Chapter 6. Conclusions

The comparisons provided in this study produce snapshots of the *Challenger* accident taken through two separate lenses. Each of the two paradigms, the classical and the contemporary, yield different answers to the most fundamental questions about the causes and consequences of the space shuttle *Challenger* failure. Referring to the classical paradigm, Alvin Toffler notes: "right or wrong, all such claims are based on seldom questioned assumptions about how things work in the real world…all of them imply cause-effect relationships, and the very way we habitually think about cause and consequence has been shaped by science."[346] The contemporary paradigm challenges these basic assumptions, attempting to find an underlying structure to the chaos, which apparently controls activities in our universe.

The introduction of the concepts of modern physics and the contemporary paradigm into the analysis of system failures does not imply that classical analysis vanishes into a cloud of uncertainty. Rather, each view brings value to the analysis of system failure. The contemporary paradigm may be viewed as an extension of the classical paradigm, providing complementary tools for the analyst attempting to understand failure. The classical paradigm adequately describes most of the conditions seen in any system failure. For example, the engineering description of the O-ring problem found in NASA documentation is accurate, as is the plan to correct this particular problem. The challenge is to take advantage of the current knowledge, while adding the benefits of these modern theories. As Figure 6-1 illustrates, together these two paradigms provide a more complete picture of the events surrounding a system failure.

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[346] Alvin Toffler, "New Science of Instability Throws Light on Politics," in Ilya Prigogine and M. Sanglier (eds.) Law of Nature and Human Conduct, (Brussels: Task Force of Research Information and Study on Science, 1985), p. 327.

