Chapter 4. Developing the Contemporary Paradigm

The classical paradigm has proven indispensable in developing and operating today's complex systems. Much of the physical world we experience on a day-to-day basis is the classical or Newtonian world. The paper on which this text is written and the building in which it was developed both are examples of the tremendous success of this branch of science. The principles of classical physics have been employed to construct systems ranging from the Roman aqueducts to today's intricate computer systems.

These principles form the basis for the school of engineering that has created the modern world. Engineers are trained to follow certain principles that have been proven to work in given situations. They know that if they employ these derived rules within the prescribed constraints, the resulting system will function as designed. This structure allows the engineering community to develop systems without constantly having to return to the basic principles of physics to determine whether a particular design will meet the requirements for a system. For example, as the science of building medieval cathedrals advanced, builders simply followed the instructions provided by those who preceded them.[238] As long as these builders did not deviate from the basic plan, the cathedral would be structurally sound.

The classical paradigm remains the predominant paradigm used by analysts seeking to understand and prevent failures in complex systems. These principles remain important parts of any explanation of system failure. Many factors surrounding a failure may be reduced to their basic components providing a better understanding of the failure. The principle of cause and effect frequently identifies a one-to-one linear correspondence between a given cause and its effect. Linear determinism reveals the thread that ties many of these factors together. Nevertheless, these classical principles do not make up the entire story surrounding a system failure. By ignoring possible contributing factors outside this well structured world, these principles lead analysts to mistakenly limit their view of how complex systems function and narrow the focus of their analyses to the exclusion of potentially relevant data. The classical principles remain valid, but they are not viewed as a complete set. In the classical paradigm, the orientation is toward a single cause and a linear cause and effect relationship. For example, a small element may cause a small effect. However, using the contemporary paradigm, multiple causes and consequences may exhibit linear and non-linear characteristics. A small element may also cause a large effect. The casualty in moving to the contemporary paradigm is not the classical principles, but the belief in the certainty of their results.

A second paradigm, the contemporary paradigm, takes advantage of the recent developments in modern physics and other sciences to describe a world that is not as orderly or predictable as described by the classical paradigm. Analysts using this paradigm do not start with the assumption that there is a single cause or a single consequence from a system failure. Neither do they assume that the contributions to the cause of a system failure are a limited set, each capable of being identified and precisely measured. They do not believe that the cause-effect relationship is always a linear deterministic process nor do they subscribe to the idea that the consequences of a system failure can not be affected.

Referred to by Kronenberg as the New Sciences of Transformation (NST),[239] these developments maintain that it is neither possible to discern all the facts surrounding a system failure or to accurately predict their interactions. This approach does not, however, result in a universe where nothing can be measured and no actions taken by an organization can help prevent system failure. Instead, it changes the basis of how analysts view system failure and provides them with a new set of parameters for dealing with it. It changes the way we seek to understand and manage complex systems.

4.1 The Essence of the Contemporary Paradigm

The contemporary paradigm does not discard all the elements of the classical paradigm, but uses Newtonian physics as a basis. The fundamental principles common to engineering design and operations still have a place in this more complex world. For example, the principles of aerodynamics used in developing aircraft are not questioned and would be accepted by a

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[238] Joseph Fragola, "Quantitative Risk Assessment Seminar," Houston, Texas 4 June 1997.

[239] Philip S. Kronenberg, "Chaos and Re-thinking the Public Policy Process," in Chaos and Society, ed. A. Albert (Amsterdam, Netherlands: IOS Press, 1995), pp. 253-265.

contemporary analyst attempting to determine the cause of an airplane accident. Classical physics is the appropriate structure for developing approximations of the real world.

The contemporary paradigm should not be viewed as in conflict with classical physics, but complementary to it. The analyst does not reject the classical paradigm outright, but considers these findings as one element in a more robust paradigm. In this manner, the contemporary paradigm provides a supplemental lens through which to view system failure.

The contemporary paradigm holds that the ‘real’ world is far more complex and uncertain than previously believed, limiting our ability to measure accurately and predict precisely either the causes or the consequences of a system failure. Proclaiming, “prediction is the realm of soothsayers and zealots,” Fragola argues we must recognize the power of classical mechanics, while simultaneously acknowledging its shortcomings.[240] Turner illustrates this concept in his discussion of major system failure:

> First, disasters, other than those arising from natural forces, are not created overnight. It is rare that an individual, by virtue of a single error, can create a disastrous outcome in an area formerly believed to be relatively secure. To achieve such a transformation, he or she needs the unwitting assistance offered by access to the resources and resource flows of large organizations, and time.[241]

The contemporary paradigm provides us with tools for increasing our ability to understand the events that lie behind the system failure. These tools are substituted for similar tools found in the classical paradigm, and provide the analyst with a broader view of the events leading up to and following a system failure. Necessarily, this alternative lens leads to consideration of more factors associated with the system failure, complicating the analysis. The contemporary paradigm assumes a more complex world, one capable of accepting the uncertainties and lack of insight that result. Two basic propositions comprise the core of the contemporary paradigm.

The first proposition is that there are multiple causes and multiple consequences associated with any system failure. In contrast to the classical paradigm that assumes lesser contributing factors leading to the “smoking gun”, the root cause of a failure, the contemporary

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[240] Joseph Fragola, “Quantitative Risk Assessment Seminar,” Houston, Texas 4 June 1997.

paradigm accepts that a complex system failure actually may have many causes. For example, if the levee system on the Mississippi River fails because the river is in flood, an analyst would seek to determine why it failed. Was the levee improperly designed, built, or maintained? Assuming none of these are true, the analyst would move to look at the river itself. Here, the complexity of the failure becomes evident. What factors caused the river to reach flood stage? Assuming that several of the tributaries also were higher than normal, how could an analyst determine that one particular tributary was "the cause"?

The consequences of this hypothetical failure are equally complicated. The most obvious consequence is the flooded area created when the levee fails. Added to this are the property damages, lost wages of residents, lost revenue to business, cost of cleaning up the area, rebuilding the community, impact to transportation which would normally pass through this location, etc.

These multiple causes and consequences may be separated by severity, effect, and time. For example, the investigators into the TWA 800 accident believe that a wiring design in the Boeing 747 fuel tank was one of the causes of the plane's explosion. This particular design had been in place for over twenty-five years prior to this accident occurring. Consequences also span decades. In 1919, a young U.S. Army major, Dwight Eisenhower, was given the task of moving a large motorized convoy across the country. Almost every system under his command failed during the arduous trip across poor roads, with the convoy making only five miles per day. The first hand knowledge served Eisenhower well when became President and was in charge of developing the interstate highway system.[242]

No amount of research will ever enable the analyst to precisely determine the "root cause" or the "ultimate consequence." Rather, the answers to these questions depend upon the analysts' frame of reference and the contemporary analyst views these searches as meaningless. First, the magnitude of the factors that must be considered in arriving at such conclusions would preclude declaring that "the cause" or "the consequence" had been determined. Second, even the measure of the cause and consequence are dependent on the observer. Using the Mississippi

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[241] Barry A. Turner, "The Organizational and Interorganizational Development of Disasters," Administrative Science Quarterly, Vol. 21, Sept., 1976, p. 395.

[242] Stephen E. Ambrose, Eisenhower: Soldier, General of the Army, President-Elect (1890-1952), Volume 1, p. 69.

River example, on the day the levee failed had there been a prevailing wind that caused the river to surge against the levee? If there was, how much did the wind add to the breach in the levee and what means were used to measure this added contribution? "The mathematician A.F.M. Smith has summed it up well: 'Any approach to scientific inference which seeks to legitimize *an* answer in response to complex uncertainty is, for me, a totalitarian parody of a would-be rational learning process."[243]

Even the proximate cause is open for discussion in the contemporary paradigm**.** In the *Challenger* failure, most analysts agree that the failure was caused by a burn-through of the O-rings. However, the joint seal could not be directly observed after the solid rocket booster was assembled. What if the seal had been improperly installed? Also, the seal held for over a full minute into the flight and failed only after the shuttle had gone through an area of unprecedented high winds. Can this factor be disregarded in the search for a single proximate cause? In the contemporary paradigm, the proximate cause loses prominence, becoming one of several causes that are used to develop a more complete picture of the system failure.

The consequences of a system failure extend far beyond the failure to disciplines and individuals only peripherally related to the failure. Following a flood of the Mississippi River in 1993, it was found that the extensive levee system installed by the Army Corps of Engineers worked well in protecting the communities near the flood. By artificially restraining the river, however, the levee system increased the level of flooding in many downstream communities that might have been spared otherwise.[244]

The second proposition is that an organization's response to an event or series of events that initiate a system failure in large part directly contributes to and in many cases actually determines the consequences. These responses may encompass multiple elements of the system failure. For example, following the Swissair Flight 111 airliner crash on September 2, 1998, the airline immediately flew the families of the passengers to Nova Scotia to be near the crash site. Although there was little the families could contribute at this location, Swissair executives recognized the need for the relatives to be near the accident in this remote part of Canada.

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[243] Peter L. Bernstein, Against the Gods: The Remarkable Story of Risk, (New York, N.Y.: John Wiley & Sons, Inc., 1996), p. 133.
[244] Kiel, p. 33.

Dealing with a second consequence, the identification of victims' remains, the authorities were careful to avoid televised views of trauma experienced during the accident. Responses such as these successfully deflected criticism away from the airline and minimized impact to their continuing operations.

This proposition contends that a system's ability to adapt to an initiating event by tailoring its response can determine the eventual consequences. The same system failure occurring at a different time or in a different location could require a different organizational response. How the responses to the initiating event are managed will alter the severity of the consequences. For example, accidents involving military aircraft occur every few months. Most of these failures receive little press coverage and are left to the involved military organizations to investigate. Typically, they issue a press statement and begin a formal in-house investigation. However, when an A-10 attack plane was lost a few years ago in Colorado, the scenario was completely different. Rumors that the plane was carrying nuclear weapons and the pilot had intentionally flown off course sparked intense media coverage. Later rumors that the pilot had been emotionally disturbed increased this coverage. The military was slow to adapt its response, increasing speculation it was concealing something from the public. A different response may have eliminated this suspicion and helped reduce the media scrutiny.

