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Influences on Consequences: Causation, Mitigation, and Prevention and Their Dimensions

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Caveat

This article is intended for advanced root cause organizational learning professionals (rooticians). Others may benefit from studying it, but it is not intended as orientation for novices or for veteran professionals who have only occasional contact with the state of the practice of root cause organizational learning.

Introduction

This article is to clarify the understanding of what factors influence the adverse consequences[1] of an adverse event. By the adverse consequences of an adverse event we mean the tangible and intangible harm, for example, the d-words: deaths, damage, "damages", (radiation and chemical) dose, defects, dismemberments, disabilities, degradation (of assets), discharges (to the environment), dollars of loss, destruction, delay, disruption, discredit, disgrace, defection (of employees and customers), damnation (by stakeholders), and the like. By adverse events we refer to the spectrum of unintended undesired occurrences including accidents, severe natural phenomena, financial adversities, health care mishaps, political adversities, and the like.

This discussion applies to adverse events that have actual consequences, expected consequences, and/or potential consequences of any magnitude. (It might break down at the case of a zero magnitude consequence, which is, to my knowledge, never investigated.) This gives:

Expression 1):

{Consequences} = {Actual Consequences} + {Expected Consequences} + {Potential Consequences}

- Actual consequences are those that have already happened.
- Expected consequences are those "in the pipeline" that will be realized such as bills not yet received and fines not yet levied.
- Potential consequences are those that could have been incurred, but were averted. Potential consequences also relate to future events to which the current event may be a precursor[2]. "Official" definitions are not available.

[1] Some writers, e.g., Dean L. Gano, "Apollo Root Cause Analysis," Apollonian Publications, Yakima, WA (1999), pp. 63-65 use the term "significance" for this concept, but we save the term "significance" to refer to the meaning of the event for an affected entity. This allows conceiving an event to be highly significant while having low consequences, as in hear miss events. Resources should be preferentially applied to events of higher significance.
[2] http://www.nap.edu/openbook.php?record_id=11061&page=79

See Figure 1 for this expressed as a taxonomy.

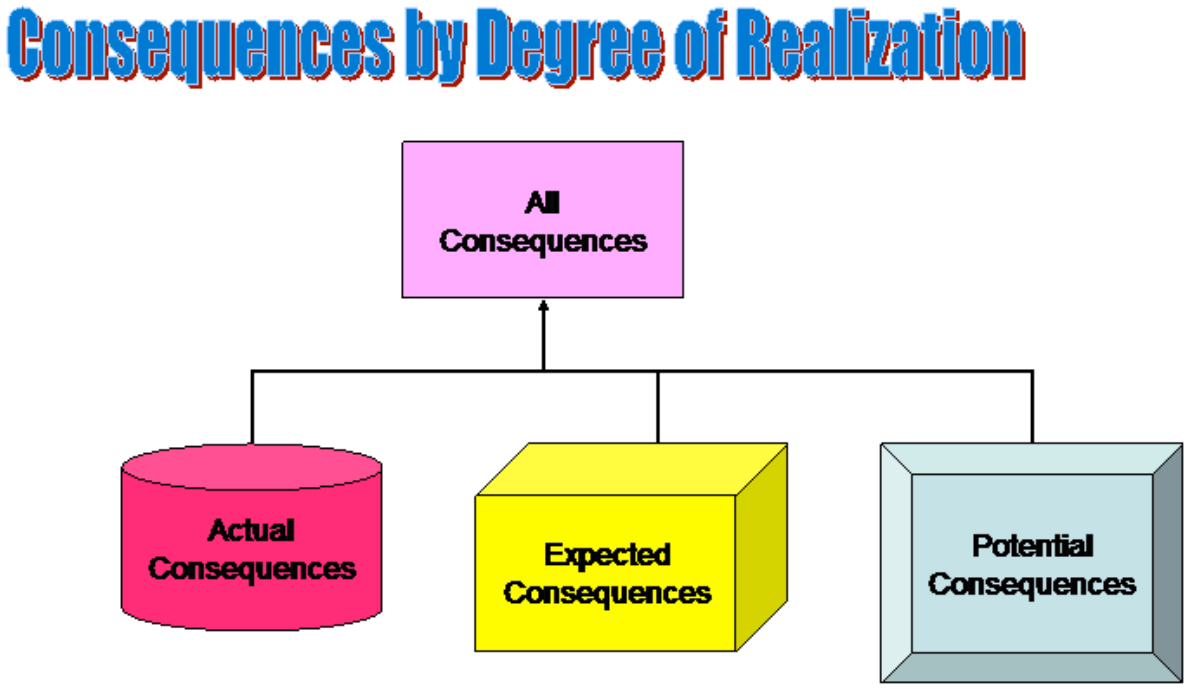

Figure 1 Consequences of Interest to Rooticians

Any of the three can be a target of a cost-effective root cause analysis. If the facts were available, one might be able to conclude that it is more cost-effective to investigate potential consequences than actual consequences. Our principal orientation is toward low actual consequence events that could be precursors to high actual consequence events.

Our orientation in this discussion is one consequence of one adverse event. However, the discussion applies generally to every consequence of every event, but for clarity we are dealing only with one.

Nature and Magnitude of Consequences

Every consequence has both a nature and a magnitude. The nature of a consequence is simply what type of harm it involves, e.g., delay of a project, and the magnitude is how much harm, e.g., one year.

In determining what factors influenced a consequence it is important to specify the consequence in terms of both nature and magnitude because some influences affect the nature of the consequence, some affect the magnitude, and some affect both. One does not understand the influences on the consequence unless one understands both what has affected the nature and what has affected the magnitude.

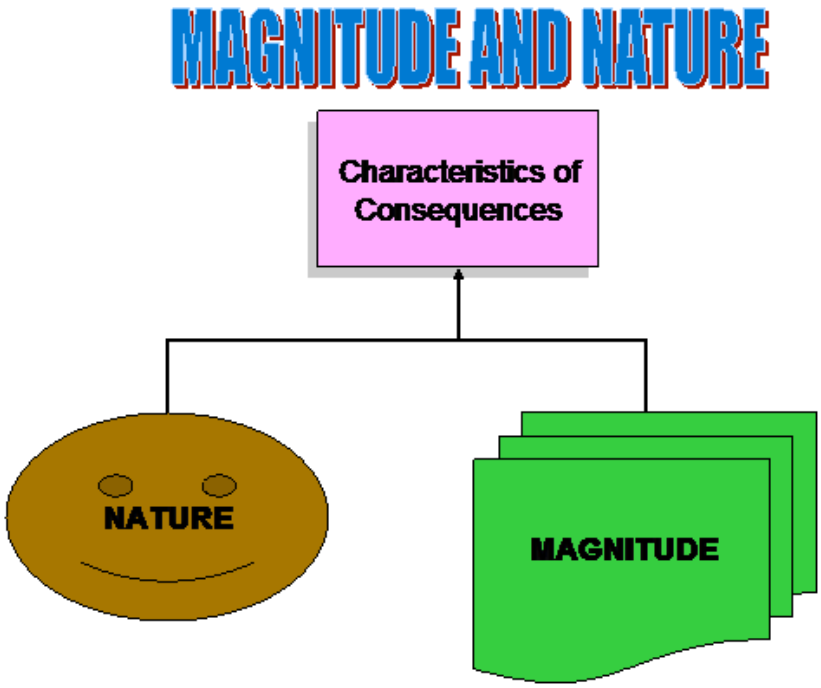

Figure 2 Every Consequence has magnitude and nature.

For another example, a fatal accident involves a number of deaths, perhaps one, perhaps more than one. Fatalities are usually easy to count.

Sometimes the magnitude can only be quantified relatively, but nevertheless the consequence has at least relative magnitude. This is usually not a problem for the root cause analysis team.

An example of a consequence difficult to quantify would be the magnitude of disgrace to an organization. But one could assess that a given circumstance was more disgraceful than another. In particular one could assert that the Davis-Besse Reactor Vessel Head Degradation[3] episode

[3] http://www.ucsusa.org/clean_energy/nuclear_safety/page.cfm?pageID=790

was more disgraceful to the U. S. Nuclear Regulatory Commission than the Indian Point Steam Generator Tube Rupture[4] episode.