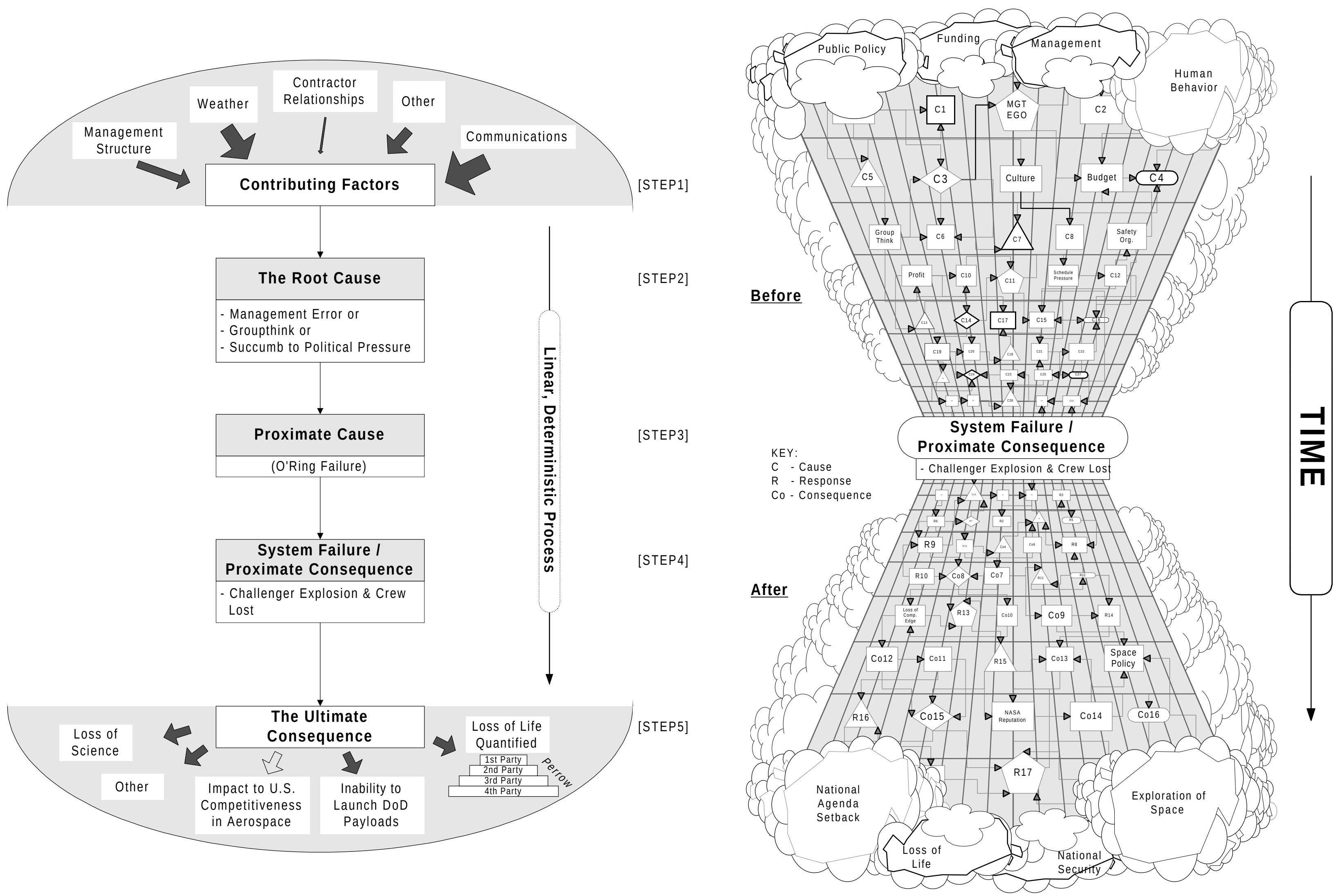

Figure 6-1 - The Classical and Contemporary Paradigms Illustrated

These alternative paradigms produce different answers because each paradigm provides a different structure and approach for the analyst to employ. It is therefore understandable as Goffman notes "that two quite intimately related individuals can spend a considerable amount of time in private thought trying to piece out what the other really "meant" by doing a particular thing and what the implications of this meaning are for the state of the relationship."[347] These alternative paradigms frame where and how the analysts look for answers as well as the questions the analysts asks and the data he or she chooses to use. As a result the "view one person has of what is going on is likely to be quite different from that of another. There is a sense in which what is play for the golfer is work for the caddie."[348]

The paradigms frame where the analyst looks. Where the classical analyst looks for, and often finds, the answer to the search for a particular cause or consequence, the contemporary analyst sees the picture differently. The classical frame of reference is one where the answers are there to be found and acted on. The contemporary frame of reference does not provide a lens where the answers necessarily are to be found, but still requires that the situation be acted on. For example, the cause of the TWA 800 flight accident may never be known with certainty, but the contemporary analyst would see many actions which need to be taken in preparation for the next such failure, regardless of the cause.

The structure of the paradigms determines what questions the analyst asks and the data he or she uses. The classical paradigm calls for every item to be examined to the extent it leads to the single cause or effect predicted by the paradigm. Other factors are discarded as they are determined not to be relevant to this search. This approach unconsciously creates an effect on the outcome of the research. “In every situation many different things are happening simultaneously--things that are likely to have begun at different moments and may terminate dissynchronously. To ask the question "What is it that's going on here?" biases matters in the direction of unitary exposition and simplicity."[349]

The contemporary analyst also asks questions, but they are open-ended questions. What do I know? What do I not know? What can I never know? No data are discarded at the outset,

[347] Goffman, p. 459.
[348] Goffman, p. 8.
[349] Goffman, p.9.

but only after they are shown to bear only marginally on the failure. Even so, these data actually are never discarded, but put aside to be reexamined as the failure analysis continues. Initially marginal data may in fact have an enormous effect on the cause or consequence of a failure. For example, no one expressed any concern about the design of the two controls centers used at the Three Mile Island nuclear power plant. These control centers were exactly alike, except they were mirror images of each other. After the accident, it was shown that this difference in the controls centers may have contributed to the operators' confusion as the failure occurred. In a second example, Alex Roland notes that the press was "embarrassed by its failure to anticipate the problems in the shuttle program before *Challenger*".[350]

Each paradigm provides different conclusions on how organizations can act to improve their understanding of and perhaps prevent system failure. They agree that following a failure an organization should investigate and correct the problem, which generated the failure's proximate cause. They differ in the approach thereafter. The classical paradigm searches for the roots of this proximate cause in an effort to prevent this particular proximate cause from developing again from this particular set of circumstances. The contemporary analyst would recognize that this particular set of causes never will repeat and look instead toward a solution which recognizes the proximate cause as it develops and attempt to remove it before the failure occurs.