The concept of uncertainty extends to the organizational response. Each system failure is different and brings with it a unique complexity. Organizations will not know in advance how a particular response will affect the consequences of the failure. Instead, they must prepare a response capability that can be modified as the effects of the response unfold. Responses may not have the anticipated effect on the consequences and the organization must be prepared to adapt accordingly. This adaptive capability cannot be based on the classical paradigm, but must reflect the uncertain nature of the universe postulated in the contemporary paradigm. The culture of the organization has to accept the resulting instability and be capable of reacting to failures and consequences that cannot be forecast accurately in advance.[245] Isenberg reports this culture in his study of a pharmaceutical company.[246] Changes in government regulations, consumer trends,

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[245] Kiel, p. 154.

[246] Daniel J. Isenberg, "Drugs and Drama: The Effects of Two Dramatic Events in a Pharmaceutical Company on Manager's Cognitions," Columbia Journal of World Business, Vol. XXII, Spring 1987.

and medical practices make this a very dynamic environment in which to operate. He quotes company managers as stating, “change is a constant here.”[247]

Although the consequence may come about, the analyst cannot be absolutely certain that it was the organizational response that made it happen. This concern is commonplace for publicists in organizations that have experienced system failures. For example, companies recalling products often place large advertisements in major newspapers and periodicals expressing their commitment to fix any problems and keep their products safe. However, if product sales rebound to former levels, this effect may simply have been the result of consumers preferring their product to their competitors’.

Although on the surface, the contemporary paradigm may appear to make it hopeless to determine the causes or consequences of a system failure, it actually provides a more robust structure for understanding and managing the risks inherent in complex systems. Several elements of the contemporary paradigm may be derived from these two propositions. These elements define the boundary limits within which the analyst must function in understanding system failure.

First, the proportions by which each cause contributes to the failure may be impossible to determine. The difficulties experienced by classical analysts in determining the cause of the *Challenger* accident illustrate this element. After millions of hours of study by thousands of analysts, there is no agreement as to the cause of this failure. If we accept that each analyst has uncovered one of several causes for the failure, we are still presented with determining their relative importance. Was the failure mostly caused by poor design or mostly by inadequate operational safeguards? How can one assess management structure against organizational culture, or budgetary pressures against operational processes? The contemporary paradigm includes a structure for comparing the relative contribution of each factor to the failure.

Even the measurement of the contribution of the various causes will depend on the frame of reference of the observer. Analysts primarily interested in management theory would view the technical details of the *Challenger* accident by considering the role management played in developing and controlling these technical systems. The O-ring problems would not be viewed

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[247] Isenberg, p. 47.

as technical issues, but as issues which should have been placed before management for consideration. A sociologist such as Vaughan would consider the effect on these technical issues that resulted from the culture in which the decisions were made. Although both views may be valid, the factors measured and the results would vary between the two.

Second, in the contemporary paradigm the smallest contributor may in fact actually generate the greatest effect. Experiments conducted by MIT meteorologist Edward Lorenz provide a famous example of how a seemingly irrelevant change may alter the behavior of a complex system. Developing computer paradigms of the earth's atmosphere, he rounded off his calculations to three decimal places instead of the six used in previous studies. Rather than a refinement of previous findings, he found a result he had never anticipated. The change in the data iterated through a nonlinear process produced a completely different outcome.[248]

Third, it is not inevitable that a given consequence will come to pass. Although a consequence may be anticipated, it may not occur for reasons that an analyst cannot determine. Also, it may be absent because responses were made in the aftermath of the system failure that prevented the consequence from occurring. A third option is some combination of the two, with the analyst challenged to determine the relative contribution of each. For example, why was the shuttle grounded for almost three years following the *Challenger* failure? Did NASA handle the situation poorly, allowing decisions to be made by an outside body? Was the public unprepared for our first loss of human life during a space flight mission?

These seemingly minor alterations to the classical paradigm change dramatically how the analyst studies a system failure. Briggs and Peat summarize the situation succinctly:

> …Randomness is interleaved with order, simplicity enfolds complexity, complexity harbors simplicity, and order and chaos can be repeated at smaller and smaller scales… They are chaotic. Yet, in this disorder is a shape.

And Kiel writes:

> In the dynamic organization, disorder, instability, and variation are not considered threats but rather inherent elements that generate the potential for positive change. Here the processes of change continuously alternate between order and disorder as organizations seek entirely new ways of achieving goals.

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[248] John Briggs and F. David Peat, Turbulent Mirror: An Illustrated Guide to Chaos Theory and the Science of Wholeness (New York: Harper and Row, 1989), p. 69

> The dynamic organization is highly energized. Uncertainty is considered an essential element of the change process; surprises are expected as work processes are transformed but they are seen as part of the risk, uncertainty, and reward of creation and innovation.[249]

The organization following the contemporary paradigm still adopts elements of the classical paradigm by examining the known causes of failure and correcting the deficiencies that led to them. These causes frequently are uncovered using standard engineering methods with solutions also developed using these methods. Databases are monitored and trends tracked to uncover anomalies in the systems. Just as it is in the classical paradigm, it is imperative in the contemporary paradigm that the basic monitoring and tracking systems be maintained.

Second, this organization apportions some, but not all, of its resources to identify, assess, and rank known potential causes for a failure. The classical approach recognizes that not all identified risks contribute equally to the risk equation and as such it does not devote equal attention to each identified risk. Rather, it assesses the risks according to their potential consequences and probability of occurrence. Those risks with the greatest potential consequences and likelihood of occurrence are the focus of further review and closer monitoring.

Third, this organization takes a holistic perspective when managing the risks in complex systems. As systems become more complex, the possibility that two systems may interact and cause a failure escalates. Therefore, it develops scenarios for selected systems in combination. For example, analysts would determine how the shuttle guidance computers react in the face of multiple rocket engine failures combined with selected electrical failures

Fourth, the contemporary organization views these first three steps as preliminary steps which are neither the focus of their prevention efforts nor allowed to consume all available resources. The organization acknowledges that looking for the “root” cause will not prevent a particular failure or similar failures from reoccurring. It fixes the identified problems and moves on. In many cases, the subsystem receiving the scrutiny that comes from being labeled the cause of major system failure is the least likely to have a problem in the future. The contemporary analyst does not accept that causes can be transferred in a linear deterministic process across disparate systems. In highly specialized systems, the lessons learned may not be applicable to a

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[249] Kiel, pp. 15-16.

second system. For example, the risks identified by NASA within the shuttle main engines were related to welds in the system. Many of these welds could not be inspected visually to verify their integrity. To reduce the risk of weld failures leading to catastrophic engine failures, NASA developed a process for replacing the affected components with components having fewer welds.

Instead, the members of the organization train and prepare for unknown causes which could produce a system failure. They recognize that the particular set of circumstances present when the last failure occurred will never reoccur in the future. Rather than study this unique situation, the organization looks at how it should prepare for this type of failure even though it is not known within which subsystem it will appear. The contemporary analysts define common elements found in failures and look for the presence of these elements anywhere across the system. They recognize, however, that all possible permutations in a complex system's failures modes are beyond the organization's resources to evaluate.[250]

Finally, they train to recognize precursor elements that indicate that the system is not behaving as expected. These elements viewed alone may appear as interesting, but isolated phenomena. Viewed from a more holistic perspective, however, they may represent a disturbing trend. For example, as the erosion in the shuttle O-rings appeared across multiple flights, NASA and Morton Thiokol instituted an intense program to determine and correct the cause of the problem. No one stopped, however, to develop a simple plot to correlate the seal erosion to other factors such as the atmospheric temperature.

The organization does not prepare for the last failure, but acknowledges that the next failure may be caused by a factor that may not be identifiable in advance. It may never even be located after the fact. This approach represents a radical shift from that employed in the classical paradigm. Both the classical and contemporary analysts search for a cause and effect relationship. However, unlike the classical analyst, the contemporary analyst is prepared to proceed even if this relationship cannot be identified. The contemporary analyst looks for the incipient failure, regardless of the factors that are creating it. If these factors can be identified and the system improved after the failure is avoided, the analyst would employ classical techniques to do so.

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[250] Petroski, p. 80.

As with the classical paradigm, the contemporary paradigm includes steps to deal with the proximate consequences. For technical matters, the immediate response steps identified in the classical paradigm are followed. The operational procedures are executed which minimize danger to individuals and to property. Other actions are taken to preserve information related to the failure for use by investigators. For widely used systems, the organization attempts to determine, if possible, whether this failure presents a risk to other systems still in use. Accidents involving passenger aircraft illustrate this process. The aircraft experiencing a potentially catastrophic failure is directed to land and preparations are made to assist the passengers and crew at the landing site. On-board recording equipment preserves the data from the aircraft systems and from the flight crew communications. The radio transmissions between the crew and the ground are recorded, as are any data in the air traffic control centers. In certain cases, the failures may require grounding of a particular type of aircraft. For example, an American Airlines DC-10 aircraft lost a cargo door causing the plane to crash. The Federal Aviation Administration grounded DC-10's until this failure mode was corrected.

However, even beginning this early, a contemporary organization behaves in a far different manner. At the same time it is executing the classical paradigm's processes, the organization already has anticipated the possibility of system failure and has prepared responses to mitigate the consequences. This organization would have developed a series of failure scenarios and created immediate response plans for each scenario. These plans would extend beyond the operational responses described above to other aspects of the system failure. Should a passenger airline experience a crash involving loss of life and the aircraft itself, the airline must make decisions about notifying next-of-kin, developing communications with local emergency response teams, and meeting with the government agency regulating air traffic. It also must decide whether to continue to fly the normal airline schedule for that day.

These responses are initiated proactively in anticipation of certain consequences. For example, when the passenger aircraft crashes, the aircraft manufacturer might issue statements intended to deflect suspicion that its products were somehow at fault. They could state that there is no evidence that the airplane malfunctioned or that there is evidence of a more widespread problem that could affect the remaining copies of this aircraft flying passengers across the country. Also, the manufacturer might volunteer to participate at no cost in the investigation to ensure that the aircraft manufacturer is not negatively portrayed in the final report.

