Human error in maintenance

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As experience grows in using RCM and RCA to improve maintenance performance, it has become evident that a significant proportion of failure modes are related to human error. In order to effectively manage these failure modes it is important to gain an understanding of how and why human errors occur.

Human beings all make mistakes. Within society this is generally perceived as a bad thing, something to be punished for by allocating blame and sometimes shame to one individual or group. This paper challenges that position and will present an introduction to understanding and managing human error within the RCM process including:

- How our minds work – short & long term memory
- How much information do we successfully process?
- Corporate levels of error
- The blame game
- Slips, lapses and deviations
- Factors affecting performance
- Strategies and tactics for managing human error within the RCM program

Introduction

This paper introduces the basics of what is collectively referred to as human error. In itself, this is a wide field of study with many different, sometimes competing theories. This paper is not intended to make us all experts in human error. Rather, it is intended to provide a broad knowledge that can be used to supplement the skill-sets of RCM facilitators and practitioners to provide a path to higher levels of maintenance effectiveness.

Why should we be interested in how our minds work in order to perform an RCM analysis? Because in understanding some of the ways that we process, filter and retain information we can develop more specific strategies to eliminate, reduce or mitigate the effects when errors occur.

Mistakes can be costly in maintenance and are reflected in safety and environmental performance, rework, additional downtime, customer service and business competitiveness.

For organizations that use Root Cause Analysis (RCA) as well as RCM there can be a lot of useful information available. RCA usually 'drills down' through several more layers of failure causation and often provides useful insights into human behavior during events. The data may not be specific to failure modes within an RCM analysis but can add considerable value to our understanding of human interactions with equipment failure.

RCA is triggered after an event has taken place. We can learn valuable lessons from them to apply proactively using RCM. RCA and RCM are separate but complimentary tools that we use to drive equipment reliability improvement.

RCM is usually applied to hardware - to simple and complex systems. As facilitators, practitioners and leaders we should encourage broad thinking with regard to the recommended actions for each failure mode. Where condition-based, rework, discard or failure-finding tasks are not applicable or effective we should not be afraid to take our thinking outside the traditional boundaries of "no scheduled maintenance" or "redesign" when dealing with human error failure modes.

More and more of our plant equipment and systems are protected to prevent human error. Generally, the worse the consequences of failure are, the more complex the protection that we design. This protection acts rather like the tumblers in a mechanical safe lock. An undesired outcome can only occur if all the tumblers are 'lined up'. One of these protective tumblers is the person who interacts with the system. This interaction may take the form of an ability to override the other tumblers and take manual control of a system. We also devote time and effort to maintaining the other 'tumblers', which leads to the opportunity for errors to occur and degrade our protection. Safety and maintenance are closely linked and catastrophic events tend to grab headlines but there are many more mistakes that are made with no such disastrous outcomes - except to our bottom line. Premature failure of incorrectly installed or incorrectly operated equipment cost organizations money, customer satisfaction, employee engagement and downtime.

A few examples below are included to illustrate the depth and costs of human error:

- A study of the US public switched telephone network over two years [Kuhn97] found that twenty-five percent of telephone outages were caused by maintenance errors on the part of telephone company personnel.

- In 1999 (National Safety Council, 2000), the financial impact of U.S. injury-related workplace accidents attributed to human error was $123 billion and 125 million lost time days.

- Human error, not equipment or system failure, underlies 80% of all industrial accidents and injuries. (Circadian Technologies, 2001)

How our minds work – short & long term memory

Throughout our lives our senses are bombarded with data. We filter, process and selectively store this data in order to make sense of the world around us.

Data is delivered via the senses – sight, sound, smell, touch and taste. Somewhere between 4 and 10 billion bits of information per second arrive in a continuous stream. Our short-term memory acts as a filter and reduces the data that we process to around 2 thousand bits of information per second. However, short-term memory is only capable of holding information for between two and seven seconds before it is displaced or pushed out by new data from our senses.

Some of the data is routed to long-term memory where we look for familiar patterns that match the incoming data. We are also pulling information in short bursts from long-term memory into short-term memory to enable us to focus our attention on the task and to 'read forward' or pay attention to the next actions in the sequence.

Figure 1 provides a simplified overview of the basic process.