6.1 Looking Back: Where we sit determines what we ask

The classical paradigm brings into focus the "real world" that we all see every day. This world provides us with the creature comforts that allow us to function in our increasingly complex society. Our trust in this paradigm may be illustrated by our reliance on rapid safe transportation. We assume that aircraft and trains are safe or they would not be in service. The contemporary paradigm brings a much less distinct world, one where the rules are not fixed and where the answers cannot always be found. This world lacks the certainty of the classical world and cannot be demonstrated using standard engineering concepts. Its vagueness makes it more difficult to explain the tremendous effects its principles may have on a particular situation. For example, in the failure of the Hyatt Regency sky walk, it has been determined using the classical

[350] Roland, p.26.

paradigm that the design change in attaching the cables to the structure created the failure. More difficult to determine is the contribution of the training received by the construction engineers who did not recognize that such a change was not safe.

Analysts using the classical paradigm believe that it is possible with enough research to discern all the answers. There is an implicit assumption that the data are available and will fit somewhere in the paradigm. Further, the analysts believe that the data may be examined and properly placed using a linear deterministic process. Every element of a system failure can be determined by breaking the puzzle into its smaller and smaller constituents. Each piece is placed into a defined data structure that positively establishes its relationship to other pieces. If there is any ambiguity, the particular item is examined further to establish its constituents so that this certainty can be obtained.

The analyst can study these pieces, and with enough effort, can reconstruct the puzzle, understanding completely how it goes together and how the resulting system functions. There is little room for ambiguity in this situation. Even in cases where the exact situation cannot be determined, the classical analyst settles on solution so that this solution may be acted on. In the TWA 800 accident, the investigators concluded that the wiring harness in the center fuel tank of older Boeing 747 aircraft caused the failure although no evidence could be found to directly corroborate this conclusion. With this statement, government regulators ordered changes in all similar aircraft.

In contrast, the analysts employing the contemporary paradigm believe these techniques are useful, but limited. The techniques help determine the basic structure of a failure and provide considerable insight into the workings of the systems involved. However, they do not positively establish the complete picture, as the techniques are applicable only to the deterministic aspects of the failure. In the contemporary paradigm, the world is “somewhat deterministic” exhibiting characteristics better described as deterministic chaos. No amount of study can reduce a system to the point where its behavior can be predicted absolutely. The factors involved are too complex and, in some cases hidden, to make any analysis complete. In addition, the analysis of a particular failure may be applied only partly to a new situation. Some things can be known, others cannot, and finally others may be known, but are not relevant to the failure.

6.2 Looking Back: What we ask determines what we see

These two different perspectives guide the analysts in their search for the facts surrounding a system failure. By asking different questions that seek different information, the data uncovered also are different. As shown in Figure 6-2 data relevant in one paradigm may be discarded by the other. Also, a classical analyst may classify a certain fact, erosion of the shuttle O-rings, as a technical problem with a second analyst defining it as a management issue. The contemporary analysts view this apparent dichotomy from a different frame of reference. They see these two conflicting conclusions as clues to a larger, less distinct, but more complete picture of the failure.

With the classical paradigm, the analyst is searching for "the cause" and "the consequence." These elements are assumed to exist. Additionally, the cause is considered to be unique and after it is found, there is no reason to look for a second one. The consequence also is viewed as indisputable. There is no provision for situations in which the cause or consequence cannot be located. A shortcoming of the classical paradigm is that the analysts cannot agree on the definition of the cause and consequence for a given system failure. Also, the classical paradigm does not expect nor can it accommodate multiple causes and consequences.

Analysts may disagree on the identity of these elements, but do not question they can be found. The reductionist approach continues to parse the data until it can be divided no further. At this point, there are answers although they may be difficult to locate. The classical paradigm assumes that there is a linear path from the cause to the proximate cause to the failure event to the consequence. In addition, this path is deterministic and may be located using classical techniques. Failure to find them is a failure of analysis, not an indication they do not exist.

