Root Cause Analysis Considerations

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SUMMARY

This booklet describes some of the more important considerations of Root Cause Analysis (RCA) and its role in the continuous improvement of equipment over the life of the plant.

Various techniques can be used to determine the underlying or ‘root cause’ of a failure however for specific problem types some techniques will be better at arriving at the underlying causes than others.

The RCA should include input from support and site staff under the guidance of a suitably experienced facilitator.

SCOPE

This booklet covers some of the main steps in carrying out an RCA investigation, identifying the underlying cause/s, reporting the findings and developing appropriate means for implementing the findings.

This booklet does not deal in detail with the development of a specific program of improvement following a RCA.
INTRODUCTION

Root Cause Analysis (RCA) is a relatively straightforward concept aimed at identifying the underlying cause/s (the so-called root cause/s) of existing or potential equipment or system failures. RCA techniques are used to facilitate the analysis of some of the most complex and intractable engineering problems experienced in industry. Several variations of RCA methodology exist but all try to identify the underlying reasons for significant failures, defects or other undesirable outcomes—the so-called ‘Root Cause’. From a practical perspective, the aim of RCA is to identify effective solutions to significant problems rather than the identification of the theoretical ‘Root Cause’. While it is valuable and relevant to identify the ‘true’ Root-Cause, it is not necessary to do so to have an effective outcome to the RCA.

Individuals experienced in one of the commercially available RCA tools can come to think of RCA in terms of that tool and often forget that there are a very large range of potential tools available to assist us in RCA applications. This is important to appreciate because not all practical problems are solvable with a single tool and another tool, or a range of other tools may prove more suitable in a particular application.

In instances where a problem does not yield readily to a determined effort using one RCA tool, re-assessment using a different approach and/or tool can sometimes give insights not provided by the initial assessment. A rich source of potential RCA tools is to be found in the many pocketbooks for Quality systems, Total Productive Maintenance, Reliability Centered Maintenance and Six-Sigma to mention some of the more common ones available. These pocketbooks describe the various tools presented in summary form with sufficient information to use the tool once familiar with it. If you are not experienced with a particular tool, additional information can be found in some of the more detailed books and support applications for the various tools. In addition, example solutions and tutorials can be sourced through dedicated training courses and sometimes directly on the internet.

Generally speaking, while RCA principles have most often been applied to the analysis of physical failures (i.e. the analysis of hardware failures) its application is more general and can be successfully applied to the analysis of non-hardware failures such as procedures, skills etc. Many significant problems encountered in industry are a combination of hardware and system or procedural failures that occur in a specific sequence that lead to the terminal failure.

For example, the ultimate in-service failure of a critical bearing may be traced back to a combination of high loading and inadequate lubrication by the RCA. While it may be thought that the high load is within the design capacity of the bearing so long as adequate lubrication is provided, however when these loads are combined with inadequate lubrication the result is an in-service failure. The inadequate lubrication may be traced back to a missed lubrication route or inadequate lubricant for the application. In this scenario the root-cause is a procedural failure where the lubrication program designed to maintain the critical component in the high stress application fails resulting in an in-service failure. The ability to identify failure of the lubrication program is just as important as identifying inadequate hardware. An indication that this type of scenario may be relevant can be seen in failures of equipment that has operated successfully for some extended period but then results in a significant failure. Unless the operating context of the hardware has changed significantly or the equipment has deteriorated significantly it is unlikely to be simply due to the hardware alone and it may be useful to look carefully at any supporting systems or procedures for contributing factors.

While the path from the problem (the observed event) to the identification of the cause/s of the problem (the initiating event or root cause/s) differs for each methodology, all attempt to achieve the following aims.
1. Clearly identify the event to be assessed.
2. Quantify the significance of the event (e.g. cost, injury, environmental impact, etc.)
3. Determine the prevailing conditions leading to the event.
4. Identify any contributing factors to the event.
5. Document evidence for each factor or condition.
6. Provide an efficient methodology for reviewing the evidence.
7. Identify the Root Cause/s.
8. Provide a mechanism for managing the recommended actions.