Opposing (Counteracting) Influences

It is clear that the magnitude (and often the nature) of each consequence is due to the net resultant influence of opposing factors, some of which tend to worsen the consequences and some of which tend to counteract, interdict, limit, arrest, stop, or otherwise control the consequences. The factors that tend to create and worsen the consequences are usually called adverse factors (causes) and the others are usually called beneficial factors.

Expression 2):

{Adverse Factors} + {Beneficial Factors} = {(All) Influences (Factors)}

Expression 2 ignores the trivial case of neutral factors. Expression 2 just says that every factor that affects a consequence can be an adverse factor or a beneficial factor. For completeness, one might observe that there can be behaviors and circumstances that are neutral, but they don't make it to the initial cut, i.e., they don't affect the consequence.

The investigator will find that there are cases in which the same behavior or condition influences the consequences both adversely and beneficially. In these cases one option is to represent them twice on the chains of factors. For example, in the *RMS Titanic* disaster[5] the calm waters made it harder to see the iceberg at a distance (adverse factor) and facilitated life boat operations (beneficial factor.) More about this under "Dual Influences" below.

But what types of beneficial factors are there?

[4] http://www.nrc.gov/reading-rm/doc-collections/enforcement/actions/reactors/ea00179.html
[5] http://www.cruiseserver.net/travelpage/ships/ws_titanic.asp

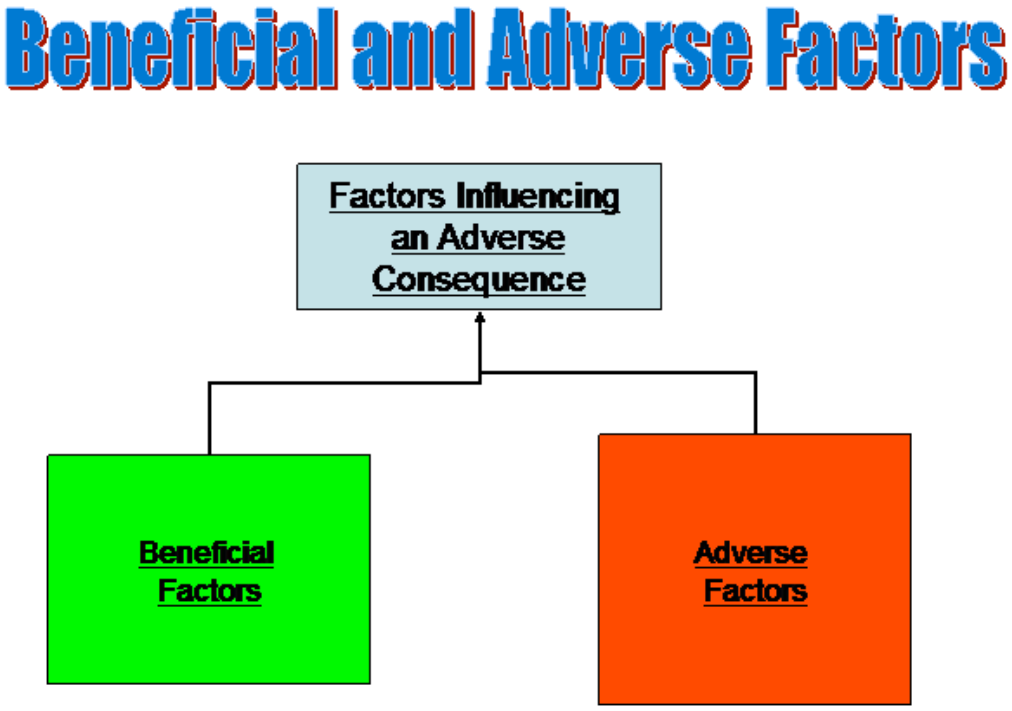

Figure 3 Beneficial and Adverse Factors

Expression3):

{Mitigating Factors} + {Preventing Factors} = {Beneficial Factors}

One never encounters preventing factors in investigating actual consequences. Preventing factors are encountered sometimes in the prospective barrier analysis of potential consequences. The concept of preventing factors is useful to the rootician in two ways. First, the question, "What could have prevented this consequence, but didn't?" can promote inquiry into otherwise missed barriers that were implicated in the consequence. Second, the concept of preventing factors can be useful in generating candidate corrective actions to prevent recurrence.

Mitigating factors go by various names, e.g., limiting factors, controlling factors, bounding factors, and the like. The term "mitigating factor" will be used to include all factors that tend to keep the consequences from being more severe; however they might come into play, without preventing the consequence altogether.

Imagine a row boat. Its exposure to taking on water from waves will be affected by its freeboard, the side height of the gunwale above the surface of the water. The freeboard will be determined by the counter influences of buoyancy and weight.

For a consequence example, one of the mitigating factors of loss of life in the *R.M.S.Titanic* sinking was that the disaster occurred on the maiden voyage and thus the ship was only booked to half its passenger capacity[6]. Opinions can vary, but it appears that had the *Titanic* sunk on a subsequent voyage loss of life could have been much greater than it was.

Another interesting example is that of the sinking of the submarine USS Squalus (SS-192). An important mitigating factor was that the depth of water was less than that necessary to crush the hull. This allowed the Navy to rescue of part of the crew[7].

The magnitude of every consequence is a result of the balancing of causal factors and mitigating factors.

Expression 4):

{Consequence (magnitude)} ← {Causal Factors} + {Mitigating Factors}

(Read "←" to mean "is implied by.")

Expression 4 covers the cases that will normally be encountered by rooticians in normal root cause analysis work, i.e., consequences of non-zero magnitude. However, Figure 4 covers all cases.

> Notice that in Figure 4 there is a shift of paradigm from earlier figures. Figures 1, 2 and 3 are taxonomies, tree diagrams that use the arrow to mean "is/are comprised of." But Figure 4 is an influence tree, a tree diagram that uses the arrow to mean "is/are/was/were influenced by." This is a crucial distinction in understanding, but is usually invisible to most readers. Some tree diagrams use both taxonomical and influential construction without serious difficulty.

[6] http://www.titanic-titanic.com/titanic%20statistics.shtml (Capacity 2500, boarded 1309, including the band)
[7] http://www.onr.navy.mil/focus/blowballast/squalus/default.htm

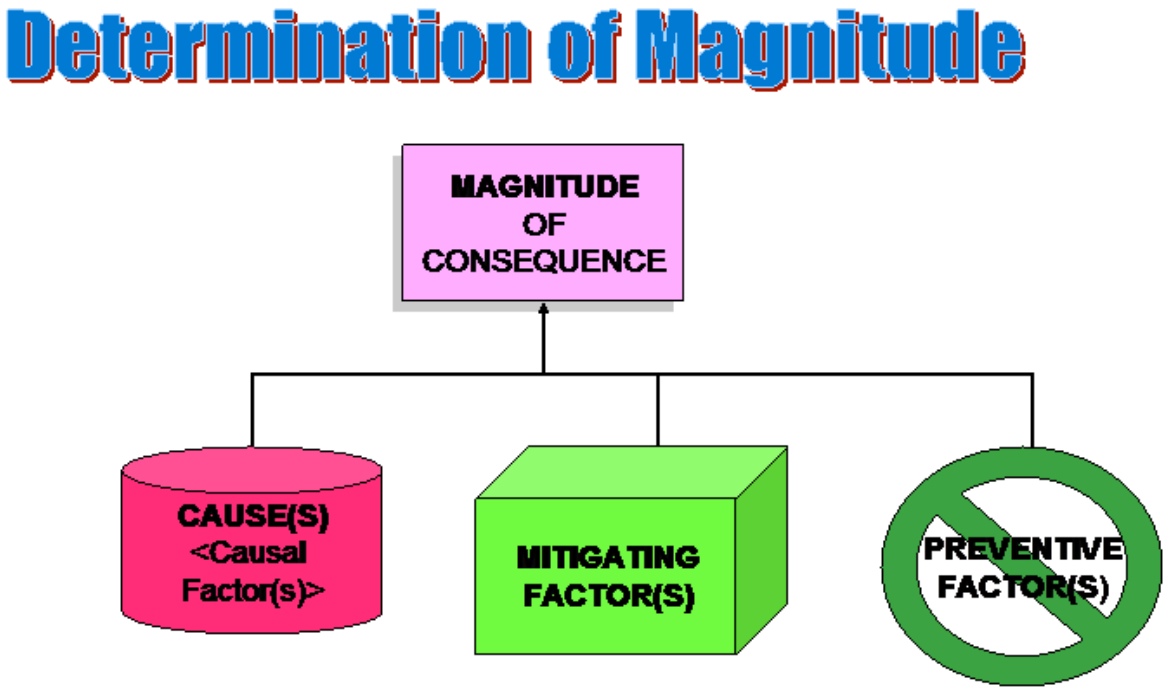

Figure 4 What determines the magnitude? When the magnitude is zero one gets to decide whether the mitigating factor(s) or the preventive factor(s) trumped.

