Chapter 2. Developing the Classical Paradigm

While the debris from the *Challenger* explosion still drifted into the Atlantic Ocean, the investigations and analyses of the failure began on several fronts. Within seconds after the mission control center in Houston received the information that the vehicle was totally destroyed, the flight director ordered that all computers be frozen to preserve the data. Flight controllers turned to their scripted contingency procedures. At the Kennedy Space Center, NASA worked with the Air Force and the Coast Guard to place rescue vehicles in the Atlantic Ocean to retrieve portions of the vehicle for later investigation.

NASA was not alone in attempting to understand the accident. The popular press produced "experts" who conjectured on the possible causes of the accident. Newspaper and magazine writers developed their own theories regarding the failure. President Reagan established a blue-ribbon investigation committee, which conducted an extensive series of closely, watched hearings and interviews.

Most of these analyses shared the common structure of the classical paradigm, beginning with investigators working around the clock in an attempt to gather all the facts surrounding the destruction of the shuttle. Thousands of people were given tasks specifically targeted at determining all the possible causes of the catastrophic failure. By identifying and cataloging each of these possible components in the failure scenario, the investigators believed they could then rebuild either physical or conceptual representations of the accident. These representations then could be used to establish, with precision, the trigger event and the root cause of the failure.

The conceptual representation employed in analyzing the *Challenger* failure is typical of the method used to investigate most system failures. In aircraft crashes, the investigation team reassembles the debris in large hangers, sifting through each piece looking for the cause of the accident. Arson investigators employ the same reductionism techniques to determine the origin of suspicious fires. When the nuclear reactor failure occurred at Three Mile Island, the analysis team actually called in NASA to apply these methods to determine the root cause of the failure.

Those using this structure enter into their analyses with four underlying, if not stated, assumptions. First, someone at some time made a mistake, or the failure would not have occurred. The mistake could have occurred at any point in the development or operation of the system that failed. Design deficiencies could remain undetected for many years, coming to the forefront only because the failure occurred. The design may have been improperly implemented. For example, the failure of the skywalk in the Hyatt Regency in Kansas City on July 17, 1981 is attributed to changes to the attachment devices on the suspension rods.[25] These changes were made by the construction engineers and never communicated to the designers. Frequently, the operator is determined to have made the mistake that resulted in the failure. When the tanker ship, the *Exxon Valdez*, ran aground, the ship's captain received most of the blame for the failure of the ship to maintain a safe course.

The second assumption is that the mistake can be traced in a linear flow to a single root cause that initiated the failure event, triggering a specified consequence. Confident in their assumption that some party made a mistake, the classical analysts apply their resources to linking the mistake to the root cause. Typically, the analysts start by uncovering what happened surrounding the system failure and work their way backward to uncover the root cause. Knowing the ValuJet airliner crashed because of a fire in the cargo hold, investigators looked to how the fire could have started, and then to how the combustible material came to be in the hold, to who put it there, and so on.

Similarly, the analysts follow a thread forward in time from the failure event to determine the consequence of the system failure. The effort then is to link the already identified root cause to a particular consequence that is viewed as the principal outcome of the failure. For example, following the *Challenger* accident, the United States lost a significant portion of the commercial satellite launch market. Classical analysts trace this loss of market share to *Challenger* and the ensuing grounding of the space shuttle fleet.

Third, the cause-failure event-consequence flow is orderly and predictable, and can be accurately diagrammed. These diagrams are possible because the analyst using the classical paradigm assumes a deterministic universe. Complex systems may require a more sophisticated

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[25] Henry Petroski, To Engineer is Human: The Role of Failure in Successful Design, (New York, N.Y. Vintage

paradigm, but this is only a question of the number of boxes on the diagram or diagrams necessary to accurately portray the links.

Finally, by studying system failures using this paradigm, analysts believe they can prevent future system failures. This belief is the reason so much effort is applied to locate the root cause of the failure. In cases where analysts disagree on the specific elements of failure or their interpretation, still they do not question the correctness of the paradigm. Instead, the arguments center on who properly applied the elements of the paradigm and who may have reached faulty conclusions.

In using this paradigm, analysts implicitly focus on certain characteristics of the failure and use the conceptual lens to more closely examine them. By doing so, the analysts minimize or ignore characteristics of the system failure which are not relevant, in their minds, to the failure under study. This approach magnifies the importance of some elements to the failure analysis and forces others into the background. Disagreements among classical analysts center on which elements should be magnified and which considered subsidiary elements.