It is important to appreciate that most RCA methodologies are not restricted to the analysis of physical failures only and can be applied to the failure of procedures, tasks and other non-physical systems. This document provides an overview of some of the methodologies useful in RCA as well as the supporting activities surrounding the analysis process.

BACKGROUND

Several popular RCA methodologies are promoted on the internet and elsewhere which claim to provide a systematic approach to analyzing failures and identifying the ‘root cause’ of that failure. In practical applications of RCA we are more interested in identifying an effective control or elimination strategy for the failure than in identifying the theoretically ‘true’ root cause.

In many situations it is not possible to identify the root cause with great confidence which means that controlling the failure is likely to become a more realistic goal. In addition, while identification of the ‘root cause’ is desirable it is not the role of the plant manager or engineer to carry out research, only to operate the plant efficiently and safely and therefore effectively managing the failure (likelihood and consequences) is often sufficient.

Appropriate application of RCA therefore must take account of what the actual aim is in carrying out the analysis and whether the ‘true’ root cause must be determined or if an effective and efficient management of the failure (and future failures) is adequate. The additional cost of determining the ‘true’ root cause can be prohibitive, difficult or impossible to achieve and may add very little or no additional value to the organization.

The ‘root cause’ of a failure can have its origins in one or more of several differing stages of the equipment life cycle including design, development and operation and maintenance. When trying therefore to identify the root cause of a failure it is necessary to look at each of these stages of the equipment life cycle and not only at the operational and maintenance stages. Specifically a failure can be fundamentally caused by inadequacy in one of the following aspects of the equipment’s design, creation, operation or maintenance.

1. Incorrect application or specification.
2. Inadequate design.
3. Inadequate manufacture.
4. Inadequate installation.
5. Inadequate commissioning.
6. Incorrect operation.
7. Incorrect or inadequate maintenance.
8. Incorrect or inappropriate modification or refurbishment.
**Incorrect application or specification**

If the equipment is inadequate for the current application (not necessarily identical to the original intended application) the equipment may suffer an unusually high failure rate as the design inadequacies become apparent under operating conditions. The inadequacy of the design can originate from incorrect use of correctly specified equipment or incorrect specification of equipment for the application.

Over time a previously appropriate equipment application can become less so as changes to the operating environment make differing demands on the equipment. The processes of most modern industries and indeed most organizations undergo continuous refinement, expansion, improvement and optimization therefore it is reasonable to expect that at least some of these changes will have negative impacts on the equipment used by the organization.

**Inadequate design**

If the design of an appropriate type of machine is inadequate this can lead to significant in-service failures which can subsequently become the subject of RCA analysis following one or more of these failures. Central to the adequate design of a machine is a detailed understanding of the duty and operating context in which it will operate as well as an understanding of the limitations of the operating organization to operate and maintain the machine correctly.

In practice, two of the major reasons for inadequate design is a failure to appreciate the equipment application and the operating context and an unwillingness to commit appropriate resources when designing the equipment (i.e. trying to do it on the ‘cheap’). Many RCA’s contain references to inadequacies in the equipment design that can be traced back to:

- A failure to understand the process and environment
- Changing operating environment and
- Unreasonable attempts to minimize cost of design/manufacture.

**Inadequate manufacture**

A correctly specified and designed machine can have inherent failures built in at the manufacturing stage if inadequate material selection and quality control is not implemented and enforced. In many applications highly critical machines routinely operate at the limits of engineering design and material properties and any loss of control on the manufacturing process can lead to significant in-service failures.

Poor control of dimensional tolerances, material variability, weld preparation and application and other manufacturing variability all lead to a sub-optimal machine with likely elevated failure rates when in service.

**Incorrect/Inadequate installation**

For physical assets such as machines inadequate installation typically can include inadequate sub-surface preparation, inadequate foundations and poor access to the equipment or other installation related aspects that can in turn lead to in-service failures of the equipment. System dynamic considerations are almost always refined or ‘tuned’ during the commissioning phase and failure to adequately address these issues can lead to very high forces, temperatures or pressures in operating equipment which in turn can lead to in-service failures.