Universality of Mitigation

We are not saying anything profound here, but are merely stating the obvious. And we are doing that because we will need the idea later.

Every adverse event that has happened so far has had at least one mitigating factor, in that it did not destroy the world. And we would thus not expect to ever encounter an event that did not have at least one mitigating factor.

To put this in slightly different words, an adverse event that had no mitigating factors would destroy the world. Hence there would be no one left to investigate it.

The most severe peacetime U. S. armed services adverse event was the sinking of *S.S. Sultana*[8] just after the Civil War. One of the mitigating factors was that the accident occurred within a

[8] http://www.rootsweb.com/~genepool/sultana.htm

short distance of shore and upstream of an island. Thus some of the servicemen were rescued and others were able to swim to safety. Without that mitigating factor, location, the consequences would have been worse.

> It is perhaps, not merely humorous to observe the following. In disasters as well as real estate, location is crucial.

Just noticing that any specific consequence that has occurred to date, however severe, could have been worse implies that there must have been some mitigation. Sometimes the mitigating factor is just that there happened to be few people in the impact area to be harmed, as in the final *Concorde* accident in which the flaming wreckage hit a hotel-restaurant[9]. But, there could have been more. Sometimes the mitigating factor is that there was no more reactant to react, as in the case of Bhopal[10]. But, there could have been more reactant.

Often the keenest insights into ideas for corrective interventions come from examining the mitigating factors[11]. By corrective intervention I mean all of the actions taken to promote more desirable future consequences.

Some of these actions address things that are "wrong" and are thus "corrective" according to most official vocabularies and some address "enhancements" and are thus "preventive" in some official vocabularies[12].

At the very least, the corrective actions taken in response to an event should not unnecessarily weaken or remove the mitigating factors that prevented the event from being even worse. The corrective actions should also not unnecessarily weaken or remove preventing factors for events that have not occurred.

For example, compare the case of USS *Squalus* (SS-192), mentioned above, with that of USS *Thresher* (SSN-593), which also sank during a test dive from the same shipyard twenty-four years later. The mitigating factor cited above was not present in the *Thresher* case and all hands perished[13].

Unless the mitigating factors are identified the danger of inadvertently weakening them exists. This is, somewhat humorously, articulated as "Never remove a guardrail that has dents in it."

Thus, from the viewpoint of future change management it is crucial to identify the mitigating factors for the event under investigation and, when involved in corrective action candidates, preventing factors for events that have not occurred[14].

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[9] http://www.safe-skies.com/concorde_crash.htm
[10] http://www.hu.mtu.edu/hu_dept/tc@mtu/papers/bhopal.htm
[11] Corcoran, W. R., "The Phoenix Handbook", Nuclear Safety Review Concepts Corporation, Windsor, CT (2003)
[12] For a typical treatment see http://www.ehs.wsu.edu/esrp490/nonconformance.htm
[13] http://www.disastercity.com/thresher/
[14] For a regulatory application see 10CFR50.59, "Changes, tests, and experiments."

A key conceptual and practical consideration is that corrective intervention directed to strengthened mitigation is on the same plane with corrective action directed to address causation. Improved mitigation can have the same ultimate effect on a consequence as fixing a cause. Root cause analysis approach that neglects mitigation is ignoring a whole class of corrective intervention possibilities[15].

Usually a root cause analysis approach that neglects mitigation can be strengthened by simply incorporating the consideration of mitigation. Neglect of mitigation in a root cause analysis approach is not, per se, fatal. It is correctable.

Dual Influences

Can a specific fact influence a consequence in more than one way? Many quantified causes can be legitimately viewed as both exacerbation and mitigation. For example, the number of passengers on the *Titanic* made the loss of life as bad as it was. But also, the number of passengers on the Titanic, being below capacity, kept the loss of life from being greater.

The same can be said for the amount of methyl isocyanate (MIC) at Bhopal.

The same can be said for the amount of time that emergency core cooling was decreased at Three Mile Island. The longer the fuel heated up the more of it melted. The sooner the heat removal was restored the less of the fuel melted.

The point of this is that many, if not all, quantified causes logically appear twice in chains of influence. At the causal appearance one needs to explain why it was as bad as it was. At the mitigating appearance one needs to explain why it was so beneficial.

DIMENSIONS OF AN INFLUENCE

The main direction of this article is to explore the dimensions of influences. “Dimensions” are just parametric attributes. For example, a building brick would have dimensions of length, width, height, weight, hardness, color, etc. So also an influence can be thought of as having dimensions also. We will be asking about what some of the useful dimensions are and what values the dimensions can have.

But we need to lay some more groundwork.

Universality of Causation: The Dimension of Involvement

It goes without saying that all adverse consequences are caused. Here we begin discussing the dimensions of causation.

Mode of involvement is the first dimension we will address. It is clear that all adverse events of history must have involved three types of causes by mode of involvement: set-up factors,

[15] The curious reader will be rewarded for researching the work of Dennis C. Hendershot. A good place to start is http://home.att.net/~d.c.hendershot/papers.htm

triggering factors, and exacerbating factors. The logic for the necessity of these three types of factors follows.

If the situation had not been set-up for the adverse event it could not have occurred. Vulnerability is a prerequisite to every consequence. Consequences only occur following a situation that has been set-up for them. The vulnerability factors enable the situation to be staged for a consequence. There is no known example of a consequence that emerged from a situation that was not vulnerable to it.

If a situation is not vulnerable (susceptible) to a certain consequence that consequence cannot occur. For example, a power plant cannot cause disease by release of biological agents.

And if a certain consequence did occur the situation must have been vulnerable to it. For example, the reactor at Three Mile Island must have been vulnerable to fuel melting due to operator error. One of the things that made it vulnerable was the amount of energy it had produced up until the time of the accident. This corresponds to the production of radioactive fission products that give off heat as they decay.

Before the accident occurs the set-up factors are latent[16], in that they are not causing consequences. They may have caused consequences before, as in events following inadequate root cause analyses, but at the time before the adverse event occurs the set-up factors were latent. This will be dealt with in the dimension of latency, below.

But vulnerability alone does not make an adverse event occur. Something must act upon a vulnerable situation for a consequence to result. Something must activate the latency.

It takes something to trigger (initiate) the event. For example, a minefield can be a latent vulnerability that can remain latent for a long time. It takes something to actuate a mine in the minefield.

Of course, one also occasionally encounters a “time bomb” situation that appears to be self-triggering. In this case the “time bomb” can be made to appear twice, once as a vulnerability factor and once as a triggering factor. Usually the “time bomb” can be broken down into constituent components of sub-systems to distinguish which amount to vulnerability factors and which amount to triggering factors

So far we have:

Expression 4):

{Event with consequences} ← {Vulnerability Factor(s)} + {Triggering Factor(s)}

But that is not the end of causation. Finally, one can always imagine any adverse event to happen such that the consequences are milder than they, in fact, were. An accident that was fatal could

[16] See, for example: http://www.hyperdictionary.com/dictionary/latent

have happened in a way that was not fatal. A very expensive event could have happened in such a way that it was not as expensive. And so forth.

For example, the Bhopal[17] accident could have happened during the work day when people were very mobile and thus could have escaped more effectively. As another example, if the September 11, 2001 attacks on the World Trade Center had occurred a few hours earlier the loss of life would have been substantially less.

Thus there must have been some factor or factors that made the consequences as bad as they were. These factors are the exacerbating (aggravating) factors. Thus we get:

Expression 5):

{Event with important consequences} ← {Vulnerability Factor(s)} + {Triggering Factor(s)} + {Exacerbating Factor(s)}

And:

Expression 6):

{Causal Factors} = {Vulnerability Factor(s)} + {Triggering Factor(s)} + {Exacerbating Factor(s)}

And if we go back to the universality of mitigation discussed above we now have:

Expression 7):

{Event with non-zero magnitude consequences actually experienced} ← {Vulnerability Factor(s)} + {Triggering Factor(s)} + {Exacerbating Factor(s)} + {Mitigating Factor(s)}

This is an important result that drives all root cause analyses that seek to explain the nature and magnitude of consequences. See Figure 5.