Such responses can increase the control an organization maintains over how a failure is perceived by government industry regulators, its stakeholders, and public opinion. Organizations who provide little detail regarding the failure, defer questions, or appear confused may be viewed as incompetent or stonewalling. For example, following the *Challenger* accident, NASA was well prepared to react to the technical aspects of the failure, shutting down computer systems and locking up files. However, it was not prepared to handle the onslaught of the media and congressional inquires. If NASA had recognized the degree of public scrutiny which would result from a catastrophic accident, it could have planned better how it would respond. Managers could have arranged public statements and been ready to deploy special teams to deal with the questions which arose. NASA's planning did not extend to measures such as these. As a result the Agency appeared to the outside world to be covering up data and stonewalling inquiries. The agency's apparent paralysis contributed to the establishment of the Presidential Commission.[251]

At the same time an organization that recklessly releases data prior to checking it for accuracy, only to have to modify it or retract it after the data are reconsidered, may appear to not be in control of the situation. Immediately after the TWA 800 aircraft crash, many speculations were placed before the public as facts. Later, those individuals and organizations were forced to retract these statements. Unfortunately by the time that the facts caught up with the rumors, an incredible amount of time and money had been spent chasing ghosts and TWA was widely criticized for its handling of the failure.

The manner in which an organization responds to a system failure dramatically affects the time it takes an organization to recover from the failure and resume normal operations. NASA's experiences with past flight failures demonstrate this effect. The second mission scheduled to land on the Moon, Apollo 12, experienced a lightening strike during launch. Systems malfunctioned, but the Apollo spacecraft was able to achieve orbit. Despite these events, NASA made the decision to continue with the mission and send the vehicle 250,000 miles to the Moon. The resulting publicity was that NASA had exhibited a "can do" spirit. When the following

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[251] Report of the Presidential Commission on the Space Shuttle *Challenger* Accident, p. 1.

mission, Apollo 13, almost resulted in the first American loss of a crew during flight, NASA was viewed as an agency that could succeed in any emergency situation. The Apollo program continued without interruption. The perception of NASA following the *Challenger* failure stands in stark contrast to these prior successes.

Responses are adaptive and continuously measured. The contemporary analyst does not accept the consequences of a system failure as inevitable. Following the initial response the analyst assesses its impact, reviews changes in its knowledge, and determines possible changes to the prescribed response plan. "A successful paradigm for organizational culture should thus include the necessity of instability to ensure that the culture itself is capable of innovative response to new demands created by its clientele or the political system."[252] For example, in 1990, a crisis-consulting firm conducted an overnight nationwide survey and found unexpectedly that a "20/20" television expose of rare problems with a consumer product actually had little impact on viewers. Consequently, the company under scrutiny immediately canceled hundreds of thousands of dollars of planned newspaper advertisements that had been prepared as rebuttals to the television story. Such ads would have kept the issue alive rather than let it quickly disappear.[253]

In a second example, in 1997, a company that manufactured chemical compounds based on phosphorus was concerned that the stricter regulations for the maximum level of radioactivity in phosphorus slag would cause widespread fear in the community and destroy the company's reputation as a "good neighbor." However, a representative community survey revealed that people were not worried and that the company's explanation had been heard, understood, and accepted by an overwhelming majority of the local citizenry. The company was still respected and trusted to maintain high safety standards. As a result, the company's leadership abandoned the highly defensive posture it was on the verge of adopting.[254]

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[252] Kiel, p. 154.

[253] Interview with Patrick Tuohey and W.C. Adams, Adams Research, Inc., Arlington, Virginia, 19 February 1998.

[254] Interview with Patrick Tuohey and W.C. Adams, Adams Research, Inc., Arlington, Virginia, 19 February 1998.

4.2 The Foundation Upon Which the Contemporary Paradigm is Built

Several new and exciting theories have emerged over the course of the past century, which take aim at the foundations of the classical paradigm and comprise the beginnings of the contemporary paradigm. These new theories hold that the ‘real’ world is far more complex and uncertain than previously believed, limiting our ability to measure and predict either the causes or consequences of a system failure. These largely 20th Century developments describe a relativistic universe that differs greatly from the deterministic certainty found in a Newtonian world. The contemporary paradigm builds on these advances in modern physics and in doing so recognizes and accounts for the shortcomings with the Newtonian concepts of reductionism, cause and effect, and determinism in analyzing system failures. These breakthroughs in modern physics cannot be viewed as a single, cohesive independent field of study, but rather are a loosely coupled compilation of ideas that frequently, but not always, build upon the findings of others.

One of the first to take aim at the classical paradigm was the famous French physicist Henri Poincaré. Poincaré's discovery that small effects could multiply exponentially and unpredictably helped to dispel the notion of determinism. Introducing the concept that small effects can have significant impact on the primary process, Poincaré argued that feedback could be nondeterministic and unpredictable as defined by classical mechanics.[255]

Reductionism fared little better as Albert Einstein unveiled his theories of relativity. In his special theory, he revolutionized our view of the physical world by arguing that the concept of an objective measurable universe is a fraud. According to Einstein, everything is relative. Special relativity theory holds that all measurements are dependent upon one's frame of reference-- or, as the saying goes "where you stand depends upon where you sit". "The consequence of Einstein's postulates", according to Huetinck, "is that there is no such thing as absolute time and absolute distance."[256]

In addition, Einstein's theory of general relativity holds that the idea of a physical universe as described by classical physics is simply a model and does not fully represent reality.

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[255] Briggs and Peat, p. 28.
[256] Huetinck, p. 157.

Time and space, Einstein contended, are interrelated. They form a continuum where all effects are propagated throughout the continuum. Matter is an abstract concept and the concepts and definitions employed by physicists are simply tools for helping man understand his surroundings, nothing more; what they are not, Einstein argued, is reality. No one can measure something without a subsequent effect on the universe; the result does not represent reality but rather our perception of it. In such a universe, the utility of reductionism is severely limited. The number of parameters to be measured rapidly becomes unmanageable. Increased computing power also is of limited value as the reductionist model is simply that - a model, and does not accurately represent the fullness of physical reality.

Classical mechanics was challenged further in the early part of the 20th century by the independent emerging science of quantum mechanics. Quantum maintains that at its most fundamental level the universe is indeterminate and not exact. The implementing arm of relativity, it asserts that at the atomic and subatomic levels exists a "fundamentally indivisible wholeness" in which it is not possible to precisely discern with total accuracy either the position or the state of motion of a particle.[257]

The world of quantum mechanics limits the use of the determinism found in classical mechanics. Here, the more one knows about the position of an object, the less one knows about its physical nature. This inability cannot be overcome by more astute observation or better measurement devices, but is instead a physical fact. However, this limitation does not compromise the ability of objects to create effects even if they cannot be accurately measured. Quantum mechanics incorporates the theory of general relativity and asserts that every object in motion produces a " wave". As an object passes through a given point in space, it affects the relative state of other objects. It carries some objects with it in its wake; it displaces others into new positions.

Atomic and subatomic particles, unlike the macroscopic objects that we are accustomed to dealing with, "do not have precisely definable positions or states of motion, but only probabilities of those quantities."[258] In this microscopic world, electrons move about an atom's

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[257] Briggs and Peat, p. 76.

[258] Curtis Suplee, “New State of Matter Heralded as Physics ‘Holy Grail,’” <u>Washington Post</u>, 14 July 1995, pp. Sec. A., pp. 1, 16.

nucleus in a spherical cloud and the best we can do is gauge the statistical likelihood that they will be in any given place at any given time. Complicating matters is the fact that no measurement can be taken without affecting the measured object. Even measuring the magnitude of this unintended effect in turn causes a subsequent effect on the system as a whole. In this "Alice in Wonderland" world, the cause-and-effect relationship becomes muddled, with the definitions of cause and of effect losing their meaning. This odd microscopic universe is not visible at the macroscopic level, where cause and effect may still be used to describe many phenomena.

Mandelbrot found this effect in his study of sets of nonlinear equations. Rather than discussing stability and instability as a set of two, the analyst must address a condition that exists at the border between them. This third member, labeled bounded instability, illustrates a complex interaction between the two that defies discussion of a clean line between them.[259] In the 1960s, previous works by Einstein, the quantum theorists, and the recently rediscovered Poincaré were merged with works by Edward Lorenz and Benoit Mandelbrot, and a new era in nonlinear thinking caught fire.

Touted by scholars "latest revolution in science” and the necessary precursor of a higher level of order an increasing number of academic papers and books grounded in this new way of thinking began to appear.[260] By the 1980s, nonlinearity had assumed the mantle as the foundation of choice for scholars engaged in the advancement of the physical and biological sciences. In 1987, James Gleick's Chaos: The Making of a New Science became a national bestseller and such concepts as "nonlinearity" and "nondeterministic feedback" crossed over into the mainstream.[261]

Chaos theory, which for all practical purposes is the compilation of the concepts of Poincaré, Einstein, and quantum mechanics into a single comprehensive paradigm, has at its foundation three basic premises. First, there is no such thing as an exact measurement. The best scientists and other observers can do is approximate real situations. Gleick uses the example of someone trying to measure the shoreline. Does one measure in and out of each crevice? Around

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[259] Stacey, p. 61.
[260] Toffler, “New Science of Instability throws Light on Politics,” p. 332.
[261] James Gleick, Chaos: Making a New Science, (New York, N.Y.: Penguin Books, 1987).

each rock? At high tide or at low tide? Difficulty also arises when the analyst has to choose which measurement system to use. Should an item be evaluated by its mass, by its volume, or by its value to society? It is, Chaos concludes, impossible to provide an "exact" measurement of anything.

Second, since there is no such thing as an exact measurement, it is impossible to accurately discern and quantify the individual components of any system. This is true, in part, because our measurements are based on our ability to perceive them physically. Our measuring instruments replicate this ability, limiting their range and scope.[262] Therefore, to best understand the system, (recognizing of course that we will never completely accomplish this objective) one must step back and examine the system from a broader perspective, a holistic approach. Chaos maintains that this holistic approach is preferable to a reductionist approach when discussing complex systems.

Third, small events can produce large and unpredictable results, creating nondeterministic feedback. To illustrate this concept Gleick uses the vivid explanation of a butterfly flapping its wings in Tokyo and impacting the weather in New York. The classical linear paradigm would never anticipate these effects. This third premise also has a profound affect on the utility of the classical cause and effect paradigm. How can one accurately determine and measure the causes of an event? Similarly, the measurement of the immediate effects of an event is not adequate to determine an event's ultimate impact on seemingly unrelated occurrences.