Similarly, poorly understood processes can lead to incorrect specifications and it is during commissioning that these errors become apparent. Commission therefore is the first opportunity the project team has to identify these shortcomings and try to develop design
changes to overcome them. Failure to adequately deal with these specification errors will leave the equipment operating sub-optimally throughout its life or until the problems becomes too great to tolerate any longer and a major design change is required.

**Inadequate commissioning**

Inadequate commissioning of the installed machine can result in damage to the equipment or incorrect set-up which in turn can lead to an unnecessarily high in-service failure rate. Typically this takes the form of incorrect setup especially when the equipment does not operate as expected and modifications have to be made on the run to achieve the assigned commissioning targets. In some instances the rush to commission the equipment as soon as possible can lead to short term fixes that have the effect of reducing the equipment reliability over time and generate a higher failure rate than would have been the case otherwise.

The rush to finish commissioning as soon as possible often leads to inadequate or no operator or maintenance training with the likely outcome of sub-optimal operation and maintenance at the very least and the increased likelihood of equipment damage if the equipment continues to be operated in this way. These negative impacts on the equipment at this stage frequently manifest themselves in subsequent failure which may trigger an RCA analysis during the life of the equipment.

**Incorrect operation**

Incorrect operation of the equipment due to a lack of operating skills or abuse (deliberate or otherwise) will inevitably lead to elevated failure rates and increased numbers of equipment outages. A well implemented project will ensure that all operators have been adequately trained during commissioning and that they are provided with the equipment and other support they need to operate the machinery correctly.

Over time however, new operating staff will be introduced to the organization to replace retiring staff or staff may be rotated from other duties to operations. It is in this situation that the failure to train the new operator/s that poor operating practice can be introduced or develop. Poor operating habits are passed on to the new operator/s from previous operators who themselves may not have been adequately trained (or ever trained).

**Incorrect or inadequate maintenance**

As with poor operations practice, incorrect maintenance of the equipment due to a lack of maintenance skills will inevitably lead to elevated failure rates and increased numbers of equipment outages. A well implemented project will ensure that all maintenance staff has been adequately trained during commissioning and that they are provided with the equipment and other support they need to maintain the machinery correctly.

Over time however, new maintenance staff will be introduced to the organization to replace retiring staff or staff may be rotated from other duties to maintain the machine. It is in this situation that the failure to train the new maintenance staff that poor maintenance practice can be introduced or develop. Poor maintenance habits are passed on to the new maintenance staff from previous staff who themselves may not have been adequately trained (or ever trained).

Similarly, inadequate or poor maintenance systems and practices will result in deterioration of the equipment and increased failure rate. As the equipment deteriorates the reliability decreases with time until the reliability is no longer adequate to meet the operating requirements of the organization.
Incorrect or inappropriate modification or refurbishment

Over time, even the best performing equipment will require upgrading and/or modification to restore deteriorating functions, repair long term deterioration of some failure modes, take advantage in technological improvements or make enhancements for improved operation, maintenance or reliability. If modifications refurbishments or other significant changes to the equipment are poorly carried out, the remaining life of the equipment can be characterized by poor reliability or performance which can give rise to subsequent RCA analysis.

Modifications or refurbishments should be treated as minor (or not so minor) projects and properly planned to ensure the changes are carried out effectively and efficiently. The involvement of the original equipment manufacturer (OEM) throughout the upgrade will ensure that the changes made are in line with best practice for the equipment and helps ensure an ongoing link between the OEM and the site which will ensure the satisfactory operation of the equipment over time.

BASIC APPROACHES

Having become familiar with one or more RCA tools we can develop experience with their use by working through examples and reviewing the work of others. As with physical tools, conceptual tools such as those used for RCA can have many subtleties not immediately apparent and only by working real examples can we develop the skills needed to carry out an effective assessment.

The more commonly used RCA tools use a variation on a ‘tree’ structure to document the individual components (e.g. actions, conditions etc.) and to indicate the linkage between these components. While it is not mandatory to utilize a tree structure for your RCA it is especially useful when new to the activity as it provides a visual image of the assessment and its progress over time. This can be especially useful to beginners or others not regularly involved in these assessments.