[17] http://www.hu.mtu.edu/hu_dept/tc@mtu/papers/bhopal.htm

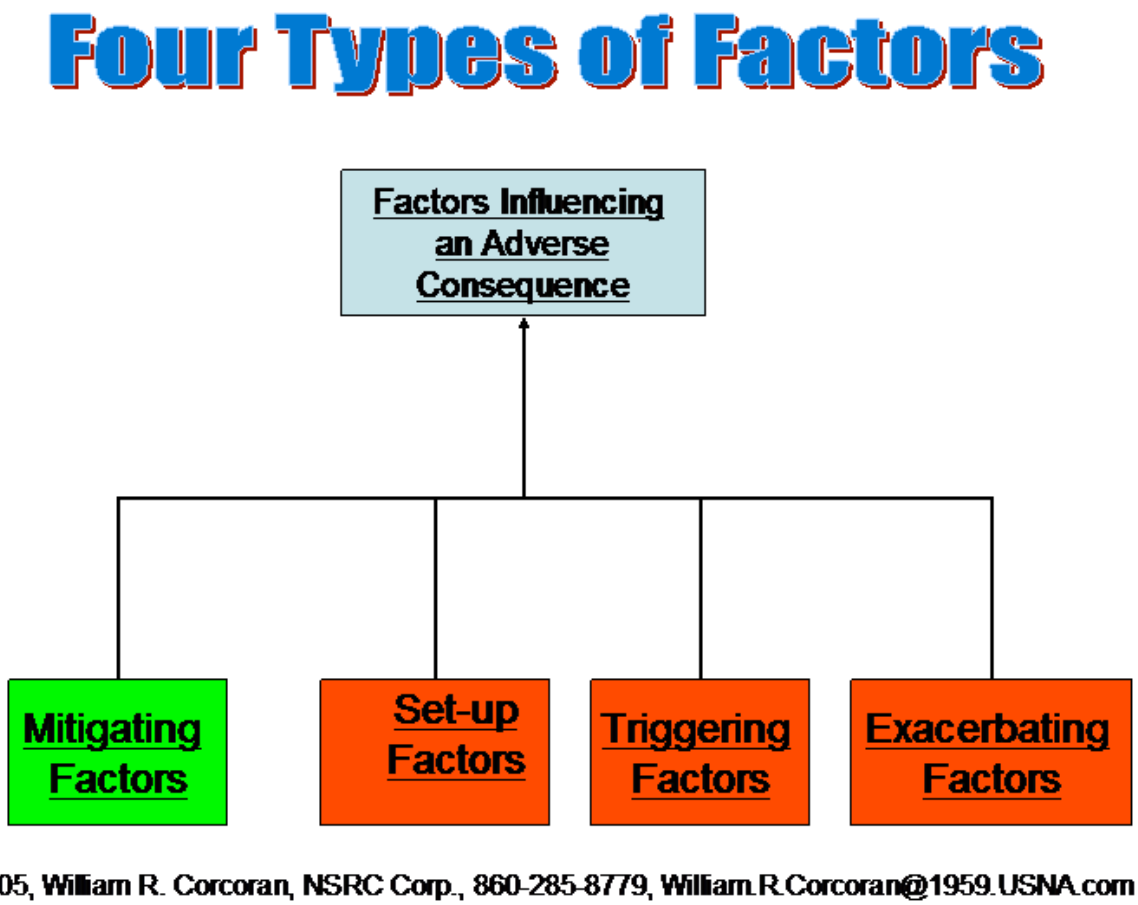

Figure 5 The Four Types of Factors Encountered in Retrospective RCA

Interim Summary

So far we have introduced all of the types of influences on a consequence by how they are involved in the consequence. Figure 6 provides a summary. For completeness, it includes the situation of a zero magnitude consequence, one that has been prevented, e.g., the averted downstream "postcursor" of the precursor event now being investigated.

The taxonomy of Figure 6 is jointly exhaustive, in that, every factor that can affect a consequence is captured in one of the categories represented. The categories are not, however, mutually exclusive.

Following that figure we will get on with other dimensions of influences.

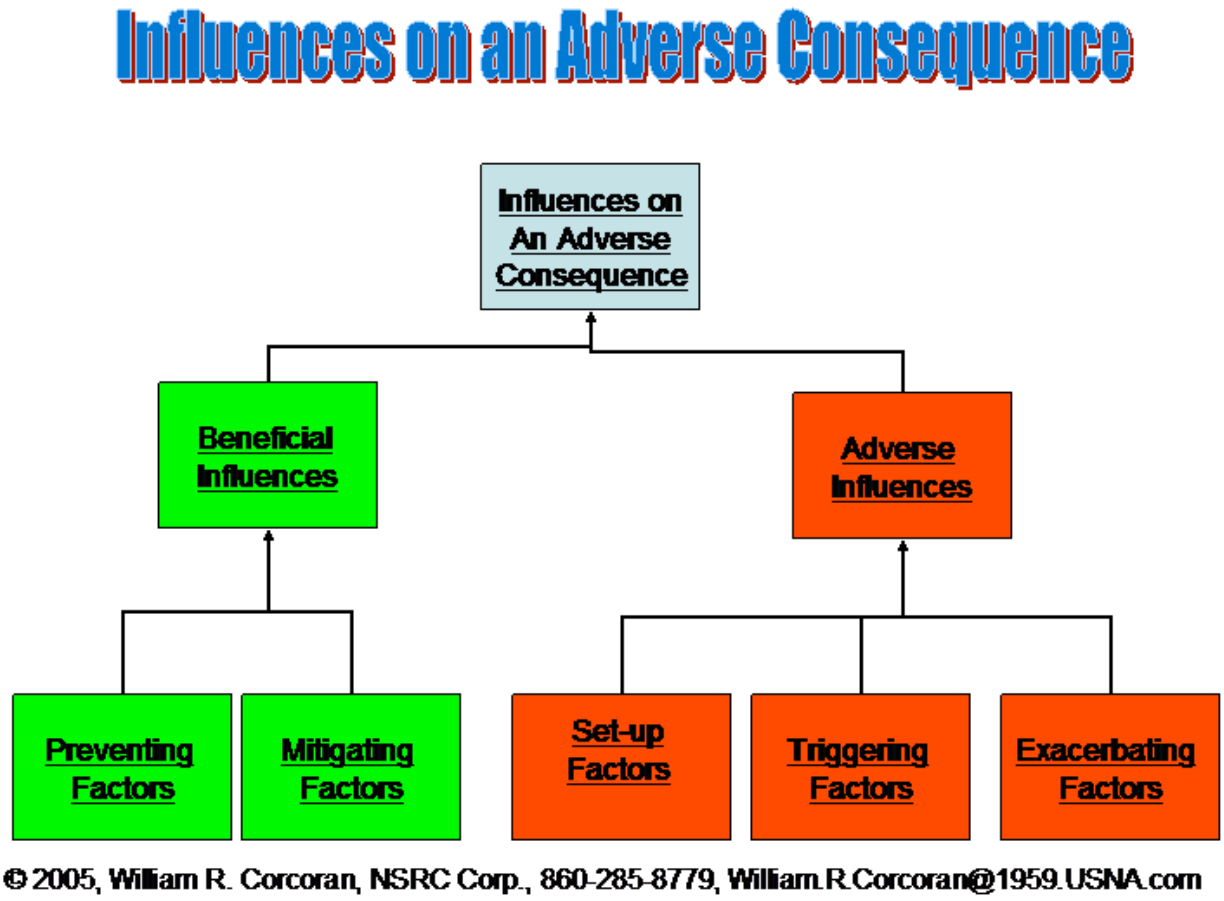

Figure 6 Summary of Influences

The Dimension of Force

In this dimension a cause can be a forcing cause that makes a consequence occur or a permissive cause that lets the consequence occur. For example, in a fatal automobile collision, impact of a victim's head with the windshield might be a forcing cause and the failure of an air bag to deploy might be a permissive cause.

