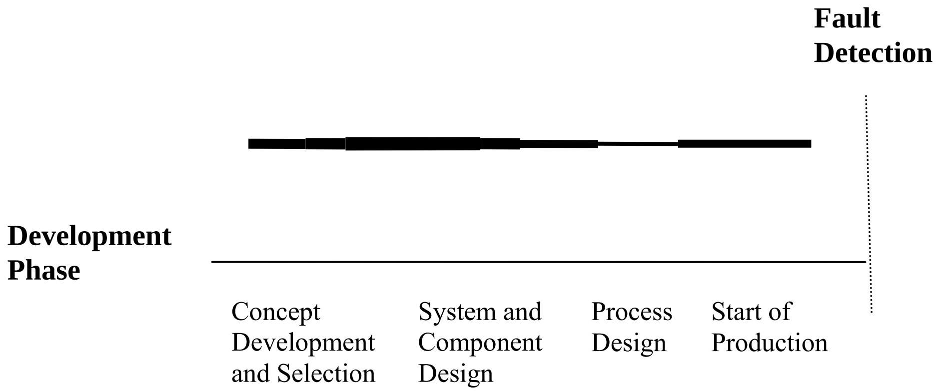

Figure 2. Estimated point of Failure Mode creation, based on interviewees' statements, the thickness of the lines is a rough indication of the number of cases represented by the line. The dotted line shows the time of fault detection, due to the selection of cases only faults detected after start of production have been analysed.

Looking at Figure 2 there is a tendency that failure modes have their origin in early development phases. Many of the failure modes that eventually occurred had their cause in the concept development and selection phase. This tendency points to a need to frontload the process, both in terms of resources and in terms of reliability enhancing efforts. The argument often used for the need of front-loading is related to the cost of corrective actions, as stated in Clausing (2004) "[Reliability] improvement means increasing robustness and reducing mistakes early in the development process, when changes are cheap to make." Interestingly, the cases presented in this paper does not merely give support for early reliability work as a means to decrease costs but also as a means to diminish failure creation with consequences in later stages of product development and in the field.

The benefits of applying reliability enhancing activities early during product development have been pointed out in e.g. Clausing (2004) and Davis (2006b), anyhow it seems as in the practical cases studied the work on failure mode avoidance is still to a large extent centred on the correction of already occurred failures. This is resource demanding in two ways; first it is more difficult to change a solution in later phases and, secondly, resources have been applied to develop solutions that might have severe inherent failure modes and later need to be radically changed. In summary a time gap seems to exist between failure mode creation and failure mode detection. This gap could be minimized through more proactive failure mode avoidance work.

It is important to point out that there are cases in which the gap between failure mode creation and detection was small. However, despite knowledge on the failure mode, corrective actions have been delayed due to time pressure in the development process. Examples are cases in which time for tests have been too short, or cases in which the interviewees has felt that management did not support in-house resources to work on failure mode avoidance related to bought components.

Many of the interviewees state that an active work on variation reduction by improving the utilisation of methods related to robustness and reliability could improve the proactive work on failure mode avoidance. This is supported by the interviewees' views on variation and lack of robustness as common causes of failure modes.

An important aspect to point out is that part of the cases studied, as mentioned earlier, concern components purchased from an external supplier. It seems as it is in those cases even harder to apply proactive failure mode avoidance work. It is in the cases of purchased components harder to control what kind of failure mode avoidance work the supplier has applied. Even though there are requirements on application of certain methods as e.g. Failure Modes and Effects Analysis the level and maturity of application is harder to control. Overall the interviewees' seem to have a view that the company has higher demands on components produced in-house than on purchased components. This experienced lack of control gives rise to situations when the failure modes are detected as late as when the component is supposed to function in serial production.

5 Discussion

It is important to once again point out that the selection of cases through the problem follow up system has taken away the possibility to identify cases in which proactive or genuinely proactive work were applied successfully. In all of the cases studied the faults were detected after start of production. However, the cases studied and the reasons that the potential failure modes were not identified in a proactive manner could provide ideas for prerequisites for proactive and genuinely proactive work.

Looking at the findings from the cases, it is on an overall level important to emphasis the need of early application of quality and reliability enhancing efforts; this to be able to reduce the time gap between creation and detection of potential failure modes. Such a reduced gap would also decrease the time pressure when taking corrective actions, and enable better reliability assurance in the case of necessary redesigns.

An interesting question for further study is if this decreased time gap can be achieved through accurate use of current "state-of-the-art" methods; or if current methods needs to be modified, or if new methods have to be introduced or if some other activities needs to be applied? It would be interesting to focus on the usefulness of quality and reliability enhancing methods, as e.g. failure mode and effects analysis (FMEA), in genuinely proactive work. Are these methods supportive of genuinely proactive work or are they constructed in ways that limit their usefulness to proactive, or even reactive, work? A more in depth study of failures focusing on the application of quality and reliability enhancing methods during the development process would be a way to study this question.

Finally, an area of interest for future research and improvements is the utilization of reliability and robustness methods, especially for the early phases of product development. How to include reliability and robustness aspects in engineering decisions regarding design and selection of concepts, systems and components in a way that feels naturally for the engineers? This is discussed in Clausing and Frey (2005), where they emphasize the importance of using naturalistic, and hence easier to understand, formulations of uncertainty instead of the probabilistic, and more abstract, approach often used in reliability engineering. The idea is to use physical terms that engineers are used to, instead of quantitative terms to describe reliability properties, and then "tune" the design for increased robustness. This can be looked at as being a physical "distance to the failure mode" (Davis, 2006a), e.g. the distance in millimeters thickness of a tire to a worn out state. Clausing and Frey (2005) propose that this way of thinking can have advantages especially in early stages of system design, i.e. it can support a genuinely proactive approach.

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