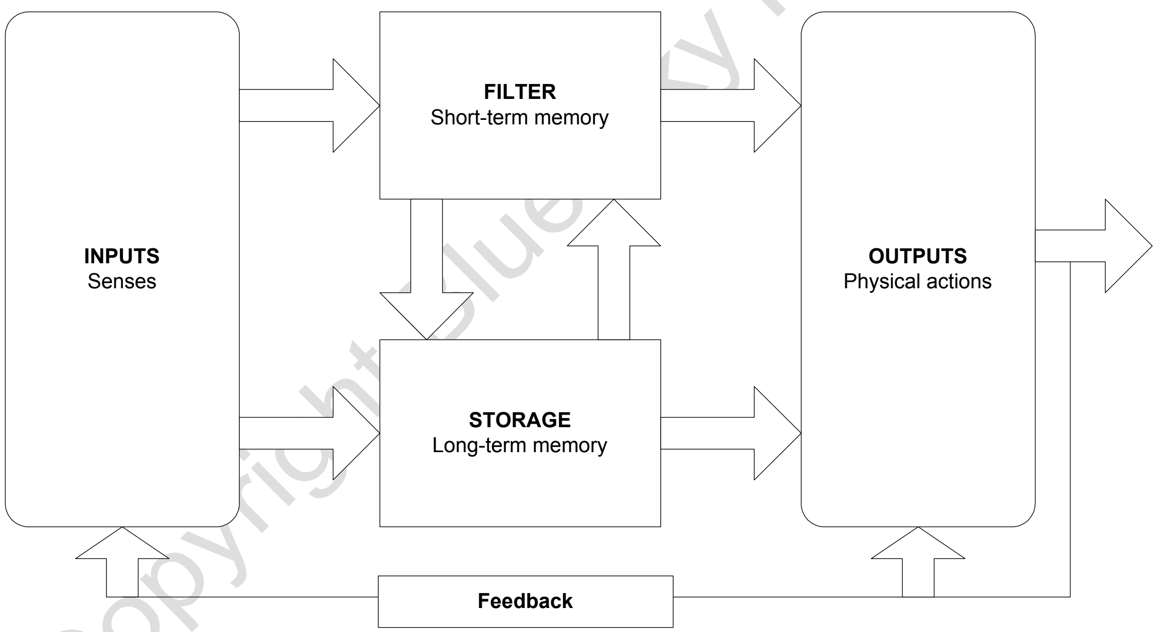

Figure 1

Our attention is a limited resource – there is a fixed amount available and it is difficult to sustain for long periods. In practical terms this means that if we are occupied within one area of interest, inevitably something is taken away from another. The bottom line for attention is that there is only so much to go around and how we spend it is influenced by a host of different factors such as preoccupation, distraction or our interest in the work at hand.

Imagine traveling to work each day following the same route. Many of us can spend time driving the vehicle without much, if any, thought. Our short-term memory has much of its capacity freed up and we can think about anything we please, we can hold a conversation with a passenger, listen to music, or even learn to speak a foreign language! Our actions are largely controlled by our long –term memory. This is part of our (human) software. We can control our actions based on stored sequences and known patterns that we use as a reference.

When we arrive in an unfamiliar location, we are not as sure of the roads anymore; does this state allow right turn on red? If I am in England, remember to drive on the left, this rental car is a stick shift so I need to use my left hand to shift gear! Where do I switch the wipers on? In these circumstances we are using a much larger proportion of our short-term memory to manage the journey. In this example, some stored sequences are very useful such as the rules of the road. We revert to using rules and concepts that we are familiar with even when we are in unfamiliar territory and even if they are not correct.

In order to perform at our best, the key is in balancing our attention. Too much can be as bad as too little. Many of us have experienced less than great performance from time to time either by 'trying too hard' or 'not keeping my mind on it'. We behave in reaction to two factors – the processes that are taking place in our head and the environment that we are in. Our performance is largely dependent upon how well we can balance and manage these two factors. Balance is a theme that we will return to several times throughout this paper.

How much information do we successfully process?

As mentioned earlier, the information that reaches our short-term memory is constantly being filtered. A large percentage of the information that is retained is successfully processed. Errors usually occur when there is some form of disruption caused by an outside influence. For example, it is when we are distracted in some way from the task at hand that a mistake occurs.

Throughout our daily lives we are processing decisions in three different levels. These levels are commonly known as skill based, rule based and knowledge based.

- Skill based: Deals with familiar, routine situations

- Rule based: Deals with problems that are non routine but that we have been trained to manage

- Knowledge based: New problems that we have not experienced before that require thinking through and require high levels of concentrated effort

There are many occasions when we use all three levels simultaneously - they are not exclusive.

Corporate levels of error

If we are to gain some understanding of errors made at the individual level we must take into account the larger system that surrounds the event. If this sounds familiar, it should – it is the operating context that we work in.

Questions worth asking about organizational culture include:

- Is this a culture that proclaims, "do things right" but then caves in under operational pressure and restores equipment to service before checks are completed?

- Is the maintenance function understood and supported at all levels in the organization?

- Does the organization turn a blind eye to violations or non-compliance with procedures?

- Does the underlying maintenance culture significantly alter as a result of personnel changes?

- Are maintenance and operational needs well balanced?

We know that these can be difficult questions because we regularly ask them.