Some set-up factors are forcing. For example, the amount of decay heat producing fission products at Three Mile Island made the reactor vulnerable to fuel melting and was a forcing cause of the melting. Discontinuing the cooling was a permissive cause in that it allowed the decay heat to remain in the fuel and thereby cause the temperature to increase to melting.

Most, if not all, triggering factors are forcing. Some exacerbating factors are forcing, e.g., wind that makes a fire worse, and some are permissive, e.g., an inoperable deluge system that allows a fire to progress.

Notice that permissive causes alone are insufficient to explain any consequence. There must be at least one forcing cause. In the absence of at least one forcing cause a consequence does not transpire. Thus we can state that for any consequence:

Expression 8):

{Causes} = {Forcing Cause(s)} + {Permissive Cause(s)}

Oversight detection, reporting, and follow-up failures are almost always permissive causes. Thus whenever oversight failures are found to be causes the analyst should seek out other causes as well. For completeness one should be aware of the pathological cases in which oversight provides forcing causes. The ones observed to date include cases in which oversight personnel perform dysfunctional physical behaviors that are involved in the event and cases in which oversight requirements cause the line organization to behave dysfunctionally.

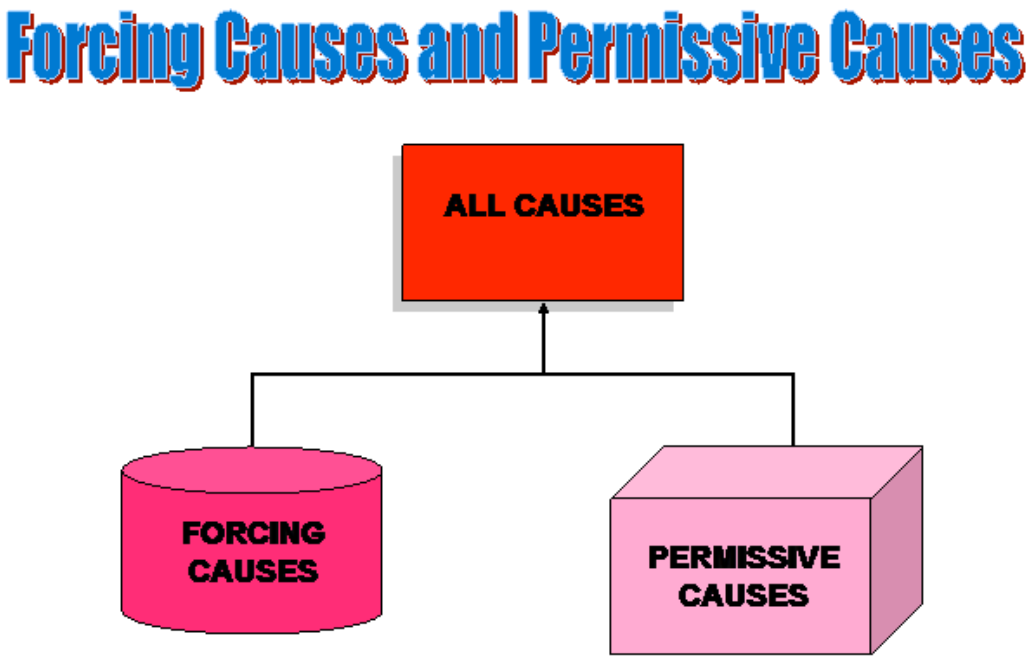

Figure 7 The Dimension of Force (vs. Permission)

Permissive causes include all negative causes such as omissions and inadequacies. (Note that "negative" is used here as an antonym of "positive" and not as a synonym of "bad.")

If an investigation finds only permissive causes it may be missing some forcing causes. In general, a successful investigation reveals both forcing causes and permissive causes. Often, but not always, forcing causes are actions and permissive causes are conditions.

The Dimension of Proximity

The proximity of a cause relates to the number of logical steps it is away from the consequence in the chains of causation. In other words, proximity relates to the number of steps between the cause and the consequence.

The closest causes are called "direct causes" or "proximate" causes. Sometimes these are called "immediate causes."

Proximate causes, in turn, are caused by "intermediate causes" at various levels of logical analysis. And clearly, it would be desirable to go deeper in some cases.

If the analysis is taken far enough one might find "basic fundamental underlying causes" whose further causation is, on some basis, less significant. There is seldom any value to taking an investigation deeper than the basic fundamental underlying causes of each chain of causation.

And the logical chain is:

Expression 9):

{Consequence} ← {Proximate Causes} ← {Intermediate Causes} ← {Deeper Intermediate Causes} ← {Basic Fundamental Underlying Causes}

(For clarity we have left out the influence of mitigating factors in the above expression.)

When the above expression is constructed for a particular consequence of a particular event it is called "The Chain of Causation." If one adds the mitigating factors, it is called the "Chain of Influence" or, equivalently, "The Why Staircase." The term "Chain of Factors" is probably conceptually better, but it does not roll off the tongue gracefully.

So now from the above expression, we have the important result:

Expression 10):

{Causes} = {Proximate Causes} + {Intermediate Causes (at various levels)} + {Basic Fundamental Underlying Causes}

In plain English "basic fundamental underlying causes" are "root causes." Thus:

Expression 11):

{Causes} = {Proximate Causes} + {Intermediate Causes (at various levels)} + {Root Causes}

See Figure 8. Note carefully that there are multiple influences at every level. Only causes are shown.

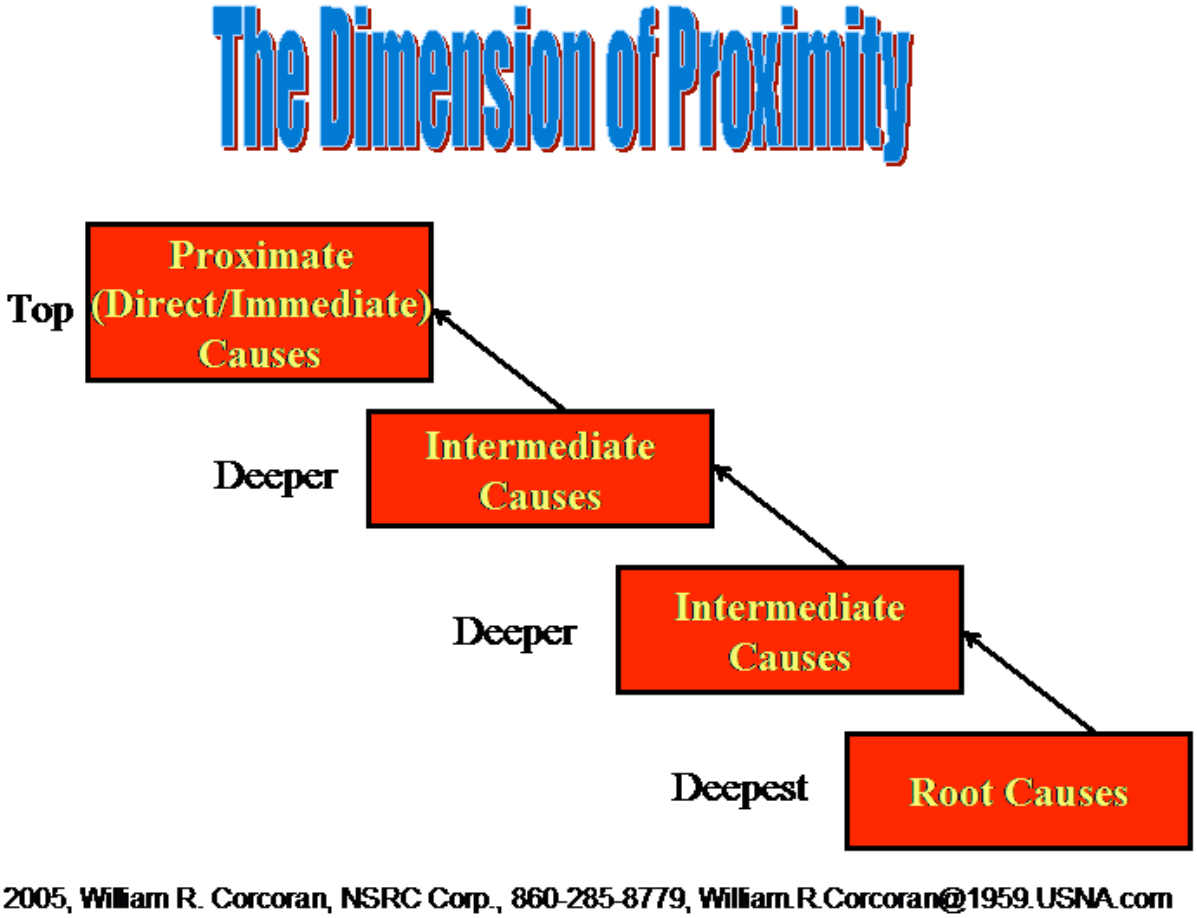

Figure 8 The Root Cause are deepest.