In the search for these elements, the analysts are seeking a set of facts that are fixed, and not subject to change by actions of the parties involved in the system failure. In the classical paradigm, no amount of preparation by the organization can affect the consequences that flow from the accident after it occurs. In the best possible scenario, the analyst can determine in advance the complete path from contributing factors to the cause to the failure to its consequences.

	Classic Paradigm		Contemporary Paradigm	
I. Basic Unit of Analysis	System failure: a Newtonian mechanical process	Events leading up to and following a system failure can be identified and measured; the cause-effect process is linear and deterministic	System failure: an NST-defined process	Events leading up to and following a system failure are governed by rules established within modern physics, chaos theory, and complexity theory using a holistic perspective
II. Organizing Concepts	All events may be divided into increasingly smaller components to isolate the source, which can be linked, through a linear process, to a known set of effects		The failure does not result from a single "root" cause, but rather from a plethora of elements contributing to the proximate cause	
	The System Failure results from a discernible cause and has measurable consequences		The proximate cause may be debated and may never be determined	
			It is impossible to identify all elements that contribute to a system failure	
	The Proximate Cause is the triggering event and the constant in the classical equation		Limitations to measurement makes the actual contribution of an element to a system failure not possible to know	
	The Root Cause can be determined and constitutes the linchpin		The interplay of the causes preclude determining whether the failure still would have occurred in the absence of one or more cause	
	The Proximate Consequence is the failure event itself		A major system failure has multiple consequences that should be considered as a group to determine the total effect of the failure	
	The Ultimate Consequences can be calculated in advance or measured postmortem		The consequences arising from a system failure can be altered through actions that take place prior to or following the failure	
III. Dominant Inference Pattern	A system failure must have been the result of some root cause, which can be found through Newtonian analysis		If a failure occurred, it must have been the result of multiple contributing factors creating multiple effects	
IV. General Propositions	Newtonian Principles		Universal Law	Our physical world is governed by a set of universal laws that are never violated, but may not be understood by us
	A system failure	results from a knowable cause	Action and Reaction	Reactions from actions surrounding a system failure may not be equal to and opposite the action
		has a traceable legacy to that cause	Failures and Answers	The answers to why a failure occurred are found in various factors which contributed to the failure
		has a consequence that can be adequately determined in advance or documented afterward	Frame of Reference	The causes and consequences are defined differently from different frames of reference
	Propositions	Decisions are made according to the principles of classical mechanics	Non-linear Effects	Small effects multiply exponentially to create multiple consequences; large effects may die away
		Eliminating the cause will prevent future failures	Measurement Perturbations	The act of measuring something can affect the object being measured
		Once the failure takes place, the consequences cannot be altered	Accuracy vs. Precision	Precise measurements do not necessarily result in the accuracy required by Newtonian mechanics
V. Specific Propositions	Knowledge	Failure modes can be known, their probabilities can be identified, and their occurrence can be eliminated	Knowledge	The cause of a failure cannot be determined absolutely
				Even the proximate cause should be debated and discussed
				Occurrences of failures can be minimized, but cannot be eliminated
				The failure event and the proximate consequence are identical
				Multiple consequences flow from a system failure
				Consequences are not limited to any specific discipline or sphere of interest
	Prescience	Our systems and processes, properly developed and maintained, allow us to monitor and prevent future failures	Prescience	Responses to a failure can affect the nature & severity of consequences
				Selected "responses" can take place prior to the failure itself
				Responses may be modified as they are implemented using feedback from their effects on the consequences
				The ultimate consequences may have resulted anyway without the organizational responses being taken
				It may not be possible to determine the contribution of the organizational response to the consequences
VI. Evidence	The analyst attempts to reconstruct the events and inserts himself into the failure producing process, bringing with him his background of knowledge, experience, and interests which determine the lens through which he views the failure		The sheer magnitude of the data pertinent to a system failure precludes any one person from grasping the failure in totality. In searching for the facts, the analyst must rely on data compiled by or interpreted by others	