This chapter is divided into four sections. The first section provides an overall survey of the literature that embraces elements of this paradigm. The second section describes the foundation upon which the paradigm is constructed. The third section outlines a paradigm that “presents the hard core of concept, procedure and inference in functional analysis.”[26] The fourth section illustrates the elements of the paradigm and how they are interrelated.

2.1 The Classical Literature

The predominant theories in the system failure literature can be divided into one of two categories: (1) those that seek to determine the "root cause" of the failure, or (2) those that seek to quantify the "consequence" of the failure. The vast majority of the literature falls into the first category, which posits that utilizing the "correct" paradigm and by conducting enough research it is possible to accurately discern the root cause of any system failure. The premise is that that if we identify the root cause early in the process, then we can prevent system failure. This body of

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Books, 1992), pp. 85-97.

[26] Merton, p. 104.

literature focuses exclusively on the cause side of the equation, presupposing the consequence as a given and asserting a direct correlation between cause and consequence.

The remaining literature focuses on the consequence of the failure, setting aside the cause side of the equation as less important**.** These analysts substitute the magnitude of the consequence as a measure of the significance of a system failure. They disregard the cause because it has little effect on this measurement.

2.1.1 The Causes of System Failure

The literature universally acknowledges the existence of a "proximate cause" for the system failure itself. This proximate cause, similar to the legal usage of the term, may be defined as the trigger event that directly leads to the failure. By definition this event is close in time to the failure, and excludes precursor actions that led up to the event. For example, the proximate cause of the *Challenger* accident was the O-ring's failure to properly seal, resulting in the destruction of the vehicle. In the ValuJet crash, the ignition and burning of oxygen canisters was the proximate cause of the jet going down.

This proximate cause is seldom, if ever, disputed. The proximate cause usually involves some technical aspect of the system involved in the failure. This aspect could be associated with a particular component of the system or how the system is operated. Finding the proximate cause is the initial objective of most investigations, but once documented resources are transferred elsewhere.

The authors instead concentrate most of their energies on finding the "real" or "root cause" for the failure. In contrast to the proximate cause, there are often multiple opinions about the "root cause" of any given system failure and this is where the debate takes place. Ranging from management malfeasance to groupthink, the literature finds little common ground in developing a conclusive finding. For example, while in the case of ValueJet Flight 592 there is general agreement that a fire produced by improperly stowed chemical oxygen generators was the proximate cause, there are multiple hypotheses about the "true" root cause. These hypotheses range from those who assert that it was the "benign tolerance" of the FAA27 to those who claim

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[27] Elizabeth Gleick, "Can We Ever Trust the FAA?" Time, 1 July 1996, pp. 48-49.

it was “adequacy of training and managing mechanics”28 to those who conclude it was the natural result of airline deregulation.29 And, the list goes on.

Those who address the “root cause” of a system failure often do so from many varying perspectives, academic disciplines, and schools of thought. It is possible to cut the literature, like a deck of cards, any number of ways. For example, an analyst could categorize the data according to the distinct field of study or school of thought of the author or journal. Following this approach, one would develop a series of categories such as the science of engineering and statistics, public policy, management, and sociology. These categories could be subdivided further; for example, engineering could be divided into design, development, and operations. In contrast, one could just as easily examine the data according to such principles as the role of ethics, communications, and decision-making in the system failure.

These diverse approaches may be separated into one of two camps: those who look inside the organization for “the cause” and those who view “the cause” as a manifestation of the organization’s role within a wider social structure. Those who look inside the organization ascribe to the behavioral school of thought. Using the metaphor of "organization as machine," the behavioral perspective views the technical and managerial subsystems of an organization as separate and distinct from the outside "environment.” The behavioral perspective looks at the organization and what transpires inside that organization. They look at the structure and function of each element within the organization and how these interact among themselves. This approach deals with the organization as a complete system and does not consider how the organization might be affected by the wider social system.

Those who focus on the relationship of an organization to the larger social arena, including the external environment, in their search for the root cause provide the alternative institutional perspective. Whereas the behavioral analysts confine their discussion to the classical description of the organization as a machine, the institutional theorists expand the definition to include the wider social system - the environment. These writers, however, still contend that it is possible to clearly identify all the pieces; they simply examine a bigger pie.