‘Top-Down’ approach

In industrial applications RCA is traditionally applied to the analysis of physical failures after the event to determine the cause of the failure and to prevent a recurrence if possible. This approach is inherently ‘top-down’ as the analysis is triggered by an event that is deemed to be sufficiently important (either for cost, safety or other reasons) to warrant the application of the RCA methodology. The RCA methodology, when implemented in this manner can be costly in staff time and can lead to other expenses for material testing, laboratory analysis, data collection etc. therefore it tends to be applied only to high cost failures or significant near misses.

The disadvantage of taking a ‘top-down’ approach is that it is usually applied after a significant failure has occurred (or occasionally after a significant near miss) and there is no opportunity to influence that particular failure. The maximum benefit possible is to prevent subsequent failures. In the event that the failure results in major cost, loss of life or significant injury or significant environmental damage or plant damage it is not adequate to simply understand why it happened and it becomes necessary to try to prevent the first occurrence not simply subsequent occurrences. Unlike the ‘top-down’ approach the ‘bottom-up’ approach has some potential to prevent the ‘first’ failure.

‘Bottom-Up’ approach

The ‘bottom-up’ approach applies RCA techniques to all or most unexpected failures experienced in the plant (and in some cases to near misses) to develop a culture of
understanding un-controlled and unintended events which if left to progress could result in a major failure with its associated consequences.

This is similar to the approach taken by industry to safety related incidents in the belief that control of the many minor events helps to reduce the likelihood of a major safety event occurring.

The major differences between the ‘top-down’ approach and the ‘bottom-up’ approach is that the ‘top-down’ approach deals with a small number of major failures after the event while the ‘bottom-up’ approach deals with a larger volume of less significant events that could lead to a major failure if left progress and therefore have the potential to influence some of the possible major failures before the event. The level of analysis is significantly less for the ‘bottom-up’ approach as the emphasis is on understanding why basic failures are occurring and taking actions to prevent their reoccurrence whenever practicable.

A practical implementation of the ‘bottom-up’ approach would be to have maintenance staff collect all failure related parts (and in some instances scheduled replacement parts that are in worse condition when removed than expected) and to periodically analyze these parts to determine the cause/s of failure. Implicit in this is the need for the maintenance staff to be trained in the preservation of failure evidence including the collection and preservation of the failed parts, the documentation of the operating context at the time of the failure, the carrying out of interviews and the taking of photographic records.

COMMON ASPECTS OF RCA

The application of RCA principles involves several themes common to all approaches. The main themes include the following:

- **Documented failure event** – a formal statement of the failure event with quantities and supporting documentation.
- **Objective** – the aim or goal to be achieved by the RCA.
- **Timeline** – the projected timeframe for the RCA and implementation of effective action.
- **Question sets** – sets of standard questions suitable for specific types of failure analysis that are used as a prompt for the RCA team to ensure all issues are considered.
- **Action line** – a detailed and quantifiable statement of the chronological order of events leading up to and including the failure event.
- **Actions** – the action that precedes the next stage of the failure event.
- **Conditions** – the prevailing conditions that impact on the failure event.
- **Evidence** – supporting information associated with the failure event.
- **Node** – the interconnection of specific failure events.
- **Branch** – labels that link a sub-RCA to a higher level RCA.
- **Comments** – local notes that provide additional information on the local node.
- **Corrective Measures** – specific actions identified to control the node or failure event.
- **KSF’s** – ‘Key Success Factors’ that must be managed and controlled to achieve the objectives of a specific RCA.
- **KPI’s** – ‘Key Performance Indicators’ used to measure progress towards the objectives of a specific RCA.
A key first step in carrying out an RCA is to clearly state the failure of interest and provide a clear statement of what the solution will ‘look like’ when it is implemented. Without this clear statement of the problem and the desired solution it is very difficult to get the RCA team member all working on the same problem and towards the same goal.