Figure 6-2 - The Classical and Contemporary Paradigms Compared

The contemporary analyst changes the picture from one of competition to one of coordination. Without the need to select the first among equals from the cause, the analyst can consider a more holistic view of the system failure. When managing in this mixed environment of classical principles intermixed with uncertainty and chaos, it is important to recognize the merits of each and the completeness of neither. Karl Weick contends that:

> To state the points more generally, what most organizations miss, and what explains why most organizations fail to learn[351] is that "Reality backs up while it is approached by the subject who tries to understand it. Ignorance and knowledge grow together"[352] To put it a different way, "Each new domain of knowledge appears simple from the distance of ignorance. The more we learn about a particular domain, the greater the number of uncertainties, doubts, questions and complexities. Each bit of knowledge serves as the thesis from which additional questions or antithesis."[353],[354]

The concept of a single cause and single consequence are considered too simplistic to adequately explain system failure. The elements that contribute to the failure may be so distant in place or time as to be unrecognizable without an analysis beyond the capability of any organization. Even if such an analysis were possible, it would be unable to explain precisely the interactions among the causes and consequences of a failure. And, even if these explanations were available, the analysts involved would have no common set of standards for measuring them across diverse disciplines.

The contemporary analyst recognizes that system failures result from many causes. All possible causes are accepted into the analysis without prejudice as to their value in determining why a particular failure occurred. It is not assumed that an apparently small contribution to the failure is of less value than one that appears larger. As with the tributaries that develop into a roaring river, the smallest stream may represent the component that causes the river to breach the levee. This approach resolves the conflict that arises in the classical paradigm when analysts attempt to determine which of the many posited elements is the "correct answer."

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[351] Scott W. Richard, Organizations: Rational Natural, and Open Systems, (Englewood Cliffs, NJ: Prentice-Hall, 1987), p. 282.
[352] John A Meacham, "Wisdom and the context of knowledge., in Contributions in Human Development, eds. D. Kuhn and J.A. Meacham, (Basel: Karger, 1983), p. 30.
[353] Meacham, p. 120.
[354] Weick, "The Collapse of Sensemaking in Organizations: The Man Gulch Disaster," p. 641.

The contemporary analyst acknowledges that the complete set of causes may never be determined. In these situations, the organization would use its best efforts to determine the causes within its available resources, then turn to a less deterministic approach to finding the lessons of the system failure. The organization would reserve a portion of its resources to determine better how precursors to the failure could have been identified though the complete set of causes were unknown. In the *Challenger* example, NASA could have looked at the solid rocket booster O-ring seal erosion not as a technical problem, but as an indication that the agency did not understand the performance of the seal system.

The consequences similarly are numerous**.** Modifying Perrow’s argument on the importance of a system failure, the classical analyst would view the failure as it affected all individuals and organizations. Extending beyond the single measurement of bodily harm to members of the public, the analysis would include measurements such as impact to national goals, economic effects, and changes in behavior patterns of people. For example, the *Challenger* accident had a profound effect on national space policy and on space-based research. The domestic launch industry has never recovered from the prior policy and the long grounding of the shuttle fleet following the accident. And the public no longer views NASA as an agency without fault.

Often, the consequences extend in time and location far beyond those involved directly in the system failure. The contemporary paradigm does not expect the consequences to be limited to the effects that can be seen in the immediate aftermath of the failure. For example, NASA’s budget levels are decreasing annually. Many analysts attribute this situation to the loss of confidence in the agency. The geographic reach of the accident is seen in the increase in use in the French Ariane rocket, which is booked to capacity for several years to come. Those authors who bound their analysis, either unknowingly or without acknowledging they that they are doing do, ignore other potential contributions to the understanding of system failure to the point where they create an unrealistic universe. As Goffman notes:

> Activity framed in a particular way--especially collectively organized social activity-- is often marked off from the ongoing flow of surrounding events by a special set of boundary markers or brackets of a conventional kind. These occur before and after the activity in time and may be circumspective in space; in brief, there are temporal and spatial brackets. These markers, like the wooden frame of a picture, are presumably neither part of the content of activity proper nor part

> of the world outside the activity but rather both inside and outside, a paradoxical condition already alluded to and not to be avoided just because it cannot easily be thought about clearly. One may speak, then, of opening and closing temporal brackets and bounding spatial brackets."[355]

This concept of "frame trapping" is seen in a review of the *Challenger* failure. The shuttle system remains unchallenged as the safest and most reliable space vehicle ever flown. As time passes, the accident is viewed more as what it was, an accident, and the industry is beginning to consider whether it is prudent to continue to limit the uses of the shuttle.

