Streamlining the Flow of Reliability Data through Failure Mapping

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By

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Introduction

Individuals who have been involved in the business of improving the reliability of physical assets used by their companies to manufacture products are likely to emphasize the importance of information to their activities. The information used to study and address problems affecting reliability is different from the information used by other engineering disciplines. While other engineering disciplines tend to focus on the functionality provided by system components and on the robustness leading to physical integrity of the systems, reliability engineering is interested in data describing:

- How long of a useful life a component will provide
- How many failures can be expected from a component over a given interval of time
- What characteristics are useful in performing diagnosis or troubleshooting
- What Failure Modes can be expected and under what conditions they will occur

While generic sources of this information have been increasing over the last twenty years or so, reliability engineers understand that generic data has limited usefulness. While the typical application of a component across an entire industry can be represented by generic data, the industry-wide data may or may not adequately represent a specific application. For instance the loading on a component may be more or less than the average represented by the industry data. The service to which a component is exposed may be more severe or less severe. There are myriad subtle differences that typically separate a specific application from the generalized performance described by generic data.

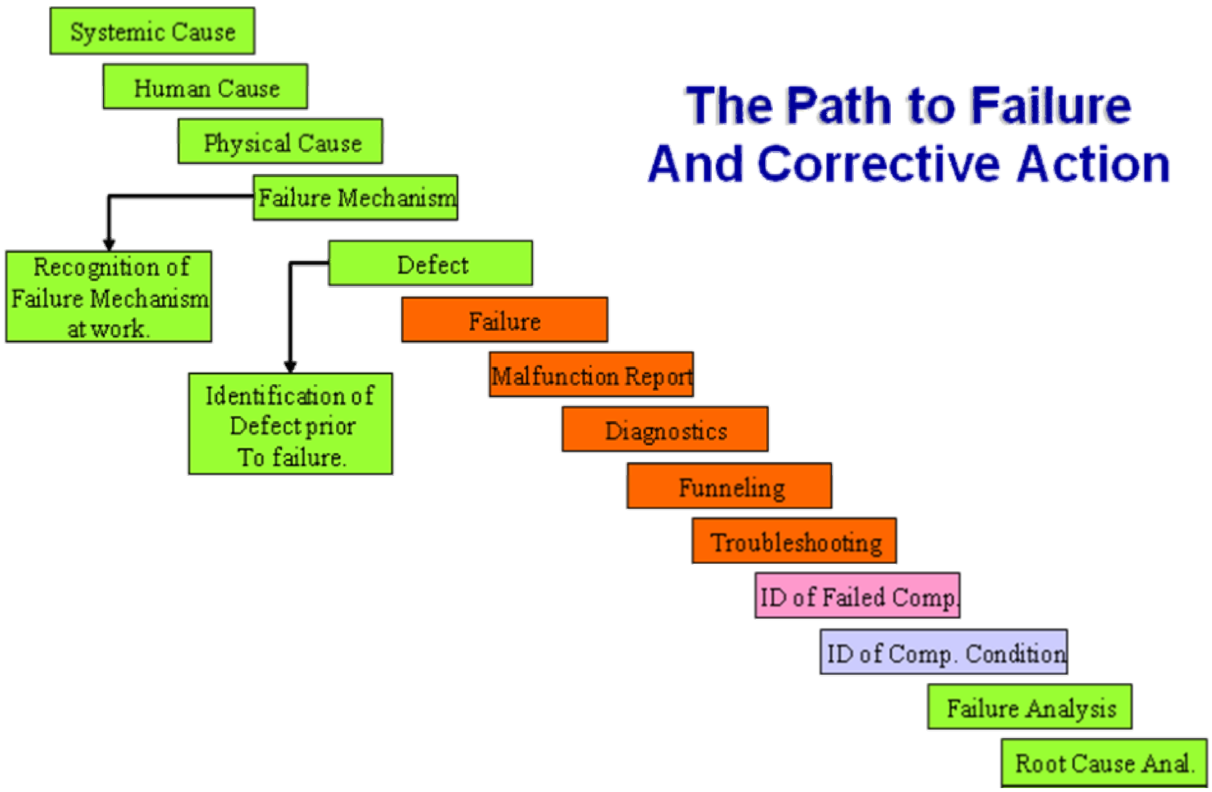
As a result, it is important for each organization to establish their own systems for collecting the information needed to determine the performance of components in their own specific applications. As an example, let's consider a plant located along the Gulf Coast of the United States. Atmospheric conditions there can lead to a greater amount of external corrosion than more dry parts of the country. As a result, Failure Modes resulting from the Failure Mechanism of corrosion would be more prevalent in the former region than the latter. Similarly, if a conveyor using anti-friction bearings was used in an area exposed to blowing sand, the bearings in that application would be more likely to fail from Failure Modes associated with the Failure Mechanism of erosion than would a conveyor in a clean, dust free environment.