Finally, in the late 1980s another strain of nonlinear thinking, Complexity, emerged. Like its older sibling, Chaos, it too is grounded in the idea of a "turbulent and disorderly universe."[263] Complexity, however, extends nonlinear thought to include a discussion of the fascinating and exciting adaptive capabilities of complex systems. Rather than focus exclusively on the cause of a failure, Complexity theorists expand the discussion to consider the response to failure. Response is considered coequal with the cause in examining the ultimate consequence of an event.

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[262] John Lienhard, “Engines of our Ingenuity,” www.uh/engines/epi1363.htm.

[263] Kiel, p. 4.

Relatively new and still not completely defined, Complexity wrestles with the second law of thermodynamics, the age-old contradiction between order and structure. As Mitchell Waldrop points out in Complexity: The Emerging Science at the Edge of Order and Chaos, ever since the Big Bang the universe has "been governed by an inexorable tendency toward disorder, dissolution, and decay, as described by the second law of thermodynamics. Yet, the universe has managed to bring forth structure on every scale: galaxies, stars, planets, plants, bacteria, plants, animals and brains."[264] He notes that:

> These complex systems have somehow acquired the ability to bring order and chaos into a special kind of balance…the edge of chaos is where life has enough stability to sustain itself and enough creativity to deserve the name of life. The edge of chaos is the constantly shifting battle zone between stagnation and anarchy, the one place where a complex system can be spontaneous, adaptive, and alive.[265]

Complexity, however, extends nonlinear thought to include a discussion of the fascinating and exciting adaptive capabilities of complex systems. These systems exist in a certain form only at certain instances in time. From one time increment to another, the system may experience instability, choose a different direction, or emerge in a different form.[266]

Rather than focus exclusively on the cause of a failure, Complexity theorists expand the discussion to consider the response to failure. Complexity recognizes that complex systems are more spontaneous and alive than static objects such as computer chips that are merely complicated. These complex systems, do not just passively respond to events the way a rock might be tossed about at the bottom of an ocean; but rather "they actively try to turn whatever happens to their advantage."[267] These complex systems are highly adaptive.

This concept can be seen everywhere. For example, Waldrop points out that the business economy is a classic example of a self-organizing and adaptive system. He states that whereas "species evolve for better survival in a changing environment - so do corporations and industries.

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[264] M. Mitchell Waldrop, Complexity: The Emerging Science at the Edge of Order and Chaos, (New York, N.Y.: Simon and Schuster, 1992), p. 10.
[265] Waldrop, pp. 11-12.
[266] Stacey, p. 12.
[267] Waldrop, p.11.

And the marketplace responds to changing tastes and lifestyles, immigration, technological developments, shifts in the price of raw materials, and a host of other factors."[268]

Today, these once revolutionary concepts in the physical sciences are seeing widespread application in engineering and scientific research. Biologists have seen the phenomenon described by Lorenz appear in insect populations and are using his theories to study their behavior.[269] High-speed semiconductors employ quantum mechanics theories. As these theories entered the literature, engineers studying transistors and early integrated circuits tested the quantum theories. One of the successes in these tests was the development of the tunnel diode. This diode, now incorporated into many circuits, is based on the probabilities that the electrons in the circuit can pass across the diode. Chaos theory also is used in meteorology. The behavior of atmospheric systems that produce hurricanes and other tropical storms long has been of interest. These storms with their apparently unpredictable movements actually exhibit some underlying patterns.

Although not at the pace of the physical sciences, the social sciences are beginning to consider these theories as well. Recently, philosophy has looked to chaos theory to explain the Zen Buddhist paradoxes often used to teach students. Instead of the apparent paradoxes leading to complete disorder they lead to “insight or even enlightenment.”[270] Exercising these theories in organizational management, some managers actually promote discussion within their organization at all levels. The former Honda chairman, Kawashima, told interviewers that he retired in part because his staff began to agree with him.[271]

4.3 Signs of the Contemporary Paradigm in the Literature

The contemporary paradigm cannot be found in its entirety in any of the system failure literature, but its elements are present with those seeking to find answers beyond those provided by the classical paradigm. Addressing elements of the contemporary paradigm in learning theory, decision theory, and organizational theory, these analysts consider the behavior of

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[268] Waldrop, p. 11.
[269] Briggs and Peat, p. 69.
[270] Briggs and Peat, p. 67.
[271] Stacey, p. 84.

nonlinear systems and the effects of complexity on the design and operation of systems experiencing failures. How positive and negative feedback affect systems and how organizations learn from modern theories also are explored.

Students of public policy and organization theory can see traces of the contemporary paradigm as far back as 1945 and Nobel Prize winning author Herbert Simon's publication of Administrative Behavior: A Study of Decision-Making Processes in Administrative Organization. In Administrative Behavior, Simon argues that the concept of "economic man" who has "preposterously omniscient rationality" is a fraud.[272] Instead Simon contends that we must recognize that "Administrative theory is peculiarly the theory of intended and bounded rationality—of the behavior of human beings who satisfice because they have not the wits to maximize."[273] Simon concludes that:

> …all decision is a matter of compromise. The alternative that is finally selected never permits a complete or perfect achievement of the objectives, but is merely the best solution that is available under the circumstances. The environmental situation inevitably limits the alternatives that are available, and hence sets a maximum to the level of attainment of purpose that is possible.[274]

More recently a number of public policy and organization theory scholars have begun to weave concepts of the contemporary paradigm into their writings. Priesmeyer argues that organizations are nonlinear systems and Kiel and Kronenberg both call for a "new paradigm for public management" grounded on the principles of modern physics. [275]

In Managing Chaos and Complexity in Government, Kiel states that "The traditional visions of public management can no longer be stretched to accommodate the growing complexity of the world."[276] He asserts that:

> Organizations are clearly nonlinear dynamic systems…and that traditional mechanical and adaptive organizational paradigms seem to have imposed an

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[272] Herbert A. Simon, Administrative Behavior: A Study of Decision-Making Processes in Administrative Organization, (New York, The Free Press, 3rd ed., 1976), p. xxvii.

[273] Simon, p. xxxviii.

[274] Simon, p. 6.

[275] H.R. Priesmeyer, Organizations and Chaos: Defining the Methods of Nonlinear Management, (Westport, Conn.: Quorum Books, 1992); L. Douglas Kiel, Managing Chaos and Complexity in Government, (San Francisco: Jossey-Bass Publishers, 1994), Kronenberg, p. 253.

[276] Kiel, p. 3.

> overly mechanistic and orderly vision of organization and change on a world of management that is really full of complexity, change, and disorder.[277]

Echoing this belief in "Chaos and Rethinking the Public Policy Process" Kronenberg argues:

> Efforts to improve public policy require better understanding of the public policy process, especially the transformational aspects of that process. We need to supplement our theories of the policy process by bringing in new insights from the "New Sciences of Transformation" (NST) - chaos complexity and autopoiesis.[278]

In Managing the Unknowable: Strategic Boundaries Between Order and Chaos, Ralph Stacey supports the need for today's managers to look beyond the classical paradigm stating:

> I explore what this new understanding of bounded instability means, what difference it makes to the actions managers must take…, and what consequences it holds for the way they approach the strategic management process. I will argue that Western managers need to embrace this new frame of reference, in which success is not stable equilibrium but a dynamic state of bounded instability that is far from equilibrium.[279]

In the universe these analysts describe, a more flexible paradigm is required to deal with this "bounded instability."[280]

Noted organizational theorist, Charles Perrow, embraces the principles of the contemporary paradigm in his analysis of complex system failures, Normal Accidents: Living with High-Risk Technologies.[281] In Normal Accidents, Perrow asserts that failure is inevitable, even normal, in complex and tightly coupled systems.[282] Drawing on the concept of nondeterministic feedback (without actually ever referring to it as such), Perrow argues that relatively unremarkable failures buried deep within a complex system can produce unpredictable and devastating ripple effects. Perrow contends that even if the contributing factors could be

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[277] Kiel, p. 9 & 14.
[278] Kronenberg, p. 253.
[279] Ralph D. Stacey, Managing the Unknowable: Strategic Boundaries Between Order and Chaos in Organizations, (San Francisco: Jossey-Bass Publishers, 1992), p. xiii
[280] Stacey, p. xiii.
[281] It is interesting to note that in Normal Accidents, Perrow embraces the principles of the contemporary model in analysis of the causes of system failure. When discussing the consequences of system failure, however, Perrow reverts to the classical approach.
[282] Perrow, Normal Accidents: Living with High-Risk Technologies.

identified, their interactions are too complex to allow the calculation in advance of their ultimate effect in bringing about the resulting system failure.

Perrow begins his argument with the observation that there is no such thing as an exact measurement or absolute perfection (i.e. reductionism). Even "common run-of-the-mill industrial plants," Perrow observes, "have a steady stream of unremarkable failures."[283] He considers the search for these causes and their evaluation pointless as they are often buried deep within the complex system. Like the butterfly effect in Gleick's Chaos, these seemingly unremarkable failures can produce effects that rapidly and unpredictably multiply. Because their interactions are non-linear our ability to predict the rate and results of this proliferation is greatly limited.[284] For example, Michael Collins, in his book Liftoff, relates how Jerry Lederer, former NASA Safety Chief, calculated that *Apollo 8* had 5,600,000 parts and that even if all functioned with 99.9% reliability, NASA could expect 5,600 defects, each capable of producing a catastrophic result.[285]

Given the inevitability of component failure and the unpredictability of its subsequent results, Perrow contends the ability to prevent the initiating effect from spreading becomes the critical factor in preventing system failures. The ability to halt an initiating event hinges on whether the system is tightly or loosely coupled. In loosely coupled systems events occur independently. Component failures can be more easily absorbed, providing margin for recovery. Tightly coupled systems, in contrast, provide no slack or buffer between items. What happens to one item in tightly coupled systems almost simultaneously affects what happens to the other items. Paradoxically, tightly coupled systems are more efficient.

Perrow's argument may be summarized using a simple example. A failure occurs to part X that interacts with both parts A and B as well as in some unexpected way with part C (complexity). While the designers knew in advance that if part X failed it would impact parts A and B they had no way of knowing that part C also would be impacted. In loosely coupled systems it will not matter as the accident will not spread quickly and there will be time to fix it.