6.3 Looking Back: What we see determines how we act

A third major distinction between the two paradigms is the role of organizational response in affecting the consequences of a system failure. In the classical paradigm, a single consequence results from a linear deterministic process initiated by the system failure. The process is predictable and can be reconstructed following the failure. Inherent in this belief is that should the failure occur again, the consequences will follow the same path because these events are fixed. The actions taken by an organization before or after the failure are not a factor in this process.

Although the classical paradigm does not consider the consequences as dynamic elements in failure analysis, the contemporary analyst views the ability to affect the outcome of a failure as an important tool for mitigating the severity of the multiple consequences. A well prepared organization is ready when the failure occurs and is prepared to adjust its actions after the failure as the consequences become better understood.

Organizations may take steps in advance of the failure to help set expectations of the probability of a system failure. For example, NASA can keep the inherent risk of space flight before the public eye and explain that a second shuttle failure is probable if enough missions are flown. The commercial airlines follow this practice in explaining the risks of air travel. They continuously point out that, as measured by miles traveled, flying is the safest mode of transportation. Also in advance, organizations may plan their post-failure actions to expedite

[355] Goffman, p. 252.

their ability to manage the consequences. An airline can determine how they will announce the accident, deal with victims' families, and participate in the failure investigation.

Following the failure, the organization may monitor the appearance and progression of the consequences. If pre-planned actions prove ineffective or if unanticipated consequences develop, they can tailor their responses to better manage the situation. For example, several years ago the company that distributes Perrier bottled drinking water faced accusations that the water was treated prior to distribution. The company denied this story even in the face of laboratory tests and public comments by former employees. Their stonewalling approach caused them to lose much of what is now a huge consumer market.

6.4 Next Steps

The increasing complexity of our world, and of the systems that support it, forces us to seek better tools for managing the risks of failure in complex systems. These complex systems are integrated into our economy and cannot be considered marginal contributors. The massive effort to prepare computerized systems for the year 2000 provides a stark example. Almost everything, from the aircraft control system to washing machines is controlled by microcircuits unprepared for the new millennium.

The level of system complexity is increasing and at an accelerating pace. Bringing new products to market once was considered a 3-5 year effort at a minimum. Today, products are conceived, designed, produced, and distributed in months, not years. Even the development of incredibly complex systems is accelerated. The new Boeing 777 aircraft was designed completely using computerized tools. The aircraft design was transferred to computerized production equipment that produced the components. These components were assembled into a complete aircraft. This was the first time a 777 existed in the physical world and this aircraft flew the initial tests.

The classical paradigm contributes greatly to our understanding of this more complex world. It allows the analyst to move from "This system failed." to "Why did this system fail" and "What does it mean to us?" The paradigm provides a foundation for explaining the basic functioning of systems and their components. Also, it explains the linkage among the cause, the system failure, and the failure's consequences. In doing so, the analyst follows a descriptive process where the failure is documented to ever-lower levels of detail. These details give insight into the issues, but assume that such an approach uncovers the complete picture of the failure.

The contemporary paradigm forces us to accept these "facts" uncovered as representative constructs of the real world. Yes, they may be very good approximations of this world, but they are not necessarily accurate or complete. The limitations in our understanding of system failure come, in part, from the insistence that the classical paradigm is complete. This paradigm provides useful information in our pursuit, for example, the possible contributing elements to the failure. The contemporary paradigm's benefit is a shift in frame of reference from certainty of knowledge to knowledge of uncertainty. This fundamental change expands the factors to be considered, but develops a more complete view of the failure and the environment in which it occurred.

The combination of paradigms provides a more complete, and more accurate, picture of system failure. This combination provides us with techniques for better understanding and preventing system failures. The utility of this union is shown by the general questions asked by each paradigm.