Unfortunately, the generic reliability data may not distinguish between the loading or extremes in service and thus be somewhat misleading. As a result, the data used when developing the original design should be viewed as a starting point. While initial predictive and preventive maintenance intervals can be based on the generic data, the actual experience gained by monitoring the results at your own specific application will be far more useful.

The remainder of this course will provide the student with information needed to understand the source of specific reliability described above and how to create the systems that will successfully gather that information. The first step in providing the reader with that understanding will be to provide an understanding of the steps that occur when a failure occurs and how humans tend to interface with those steps. Clearly, most of the location and application of specific reliability information is the result of dealing with failures.

The Path to Failure and Corrective Action

One tool that is frequently very helpful in understanding the flow of information related to asset failures is the following diagram showing the typical events that occur as part of the Path to Failure and Corrective Action. The usefulness of this diagram is that it tends to parse the steps and, therefore, their associated information into finite, distinct elements.



The Path to Failure and Corrective Action includes the following elements:

- A **Systemic Cause** is a "weakness" in the current organization, procedures or processes that create a trap that an individual can step into. This trap will allow the individual to either take some action or failure to take an action that avoids creating a Physical Cause.

- The **Human Cause** is the specific individual who steps into the trap provided by the systemic cause. He or she either performs some act or fails to perform an act. In either case, the behavior is typically accepted within the "system" where that individual works. As a result of the action or inaction, a physical cause is left to exist in the work place.

- The **Physical Cause** is a specific condition left existing in the work place that opens the door for a Failure Mechanism to begin producing deterioration of some component. The Physical Cause is not the Failure Mechanism. It is the condition that releases the Failure Mechanism to begin working and producing deterioration.

- The **Failure Mechanism** is one of nature's tools for producing deterioration. Without the presence of the Physical Cause, the Failure Mechanism would have been kept in check. Once the Physical Cause is present, the Failure Mechanism is no longer in check and is free to begin causing deterioration. For mechanical systems, there are four possible Failure Mechanisms: Corrosion, Erosion, Fatigue and Overload. If, for instance, an individual (the Human Cause) failure to install a protective seal (the Physical Cause) and water was allowed to intrude into a system containing different kinds of metal, corrosion (the Failure Mechanism) may begin causing deterioration.

- A **Defect i**s the condition that exists when the Failure Mechanism has produced so much deterioration that the component in question is no longer able to perform its required function. The presence of a Defect is not always simultaneous with the time at which the Failure occurs. Frequently, the Defect will prevent a component from performing its intended function at times of maximum loading. In these situations, the failure will occur only after the Defect has formed and when the loading is sufficiently great to exceed the capability of the deteriorated component.

- The **Failure** occurs at the exact point in time when the capabilities of the deteriorated component is exceeded by the loading placed on it. The time relationship between the formation of the Defect and the Failure is not always clear.

- The **Malfunction Report** is the event when an individual reports that a failure has occurred. The Malfunction Report can take on a wide range of forms with some providing highly exact and useful information and others actually being fairly misleading and doing more harm than good. The most beneficial form for the Malfunction Report is to simply identify the specific Function that has been impaired and the specific behavior that is currently being observed.

- The **Diagnosis** is the non-invasive process performed using only remotely available information that highlights the possible Failure Modes and the order of their likelihood. The Diagnosis is a step that is useful in evaluating how effectively reliability information has been gathered and organized in the past. If a remote diagnosis can lead the troubleshooter to the actual Failure Mode a significant portion of the time, the reliability information system is accurate and comprehensive. If that is not the case, the reliability information system is lacking.

- **Funneling** is a step in which the available Diagnostic information is screened to determine the most likely Failure Mode and the one that the Troubleshooter should attack first. If there are a number of possible Failure Modes, funneling can be used to determine the order in which they should be approached.

- **Troubleshooting** is the invasive step involving physical disassembly of an asset looking for the Failure Mode (the failed component showing a specific deteriorated condition resulting in its inability to perform its required function). Troubleshooting consumes time and resources. Troubleshooting can also result in leaving defects in areas of the asset that were disassembled. If the areas of the assets that were disassembled are unrelated to the actual Failure Mode, the Troubleshooting can cause wasted resources and result in additional failures. As a result, it is important that the focus and order of Troubleshooting be directed and accurate.