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[28] James T. McKenna, “Maintenance Training Undergoes Review,” Aviation Week & Space Technology, 2 Sept. 1996, p. 158.

[29] Howard Gleckman, “A Hard Truth About Deregulation,” Business Week, 15 July 1996, p. 34

2.1.1.1 The Behavioral Perspective

The behavioral research can be further subdivided into four basic root causes of system failures. These causes are technology, individuals, groups, and management. In addition the analysis of each of these causes benefits from the principles of other schools of thought. For example, sociologists may discuss the personalities of the individuals involved. Did the organization recruit aggressive individuals, inclined to assume responsibilities and tasking risk? Or did it solicit individuals who could be counted on to do exactly what they were told, but do nothing else? Likewise, the principle of ethics cuts across many categories where one might find ethical individuals with unethical management or groups which sacrifice the principles of the organization for their own benefit. Therefore, while the discussions presented below are built around the four basic categories of behavioral research, the terminology and findings of other disciplines are included where appropriate.

2.1.1.1.1 Technology

Poorly designed or faulty components, improperly applied technology, and neglecting to employ available technology which could have prevented the system failure are three commonly cited reasons for systems failures. The literature contends, for example, that poorly designed or faulty components caused the high accident rate seen in early models of the DC-10 aircraft program. In early flights of the DC-10 aircraft a poorly designed cargo door latching system consistently failed, causing accidents and deaths of passengers according to Robert Benzon, the Lead Investigator for Aviation Accidents at the National Transportation Safety Board.[30]

Richard Korman writes that the 1987 collapse of the L'Ambiance Plaza in Bridgeport, Connecticut can be traced to improperly applied technology. Korman quotes a “scathing attack” by Neil M. Hawkins, professor of civil engineering as citing the improper use of support structures at the building's lowest levels as the root cause of the bridge’s failure.[31]

Writing on how to fight bank failures, Ada Focer provides a good example of the effects of neglecting to employ available technology. She argues that the lack of a uniform loan

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[30] Interview with Robert Benzon, National Safety Transportation Board Lead Investigator for Aviation Accidents, 23 May 1994.

[31] Richard Korman, “L’Ambiance Plaza Won’t Rest Easy,” <u>ENR</u>, 4 Nov. 1991, Vol. 227, pp. 14-16.

performance tracking system is the root cause in the number of U.S. bank failures. Focer states that:

> No one systematically tracks the lending records of individual bankers. Reintroducing accountability into the banking system by introducing a uniform loan performance tracking system—not the reduction or elimination of deposit insurance –would be the most direct and effective approach to fighting bank fraud, bank failure, and plain old bad and sloppy lending.[32]

Finally, in another more recent example Merit Birky, a member of the National Safety Transportation Board team chartered with investigating the crash of Value Jet 592, states that "the fundamental problem was lack of fire detection and suppression." He concludes that had this fire detection and suppression system been installed "this airline would not have crashed."[33]

2.1.1.1.2 Individuals

The most commonly cited root cause of system failure is error on the part of those individuals responsible for the day-today operations of the system. In fact, sixty to eighty percent of all system failures analyses conclude that the root cause was individual or "operator error."[34] Following are five examples:

- Crew error was cited as the root cause of the December 1990 runway collision of two Northwest Airlines aircraft at the Detroit Metropolitan Airport.[35]

- "Operator Error Blamed for Air Traffic Blackouts," shouted the headline of Matthew Wald's article in the Houston Chronicle reporting that the Federal Aviation Administration had determined that 7 of 10 major power failures of the aircraft control system resulted from incorrect actions by technicians.[36]

- Insurance agents most often shoulder the blame for insurance company insolvencies. "According to William Feldhaus, associate professor of risk management and insurance at Georgia State University,…[there is a] growing tendency to blame agents for failing to predict an insolvency."[37]

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[32] Ada Focer, "Accountability in Lending," New England Business, Dec. 1990, Vol. 12, pp. 8-9.

[33] James T. McKenna, "Chain of Errors Downed ValuJet," Aviation Week & Space Technology, 25 August 1997, p. 34.

[34] Charles Perrow, Normal Accidents: Living with High Risk Technologies (Basic Books, 1984).

[35] Christopher P. Fotos, "NTSB Blames DC-9 Crew Error for Detroit Runway Collision," Aviation Week, Vol. 134, 1 July 1991, pp. 27-28.