Without understanding the organizational context, any failure analysis that involves human error is naturally drawn to the behavior of the individual(s). There can be a tendency to focus on who did what without looking at the underlying issues that may surround their behavior.

Hindsight almost always provides us with a clearer view of an event than the people who were involved at the time the event took place. Many of us have heard:

"What were they thinking?"

"How could he/she be so careless?"

"I could never make a simple mistake like that"

"All our people have been trained – how could this happen?"

"Who did it?"

"If they had followed procedures this wouldn't have happened"

If we create a maintenance environment that is ambiguous, we have created an environment ripe for error.

An example of individual and corporate error is the Clapham Junction Rail Collision that occurred in the UK on a busy rail route into London at 8: a.m. on December 12th, 1988. Thirty-five people were killed, and five hundred were injured. Three crowded commuter trains collided when a track-side signal failed in an unsafe condition. Installation work had been completed two weeks prior to the accident as part of a signaling system upgrade project.

The resulting inquiry into the accident revealed several key issues. The direct cause of the accident was a technician's wiring error – he had disconnected a wire but failed to cut back the exposed conductor and insulate it. This conductor later came into contact with a relay terminal and the scene was set for disaster. It was simply a matter of time until trains were in the right sequence to trigger the event.

The inquiry also identified other contributory factors:

- The technician had only had one day off work in the previous 13 weeks
- The technician's supervisor had failed to monitor or correct unsatisfactory working practices
- The supervisor's manager had visited the site prior to the accident and had seen wiring that had not been cut back / insulated and had taken no action to correct the practice.
- The Testing & Commissioning Engineer failed to carry out an independent wire-count before restoring the equipment to service even though he had adequate time and staff available
- There had been an extensive business reorganization creating role changes for many senior engineers and managers

The inquiry and report swept on upwards through the hierarchy of managers (permanently damaging and, in several cases, ending careers). The technician involved still works in signal engineering.

As a result of this inquiry, millions of wires throughout the entire UK signaling system had to be individually checked for similar conditions because the practice of not cutting back or fully insulating redundant wiring was so widespread. The cost of the remedial work ran to many millions of dollars.

The Blame Game

A common misconception surrounding human error is that a few careless or reckless individuals cause the majority of errors. It is tempting to suggest that if these few problematic individuals are retrained, disciplined or let go that the problem will go away. Sidney Dekker refers to this as the Bad Apple Theory. However, we all make mistakes and as a general rule, the more experienced the individual is the more likely they are to occupy positions of greater responsibility - the errors they make may have the most costly effects.

Assigning blame may satisfy our basic reactive emotional needs to 'do something' but what does a moral judgment of this sort actually achieve? What purpose does it serve to punish someone who had the best intentions for the organization because their planned actions fail in some way? How likely is it that someone reaches a point in an event where they recognize their actions as wrong or reckless and then disregards that realization and continues? It usually made sense to them at the time the decision was taken. Human error can hardly be treated as a moral issue and pointing out that somebody did something wrong or omitted to something right does nothing to contribute to our understanding of why they behaved in the way they did.

We should be clear that if the planned actions of an individual or group are carried out with known ill intentions, a moral judgment (blame) might well be a justified reaction. For most cases this can be grouped under 'violations'. We will return to violations a little later in the paper.

We are not suggesting that there should never be consequences for errors made either. We should all be held accountable for our errors as individuals or at the organizational level. That way, we can genuinely learn from our experience and be able to move forward. Being accountable is not the same as being punished.

Slips, Lapses and Deviations

James Reason provides us with a useful definition of error that distinguishes between controllable actions and those that are subject to random unpredictable influences.

"An error is the failure of planned actions to achieve their desired goal, where this occurs without some unforeseeable or chance intervention."

Error can be split into two areas - unintended action(s) and intended action(s). Unintended actions encompass slips and lapses. Intended actions include rule-based mistakes, knowledge-based mistakes and violations.

Intended Actions	Unintended Actions
Rule-based mistakes	Slips
Knowledge-based mistakes	Lapses
Violations	

A slip is associated with a loss of attention in short-term memory. Put simply, a planned task is performed in an incorrect manner or in the wrong order - it is a good plan incorrectly executed. Slips are also associated with skill-based error. They can (and do) occur even when someone is trained, experienced and qualified to perform the work. A routine task is often driven by 'automatic' routines from memory that place minimal demands on our concentration. Replacing machine guards, taking oil samples, fitting lock wires are all examples of tasks that, for the most part, we entrust to our skill-based routines.

A lapse is linked with a long-term memory failure and can occur when the stored information in long-term memory degrades, when data that we know is stored cannot be called up for use when we need it or, most commonly when there is not enough attention given to ensure that information received for use into our short-term memory is retained long enough to complete the action. Missing out steps in a procedure can manifest themselves as losing our place in a procedure and either repeating steps previously completed or jumping ahead in the list. Items toward the end of a list are also likely to be missed because we have a tendency to begin thinking about the next job we are going to perform. External distractions play a major role in disrupting our concentration and introducing errors.