- **Identification of the Failed Component** is the next step in the process. Frequently, repairs are reported as being complete after replacing a component that is not defective. In these cases there are two problems: First, resources have been wasted on the replacement of a good component and, second, the failure causing defect still remains in the asset and is likely to cause future failures. It is critical that the Failed Component be found.

- **Identification of the Condition of the Failed Component** is a part of the step above. It is separated in this discussion to highlight its importance. Identification of the Condition of the Failed Component serves two purposes. First, it ensures that a defective component has been identified. Second, the condition of the failed component serves as a link to identification of the Failure Mechanism. If the deterioration leading to the current failure is to be eliminated so future failures can be prevented, it is important to understand the Failure mechanism that is producing the deterioration.

- **Failure Analysis** is the step in which the condition of the failed component is analyzed by a skilled individual who can identify the Failure Mechanism.

The Failure Analyst must have the technical knowledge needed to relate failure clues to specific Failure Mechanisms.

- **Cause Analysis** is the process of using information identified along the Path to Failure and Corrective Action to identify the Physical Cause, the Human Cause and the Systemic Cause. Typically, if a weakness exists in an organization systems, that weakness is causing many more failures than the one being studied. Finding and identifying that Systemic Cause will result in the elimination of a large number of failures.

- **Recognition of Failure Mechanisms at Work** is an activity that can be generated using knowledge gained from the Path to Failure and Corrective Action. Since Failure Mechanisms are typically in place and producing deterioration for a long time before formation of the Defect and the Failure, it is possible to identify the Failure Mechanisms and arrest their progress thus preventing failures.

- **Identification of Defects Prior to Failure** is another preventive opportunity presented by understanding the Path to Failure and Corrective Action. Since the Defect also exists for some period of time prior to failure, it is possible for observant individuals to find Defects and prevent failures. Obviously, there is less time to find Defects than Failure Mechanisms but the opportunity still exists.

Now that we know the discrete steps that occur during the Path to Failure and Corrective Action, it is useful to understand the level of human interaction during each step. Clearly, in situations where human interaction currently exists, we can modify that interaction in a way that makes it more effective. In those cases where human interaction does not exist, it is possible to reshape the step to create useful human interaction.

Analyzing the Characteristics of Events along the Path to Failure

There are three characteristic ways in which human interaction with the Path to Failure and Corrective Action can occur:

1. Events can currently involve some amount of human interaction and that human interaction can currently be managed in some manner.

2. Events can currently involve some amount of human interaction and that human interaction may not currently be managed in any manner.
3. Events may not typically involve any conscious or proactive human interaction.

The first list of activities are those that currently involve some amount of human interaction and that human interaction can currently be managed in some manner:

- Malfunction Report
- Diagnostics
- Funneling – Triage
- Troubleshooting
- Identification of the Failure Mode (Failed Component and its Condition)
- Failure Analysis (Identification of the Failure Mechanism)
- Cause Analysis

The second list of activities is those that currently involve some amount of human interaction and that human interaction may not currently be managed in any manner:

- Creation of the Systemic Cause
- Events that cause the Human Cause

The third list of activities is those that may not typically involve any conscious human interaction:

- Circumstances leading to the Physical Cause
- Forces of nature resulting in the Failure Mechanism
- Formation of the Defect
- The combination of the presence of the Defect and the system loading that result in the Failure

In moving toward an understanding of how we might better deal with the information associated with this series of events, there are several points that should be kept in mind:

- Nature determines the path to failure.
- Successful human intervention requires an understanding of how nature works.
- Computers cannot effectively process paragraphs.
- If your system allows people to report failures or close jobs using paragraphs, you will be unable to process the information without ample of time being spent by individuals interpreting the information.
- Your “system” will perform only as it is designed to perform.

Analyzing How You Would Like to Interact with Events

As each failure passes along the string of events described above as the Path to Failure and Corrective Action, it seems as though we would like to automate the process so it requires as little human involvement as possible while still making all the right choices. We would also like the automated process to preserve critical information in a way that will support on-going efforts to improve reliability performance and reduce future failures. Unfortunately those characteristics seldom fit together:

- A highly automated process with little human involvement
- Right decisions at each step
- Preservation of critical data in a manner that will support future improved performance

As a result, the system that provides all of those characteristics is typically a balance of all the objectives described above. Achieving that balance demands that we keep the following in mind:

- What your system can do depends on the level of human involvement.
- What your system can do also depends on how the information can be processed. In other words, it depends on the structure of the information and how much discipline is applied to the use of the structure.