[36] Matthew Wald, "Operator Error Blamed for Air Traffic Blackouts", Houston Chronicle, 20 January 1996, Sect. A. p. 6.

[37] Fannie Weinstein, "There's more than one's yardstick to measure your carrier's financial stability," Insurance Review, Vol. 49, Nov. 1988 p. 63.

- Nurses are increasingly being named as defendants in malpractice cases. Their “legal accountability has increased…and they are expected to exercise judgment and to assume accountability for the judgment or assessment if it is negligent.”[38]

- A review of the savings and loan failures found that regulators failed to manage the deposit insurance system effectively. Richard Nelson writes that “strong arguments support the hypotheses that regulatory failure contributed to the S&L debacle. In contrast, the arguments favoring the regulatory agencies structure hypotheses [as the root cause] are mixed and inconclusive. Thus, simply changing the regulatory agencies’ structure probably would not have prevented the S&L debacle. Apparently, the regulatory ineffectiveness that led to the S&L debacle has less to do with the agencies’ structure than with the behavior [real root cause] shared by regulators, whatever their agencies’ structure.”[39]

Not surprisingly, these front line operators find themselves the focus of system failure investigations and subsequently held to greater levels of responsibility than other employees.

2.1.1.1.3 Groups

Other literature argues that many systems failures may be traced to actions carried out by groups. Irving Janis coined the term "groupthink" to describe this phenomenon. With roots in social psychology, this phenomenon is defined as "a deterioration in mental efficiency, reality testing and moral judgments as a result of group pressures."[40]

Groupthink holds that highly cohesive groups often fail to explore alternative courses of action, prepare for unforeseen circumstances, or develop adequate contingency plans. One of the better known characteristics of groupthink is an instance where the group members remain loyal to previously committed-to group decisions even though the decisions are not working out. In these situations, each member of the group individually thinks he/she is headed in the wrong direction but does not object.

For example, in her analysis of the American response to the 1963 Diem coup in Vietnam, Moya Ann Ball shows how language used by decision makers in their deliberations in

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[38] Janie Fiesta, “Failure to Assess,” Nursing Management, Sept. 1993, pp. 16-17.

[39] Richard W. Nelson, “Regulatory Structure, Regulatory Failure, and the S&L Debacle,” Contemporary Policy Issues, Vol. XI, January 1993, pp. 108-115.

[40] Irving L. Janis, “Groupthink,” Classics of Organizational Theory, eds Jay Shafritz and Steven Ott, (Pacific Grove, Cali., Brooks/Cole Co., 1992), p. 194.

the days leading up to the coup created a framework for the process. This framework, in-turn, had the effect of foreclosing certain options.[41] Participants, she found, were unwilling to challenge the validity of past decisions or express doubts about the underlying assumptions on which decisions were based. Ball asserts this extension of the groupthink phenomenon was the root cause of the failed American response.

In their article entitled "Group Decision Fiascoes Continue: Space Shuttle *Challenger* and a Revised Groupthink Framework," Moorhead, et al. add time and leadership as moderators to the concept of groupthink.[42] Analyzing the space shuttle *Challenger* disaster, the authors conclude the decision to launch *Challenger* was the result of a defective decision-making process. The authors argue that in situations where the decision-makers are under pressure to make a decision quickly, the development of groupthink may be accelerated. In these situations the leadership role becomes increasingly important either promoting or deterring groupthink. To prevent the groupthink phenomenon, the leader's role and responsibilities must be clearly defined and he or she must employ a style, which demands open disclosure of information and conveys the importance of such disclosure.

Matie Flowers also examines the leadership question, arguing that groups with leaders who discouraged participation showed more signs of groupthink.[43] Similarly, Carrie Leana's work supports the detrimental effects of directive leadership predicted by Janis and found by Flowers.[44] She asserts that groups with leaders who encouraged member participation generated and discussed significantly more potential solutions to problems than did groups with leaders who discouraged member participation. She also contends that groups with a directive leader who proposed a solution early in the process were more likely to adopt the leader's proposed solution as the final group choice.

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[41] Moya Ann Ball, "A Case Study of the Kennedy Administration's Decision-making concerning the Diem Coup of November, 1963," Western Journal of Speech Communication, Vol. 54, Nov. 1990, pp. 557-575.

[42] Gregory Moorhead, et al., "Group Decision Fiascoes Continue: Space Shuttle *Challenger* and a Revised Groupthink Framework," Human Relations, Vol. 44, June 1991, pp. 539-551.