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[283] Perrow, Normal Accidents: Living with High-Risk Technologies, p. 43.
[284] Gleick, p. 20.
[285] Collins, p. 225.

But if the system is tightly coupled and the failure process cannot quickly be turned off, system failure is inevitable.

Complicating matters, Perrow contends neither organizational nor technological innovations will prevent system failures.[286] While he acknowledges "better organization will always help any endeavor"[287] he quickly points out that in many cases the organizational structure is inconsequential as far as its ability to prevent system failures. He argues that:

> because of the complexity, they are best decentralized; because of the tight coupling, they are best centralized. While some mix might be possible, and is sometimes tried, this appears to be difficult for systems that are reasonably complex and tightly coupled, and perhaps impossible for those that are highly complex and tightly coupled.[288]

Likewise, he asserts that better technology will not prevent system failures. Better technology merely "allows those in charge to run the system faster, or in worse weather."[289] Furthermore, hidden paths often defeat safety devices added to the system in the system.[290] In fact, Perrow argues there are many examples of safety devices actually increasing the probability of failure.[291]

Given the inherent risk associated with complex systems one might conclude that linear systems would be preferable. Perrow reminds us, however, this is not the case. Complex systems are preferable because they are more efficient and economical than linear systems; they employ fewer components to carry out the same task utilizing less space, time and energy. Unfortunately, however, Perrow’s analysis, while interesting, provides practitioners with little assistance in managing the risks of failure in complex systems.

In To Engineer is Human: The Role of Failure in Successful Design, Henry Petroski**,** contends that system failures provide invaluable data to those designing and developing complex systems. Petroski extends the discussion of consequences to include the beneficial aspects of system failure. He develops a portrait of systems engineering which is anything but the dry, logical development sequences envisioned by most people. He points out that the consequences

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[286] Perrow, Normal Accidents: Living with High-Risk Technologies, p. 5.
[287] Perrow, Normal Accidents: Living with High-Risk Technologies, p. 10.
[288] Perrow, Normal Accidents: Living with High-Risk Technologies, p. 334.
[289] Perrow, Normal Accidents: Living with High-Risk Technologies, p. 11.
[290] Perrow, Normal Accidents: Living with High-Risk Technologies, p. 11.

of a failure always are a key component of the design process, with designers working to minimize the consequences on parties removed in time and location from the failure event. Using the American Airlines DC-10 accident in Chicago, he illustrates that the overall consequences to those not directly associated with the flight were in fact minimal. The airline is operating successfully, the aircraft was modified to prevent such future accidents, and the traveling public has done nothing but increase their use of public air transportation.[292]

Arguing that system design is a complex, rather murky process, individuals employ engineering principles to achieve a given goal and often depart from “accepted practices” to derive supposedly improved systems with greater capability, lower cost, and improved margins of safety. Airplanes once were made with wood and fabric as the primary components. The first engineer to use a metal frame and skin in an aircraft obviously departed from standard procedure. Similarly, the German and British development of the jet engine for propulsion was an untried method outside the sphere of accepted practices.

Pushing the envelope of engineering knowledge or seeking to expand the boundaries of exploration always includes the risk of the inevitable system failure. The de Havilland Comet was the first jet aircraft to enter regular passenger service. After the plane literally exploded in flight, the manufacturer and other experts investigated the cause. They found that the alloy used to manufacture the fuselage showed unanticipated cracking at well below projected time periods. The cracks would propagate and the pressurized fuselage disintegrate. The court of inquiry explained the situation as follows:

> Throughout the design of the de Havillands relied on well-established methods essentially the same as those in general use by aircraft designers. But they were going outside the range of previous experience and they decided to make thorough test of every part of the structure.
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> …They believed, and this belief was shared by the Air Registration Board and other expert opinion, that a cabin that would survive undamaged a test to double its working pressure… would not fail in service under the action of fatigue…[293]

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[291] Perrow, Normal Accidents: Living with High-Risk Technologies, p. 19.
[292] Henry Petroski, To Engineer is Human: The Role of Failure in Successful Design, (New York, Vintage Books, 1992), p. 96.
[293] Petroski, p. 177-179.

Focusing on the engineering and design aspects of failure, Petroski contends that system failures provide invaluable data to those designing and developing complex systems. He believes that it is these constant attempts to refine the art of engineering that allow us to develop better systems that are more useful to society. It is here where he identifies the utility of system failure in this quest. He argues that we learn far more from our mistakes as illustrated by system failures than we do in the successful designs. Of course, he does not argue in favor of letting these failures occur, but views them as unique opportunities to learn at an accelerated rate impossible when all attempts at advancing the state of the engineering art are successful. For example, he uses the development of suspension bridges as a case study in engineering development. The failures, many spectacular, focus the industry on the key elements of suspension bridge design and prevented future accidents that might have had greater consequences.[294]

In Complexity: The Emerging Science at the Edge of Order and Chaos, Mitchell Waldrop argues the ability to adapt to the situation in the aftermath of the system failure is critical if the organization is to survive. The ability of complex systems to change and adapt is possible because of what Waldrop refers to as self-reinforcement or what is sometimes called positive feedback, the ability for small effects to become magnified under the proper conditions instead of simply dying away.[295] In other words, with small actions that need not be large and all encompassing, the organization can affect its own future.

It is important, however, to distinguish between unconscious adaptations such as mutation and the conscious adaptations made by thinking individuals and organizations. While mutation may ultimately result in a species' survival, it does not arise from a decision by a particular member of that species to changes in its own composition or abilities. In contrast, conscious adaptation focuses on changes made by an individual or organization that affect future events during the lifetime of the current members. This ability to adapt is crucial because complex systems are able to learn from experience and evolve for better survival in an ever-

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[294] Petroski, p. 232.

[295] The principles set forth earlier by Einstein and the Chaos theorists embrace the theory that small actions ultimately can generate significant effects. Similarly, large perturbations can result in trivial or no effects to non-linear systems.

changing universe. This characteristic is very similar to Contingency Theory that holds that an organism's survival is contingent on its ability to adapt and fit into its environment.[296]

In an organizational setting, this adaptability influences agenda setting and the transformation of the way we view issues and events. Rather than a distinct beginning and end to the event sequence, Kronenberg suggests that a more appropriate metaphor may be the "cloud" metaphor. Kronenberg's cloud metaphor includes an issue transformation step that accommodates changes that ultimately feed back to the beginning of the cycle to have a later effect on future actions within the system.[297]

Discussing the behavior of individuals within an organization, Karl Weick, as well as James March and Herbert Simon, noted that following an initiating event, the response of each actor affects the response of the other actors. In turn, each may attempt to shape the response of others as programmed and unplanned actions are carried out, and as meaning is attached to the failure. The individuals involved attempt to understand the world around them and interact accordingly. These actions are not simply efforts to better capture a picture of the overall situation, but more an attempt to integrate the observer's impressions into the preexisting framework of reality that all people carry within them.

Weick termed this concept sensemaking, defining reality as an ongoing accomplishment that emerges from efforts to create order and make retrospective sense of what occurs. Weick notes that while much of today's organization theory still "begins and ends with decision making" he contends that we need to replace the less appropriate normative model of "economic man" with models more pragmatic about social relations.[298] Whereas decision making is about strategic rationality, with clear questions and answers that attempt to remove ignorance, sensemaking is interested in contextual rationality. In the words of Weick, "the basic idea of sensemaking is that reality is an ongoing accomplishment that emerges from efforts to create order and make retrospective sense of what occurs."[299] The firefighters in the Mann Gulch Disaster, for example, did not face questions like where should we go, when do we take a stand,

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[296] Kronenberg, p. 255.

[297] Kronenberg, p. 253.

[298] Karl E. Weick, "The Collapse of Sensemaking in Organizations: The Mann Gulch Disaster," Administrative Science Quarterly, Dec. 1993, p. 634.

[299] Weick, "The Collapse of Sensemaking in Organizations: The Mann Gulch Disaster," p. 635.

or what should our strategy be? Instead, they faced the more fundamental problems that their old labels were no longer working. They had outstripped their past experience and were not sure which way was up and which was down, or who they were.

In his examination of organizations and decision-making Weick asks, "how can I know what I think until I see what I say?"[300] Sensemaking refers to this process whereby organizational members translate an organizational event and construct a meaningful explanation for that event. Individuals are not seen as living in, and acting out their lives in relation to, a wider reality so much as creating and sustaining images of a wider reality, in part to rationalize what they are doing. They realize their reality by reading into their situation patterns of significant meaning. Organizations talk to themselves over and over to find out what they are thinking – a good deal of activity consists of reconstructing plausible histories after-the-fact to explain who they are and how they got there**.**

Sensemaking is based upon the view that the social world has a very precarious ontological status, and that what passes as social reality does not exist in any concrete sense, but is the product of the subjectivist and inter-subjective experience of individuals. The methodology used seeks to explain the world from the viewpoint of the actors involved in the social process. Since the researcher must interpret her observation through a lens that is unique to the researcher, the knowledge that is gained is biased through the viewpoint of the person making the observation.