The classical paradigm seeks:

1. What happened?
2. What triggered this failure?
3. What happened next?
4. How was this triggering event allowed to develop?
5. What was the outcome of the failure?

The contemporary paradigm adds:

1. Is the triggering event the result of a single cause?
2. How good is the failure data set?
3. How far do the consequences reach?
4. Did these consequences have to come about?

Attempting to answer both sets of questions provides a framework that links the non-deterministic elements of system failure analysis to the more conventional, deterministic theories. This new framework will recognize that the complete prevention of failure cannot be achieved; instead it will make provisions for preparing and responding to system failure.

Wisdom, Meacham contends, is an attitude rather than a skill or a body of information:

> To be wise is not to know particular facts but to know without excessive confidence or excessive cautiousness. Wisdom is thus not a belief, a value, a set of facts, a corpus of knowledge or information in some specialized area, or a set of specialized abilities, or skills. Wisdom is an attitude taken by persons toward the beliefs, values, knowledge, information, abilities, and skills that are held, a tendency to doubt that these are necessarily true or valid and to doubt that they are an exhaustive set of those things that could be known.
>
> In a fluid world, wise people know that they don't fully understand what is happening right now, because they have never seen precisely this event before. Extreme confidence and extreme caution both can destroy what organizations most need in changing times, namely, curiosity, openness, and complex sensing. The overconfident shun curiosity, Because they feel that they know most of what these is to know. The overcautious shun curiosity for fear it will only deepen their uncertainties. Both the cautious and the confident are closed-minded, which mean neither makes good judgments. It is this sense in which wisdom, which avoids extremes, improves adaptability."[356]

6.5 Areas for Further Research

In addition to the original contributions to the system failure literature described above, my research may have broader implications in the study of public policy.

1. Apply the contemporary paradigm to other system failures to determine its utility. Policy makers should be able to use this model as a template for comparing diverse systems and their associated failures. Studies should determine if the tool is scaleable and can be used to study the failure of large and small systems. This new tool could assist in decision making, risk management, and contingency planning.

2. Test components of the contemporary paradigm separately. Separate propositions, such as the value of response planning, may be considered separately. Past failures may be reviewed to

[356] Meacham, p. 187.

determine if a different response could have led to different consequences. Current failures also may be studied to determine the effects of response planning.

3. Survey practitioners' methods to identify those using elements of the contemporary paradigm. Practitioners' procedures, such as increases in personal accountability for individuals, may indicate an awareness that rote processes are not reliable for preparing for and responding to system failure. The practitioners' methods should be compared to the system failure literature to determine any inconsistencies among them, and to analyze why the inconsistencies are present.

Finally, a separate benefit would be to validate the utility of modern physics concepts in the study of public policy problems. These modern tools could greatly aid policy makers as they attempt to more fully understand and manage complex public policy issues.

6.6 Closing Thoughts

Caution is required, however. For, despite the allure of Chaos and Complexity, to reject the classical paradigm in its entirety would be nothing short of a pyhrric victory. Those authors who completely reject classical mechanics have fallen prey to the mistakes made by their brethren; they have falsely concluded that their theory offers "the answer." To argue that there is no place for classical mechanics is not only shortsighted, but also simply ridiculous. After all, are not certain subsystems within an organization linear? Nonlinear thought does little for the bridge builder or the automobile manufacturer. To paraphrase Mark Twain, the death of classical mechanics is greatly exaggerated.

The answer to how to best manage the risks of failure in complex systems lies somewhere in the middle. Any systems failure paradigm must be an integrated approach, encompassing elements of both linear and nonlinear thought. We must, as David Bohm has proposed, move science closer to art. As such it is imperative that we "stop discarding alternative scientific theories in favor of one 'accepted' theory"; and instead, recognize "the possibility that scientific truth, like artistic truth, is a matter of endless nuance, of 'worlds in rotation.'" As Bohm reminds us, the "the root of the word theory, means 'to see' and because of reality's infinite nuances there may be many, even opposing, ways to see what nature is doing."[357]

Sometimes you get shown the light in the strangest of places if you look at it right.

Robert Hunter, *Scarlet Begonias*

[357] Briggs and Peat, pp. 200.