[43] Matie L. Flowers, "A Laboratory Test of Some Implications of Janis's Groupthink Hypothesis," Journal of Personality and Social Psychology, Vol. 1, Dec. 1977, pp. 288-299.

[44] Carrie R. Leana, "A Partial Test of Janis' Groupthink Model: Effects of Groupthink and Leader Behavior on Defective Decision Making," Journal of Management, Vol. 11, Spring 1985, pp. 5-17.

2.1.1.1.4 Management

Management, a portion of the literature contends, is ultimately responsible for organizational failures because of the role it plays in shaping bureaucratic structures,[45] providing adequate training, [46] articulating the need for safety to the organization,[47] and ensuring open communications throughout the organization.[48]

In some cases management also is cited as the cause for failure for its unethical behavior. Nicholas Carter, for example, concludes that senior NASA managers were ultimately responsible for the space shuttle *Challenger* failure because they agreed to build and fly a "less than safe" vehicle solely for personal ego gratification. [49] Likewise, Tom Bancroft, writing about the *Challenger*, argues that managers ignored critical evidence that could have prevented the failure of the rocket booster manufactured by the Morton Thiokol Company. Bancroft contends that this raises "serious ethical questions about Morton Thiokol's top management."[50]

2.1.1.2 The Institutional Perspective

The institutional perspective contends that the organization, in addition to its technical and managerial suborganizations, is part of a wider social system. Those who ascribe to this school of thought view the organization as an organism as opposed to the classical description of it as a machine.[51] They see organizations as a “tangled web of relationships”[52] with close and intermingled relationships with their environments.[53]

This wider social system frequently referred to as the environment, serves as the predominant element in the root cause equation for system failure. The organization may be relatively independent in terms of formal controls but, in terms of the functions it performs and the resources it can command, it is always dependent to some degree on its environment.[54]

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[45] Jay Fiegan, “Four-Star Management,” Inc. Vol. 9, January 1997, pp. 42-51.
[46] Bernard Thompson, Managing for Safeness,” Management Solutions, Vol. 32, March 1987, pp. 42-43.
[47] Therese R. Welter, “Averting Disaster,” Industry Week, Vol. 235, 21 Sept. 1987, pp. 43-40.
[48] Russell P. Boisjoly, et al., “Roger Boisjoly and the *Challenger* Disaster: The Ethical Dimension,” Journal of Business Ethics, Vol. 8, April 1989, pp. 217-230.
[49] Nicholas Carter, “The Space Shuttle *Challenger*, in Ethics and Politics, eds. Amy Gutmann and Dennis Thompson, (Chicago: Nelson-Hall Publishers, 1990).
[50] Tom Bancroft, “Two Minutes,” Financial World, Vol. 158, 27 June 1989, pp. 28-32.
[51] James D. Thompson, Organizations in Action, (New York: McGraw Hill, 1967); James G. March and Johan P. Olsen, Rediscovering Institutions: The Organizational Basis of Politics, (New York: The Free Press, 1989).
[52] Charles Perrow, Complex Organizations (3rd ed.), (New York, N.Y.: McGraw-Hill, Inc. 1986), p. 160.
[53] Perrow, Complex Organizations, p. 166.
[54] James D. Thompson, p. 10-11.

Charles Perrow asserts in Complex Organizations that “we cannot understand current crises or competencies without seeing how they are shaped. The present is rooted in the past, no organization (and no person) is free to act as if the situation were *de novo* and the world a set of discrete opportunities ready to be seized at will.”[55]

These authors contend that system failure is the result of an organization’s inability to manage or control external influences that ultimately compromise safety. Romzek and Dubnick, for example, assert that:

> Using an institutional perspective, we contend that the accident was, in part, a manifestation of NASA’s efforts to manage the diverse expectations it faces in the American political system…This case study shows that many of NASA’s technical and managerial problems resulted from efforts to respond to legitimate institutional demands. Specifically, we contend that the pursuit of political and bureaucratic accountability distracted NASA from its strength: professional standards and mechanisms of accountability.[56]