The time frame in which the RCA is to be carried out and the findings implemented must be clearly stated at the outset so that the resources and effort needed to carry out the RCA can be assessed. In many practical cases the timeline can only be estimated at the outset as some intractable problems can take much longer to solve than initially thought and the RCA team has to persevere until an acceptable solution is found.

Standard questions can be useful in highly complex failure events or as an aid to inexperienced assessors to encourage them to ask probing and related question in a bid to draw out the available information from those preset at the failure event or from other sources and witnesses. The limitations of question sets are that they can limit the questions asked and make the investigation process overly procedural. In addition, the use of inappropriate question sets can lead to information being missed that might otherwise have been identified in a less structured but more dynamic or free-flowing investigative environment.

The relationship between specific events leading to the failure event can be positioned along a timeline or other chronological sequence and the relative position of these events on the timeline can provide vital information to the RCA team. When evidence is assessed following a failure it can often be difficult to determine the sequence of events and therefore which are causes and which are effects.

By laying out a detailed timeline and placing the individual events on that timeline it can be much easier to see the interaction between specific causes and effects. In many instances changing the position of events on the timeline completely changes the cause and effect relationships and therefore the identification of the root cause. It is important therefore to gain the best understanding possible of the failure sequence as some events can be many minutes or hours apart while others are almost (but not actually) simultaneous.

In addition to the above components of the actual RCA there are a number of organizational features common to effective RCA’s, namely:

- **RCA policy** – the site or organizational policy on the use of RCA’s.
- **Champion** – senior manager who oversees the application of RCA methodologies on the site or across the organization and who ensures that recommended actions are implemented.
- **RCA facilitator** – the lead person in charge of a specific RCA.
- **Cross functional team** – the group of people having complementary skills and experience brought together to carry out a specific RCA.
- **Authority** – the agreed authority provided by the organization to conduct the RCA and implement results.
- **Budget** – the financial resources needed to carry out the RCA.
- **Reviewer/s** – a competent RCA assessor/s who review the output from the RCA session to ensure conformity with the basic approach and with company policy.
- **KSF’s** – ‘Key Success Factors’ that must be managed and controlled to achieve the objectives of the organization in implementing an RCA program.
- **KPI’s** – ‘Key Performance Indicators’ used to measure progress of the RCA program across the site or organization.
COMMON TOOLS

Commercially available RCA analysis systems suitable for industrial applications have been developed over many years and are readily available. Several of these methodologies are in regular use in industry with the more common ones being ‘Apollo Root Cause Analysis’, ‘Taproot’ and ‘Kepner-Tregoe’. These tools amongst others are based on fundamental concepts that have been developed over many years. These fundamental concepts include Fault Trees, Event Trees, Cause and Effect Charts, Change Analysis, Human Performance Analysis, Barrier Analysis, Energy Flow Analysis, Systems Analysis, Constraint Analysis etc.

These tools differ in their effectiveness for different applications and the selection of the most appropriate tool or tools is an important aspect of RCA analysis. It is important to appreciate that there are no ‘good’ or ‘bad’ tools only appropriate and inappropriate ones depending on the circumstances.

Many of the basic tools common to Total Quality Management, Six Sigma and Reliability Analysis amongst others are appropriate and effective RCA tool in some circumstances. It is beholding therefore on the RCA facilitator to have more than a passing familiarity with a broad range of potential RCA tools and help the analysis group decide on the most effective one to use in a given situation.

A relatively simple way to get started in implementing RCA in your organization is to select one of the more established tools and develop experience working through examples. As your experience develops you will be in a better position to determine which support software (if any) is likely to suit your needs. It is difficult to improve on the ease of use provided by the simple whiteboard and ‘post-it notes’ much loved by RCA trainers.

GENERIC RCA IMPLEMENTATION METHODOLOGY

In the introductory section of this booklet we identified the underlying, generic components of a RCA and we will expand on these in this section. To recap, the generic components were identified as:

1. Clearly identify the event to be assessed.
2. Quantify the significance of the event (e.g. cost, injury, environmental impact, etc.)
3. Determine the prevailing conditions leading to the event.
4. Identify any contributing factors to the event.
5. Document evidence for each factor or condition.
6. Provide an efficient methodology for reviewing the evidence.
7. Identify the Root Cause/s.
8. Provide a mechanism for managing the recommended actions.