March and Simon in their classic text, Organizations, distinguish between these responses which result from *learning*, a relatively slow process occurring over time, and *evoking*, defined as elements influencing behavior at a particular time, such as in the aftermath of a systems failure.[301] They further classify these elements in three categories: "a) values or goals: criteria that are applied to determine which courses of action are preferred among those considered; b) relations between actions and their outcomes: i.e., beliefs, perceptions, and expectations as to the consequences that will follow from one course of action or another; and c) alternatives: possible courses of actions." This structure allows individuals to choose among alternatives with the

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[300] Karl E. Weick, The Social Psychology of Organizaing, (New York: Random House, 2nd ed. 1979), p. 5.
[301] James G. March and Herbert A. Simon, Organizations, (New York, N.Y.: John Wiley & Sons, Inc., 1958).

choice based on multiple elements, each of which may or may not evoke a given response.[302] March and Simon capture this concept as it applies to organizations:

> When a set of action alternatives is evoked, a network of consequences and evaluations is simultaneously evoked; subsequently, the connections relating possible choices to probable outcomes are extended. Control over the perception of consequences is one of the crucial types of influence..[303]

Practitioners are consciously or subconsciously adopting elements of the contemporary paradigm in their operational processes. Three examples include:

1. Pharmaceutical companies studied by Isenberg used system failure as learning events. Isenberg summarized their approach as follows:

   > …Managers can only benefit from the opportunity to reflect back on these surprises in order to learn from them. In a sense, the response can be seen as a fixed investment on which there is a return in the form of learning. Even though most surprises are unpleasant ones, there is a lot of positive learning that can be derived from examining those experiences and the managers' novel cognitions and behaviors.[304]

2. NASA's shuttle training aircraft managers are using the concepts of the contemporary paradigm "instead of the usual manual optimization" in an effort to "improve simulation of the final pre-touchdown flare by making gains sensitive to more variables." These managers are using a nonlinear paradigm that compares output to desired pitch and responds accordingly."[305]

3. California, in an attempt to quickly rebuild bridges in the aftermath of natural disasters (e.g., floods and earthquakes), has developed a "novel four-lane bridge kit that can be shipped to any part of the state and erected within 48 hours of a catastrophe.[306]

These examples, coupled with the research found in the literature, illustrate that the sciences of modern physics are beginning to find their way into both the academic environment and the practitioners' world. These few examples exhibit this trend, but also show that this adoption is incomplete. For example, NASA very successfully has used simulations to uncover issues associated with systems operations. This approach is the primary training mechanism both

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[302] March and Simon, p. 10-11.
[303] March and Simon, p. 58.
[304] Isenberg, p. 49.
[305] "Shuttle Experiments with Fuzzy Logic," ed. Michael A. Dornheim, Aviation Week & Space Technology, 23 Nov. 1997, p. 17.
[306] "Disaster Relief in a Day: Railroad Surplus Offers Easy Crossings," Curt Suplee, Washington, 14 April 1995

for astronauts and the flight control teams. However, this approach is not used in management training or in simulations for mishaps requiring senior management decisions.

The principles of modern physics theories and their implementation demonstrate a basic structure that may be placed into a paradigm similar to that used in classical physics. This paradigm provides a technique for discussing any system failure using common terminology. The contemporary paradigm differs from the classical paradigm because the underlying physics are not the same. The contemporary paradigm does not look for a deterministic approach to a failure, so there is no assumption that a specific investigation will uncover one. The events are not viewed as unfolding in a linear sequence, so no linear path is followed in the research. However, this apparent lack of structure in the contemporary paradigm does not preclude the analyst from developing a framework that places the failure within specified boundaries.

4.4 The Contemporary Paradigm

This evolutionary synopsis provides the basis for summarizing a contemporary paradigm that can be applied to system failure. Those analysts who use this paradigm will find few precedents from which to draw. Instead, they would look to the modern science principles to guide their path in what is knowable and worth pursuing, knowable but not relevant, and unknowable. The physical forces that destroyed the *Challenger* vehicle should be known to determine whether the system design or operation needs to be altered. A complete understanding of the accident, including its precursors, causes, and consequences will never be known.

There is no widespread use of this paradigm today, but enough elements are being used to make it worth examining. Various elements of the paradigm outlined below are being used in the physical sciences, engineering and the social sciences. Specifically the concepts that the world is chaotic, that some factors in a situation may never be known, and that small input to a situation may have larger unanticipated impacts are beginning to appear in literature. Failures are viewed better using a holistic approach that allows the analyst to step back and consider the events in their entirety. The analyst does not expect to find a specific solution on a clearly outlined linear path. The alternative path that comes to light shows that organizations should train their employees to expect the unexpected and to forego rote training in preference to a skill-based approach. Merton emphasizes the interrelationship of these factors:

> The concept of structural constraint corresponds… to Goldenweiser's "principle of limited possibilities" in a broader sphere. Failure to recognize the relevance of interdependence and attendant structural restraints leads to utopian thought in which it is tacitly assumed that certain elements of a social system can be eliminated without affecting the rest of that system.[307]

I. Basic Unit of Analysis

The system failure is defined as an NST-process in which the events leading up to and following a system failure are governed by rules established within modern physics, chaos theory, and complexity theory. Further exploration of a system failure will not necessarily produce more accurate or precise information about the causes or consequences of the failure.

II. Organizing Concepts

A. *Elements contributing to the Failure*: The failure did not result from a single "root" cause, but rather from a plethora of elements contributing to the proximate cause. In addition, the proximate cause may be debated, and may never be determined with finality.

B. *The Unknowable Elements*: It is impossible to identify all of the elements that contribute to a system failure. These unknowable elements cannot be discovered through more research or better testing.

C. *Degree of Contribution by Each Element:* The elements do not contribute equally to a system failure.

  - *Limitations of measurement.* The actual contribution is not possible to know with certainty. However, measurements obtained may be useful in identifying the causes or consequences of a system failure, and for responding to the failure.
  - *Summing the measurements*. Even when it is known, the analyst cannot distinguish the contribution as the one that resulted in the failure occurring. The interplay of the causes

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[307] Merton, p. 107.

precludes determining whether the failure still would have occurred in the absence of one or more cause.

D. *Multiple Consequences*: A major system failure does not have a single consequence. Its multiple consequences are considered as a group to determine the total effect of the failure.

E. *The Inevitable Consequence Myth*: The consequences arising from a system failure are not written in stone. The consequences can be altered through actions that take place prior to or following the failure.

III. Dominant Inference Pattern:

If a failure occurred, it must have been the result of multiple contributing factors creating multiple effects

A. The contemporary paradigm provides insight by illustrating that these multiple cause factors are possible and can be mitigated.

B. The paradigm illustrates where different actions or non-actions would develop into different outcomes following the failure.

IV. General Propositions:

This paradigm presents a significant challenge to any analyst developing overarching propositions regarding it. The difficulty may be illustrated using the all-too-common occurrence of train/automobile collisions at railroad crossings.

1. Slight changes in the schedule of either the driver of the automobile or the train engineer would have eliminated the collision.

2. If the automobile driver had recognized the possibility of a collision because the car was sitting on the tracks, the driver could have saved all passengers' lives by having the occupants leave the vehicle.

3. The Railroad Company has little or no control over certain consequences of the collision. Should the occupants of the vehicle be children, the public outcry likely would be greater than if the driver was an inebriated adult.
4. Obviously there is a failure here, but was the cause driver inattention, poor markings at the crossing, excessive train speed, or something else?

Although the world represented by the contemporary paradigm appears almost random, it is possible for a theorist to develop general principles that provide structure to the argument.

A. *Universal Laws*. Our physical world, although it does not behave strictly according to laws of classical mechanics, is governed by a set of universal laws. These laws are never violated, but may not be understood by us.

B. *Action and Reaction*. Like the action/reaction principle of Newtonian mechanics, this principle holds that there are reactions from actions taken prior to or following a system failure. However, it differs from the linear deterministic view that the reaction is equal and opposite from the action.

C. *Failures and Answers*. The concerned parties do not find the answers to why a failure occurred as a part of a coordinated effort. Instead, components of the answers are found in various factors that contributed to the failure.

D. *Frame of Reference*. The causes and consequences are defined differently from different frames of reference. There is no preferred frame of reference, only those defined by the analyst. The chosen frame of reference may affect the view of the analyst and any measurements taken.

E. *Non-linear Effects*. Small effects multiply exponentially to create multiple consequences. Also, large effects may die away. These effects may not be determinable in advance of or following the system failure.

F. *Measurement Perturbations*. The act of measuring something can affect the object being measured. Improving the fidelity of measurement of one characteristic can prevent an analyst from measuring another characteristic.

G. *Accuracy vs. Precision*. Measurements can be taken precisely, but this does not necessarily result in the accuracy required by Newtonian mechanics. For example, the length of the seashore may be measured at mean high tide or at low tide. Both are equally correct.

V. Specific Propositions

A. *Knowledge*

1. The causes of a failure cannot be determined absolutely.
2. Even the proximate cause should be debated and discussed.
3. Occurrences of failure can be minimized, but cannot be eliminated.
4. The failure event and the proximate consequence are identical.
5. Multiple consequences flow from a system failure.
6. Consequences are not limited to any specific discipline or sphere of interest.

B. *Prescience*

1. Responses to a system failure affect the nature and severity of consequences.
2. Selected “responses” can take place prior to the failure itself.
3. Responses may be modified as they are implemented using feedback from their effects on the consequences.
4. The ultimate consequences may have resulted anyway without the organizational responses being taken.

5. It may not be possible to determine the contribution of the organizational responses to the consequences.

IV. Evidence:

The sheer magnitude of the data pertinent to a system failure precludes any one person from grasping the failure in totality. Complex systems frequently have been developed over several years, with the actual design the product of years of prior preparation. In many cases, it is difficult to distinguish where the actual design originated. In searching for the facts, the analyst must rely on data compiled and interpreted by others in order to draw their own conclusions.

1. Data may be obtained from records, observer accounts, interviews with participants, post-failure investigations, and personal knowledge of the analyst.
2. These data bring with them the personal bias of those who developed them. Also, the data may be affected by the frame of reference from which they are viewed.
3. Data developed for a specific purpose (e.g., operational procedures) may not provide the necessary background to understand its contribution to the failure.
4. The passing of time colors the memories of those involved in the system failure.
5. The complete data set can never be determined, so the analyst must judge when to declare the data sufficient.

4.5 The Contemporary Paradigm Illustrated

The contemporary paradigm, shown in Figure 4-1, does not exhibit the linear, deterministic characteristics seen in the classical paradigm. It incorporates, however, all of the elements relevant to the failure, including the events occurring prior to the failure, those activities surrounding it, and the actions taken as a result of the failure. As with the classical paradigm, the contemporary paradigm considers events that may have been remote in time or in geographic distance from the failure. Missing is the step-by-step progression from one element to another and the “clean” interfaces which characterize the classical paradigm.

The Before section of the illustration shows the complex nature of the events leading up to a system failure. The section has three components: the clouds that form the perimeter, the individual polygons within the clouds, and the interconnecting links between the polygons. The clouds represent the general factors that have an overall contribution to the system failure. For descriptive purposes, these factors may be grouped according to disciplines of study. For example, management theory explains how large organizations such as NASA are structured and how they function. In the *Challenger* accident, NASA's management is cited as a contributor to both the agency's culture and the specific actions taken by the individual participants. Public policy pressures levied by the Administration and the Congress are a second factor cited as an influence on NASA's actions preceding the launch of STS-51L.