Romzek and Dubnick contend that the combination of two factors, the specified entities inside or outside the agency that define and control expectations and the degree of control these entities are given over defining those expectations, produces four types of accountability systems: bureaucratic, legal, professional, and political. They assert that expectations are managed under the bureaucratic system through hierarchical relationships, under the legal accountability system through contractual relationships, under the professional system through deference to expertise, and under the political accountability system through responsiveness to constituents. An agency manages its expectations using the most appropriate accountability system, often adopting more than one. Nevertheless, "institutional pressures generated by the American political system are often the salient factor and frequently take precedence over technical and managerial considerations."[57] Romzek and Dubnick in their assessment of the root cause conclude that:

> The primary contention of this paper is that the Rogers Commission was shortsighted in focusing exclusively on the failure of NASA’s technological or management systems. The problem was not necessarily in the failure of those systems, but rather the inappropriateness of the political and bureaucratic accountability mechanisms which characterized NASA’s management approach in recent years [Which was inappropriate for the technical task at hand]…In

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[55] Perrow, Complex Organizations, p. 158.

[56] Barbara S. Romzek and Melvin J. Dubnick, “Accountability in the Public Sector: Lessons Learned from the *Challenger* Tragedy,” Public Administration Review, May/June 1987, p. 227.

[57] Romzek and Dubnick, p. 229.

> more prescriptive terms, if the professional accountability system had been given at least equal weight in the decision-making process, the decision to launch would probably not have been made on that cold January morning.[58]

A second group of authors cite the organization's inability to work with its stakeholders to obtain the required support as the root cause of a system failure**.** For example, former NASA historian Alex Roland claims that from the very beginning NASA's inability to work effectively with the Office of Management and Budget and Congressional decision makers to obtain the necessary funding led it to build a less than safe system.[59] NASA's ineffectiveness in working with these stakeholders resulted, in Roland's opinion, in the development of a flawed national space policy. He concludes that:

> While all of these steps are positive, perhaps even necessary, they deal with the proximate causes of the *Challenger* accident: they do not address the more fundamental problem besetting the US space programme. The Shuttle accident was the result of flawed policy.[60]

Roland further argues that another space shuttle system failure is inevitable. He asserts that "as it did in the first half of the 1980's, the shuttle will start to eat up the rest of the NASA budget. Other programs will be cut back or cancelled [sic]. Pressure will rise again to avoid costly launch delays. Technical problems will be ignored or deferred, as they were before *Challenger*, or the funds to fix them will come out of the operations budget, raising costs still higher."[61] Roland argues that NASA is caught in a vicious cycle; its inability to work effectively with its stakeholder will continue to lead compromises that will produce another space shuttle system failure.

2.1.1.3 Which Cause is THE CAUSE?

Almost always, agreeing on the proximate cause, proponents of both the behavioral and institutional perspective contend that, with sufficient research, it is possible to discern the root cause of any system failure. Each author within a given group seizes on a single root cause, but the universe from which this cause is drawn varies by perspective. As indicated by the discussion of the literature, the analysts limit the possible causes to those that can be explained

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[58] Romzek and Dubnick, p. 235.
[59] Alex Roland, "Priorities in space for the USA," Space Policy, May 1987, pp. 104-111.
[60] Roland, p. 104.

by some particular theory within the school of thought to which they adhere. For example, the institutional analysts look to the political climate in which NASA operated and the budget restrictions placed upon the shuttle program to locate the root cause of the *Challenger* accident. In contrast, students of management theory turn to the NASA management structure and the managers' interactions with the corresponding contractor management for the answer. As Jon Palfreman, a senior producer for the Public Broadcasting System notes:

> Given the entry of experts into a controversy, one might expect these disputes would be settled quickly. In fact, studies rarely seem to settle controversial issues. To the contrary, it often appears to the public that scientists are reporting conflicting, inconsistent results. Sometimes (for example, cancer, diet and health) the studies do really produce contradictory results. But even supposedly definitive studies have uncertainties that can be interpreted in various ways. And proponents of a causal link can, if they choose, simply "move the goal post" and change their hypothesis.[62]

Few of the authors, however, are so naïve as to believe that this root cause arises without significant contributions from other elements. These elements may affect the timing of a system failure or impact the ability of post-failure investigators to locate the root cause. However, these elements may continue to be present, but without the root cause there would have been no failure. For example, Diane Vaughan in her widely popular analysis of the *Challenger* failure, The *Challenger* Launch Decision: Risky Technology, Culture and Deviance at NASA, acknowledges that the engineering design of the solid rocket booster contributed to the *Challenger* failure. Nevertheless, she concludes that it was the NASA culture that was the root cause of the accident. In settling on the culture as the culprit, she attributes the less than robust solid rocket booster design as a manifestation of this culture. In a different culture, there would have been different contributing elements, but she would contend they were of secondary importance.[63]

Nevertheless, the search for the "root cause" dominates the literature in each camp. Each analyst believes that the single root cause is there to be uncovered. Like archeologists conducting a dig, they may not find the object initially, but they will find it if they continue to

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[61] Alex Roland, "The Shuttle's Uncertain Future," Final Frontier, April 1988, p. 27.