As stated earlier, it is important to appreciate that RCA methodologies generally speaking are not restricted to the analysis of physical failures only and can be applied to the failure of procedures, tasks and other non-physical systems.

**Identify the event to be assessed**

The problem to be assessed is often identified as a result of some undesirable event such as an expensive equipment failure, a near miss safety incident, a customer complaint etc. It should not be assumed however that the initial description of the problem is necessarily accurate or even...
that it relates directly to the actual problem. It is easy to take the initial statement of the problem at face value and not explore the surrounding issues carefully to identify the true scope of the problem.

In practical situations the initial description of the problem is really a description of the evidence seen at the end of the event timeline rather than the causal action at the beginning of the timeline and which subsequently lead to the undesirable outcome. This is the ‘root-cause’ that we are interested in. Recognizing that we could be misdirected by incomplete or incorrect information provided in the initial statement of the problem we must strive to develop as accurate and all-encompassing a description of the problem as possible right at the outset.

Failure to clearly identify the problem is one of the most common mistakes in the application of RCA. Including an unnecessary topic in the problem statement from the outset can misdirect effort and waste time and resources as well as creating the possibility that this could mask the true problem. Similarly, if an important issue is left out of the problem statement it can easily go unanalyzed throughout the RCA process and lead to an incorrect or at the very least and incomplete solution to the problem. As we will be using the problem statement to determine our progress and success it is important that it be as thorough as possible.

A useful way to remember the important issues to consider at this stage of the RCA is the traditional newsman’s standard questions - ‘who’, ‘what’, ‘where’, ‘when’, ‘how’ and ‘why’ provide us with a good starting point for the investigation as well as ensuring that the main issues are considered.

Who reported the problem – provides a contact/s with whom we can follow up with for additional information and clarification and most importantly as a source of first-hand information.

What actually happened – the first statement of the problem from firsthand accounts.

Where did it happen – the spatial information relating to the problem or event (i.e. where specifically did it occur)?

When did it happen – the temporal information relating to the problem (i.e. what was the sequence and timing of events)?

How did it happen – the cause-and-effect relationships between events (i.e. what action caused each event to occur)?

Why did it happen – what was the initiating action in the chain of events (i.e. what first occurred to cause the chain of events to occur)?

Useful as these prompts are it is important not to follow them blindly and it is usually necessary to supplement these questions with additional and more detailed questions. In addition, photographs, drawings, reports, logs etc. will also be required where applicable to provide the evidence needed to substantiate the claims and counterclaims inevitably encountered in a RCA study.

In particular we will need to be able to clearly state why the problem is important enough to justify a RCA and therefore we need to identify how the problem impacts on the organization, departments, systems, assets and most importantly on people. While the initial identification of the problem was likely made because the one or more of these impacts were apparent and significant it is often the case that additional impacts arising from the problem can be overlooked.

Drawing out the available information can often be difficult to accomplish and a structured approach such as a ‘Brainstorming’ workshop can be of immense value in providing a structured means of identifying and collating this information. The participants in the Brainstorming session
need to be carefully chosen to ensure that the necessary expertise is available and that a wide cross section of views is available to broaden the topics considered. A common mistake is to gather a group comprising like-minded people and trying to develop a holistic view of the problem based on a group with a narrow view of the problem. This can easily arise in an industrial setting where highly trained and competent technical staff Brainstorm a problem and completely miss non-technical aspects of the problem such as operations, marketing and HR issues.

An experienced facilitator with a cross-functional team can be effective in overcoming this problem. Use of standard Brainstorming tools such as ‘Fish-bone’ diagrams, ‘Cause and Effect’ diagrams etc. can also provide a structured approach to this exercise and help draw out the important information needed for the RCA.