- The timeliness and usefulness of the information depends on the way the information is analyzed and how the reports are structured and distributed.

- An effective organization is a balance between being a "Knowledge-based" organization and an "action-based" organization.

It is important to ask, in those situations where there is some form of managed human interface with events in the Path to Failure and Corrective Action: what would you like the system to do to facilitate the human interface?

- In creating the Malfunction Report, it would help if the system would assist. Clearly there are a limited number of functions performed by the asset and there is also a limited number of behaviors associated with each aberrant function. The system should limit the ability of the user to input an incorrect function by providing a list of only the possible functions. Once a function is chosen, the system should automatically present only those behaviors associated with the selected function. In situations where a user wants to select a function and/or behavior that is not on the list, it would be better for the individual to talk to another human being than to contaminate the system with meaningless input.

- Once an appropriate Malfunction is input into the system, the system should automatically display all immediately useful information. For instance, if it is occasionally possible to immediately recover from the reported malfunction, the system should display the steps that must be taken to provide the immediate recovery. For example there are occasions when functionality can be restored by resetting a breaker or recycling a computer.

- The system should also present data linking the reported malfunction with specific Failure Modes and the relative likelihood of each.

- The system should assist in performing diagnosis. If capabilities for remote diagnosis have been integrated into the system, the information collected through that portion of the system should be linked to associated events and displayed.

- The system should assist in producing "saves". (A save is a situation where a failure occurs but it is possible to restore functionality with little or no downtime.)

- The system should assist in “triage”. Triage is the activity of applying available resources in a way that the greatest benefit is achieved. An effective system of triage will apply scarce resources to the most serious needs first, but only when there is a reasonable chance of success.

- The system should assist in directed troubleshooting. Troubleshooters should be directed to attack the most likely cause first and other possible Failure Modes in order of decreasing likelihood.

- The system should assist in identifying the Failure Mode. In addition to identifying specifically what component is likely to be defective, the system should identify the condition that failed components have experienced in the past.

- The system should be the sole repository and processor of information. Failure related information should not be stored outside the reporting system and steps needed to reduce and process the data should be accomplished within the system.

It is also important to ask, in those situations where there is some form of unmanaged human interaction with events in the Path to Failure and Corrective Action: what would you like the system to do to facilitate the human interface?

Creation of the Systemic Cause is one place where there is human interaction, but it is typically not intentional. While the automated system for processing data is not likely to provide a tool for producing improvement, the overall work management process can include a mechanism for closure.

If the Cause Analysis has shown that the organization, procedures or processes have holes that allow human behavior to create physical causes, there should be regular reviews of findings with all members of the organization including senior managers. Once informed that they are a part of the problem, it is likely that they will make changes needed to become part of the solution.

Similarly, actions that produce the Human Cause or Physical Cause of failures should be highlighted in routine reviews to provide an opportunity for senior managers to lead activities leading to resolution.

Finally, in those situations where there is no human interaction with events in the Path to Failure and Corrective Action, what can be done to facilitate an effective human interface?

There are four such steps:

- Physical Cause
- Failure Mechanism
- Defect Formation
- Failure

In each of these steps, if human intervention was possible, it would also be possible to prevent the event from occurring.

In the case of the Physical Cause, the more individuals in the workplace are familiar with Physical Causes, the more likely they are to recognize them when they see them. A good way to involve individuals in finding, reporting and correcting Physical Causes is to provide a regular newsletter with descriptions of Physical Causes that have been found to cause failures in the past. The following is a list of the kinds of Physical Causes that almost anyone in a plant should be able to identify:

- The absence of a support leading to vibration resulting in fatigue
- The absence of a seal allowing water intrusion causing corrosion
- Abrasive blasting close to unprotected rotating equipment resulting in erosion
- Exposure of electrical insulation to sunlight causing UV damage and deterioration
- Exposure of electrical insulation to heat causing damage
- Exposure of electrical insulation to chemicals causing deterioration causing damage.
- Loading at greater than the design capacity causing overload

A newsletter containing pictures and details will lead to broad understanding of causes and results among all employees. Knowing what to look for opens the door to finding problems before failures.

The same is true of Failure Mechanisms common to a facility. The following are a few examples:

- Uniform corrosion produces rust and scale that can be easily recognized. Once areas of corrosion are added to a list, numerous areas can be efficiently addressed with a single touch-up paint program. Left unattended additional deterioration will occur.

- Once individuals are familiar with fatigue, its cause and the resulting failures, it will be possible for people to intervene when they see unrestrained vibration or other forms of movement that seems unusual.