The polygons represent the individual elements which have been identified either as the root cause of the accident or as contributing elements to these root causes. In contrast to the classical paradigm, there are many root causes and even more contributing elements. No distinction is made among these elements. Other polygons are labeled simply "C1, C2, C3"… to represent the unknown factors which contribute to the causes of the accident. Although these factors may not be known directly, the analyst knows they exist and can attempt to account for them by looking for the effects they have on other elements.

The interconnecting links demonstrate the complexity of the contemporary paradigm. Some elements have multiple direct input from other elements and may have multiple outputs. For example, the culture within NASA was affected by groupthink and by the actions of senior management. This culture also affected the way the safety organization was structured and the decision making process the shuttle program followed. Not seen but still visible are the influences on these links created by the pressure from the clouds that surround the polygons. For example, public policy concerns might strengthen the link between groupthink and the desire to meet schedule while weakening the link from culture to safety. Unlike the classical paradigm, the contemporary paradigm includes feedback and feed forward links which allow factors to evolve as the time to the failure approaches.

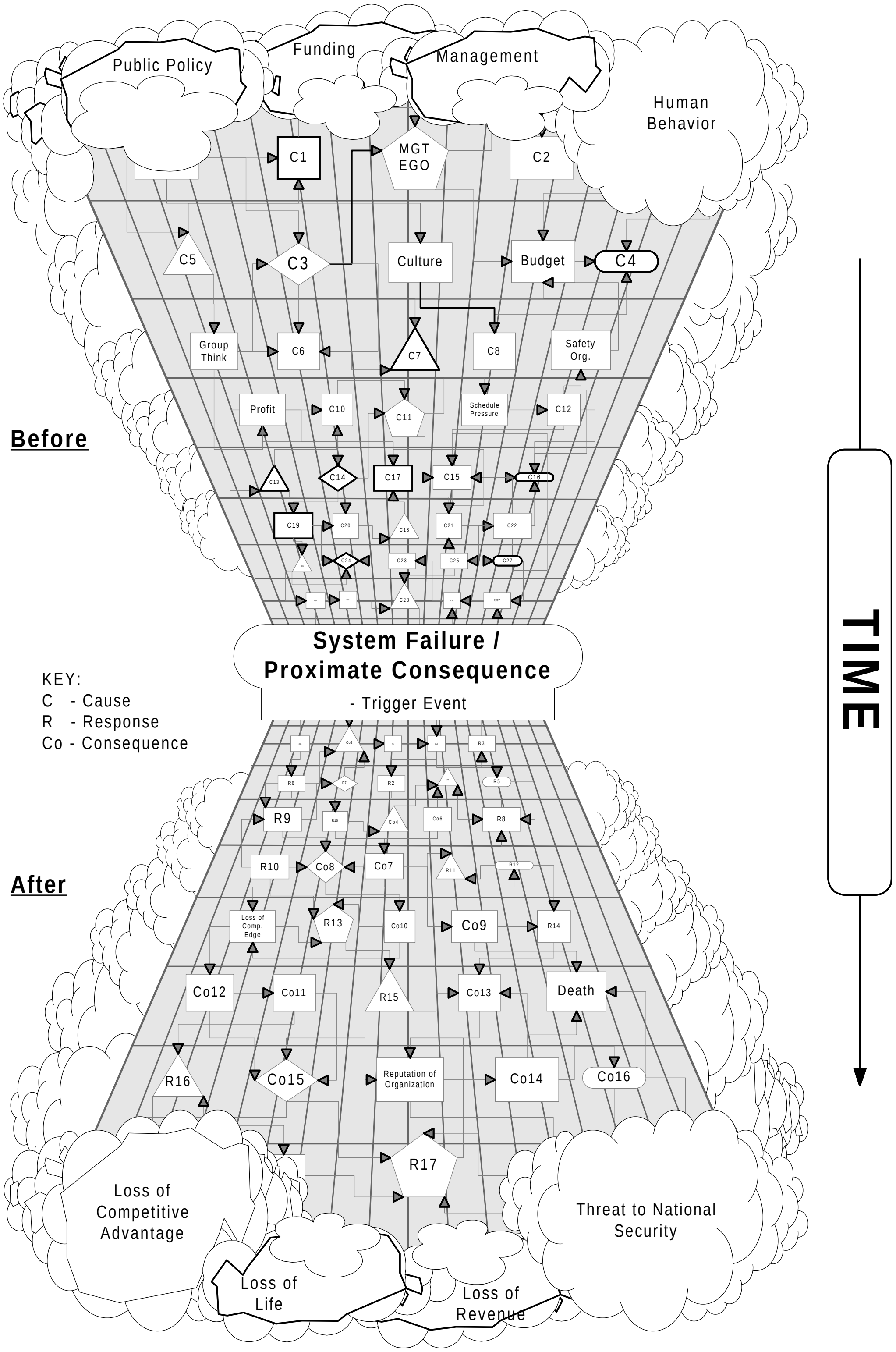

Figure 4-1 - The Contemporary Paradigm

Without a single identified root cause to the failure, there is no linear connection between such a cause and the system failure/ proximate consequence. Instead, the causes all flow into the failure as a combined whole. Like the tributaries that feed a river to create a flooding force, each has some contribution to the river overrunning its banks. This paradigm also recognizes that it is of limited value for the analyst to attempt to uncover exactly which of these tributaries caused the failure. This exact combination of factors will not occur in the future and documenting them is a waste of resources.

The After section of the paradigm mirrors the combination of exactitude and lack of knowledge seen in the Before section. Moving from the proximate consequence, the consequences from the accident are numerous and in many ways interconnected. Here, the polygons labeled ‘Co’ represent specific consequences that have been identified as coming about as a result of the system failure. The polygons labeled ‘R’ represent the responses taken by individuals or organizations following the system failure. Also included are consequences and responses that are numbered to represent those elements that the analyst knows to be present, but which cannot be measured directly. Also, rather than the consequences following linearly as they do in the classical paradigm, this paradigm shows the consequences and the responses intermingled.

Both types of polygons are linked in a complex maze of interconnections. One consequence may affect other consequences. For example, the loss of the shuttle adversely affected space based research planned for the late 1980’s and also affected the Department of Defense national security posture. Consequences also may be affected by responses. The President’s decision to limit the types of payloads flown on the shuttle created a series of domino effects within the space industry. Expendable rocket launchers saw business increase dramatically. Satellite manufacturers were forced to redesign spacecraft designed specifically to launch on the shuttle. NASA was left with a reduced fleet that had lost it primary payloads, commercial satellites.

The clouds in this section surrounding the polygons also represent the larger, less distinct factors associated with the system failure. Made up of both consequences and responses, these factors affect the failure but cannot be measured directly by the analyst. For example, the

Challenger accident undoubtedly affected the American policy for the exploration of space. However, how much influence did it have on our decisions involving returning to the Moon or going to Mars? Is the current commitment to the International Space Station the result of NASA needing some human space flight success or a mission for the shuttle?

4.6 The Contemporary Paradigm Demonstrated

The introduction of the concepts of modern physics into a field does not imply classical analysis vanishes into a cloud of uncertainty. The Newtonian paradigm remains a good approximation of the world in which we live. As explained by Brooks and Peat,

> The equations and theories describing the rotation of the planets, the rise of water in a tube, the trajectory of a baseball, or the structure of the genetic code contain a regularity and order, a clockwork like certainty, that we have come to associate with nature's laws.[308]

The contemporary paradigm has not approached the level of maturity of the classical paradigm, but could be a useful tool for managing the risk associated with complex systems. However, the managers employing this tool have to change their mindset regarding what constitutes useful data, and at the same time relinquish traditional (perhaps revered) management tools. Stacey captures this transformation:

> Today's dominant mindset leads managers to think that they must find the right kind of map before they launch their businesses upon the perilous journey into the future. After all, the "common sense" belief is that you need to know where you are going and have some notion of how to get there before you set out on your journey. Unfortunately, common sense often turns out to be a poor guide to successful action: the whole idea that a map can be drawn in advance of an innovative journey through turbulent times is a fantasy.[309]

The challenge is to take advantage of the current knowledge provided by classical principles while adding the benefits of these modern theories. In this approach, classical principles are not discarded, but there are limitations on their application. Choices as to the value of a system must be evaluated in terms of their risks to society. The complex systems in use today bring with them a significant risk to the safety of people and the environment. However, the degree of safety built into the system and the amount of money available to do so remains a

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[308] Brooks and Peat, p. 14.

tradeoff. Systems can be made safer, but these designs entail added costs. Systems can be protected, but this action adds mass and size to the overall design perhaps to the point where they can no longer function. For example, all consumer protection devices in automobiles from seat belts to 5mph bumpers, to air bags have added to the cost of transportation. The contemporary paradigm provides a means for parsing these alternative safety mechanisms to determine which provide more capability at lower cost, and which potential failures should be concentrated on by an organization.[310]

This combination of paradigms provides a useful framework to explore system failures in a way that illuminates their dynamics better than frameworks grounded in classical mechanics alone. It allows the analyst to explore a system failure beyond the boundaries artificially imposed by the classical paradigm. The consequences are not limited to a specific time period or field of study. And the actions taken by an organization following the accident are considered an integral part of understanding the failure in its entirety. The contemporary paradigm allows us to consider new dimensions of system failure through this use of the elements of classical mechanics. These elements provide a structure for applying the new paradigm. The contemporary analyst accepts in large part that the classical paradigm's basic of unit of analysis is a Newtonian mechanical process. This process creates the basic form for studying the failure and categorizing the data. For example, the aircraft used in the TWA 800-flight failure apparently self-destructed. The investigators from the FAA and the National Transportation Safety Board (NTSB) conducted a remarkable search to locate the wreckage, and to research all of the details regarding that model of the Boeing 747 aircraft.

Although many of these elements of the classical paradigm are essential to understanding it, the TWA 800 accident is far more complicated. For example, how could the failure mode go undetected for decades before the accident occurred? How did Boeing react to the failure, and what changes have been made internally to deal with future failures such as the recent Swissair crash? In a different arena, how has the failure affected public statements by local and national official who have seen how the "official record" can change from hour to hour following such a failure?

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[309] Stacey, p. 1.
[310] Petroski, p. 6.