In practice there is usually little or no argument about what the proximate or direct causes were. For the analysts who do the work, there is also little argument about what the intermediate causes were.

But there is often great argument about what the basic fundamental underlying causes, i.e., root causes, are. Some of this argumentation is confounded by mixing the dimension of proximity with the dimension of tractability.

For example, some writers state that for a cause to be a "root cause" its correction must be within the capability of the organization's management[18]. This makes no sense and it confounds proximity with tractability. See below.

[18] Typical of this approach is "A root cause is a most basic cause. It can reasonably be identified, management has control to fix it, and effective recommendations for preventing its recurrence can be generated." In "Collecting Data for Root Cause Analysis" by Rooney and Vanden Heuvel, Quality Progress, November 2003, Page 104

Furthermore, by stating that a cause is beyond the control of the organization, the organization is depriving itself of the opportunity to explore potential ways to get control. To state that a cause is beyond the control of one's organization is inviting a regulatory body to explore ways of removing the organization's ability to cause similar consequences.

Notice that the dimension of proximity is independent of the dimension of type of involvement. For example, a root cause can affect set-up, triggering, or exacerbation.

Another problem is that some writers define a root cause as one whose removal or elimination will prevent recurrence. This confuses the dimension of proximity with that of solution sufficiency. See below.

In selecting corrective actions intended prevent recurrence as required by some regulations[19] it helps to understand the chain of influences (chain of factors). Notice that action to address any cause or to exploit any mitigating factor in the chain is, at least conceptually, capable of preventing recurrence of the consequence. In fact, it is potentially capable of preventing any effect above it in the chain of influences, hence the consequence itself.

But the problem is that all of the unaddressed causes below the corrected cause are still available to cause the cause that was addressed. This is the motivation for deep investigation and deep intervention.

Addressing causes at inappropriately shallow levels is sometimes called "Pruning the poison ivy."

The Dimension of Tractability

The most tractable causes are those that can be easily eliminated by the organization. The least tractable causes are those that have to be dealt with in a roundabout way. For example, in the case of a fall injury, a cause is gravity. The organization cannot eliminate gravity, but it can implement a fall protection program that includes fall prevention harnesses and other safety measures.

One of the problems with definitions of "root cause" that involve tractability is that they tie one attribute (tractability) to the base concept of "root cause." This would be like defining a dog as a member of the canine species that is good with children. It clearly excludes much of what should be included.

[19] For example, 10 CFR 50, Appendix B, Criterion XVI, "Corrective Actions" found at http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-appb.html

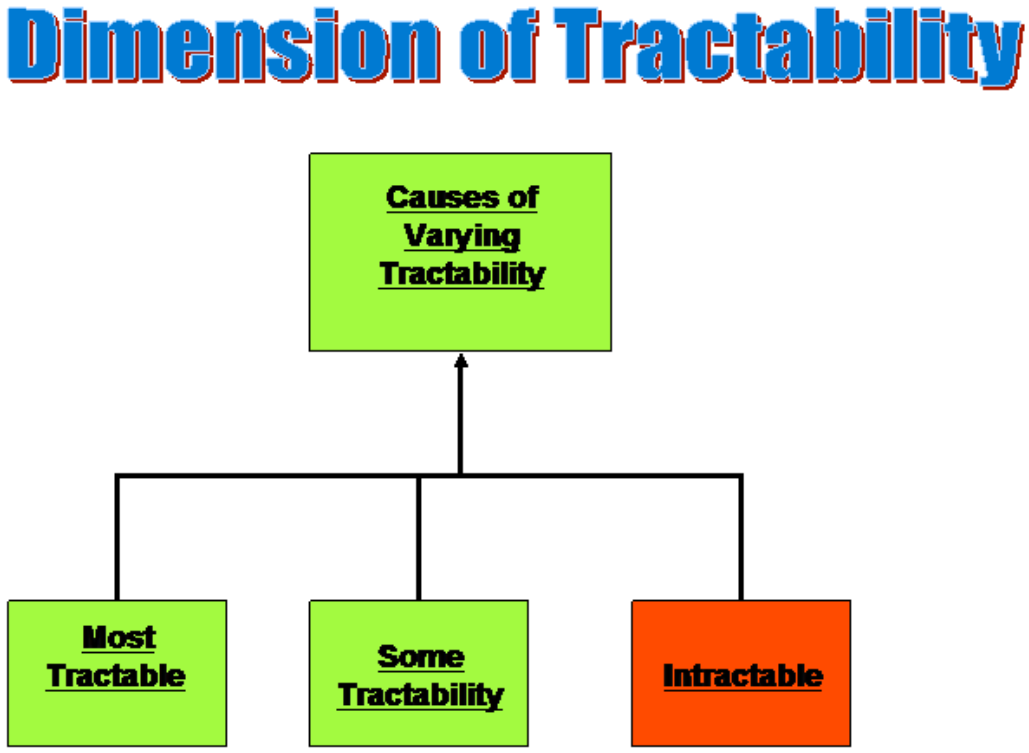

Figure 9 The Causal Factors that management has control over are tractable.

A consequence of using chlorinated fluorocarbons was a hole in the Ozone Layer. That cause was mitigated by shifting to a different refrigerant and banning the manufacture of chlorinated fluorocarbons. Thus a cause of the hole in the Ozone Layer was tractable, albeit with costly world-wide effort.

A consequence of having air bags (supplementary restraint systems) in automobiles was that small people were killed by the air bags. The air bags were required by a law that was beyond the control of the automobile manufacturers. A variety of solutions were advanced, including weakening the deployment systems and recommending that small people be seated in seats that were moved back as far as they could go. Thus a cause of air bag induced casualties was tractable.

The Dimension of Latency

This dimension is binary. At any given time a particular cause can be either active or latent. Latent just means "present but not active", (only) potential, (still) dormant, and the like[20]. Thus we obtain:

[20] See the previously cited definition at http://www.hyperdictionary.com/dictionary/latent

Expression 12):