- If grit is obvious in the wind blown air and there are build-ups of sand and abrasive materials around pump and compressor bases, it is likely that the material is making its way into seals and other close clearance areas. Individuals who become aware of such contamination can be sensitive to signs that contamination has entered their systems and request bearing housings be flushed and oil refreshed.

- While not as apparent, individuals close to operating equipment can also be sensitive to overload conditions. When loads gradually grow over the course of several years, it is difficult to see the change. On the other hand, equipment overloading is frequently accompanied by record production levels and other signs of accompanying growth. When there is growth without bottlenecking or capacity increasing project to rationalize the source of the added capacity, one should be sensitive to the systems that are operating beyond their design capacity to support the new capacity.

Defects are frequently less apparent than Failure Mechanisms. Small cracks resulting from fatigue are difficult to see if not accompanied by leaking or weeping. Thinned areas resulting from corrosion or erosion are frequently obscured by insulation, coatings or corrosion product. For individuals to find defects, they have to have a good idea where such defects have occurred in the past. As with Failure Mechanisms above, a newsletter describing defects that caused failures or were caught in time to prevent a failure will help people in the workplace remain vigilant. Some form of highly visible reward for finding a defect and preventing a failure will also encourage broad participation and keep eyes wide open.

The last step on the Path to Failure and Corrective Action that typically does not have direct human involvement is the Failure. While once the Failure has occurred, it is no longer preventable; it is possible to mitigate the results and to prevent future recurrence. The idea of having a regular newsletter to make everyone in a workplace aware of failures, their cause and clues that might have helped prevent them are good ones.

Critical Issues to Consider in the Flow of Information

When analyzing the flow of information that is always a part of the Path to Failure and Corrective Action there are some simple truths that help us understand how we must deal with the information if we are going to force it to serve our purposes:

- A computer cannot sort paragraphs. If we allow the information at any critical point in the steps of the process to remain in the form of a paragraph, the useful information contained therein will remain useless without significant interpretation by a human. That fact will severely limit the effectiveness of the computer.

- Failure to take advantage of "save-opportunities" results in regrets. While the information being processed contains value, it takes work to harvest the value. Failure to mine the value provided by history and experience will result in the repeat of unnecessary failures.

- Failure to properly perform triage, results in ineffective use of resources. In a situation where critical resources are scarce, failure to perform triage will result in scarce resources being used to address needs of lesser importance. In situations where there is an abundance of resources, failure to use triage and show an ability to survive with a smaller consumption of resources will lead to waste and inefficiency.

- Improperly performed diagnosis results in inefficient and ineffective troubleshooting. Troubleshooting is a necessary workforce and time intensive activity. Failure to effectively use all the information that is available prior to setting hands on the asset or starting disassembly of it, will result in diagnosis being done when the troubleshooter is fumbling around in the belly of the stricken beast.

- Failure to differentiate multiple Failure Modes results in partial solutions. The usable life of a component is frequently calculated based on a number of life ending conditions. If those conditions are not treated separately, only one of them, possibly the most pronounced, will be solved and the others will remain unsolved.

- Failure to identify and address multiple Failure mechanisms will result in continued deterioration. Just as a component can fail from multiple Failure Modes, it can deteriorate from several Failure Mechanisms. An antenna whipping around in the wind can be rusting at the same time it is experiencing fatigue. Tying it down will prevent the fatigue, but it will continue to corrode.

- Failure to identify the various causes ensures their continued existence. Physical causes are simple dumb actions resulting from the physics of the situation. They will not change until the physics is altered. Human causes are endorsed and supported when they are ignored. People think they are doing the right thing when no one tells them different. Elimination of Human Cause requires human intervention. Systemic Causes are the result of management practices. If managers are not made to see that systems they have created in the past are faulty, they will keep moving on to the next thing rather than circling back to correct the problems they created in the past.

Keeping all these things in mind, we can identify the characteristics of the systems (human and computerized) that are needed to manage solutions and form the basis for future improvements in performance:

- There must be a concise sortable format for the Malfunction Report.

- There must be a concise sortable format for the Failure Mode.

- The system must link Malfunction Reports with the Failure Mode used as a solution and the system must be able to calculate the relative frequency of each cause.