**Quantify the significance of the event (e.g. cost, injury, environmental impact, etc.)**

Whenever possible, it is important to quantify all reports, observations, claims, statements and losses to provide a means of comparing the magnitude of the contribution of each to the problem and to help identify the most promising paths to develop further. In the event that an objective measure cannot be assigned to an action, report etc. it can be acceptable to assign a score from an agreed score table to allow relative comparisons to be made.

Scales that can be used to assign confidence levels to specific reports, data etc. can be useful in determining where knowledge is adequate while highlighting data and knowledge that is still inadequate to support the RCA decision process.

**Determine the prevailing conditions leading to the event.**

A detailed record should be made of the operating context and parameters in effect leading up to and at the time the failure occurred. This evidence should be collected from operating records, eye witnesses, shift logs, failed components, photographs etc. A consistent, structured approach to the identification, collection, recording and preservation of evidence pertaining to the failure should be in place before the failure occurs to maximize the likelihood of all relevant information being collected and preserved.

As time elapses after the failure incident has occurred the quantity and quality of evidence reduces as does the ability of eye witnesses to recall facts without distortion. For this reason all practicable efforts should be made to collect evidence as soon as possible after the failure and to document and preserve that evidence.

**Identify any contributing factors to the event.**

Any evidence collected should be reviewed systematically by competent personnel and all reasonable conclusions drawn from the individual components of the evidence as well as from the totality of the evidence. In some instances it is the combination of individual facts that leads us to the cause rather than any single piece of evidence.

The more destruction that is generated by the failure mechanism as it progresses, the more difficult it can be to link the evidence to the root cause as the primary evidence (evidence of the root cause failure) can be obscured by secondary evidence (evidence of subsequent damage to the failed and other parts as the failure mechanism progresses). In some instances the failure mechanism can be almost instantaneous (e.g. seconds) while in other cases the failure mechanism can extend over a considerable period of time (e.g. minutes, hours or even days).

The ability to work back along the timeline from the evidence - which by its nature is evidence of the later stages of the failure mechanism, - to the root cause requires both skill and experience.
and one should make use of any objective assessment methodologies available and which are appropriate and cost effective for the application. It is generally easier to link the available evidence to the root cause for a failure having a short duration failure mechanism with few stages from the root cause to the failed state than it is for a failure that has a long and torturous failure mechanism which generates a significant amount of secondary damage thereby obscuring the root cause.

For example, a fatigue failure of a pump shaft can progress steadily to the point where the shaft fractures and the equipment becomes inoperative. The relatively simple failure mechanism and low likelihood of secondary damage makes the link between the available evidence (fatigue marks on the fracture surface) and the root cause (e.g. misalignment) relatively easy to identify.

Failure mechanisms having many stages from the root cause to the failed state can generate considerable secondary damage and obscure the root cause to the point where identifying the root cause can be very difficult and in some cases impossible to identify with any certainty.

For example, fire damage to equipment following failure of a mechanical seal on a combustible products pump may obscure the root cause (e.g. seal failure) to the point where the root cause cannot be determined with confidence. In reality, while we are only able to examine the evidence — fire damage, the root cause may be linked to the evidence as follows.

(8) Collapsed structure → (7) fire damage → (6) fire → (5) ignition source → (4) fuel leak from seal → (3) seal damage → (2) bearing failure → (1) inadequate bearing lubrication*

From examination of this example timeline it can be seen that the evidence is fire damage and the root cause for this example is inadequate lubrication of the pump bearings. In practice the root cause could be pushed further back to identify additional factors.

*→ (0) failure of the maintenance program → (00) inadequate management

Clearly, the true root cause of a failure can be deeply rooted in an organization and it can require significant changes to ‘the way things are done’ as well as to systems and hardware before any lasting impact can be made to the failure mode under consideration.

Failure to consider all of the evidence, or jumping to conclusions based on an inadequate assessment of the evidence will in almost all cases lead to an incorrect finding. The likelihood that a recommendation based on incorrect data or interpretation of the evidence would provide a satisfactory outcome is low and therefore inevitably the result of poor analysis is poor outcomes.