{Causes} = {Latent Causes} + {Active Causes}

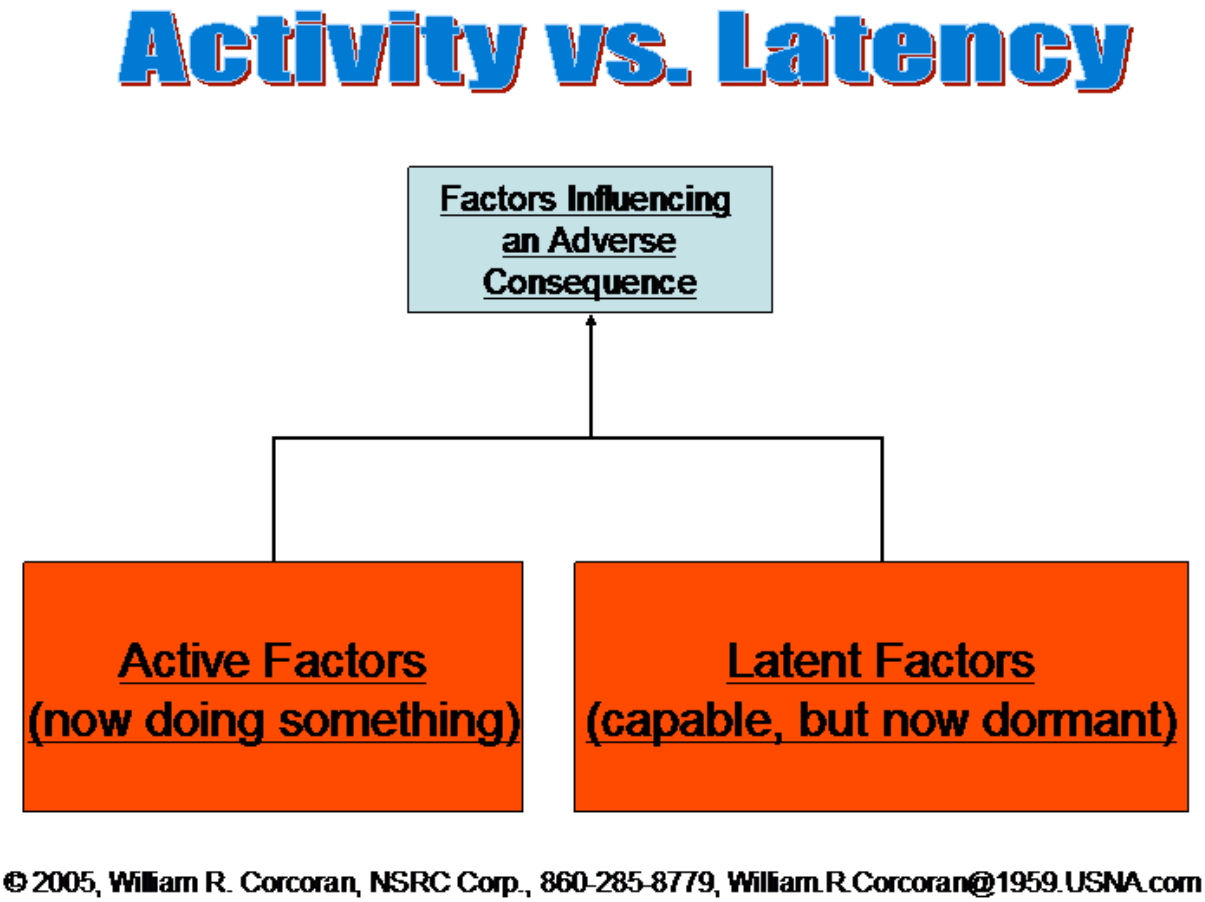

Figure 10 The ones found in investigations were previously latent before the event.

Of course, a cause can be previously latent. These are the causes that are found (sometimes for the first time) after an adverse event. For example, certain flaws in operator training were previously latent causes of a meltdown at Three Mile Island Unit 2[21].

Actual latent causes (of potential consequences) are often found in investigations, but the actual causes of a real consequence must have been active in order to be involved in causing the consequence.

If one studies a Gantt Chart[22] of the causes of an event one will see that all of the causes existed at the times they were effective in influencing higher level causes. While they existed, but before

[21] Kemeny, John G., "Saving American Democracy: The Lessons of Three Mile Island," TECHNOLOGY REVIEW, June-July 1980, pp. 65-75, Massachusetts Institute of Technology
[22] http://www.me.umn.edu/courses/me4054/assignments/gantt.html

they were effective in influencing higher level causes they were latent. When they were effective they were previously latent.

The dimension of latency is often confounded with other dimensions. Latency, in fact, is independent of other dimensions. Importantly, a cause can be both latent and visible, like a hole no one has fallen into, but which many people have seen. Until someone falls into the hole it is a latent (potential) cause of an injury. A properly planted land mine would be an example of a latent cause that is not visible. This suggests the dichotomy:

Expression 13):

{Latent Causes} = (Visible Latent Causes} + {Non-visible Latent Causes}

It is useful to consider another dichotomy of latent causes. On one hand we have latent causes that need activation, e.g., land mines. And on the other hand we have self-exacerbating and self-triggering latent causes, e.g., time bombs. Metaphorically we have:

Expression 14):

{Latent Causes} = {"Land Mines"} + {"Time Bombs"}

The Dimension of Domain

The term "domain" as applied to dimension is defined extensionally[23], i.e., by listing the potential values. The potential values of the dimension of domain include "hardware", "human behavior", "organizational", "cultural", "systemic", "regulatory", "cultural" and the like.

Some professionals simplify this to "physical", "human", and "systemic" (or some other such term), but this diminishes the potential richness of this dimension. Some writers use numbers of p-words for domains, e.g., "people, process, plant" (3 P's) or "people, process, plant, procedures" (4 P's), "parts, position, people, paper, paradigms" (5 P's), etc. Some rooticians use lists of m-words, e.g., materials, methods, manpower, etc.

Effective understanding of causation often requires proceeding deliberately down the Why Staircase by first looking for hardware causes of physical effects, then human behavior causes, then organizational causes, and so forth. This makes good sense and can be shown non-rigorously as:

Expression 15):

{Physical Consequence} ← {Physical Causes} ← {Human Behavioral Causes + Other Causes} ← {Organizational Causes + Other Causes} ← {Deeper Underlying Causes}

[23] ISO 704, http://www.ohi.shom.fr/Dhydro/Html/site_edition/Help_HTML/isodef.html

In cases of complex causation it also makes sense to explicitly articulate the potential values of the dimension of domain early in the investigation and to revisit it as the investigation progresses. These values can be used to identify lines of inquiry[24] and sources of evidence.

The Ishikawa Fish Bone Diagram[25] is often a visual representation of the dimension of domain. It doesn't make sense to have more domains than are needed in a given investigation. However, each domain introduces a new line of inquiry and thus new possibilities for intervention.

The Dimension of Self-Sufficiency

A cause can be either 1) self-sufficient to cause a consequence or it can be 2) a contributing (contributory) cause. Sufficiency is one of the truly dichotomous (binary) dimensions. This can be shown as:

Expression 16):

{Causes} = {Self-sufficient Causes} + {Contributing Causes}

Self-sufficient causes appear to be self-sufficient because other causes are taken for granted. For example, one might say that a gunshot wound to the head is self-sufficient to cause a fatality. When this is said, the speaker is taking for granted that the victim's head was penetrable, that the attacker's weapon was within range, etc.

In actual root cause analysis it is almost never enough to stop at self-sufficient causes. Thus in actual practice, all identified causes are contributing causes. Therefore, it usually adds little value to spell out that a cause was contributory.

The dimension of sufficiency is often confounded with the dimension of proximity. This is done by creating a false dichotomy of "root causes and contributing causes." In actuality, most root causes are contributing causes. Notice that most contributing causes are not basic fundamental underlying (root) causes because they are closer to the consequence.

All contributing causes that are not themselves root causes have their own root causes.

The Dimension of Solution Sufficiency

When a cause is solution-sufficient its solution (removal, elimination, control, etc.) will be sufficient to prevent the consequence under investigation. Otherwise it is solution insufficient. When a cause is solution-insufficient other corrective actions are needed to gain confidence that the consequence will not be repeated in the same way. Some writers confuse the dimension of solution sufficiency with the dimension of proximity[26].

[24] For a typical use of this term see http://the.honoluluadvertiser.com/2001/Mar/11/311localnews14.html
[25] For a typical example see http://silosandsmokestacks.org/resources/FieldTripGuide/the_ishikawa_fish_bone_diagram.htm
[26] http://www.apollorca.com/about/f4.shtml

This is shown as:

Expression 17):

{Causes} = {Solution-sufficient Causes} + {Solution-insufficient Causes}

For example, if one accepts that two of the causes of the specific loss of Challenger were "Groupthink" and O-ring thermal embrittlement, then one finds one of those causes to be solution-sufficient and one to be solution insufficient. Stamping out Groupthink will not guarantee that a repeat event will not occur. But eliminating O-ring embrittlement will guarantee that the specific accident that occurred will not repeat.

The Dimension of Magnitude

Clearly, size counts. In general, bigger causes create bigger consequences.

The relationship between the magnitude of a cause and the magnitude of the consequence will depend on the details of the interaction. Some values of the dimension of magnitude include numbers of exposed people, mass of combustibles available, masses of reactants, height of fall, etc.

Sometimes the magnitude of a cause will determine whether there was a particular type of consequence or not. For example, one might well imagine that if the iceberg had been smaller, the damage to the *Titanic* may have been insufficient to cause sinking. Similarly, the magnitude of the collision velocity was also important. Similarly the range (distance) to the iceberg at the time of sighting was also important.

The exception is "cliff edge effects" in which a microscopic increase in the magnitude of the cause results in a step change in consequences. In these cases, what matters is the last increment of causation that "goes over the cliff."