The classical paradigm's limitations illustrate how an analyst could view the same situation from a different, broader perspective. Using this approach, the analyst can challenge the fundamental elements of the classical paradigm. For example, the vast majority of the current system failure literature begins with the basic premise that it is possible to identify and quantify each of the components in a system, subsequently determining "the answer". This approach does not work in many situations. The TWA 800 crash provided few clues from which to develop this answer. Flight recorders showed all systems were performing normally until the instant the airplane broke up. The cockpit voice recorders showed only normal in-flight conversation among the crew prior to the explosion.

Unfortunately, much of the classical literature also appears to have been written to induce an obvious interpretation and to affirm this interpretation through details. Erving Goffman supports this observation, noting "the tendency to interpret new clues within a framework of normal expectations has been reported in virtually every disaster studied."[311] In the *Challenger* failure, the early focus on the O-rings caused analysts to research these items to the exclusion of all others. Although the Presidential Commission considered thoroughly and reported on multiple potential causes for the accident, these other factors went virtually unreported.

The natural tendency is the creation of a world congruent with our model of analysis; how we frame the problem prejudges the problem that in turn prejudices the answer.[312] Having seized on the solid rocket booster joint seal as the culprit, the question then became understanding how such a situation could have been allowed to develop. Classical analysts brought with them their perspective and applied their frame of reference. To management analysts, it was management; to engineers, it was poor engineering design. Each analysis faults the rest of the literature as being incomplete and hails its own research as the correct interpretation. This effect has been observed by psychologists who report that people recall events in proportion to the importance of these events to them.[313]

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[311] Goffman, p. 449.
[312] Perrow, Normal Accidents: Living with High-Risk Technologies, p. 322.
[313] Isenberg, p. 46.

Not only do intelligent, rational people disagree on the answers, they seldom agree on the facts. In Against the Gods: The Remarkable Story of Risk, noted investment guru Pete Bernstein notes:

> Utility theory requires that a rational person is able to measure utility under all circumstances and to make choices and decisions accordingly – a tall order given the uncertainties we face in the course of a lifetime. The chore is difficult enough even when, as Bernoulli assumes, the facts are the same for everyone. Different people have different information; each of us tends to color information we have in our own fashion. Even the most rational among us will often disagree about what the facts mean.[314]

This classical literature asserts that by identifying the root cause early in the process an organization can predict - and, of course prevent - system failure. For example, Romzek and Dubnick in their examination of the space shuttle *Challenger* failure argue that the cause of this failure was NASA's inability to manage expectations. Even after the shuttle was shown not to be the operational system promised, but instead a development project, NASA continued to issue flight manifests in the early 1980's with the fleet flying 30 or more times a year. The agency continued to press for all U.S. payloads to be transferred to the shuttle and resisted continuing the expendable rocket fleets.

This inability to manage expectations in turn led to external pressures that eventually translated into poor decision making. The shuttle fleet had never flown more than eight missions in a year, and the planned preparation templates never approached those actually achieved at the Kennedy Space Center. NASA managers felt the pressure, pushing to change requirements and ordering two and three shift operations. People became afraid to "call a spade a spade" and surface problems to management.

Analysts using the contemporary paradigm would take the same facts and view them from a dramatically different perspective. They would not look to finding the cause of this particular accident as the solution for preventing similar failures in the future. The overall structure of the shuttle program would be considered to discriminate between elements that were related only to this failure scenario and those representing endemic problems within the organization.

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[314] Bernstein, p. 111.

The analyst would examine the causes to eliminate or control any known hazards, but would consider this part of standard risk management. These data would be viewed as important to prevent this particular failure from occurring in the future. Also, the failure would be analyzed to determine if the lessons learned could be applied to similar systems which might be susceptible to a failure. For example, the Department of Defense could use the data from the *Challenger* accident to review the risk presented by using the single O-ring design in the joints of the Titan rocket solid rocket boosters.

However, correcting particular failures would be viewed as having minimal or no effect on future failures. Instead, the analyst would consider the environment in which the failure took place to attempt to determine the many factors that influenced the failure. This research may show that while the organization considered the immediate factors surrounding the failure, it did not look within itself to determine if these factors result from basic assumptions within it. In doing so, the organization may overlook assumptions which no longer apply or which mask the presence of a greater problem.

For example, the Maginot Line was intended to defend France from German invasion prior to World War II. The line was a string of fortified installations along the French and German borders that were built after World War I. The French manned these fortresses to prevent an invasion from German troops in the escalating tensions during the 1930's. The line failed in its purpose when Germany went around the line through Poland into France**.** The French had failed to consider the risk that resulted from their strategy. First, they did not consider the limitations imposed by consuming their resources in a fixed set of installations. Second, they did not view the picture as broadly as the Germans because they considered the Polish border as safe. Third, they had no plans to redistribute defense forces along the Polish border as the Germans attacked. France fell with virtually no resistance.[315]

The German high command, which had uncovered a weakness in the French approach, did not look further for a cause. They recognized that an unprotected border necessarily presented a weakness in their defense. Much as the Soviet Union did after WWII, the Germans created a buffer zone around their country where possible. They corrected the weakness by

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[315] Steven E. Ambrose, Citizen Soldiers, (New York, N.Y.: Simon & Schuster, 1997), pp. 132-136.

occupying Poland and poured millions of pounds of concrete into a “better” Siegfried Line. This line was composed of an elaborate series of concrete mazes designed to trap Allied armored forces and slow their progress across the French/German border. The line also was supported by hundreds of “pillboxes” protecting German troops who were stationed to stop any Allied attempts to breach the line.

The German high command did not realize that the fixed defense offered by the line was ineffective in the very kind of mobile warfare they had introduced**.** The Blitzkrieg (Lightning War) used to attack the continent had made fixed defense obsolete. Using modern vehicles, troops, artillery, tanks, and support convoys rapidly could be moved from one location to another. Defenders were forced to respond to these movements and redeploy their assets. As a consequence, the line was of little use in defending against the Allied forces.

A contemporary analysis would consider all of the factors which could have led to the line failing, and also would look at ways to accommodate factors not yet identified. For example, an analyst would recognize the inherent limitations in a fixed defense. This does not mean the line would not have been constructed as a deterrent against Allied forces. For example, the line was a factor in the Allied strategy as it invaded the continent. American soldiers fighting in the line had to develop new strategies for overcoming the enemy not practiced before the invasion. However, the Allies viewed the line simply as an obstacle to be overcome once, not as a mobile threat such as tank battalions that must be faced again.

Also, the use of resources to build and staff the line would be considered against the risk of not applying these resources elsewhere. The manpower, machinery, and other resources consumed to build and staff the line depleted the reserves available to staff other fronts. Even Normandy, where the Allied invasion occurred, had installations that had never been completed because of inadequate materials to construct and staff them.

The contemporary paradigm elevates the importance of response as a factor in the study of system failure. First, this concept increases the importance of studying the consequences of a system failure. The more completely understood the breadth of the consequences, the more analysts can determine whether responses have the desired effect or any effect at all. Second, the response itself becomes an active part in managing the risks of system failure. The existence, severity and ultimate impact of a failure may in part be determined by responses that take place after the initiating event. Rather than the traditional "feedback" loop, there is a "feed forward" loop which directly influences the consequences.

This effect is demonstrated in the aftermath of the bombing of the Oklahoma City federal building. The immediate assumption was that the bombing was carried out by Arab terrorists. In the American psyche at the time, that was the only possible source for terrorists. Syndicated columnist Mark Barnes lamented that:

> Immediately after the Oklahoma City bombing the cry went out to round up the usual suspects. Anyone vaguely resembling an Arab came under dark suspicion. Those unfortunate to fly airplanes that day were particularly vulnerable. Including that poor man of Lebanese decent on a business trip to Switzerland whose shaving kit suddenly became, in the astute eyes of officials., a virtual warehouse of bomb making materials and, who for 24 hours, found himself in the Twilight Zone of all Twilight Zones.
>
> As the smoke cleared, and the evidence quickly mounted, it became known that this was not a foreign job, but as the news so quickly dubbed it "one from the heartland.[316]

One month later, the link to domestic militia groups radically changed this basic public perception. The long lasting effect can be seen in the Atlanta Olympic bombing. Although the authorities seized on the wrong suspect, there was no immediate assumption that the possible suspects were limited to foreign nationals hostile to the United States.

These effects can be created or altered either unconsciously or consciously by any number of interests. These interests include the stakeholders, external groups or agencies, or simply one individual. For example, the security guard in Atlanta who alerted authorities to the bomb immediately became a suspect. National crime agencies, including the FBI, consumed untold resources to implicate this ultimately exonerated individual. In a second example, the Mayor of New York City consciously affected the public perception of TWA, the federal authorities, the cause of the accident itself, and the quality of the response efforts. All of this was created from a very small and emerging base of data.

In a third example, NASA failed to mediate the initial view that the Hubble Space Telescope was essentially a failure shortly after it was launched. The scientific community held

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[316] Mark Barnes, "Round up the Usual Suspects," http://www.zpub.com/z/barnes/markb4.html.

otherwise, noting that the flawed mirror still provided better resolution than available from terrestrial telescopes and the other six major scientific instruments were functioning as designed. Doyle McDonald, a member of the NASA advisory task force investigating the Hubble repair, commented that “The only thing the media cared about was the problem being encountered. No one realizes the tremendous successes we realized using the telescope with the flawed mirror. When we repaired the flaw, this was not news.”[317] The most “visible” failure was allowed to dominate because NASA did not prepare for or recognize the need afterward for a communications and public relations response program to influence public perception. Today, the telescope continues to provide breathtaking scientific observations after almost a decade in space. NASA has compounded its original error by not publicizing the basic integrity of the Hubble design or the work successfully completed which allowed the telescope to perform beyond its original design requirements.

While this discussion may appear to paint a somewhat bleak picture for those involved in the study of complex system failures and their consequences, it does not mean that researchers should pursue alternative careers. Although our ability to accurately measure and predict is limited, the world is not completely random. Rather, it is "somewhat deterministic"; the limits of our ability to know are merely bounded. Even though no two dynamic systems behave identically we can still approximate their outcome. This concept is captured eloquently by Bernstein, who states:

> The essence of risk management lies in maximizing the areas where we have some control over the outcome while minimizing the areas where we have absolutely no control over the outcome and the linkage between cause and effect is hidden from us.[318]

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[317] Interview, April 30, 1995.
[318] Bernstein, p. 197.