Evidence from the similar incidents at the same or other locations can provide hints to the root cause and help identify the root cause even if the failure mechanism is ‘messy’ and generates a lot of secondary evidence. Extreme cases of ‘messy’ failure evidence can be seen in the results of major fires, aircraft accidents or explosions. In all of these cases the final evidence is very largely secondary evidence with a relatively small amount of primary evidence heavily obscured by the secondary damage characteristic of the ‘messy’ failure mechanism.

**Document evidence for each factor or condition.**

Evidence collected immediately after a failure should be carefully collected, documented, stored and analyzed if it is to be of use in identifying the root cause at a later date. In extreme cases the
team conducting the RCA may be made up of different people to those who collected the evidence and their only connection with the failure scene may therefore be via the evidence record. In most commonly encountered industrial situations those collecting the evidence are likely to be involved in any subsequent RCA and therefore the link between the evidence and the RCA team is not as tenuous as for the extreme example mentioned above.

It must be remembered however that not all of the RCA team members are likely to have had an opportunity to inspect the failure site and participate in the collection of evidence and therefore these people at least will be relying on the quality of evidence collection as well as on the quality of the documentation to inform them of the salient points. Without clear documented evidence it can be very difficult to determine later what events occurred, when these events occurred, the impact of individual events and the relative importance or significance of events.

Detailed descriptions of the evidence, where it was found, its proximity to other evidence, its condition when found, photographic records, transcripts and tapes of interviews, operating logs, computer printouts etc. are all potentially valuable information and can be major contributors to the evidence trail.

**Provide an efficient methodology for reviewing the evidence.**

Review of the evidence should be carried out by competent staff familiar with the failed system or equipment and who have experience in the analysis of failures. Failure to analyze the available data correctly can lead to erroneous outcomes and the implementation of ineffective solutions.

Individual pieces of evidence should be considered in isolation and as much information gleaned from the evidence as practicable. The evidence should then be reexamined in combination with other evidence to determine if there are interactions and dependencies between different pieces of evidence.

It is important to have a high level of confidence in the conclusions based on the evidence and therefore it is important to double check all evidence supporting these conclusions. In particular, the spatial positioning of evidence (i.e. where it was found relative to other evidence) and its temporal positioning (i.e. when it was generated on the timeline) are of crucial importance to any subsequent RCA.

It is very common to find after some considerable time examining the evidence that assumptions or beliefs regarding the spatial positioning of evidence or its chronological order, is found to be incorrect or can be interpreted in another way to that previously considered. These major shifts in evidence interpretation can completely change the outcome of the RCA and only by maximizing the confidence the RCA team has in the evidence and its interpretation can the final recommendations be made with confidence.

Not all of the evidence collected will necessarily have the same impact on the RCA findings and therefore having confidence in critical evidence is more important than having confidence in less significant evidence. For this reason once a piece of evidence has been identified as significant it should be double checked for accuracy in recording and additional supporting evidence sought to corroborate it. Evidence determined to be important to the analysis will need more consideration and supporting data that less important evidence. The practical difficulty in determining which evidence is most important is that it can be very difficult to determine the importance of evidence until the analysis has progressed significantly and a clearer ‘picture’ of the failure starts to develop. For this reason every effort should be made to prevent ‘bias’ entering into the analysis and in many cases this is best achieved by separating the data collection and analysis from the development of conclusions.
Identify the Root Cause/s.

Identification of the root cause of a failure does not necessarily come at a single point in the analysis and can develop over time as small pieces of evidence accumulate and help to sway confidence in one possible cause over another. In other cases the discovery of a single piece of evidence can establish the root cause simply by the fact that that evidence clearly links a critical step in the failure mechanism.

REPORT RCA FINDINGS

A RCA undertaking is only beneficial to the organisation if it has been well focused, professionally undertaken and the findings implemented by the organisation to implement the changes identified by the analysis. Failure to document the RCA process and communicate the findings to the appropriate people and sections in the organisation means that the findings are never implemented and no gain is achieved from the RCA process. In addition, the failure that was the focus of the RCA will continue unchecked into the future.
Example: ‘Tree-based’ diagram of the type commonly used in Root Cause Analysis.
BIBLIOGRAPHY

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