The Dimension of Timing

Timing is often a key dimension of a cause. The consequences of some industrial accidents are worse because their causes came to fruition during a period in which there were many workers available to be victims. Some consequences are less severe because the accident happened when workers were available to combat the accident. Often the difference between a fatality and a non-fatality is the amount of time the victim was exposed. The influence of timing on the Bhopal consequences and the WTC consequences were mentioned above.

Other Dimensions of Causation

There are other causal dimensions as well. Some will be addressed in Table 1 along with the dimensions discussed above.

TABLE 1

CAUSE DIMENSIONS AND POTENTIAL VALUES[27]

TABLE 1
CAUSE DIMENSIONS AND POTENTIAL VALUES

DIMENSION	POTENTIAL VALUES	COMMENT
Involvement		How was the cause involved in affecting the consequence?
	Set-up Factor (Vulnerability)	Every consequence has at least one.
	Triggering Factor (Trigger, Initiating Factor, Precipitating Factor)	Every consequence has at least one.
	Exacerbating (Aggravating) Factor	All but the mildest of consequences have at least one.
	Preventing Factor	A preventing factor will never be seen in a retrospective root cause analysis of an event that has either actual consequences, expected consequences, or both.
Force		Did the cause make the consequence happen, or did it just let it happen?
	Forcing	A forcing cause makes a consequence happen.
	Permissive	A permissive cause allows a consequence to happen.
Proximity		How many steps away from the consequence is this cause?
	Proximate (Direct)	Occasionally direct causes are non-intuitive, e.g., the case of a fatality that is initially attributed to an automobile accident that is later determined to have been caused by a heart attack.

[27] A potential value of a dimension is something that it could be. For example, one potential value of the dimension of length (of a brick) would be "10.5 inches."

TABLE 1 CAUSE DIMENSIONS AND POTENTIAL VALUES		
DIMENSION	**POTENTIAL VALUES**	**COMMENT**
	Intermediate (at various depths)	There is no known reliable process for limiting the number of layers of causation in an investigation.
	Root (fundamental, basic underlying)	Of course root causes can have deeper underlying causes, but these, on some basis, are less significant.
Tractability		How amenable is the cause to effective intervention?
	Eliminatable	
	Accommodatable	
	Controllable	
	Reducible	
	Isolatable	
		These are just some of the vast possibilities of tractability.
Latency		What was the state of the cause at the time of interest?
	Latent	Latent causes are either "landmines" that require external activation to cause harm or "time bombs" that are self-actuating. A latent cause never harmed anything. Harm is caused by causes that were active at the time of causation.
	Active	To have participated in causing harm a cause must have been active at least for a short time.
		Example: The toxin on the leaves of poison ivy is a latent cause of skin rash until it is activated by contact with susceptible human skin.
Domain		What lines of inquiry are suggested? In which domains are the causes located?

TABLE 1 CAUSE DIMENSIONS AND POTENTIAL VALUES		
DIMENSION	**POTENTIAL VALUES**	**COMMENT**
	Hardware (equipment, physical assets)	
	Human Behavior	
	Human Factors	The Human Factors domain includes all aspects of the person-machine interface as well as other interfaces with people.
	Procedural	
	Organizational	
	Managerial	
	Oversight	
	Cultural	
	Investigational	Aspects of how (prior) events and anomalies are investigated sometimes leaves causes to become involved in later events.
	Systemic	
		These are some of the vast possibilities of domains that could be involved.
Sufficiency		Accounts for the entire consequence by itself or just contributes.
	Self-sufficient	Most causes that are called self-sufficient are so called because other causes are taken for granted.
	Contributory	Take away a contributing cause and you get lesser consequences, possibly no consequences.
Solution Sufficiency		A solution-sufficient cause is any cause that, when controlled or removed, makes the problem go away. In the case of a fire, removing fuel, oxygen, or an ignition sources prevents the fire from occurring.

TABLE 1 CAUSE DIMENSIONS AND POTENTIAL VALUES		
DIMENSION	**POTENTIAL VALUES**	**COMMENT**
	Solution sufficient	Most consequences arising from adverse events have multiple solution sufficient causes.
	Solution-insufficient (or non-solution sufficient)	Take away a solution-insufficient cause and you get lesser consequences or some improvement in risk, but no assurance of non-recurrence.
Magnitude		How much, how many, how fast, how long, how far, …?
	Number, mass, velocity, volume, height, …	
		The magnitude of a cause influences the nature and magnitude of the consequence.
Extent		How much more, how many others, how widespread, …?
	Isolated	This cause is the only one like it.
	Local	This cause is confined to one type of equipment, one work group, …
	Global	This cause could be replicated all over the organization.
	Endemic	This cause permeates the organization.
	Sporadic	This cause appears at various places in the organization.
	Occasional	This cause returns from time-to-time.
Age		How long the cause has been in existence can be important.
	Original design	
	Result of use-related degradation	
	Result of age-related degradation	
	Result of a recent change	

TABLE 1 CAUSE DIMENSIONS AND POTENTIAL VALUES		
DIMENSION	**POTENTIAL VALUES**	**COMMENT**
		These are some of the vast possibilities of cause age dimension values that could be involved.
Commonality (risk considerations)		What other effects have been impacted by this cause?
	Common	This cause has impacted other effects than the one in consideration.
	Not Common (Unique)	This cause only affects the consequence in consideration.
Commonality (quality considerations)		Deming said that all variation is due to either common causes that are inherent to the system or to special causes.
	Common Cause	A cause inherent in the system.
	Special Cause	A cause that is not inherent in the system.
Infraction		Which, if any, requirements of rules, regulations, standards, expectations, etc. were infracted by this cause?
	Federal infraction	
	State infraction	
	Standard infraction	
	Infraction of common good practice	
Origin		Where did this factor come from?
	Design	
	Management requirement	
	Regulatory requirement	
	Training	
	Natural phenomenon	

TABLE 1 CAUSE DIMENSIONS AND POTENTIAL VALUES		
DIMENSION	**POTENTIAL VALUES**	**COMMENT**
		These are just a few of the values of the dimension of origin. They are neither mutually exclusive or jointly exhaustive.
Timing		When did the cause occur and how long was it effective?
	Beginning and end times/dates.	Some causes must be simultaneous with other causes to be effective at all. Others have effects on the consequence depending on how long they last.
END OF TABLE 1, CAUSE DIMENSIONS		

Dimensions of Mitigation

Just as causal factors have dimensions, mitigating factors do also. Table 2 deals with mitigating factors.

As one might suspect, many, if not all of the dimensions of causation are also conceptually applicable to mitigation as well. But some dimensions of mitigation are unique to mitigation, or are at least more relevant to mitigation than to causation. The table below is intended to cover those dimensions that are more relevant to mitigation than to causation.

TABLE 2
MITIGATING FACTOR DIMENSIONS AND POTENTIAL VALUES

TABLE 2 MITIGATING FACTOR DIMENSIONS AND POTENTIAL VALUES		
DIMENSION	**POTENTIAL VALUES**	**COMMENT**
Intentionality		To what extent was the mitigating factor intended to do what it did?
	Intentional	An intentional mitigating factor is one that was intended to do what it did to mitigate the consequence. The opening of a pressure relief valve at its setpoint to prevent rupture of a vessel would be an intentional mitigating factor.
	Fortuitous	A fortuitous mitigating factor is one that was not intended to do precisely what it did. For example the discovery of flooding at an early stage by a security employee doing infrequent inspections would be considered to be fortuitous.
		Whether one classifies a mitigating factor as intentional or fortuitous, it would be a good idea to explain the basis for such classification.
Robustness		To what extent can this mitigating factor be counted on?
	Flimsy	This type of mitigation cannot be counted on. An example would be a fire detected in an early stage by an employee who was visiting the plant on a holiday.
	Moderately robust	Most of the time this type of mitigation can be counted on.

TABLE 2 MITIGATING FACTOR DIMENSIONS AND POTENTIAL VALUES		
DIMENSION	**POTENTIAL VALUES**	**COMMENT**
	Robust	This type of mitigation can almost always be counted on.
	Extremely robust	This type of mitigation can always be counted on.
END OF TABLE 2, MITIGATING FACTOR DIMENSIONS		

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Differing Professional Opinions

Persons with differing professional opinions are requested to share them with the author at 860-285-8779 or William.R.Corcoran@1959.USNA.com