- The system must be capable of using the Failure Paths as a basis for storing and presenting related information including:

    - Diagnostics

    - Remote diagnostics

    - Information useful in providing immediate “saves”

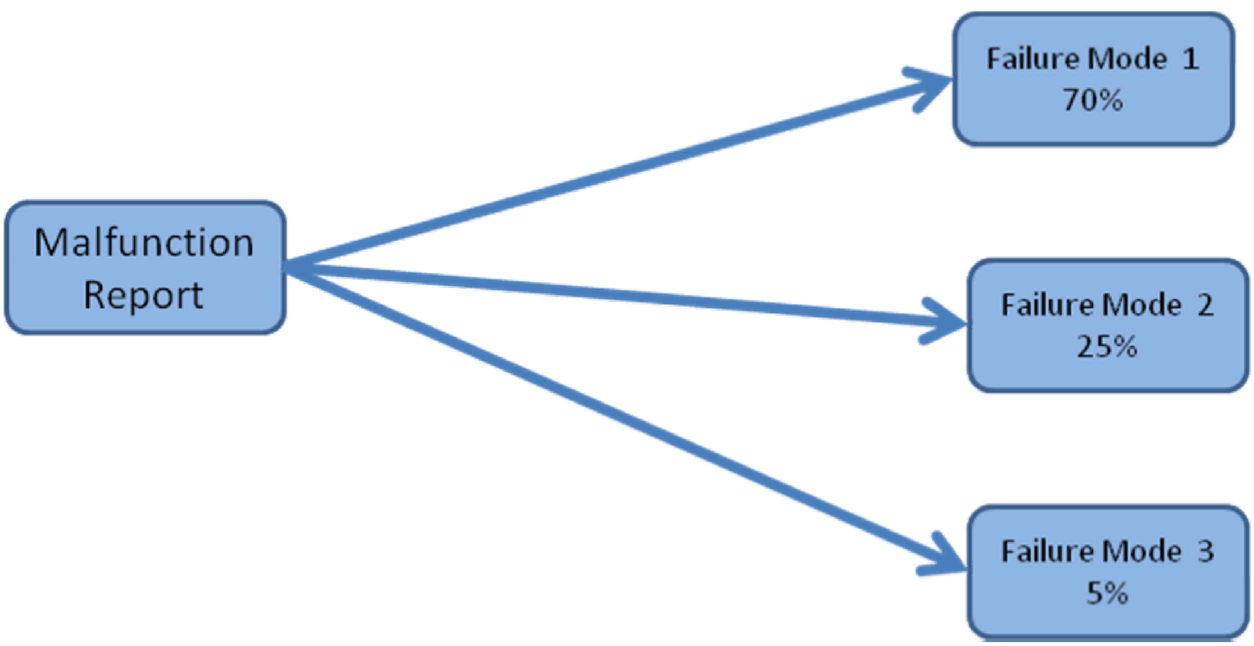
    - Information that is useful in performing triage

- The capability to separate and distinguish different Failure Modes affecting the same component
- Identification of Failure mechanisms
- Identification of multiple causes at each of the three levels of Root Cause

- The system must be capable of operating within the capabilities of current conventional database designs.

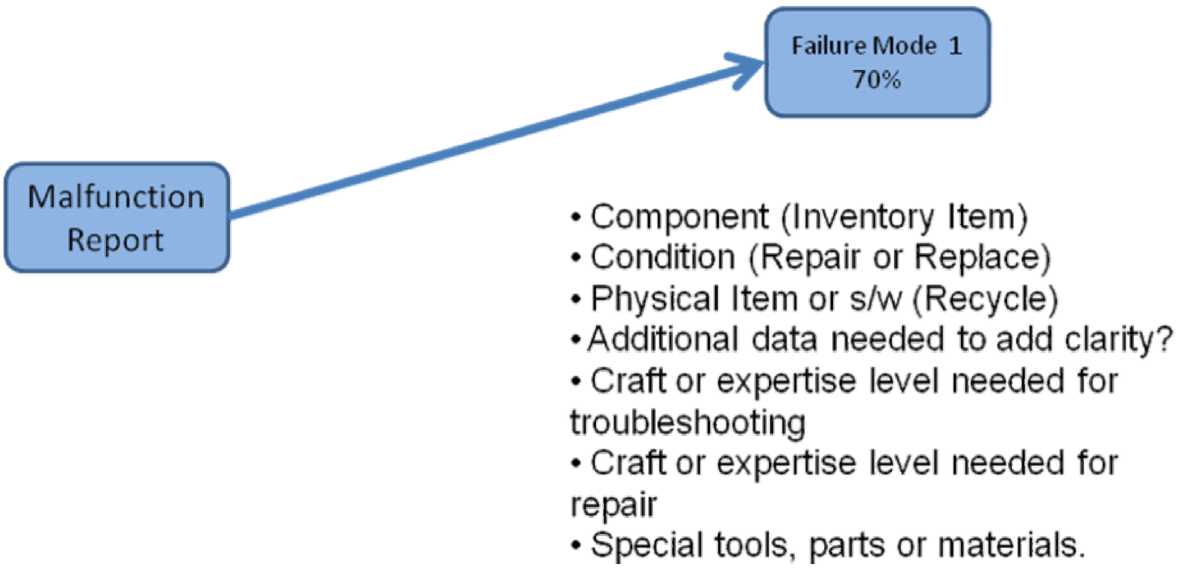
A Graphical Representation of the Structure of Failure Mapping Information