Rule-based mistakes (intended actions) also split into two categories. A good rule can be incorrectly applied. For example a procedure that is correct for application on a MK1 compressor is inadvertently applied to a MKIII compressor that looks the same but requires different maintenance. Conversely, a bad or inadequate rule can be followed diligently but fails to achieve the intended goals.

Knowledge-based mistakes generally occur when a situation arises that we have not experienced before. In this situation we search for a matching pattern in our long-term memory and when we cannot find a good match we tend to 'go back to basics' and find the closest pattern that can then be modified to fit the new circumstances. Errors of this type are typically more likely to occur when someone is performing a task for the first time or when the task is infrequent. In answer to the question "At work in the last year or so, how often have you done an unfamiliar job, despite being uncertain whether you were doing it correctly" just under 60% of aircraft maintenance personnel stated that they had done this. (A. Hobbs and W. Williamson, Aircraft Maintenance Safety Survey - Results, 2000).

The last group of intended actions is violations. While slips, lapses and mistakes are unintentional; violations are deliberate but generally not malicious in character. The exception is premeditated sabotage, which is outside the scope if this paper.

Intentional violations are the result of a considered decision except where the behavior has become so deeply embedded into a maintenance culture that it becomes the norm. Not performing functional tests before returning equipment to operational status, using incorrect tools, not locking out equipment and deliberately missing steps in a sequence because they are perceived as low value are all examples of deliberate violations. 'Pencil whipping' a maintenance procedure is an intentional action.

Many violations become routine and are well intentioned in that they are perceived as 'getting this job done as quickly as possible' or bypassing steps in procedures that appear to be irrelevant or unimportant to the person doing the task. Sometimes we decide to cut corners because of operational pressures whether they are real or perceived.

Factors affecting performance

It is well documented that human performance is adversely affected by fatigue. This lower performance can manifest itself in a lack of concentration because we have to work harder just to keep up. We may become irritable and frustrated by routine tasks leading to a higher temptation to commit violations. Cramped, badly lit, high temperature, low temperature, uncomfortable working conditions can lead to fatigue setting in much earlier than with ideal conditions for work. In the maintenance business, such conditions can sometimes not be avoided.

As previously mentioned in this paper “The technician had only had one day off work in the previous 13 weeks”. Much of the time was committed to working shifts of twelve hours duration and committing to excessive overtime working was an accepted practice in the industry at that time.

Shift patterns can lower performance levels. For many industries limited technical support for maintenance personnel may be available at night or outside office hours. It may be as simple as the fact that work can take longer to set up if lighting has to be provided.

Our own emotional state or the emotional state of people around us can lead to lack of rest even though we are not actually working long hours. Many of us experience emotional issues such as bereavement, divorce, money problems, the birth of a new child, a sick child or moving house during our lives. Events in our personal lives can ‘bleed’ over into our working lives and usually have some effect on our performance through fatigue and / or distraction.

Poor communication between individuals or departments leads to a level of frustration that can degrade not only individual performance but can affect a whole team if it is left unchecked.

Strategies and tactics for managing human error within the RCM program

Accepting part or all of the previous sections of this paper, how does it affect RCM?

The majority of RCM processes include the opportunity to define failure modes associated with forms of human error. In most cases the actions resulting from analysis of these failure modes lead to some form of redesign that might include hardware, software, human interface, procedures and training standards.

Most people accept that introducing RCM is challenging – perhaps the most challenging of all the maintenance methodologies. It demands changing the way we think in order to change the way we act. It also creates an opportunity to continue to drive into areas such as human error.

We are not suggesting that RCM analyses should attempt to include all human error root causes. That would expand the work to unmanageable proportions. What we can do is to look for trends in the failure modes that are recorded and identify areas where we can begin to reduce the amount of errors that occur.

Provide improved written procedures, easy access to the correct tools, equipment manuals and build on an already successful safety conscious working environment that distinguishes between blame and accountability.

Strategic Intent	Tactic	Goals
Minimize errors during task execution	Develop procedures from the RCM analyses that are formatted as checklists and are formally reviewed prior to publication.	1) Identification of task sequences where a procedure may be vulnerable to being misread or misinterpreted.
		2) Manage slips and lapses.
Consistent maintenance delivery	Develop formal and informal real-time observations of procedure adherence	1) Move toward a behavior-based maintenance culture
	Continue to support a blame free environment	2) Encourage open, honest discussion of errors

In using these human error failure modes to identify and address areas of weakness identified by RCA and RCM we will be taking our programs and projects beyond implementation and into consistent, sustainable delivery.

Questions / comments?
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