A single Malfunction Report (Impaired Function – Current Behavior) can be caused by several different Failure Modes (Defective Component – Condition of the Component):



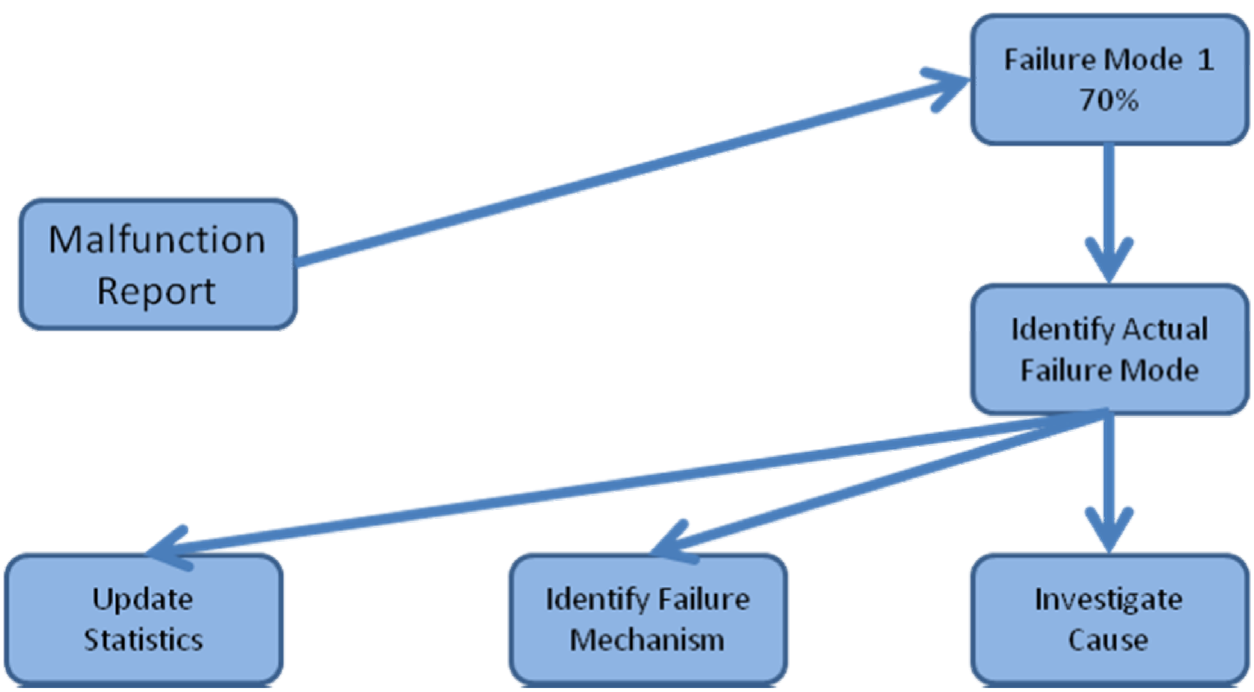
The Failure Mapping database should identify the link between each Malfunction Report and all the Failure Modes that could cause it along with the historical frequency of their occurrence.

Each Failure Mode should be stored along with information that will assist in its resolution:

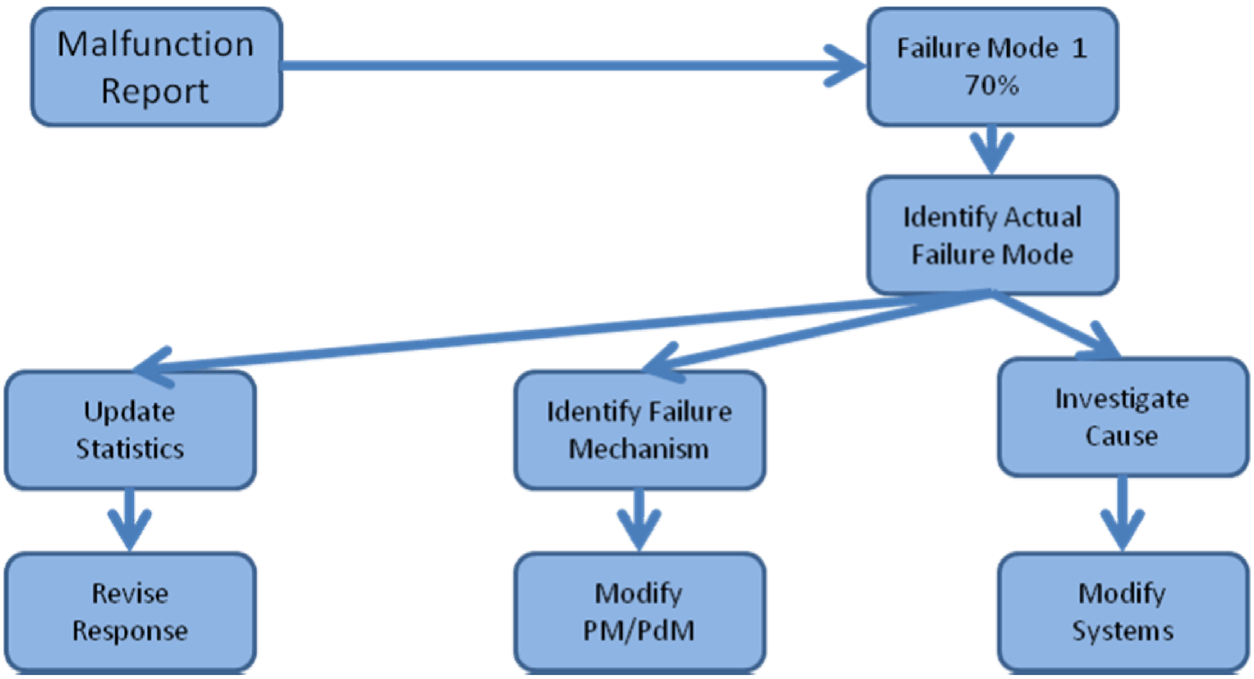


The Failure Mapping database should store information associated with each Failure Mode to facilitate rapid recovery.

Identification of the actual Failure Mode that caused a specific event should trigger a series of steps needed to "close-out" the information flow for that event:



The availability of that information enables further actions that will enhance long term performance and provide for asset improvements:



The updated statistics will identify the Failure Mode that is most likely and should be the first target of the troubleshooter. Addition of new Failure Mechanisms or current Failure Mechanisms appearing in new locations suggests the addition of new Predictive or Preventive Maintenance. Once the cause is understood, it may be possible to alter the organization, procedures or processes to prevent reoccurrence.

Key Linkages between Information Contained in the Path to Failure

Clearly, when one begins to collect and use an information system that has been enhanced by Failure Mapping, he or she will start to realize that one piece of information enables another piece of information. Without the first piece of information it is impossible to obtain the second.

For example, identifying an actual failed component ensures that the defect has been removed. If a component is removed and it is not shown to be defective, the defect may remain in the system and the failure will occur again.

Another key piece of information is the Condition of the defective component. The Condition of the defective component is linked directly to the Failure Mechanism. The component condition will reveal if it showed signs of wear, fatigue or products of corrosion. This information will provide a better understanding of the Failure Mechanism.

Understanding the Failure Mechanism is critical to identify the Physical Cause. If the Physical Cause is not identified and eliminated, the Failure mechanism will once again begin creating deterioration and ultimately the failure will re-occur.

Finally, identifying the Human Cause (i.e. that is the specific person who created the Physical Cause) is critical to identifying the Systemic Cause. Without talking to that person and finding out why he did what he did, we will never know. Only a very small portion of Human Causes are the result of malice or intentional effort. In most cases, the person who created the Physical cause did so because of some situation outside of his direct control. Finding out the reason and identifying the Systemic Cause offers the opportunity to correct this failure as well as many others being caused by the same Systemic weakness.

Your Role in Capturing and Using Reliability Information

While many people work on a building during its construction and many others work in the building after it is complete, there is only one architect. The architect is the person who has the vision to see how the building will be shaped and how it will be used over its lifetime.

In much the same way, someone has to act as the architect for the information system used to address day-to-day problems and, when properly designed, to provide the intelligence needed to improve future performance. Understanding how the pieces fit together and knowing the value the information will ultimately provide, you can perform the role of an architect for your information system. You can lead the way in the development and application of new and more effective information systems for reliability.