[62] Jon Palfreman, "The Risk Communication Food Chain," an unpublished paper presented at the International Conference on Probabilistic Safety Assessment and Management, 13-18 Sept. 1998, New York City, USA.

[63] Diane Vaughn, The *Challenger* Launch Decision: Risk Technology, Culture and Deviance at NASA, (Chicago: The University of Chicago Press, 1996).

look and look in the right places. Proponents of a particular root cause simply believe the other analysts are digging in the wrong place. In cases when the proximate cause cannot be determined, the cause literature is scarce. For example, in the TWA 800 flight accident, few articles have been written to determine the root cause because there is no way to trace it from a proximate cause. The classical paradigm does not make provisions for such occurrences.

2.1.2 The Consequences of System Failure

The consequence literature almost always describes the failure event itself as the consequence of the system failure. For example, most analysts define the consequence of the *Challenger* failure as the destruction of the vehicle and the death of seven astronauts. The consequence of the Chernobyl nuclear power plant failure is seen as the loss of the plant and the exposure of thousands of citizens to radioactive elements. The consequence of the TWA Flight 800 and Swissair Flight 111 explosions are viewed as the loss of the passengers, crew, and aircraft. This finding may be labeled the “proximate consequence” which is similar to the proximate cause construct discussed earlier. Like its cousin, proximate cause, the proximate consequence of a failure in a large complex system is often obvious, and is seldom disputed.

Unlike the cause literature, most of the consequence literature does not venture beyond analyzing the proximate consequence. Those analysts who do search for consequences beyond the proximate consequence tend to, like the cause analysts, seize on one consequence and magnify it to the exclusion of all others. In contrast to the cause literature that is divided according to broad measures such as technology, management, and operator error, the consequence literature is divided largely according to the specific area of research which the author is pursuing. Within their sphere of interest, the analysts attempt to determine the ultimate consequences that may be derived from the proximate consequences. Using the Chernobyl example, one consequence of the accident would be the public’s renewed questioning of the safety of the nuclear industry. A second would be the economic impact on the communities that received power from the nuclear plant and those communities that provided the workforce no longer required to operate the reactor. A third consequence would be to future generations exposed to the radiation.

In a third example, following the *Challenger* failure, space policy analysts discussed the impact to America's share of the launch vehicle market, while scientists bemoaned the setback to space-based research. space scientists, the aerospace community, and the military all wrote about the consequences as it affected their particular area. In a specific instance, writing in the New Scientist, Baker contends that as a consequence of the accident, space science research was set back years.[64] He states "the fate of the shuttle has resulted in the loss of 38 years from the science projects discussed here, which are only the more prominent of many programmes now abandoned or frustrated."[65]

Discussing the aerospace community, Wayne Biddle argues that the accident left the country with a severely weakened space agency.[66] He contends that NASA's reliance on the shuttle as the sole launch vehicle was bringing the space program down "rather than the *Challenger* accident itself." While acknowledging the effects of the *Challenger* failure on space science research, he focuses on the need for NASA to develop a mixed fleet of shuttles and unmanned rockets, warning that "extinction is the consequence of the present policy."[67] Beck echoes this conclusion, calling the space program the eighth victim of the accident.

In a 1988 Business Week article Judith Dobrzynski presents an interesting consequence of the space shuttle *Challenger* accident, one that defies conventional wisdom.[68] In her interview with Charles S. Locke, the Chairman and CEO of Morton Thiokol, the company that manufactured the space shuttle's solid rocket boosters, Locke discusses the consequences of the accident as they related to Morton Thiokol. Although the Presidential Commission would determine the proximate cause of the *Challenger* malfunction to be the solid rocket booster's O-ring failure to properly seal, Locke commented that the Morton Thiokol Company would suffer no long-term consequences as a result.[69] In fact, he bolsters his argument by pointing out how

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[64] David Baker, "Science crashed with *Challenger*," New Scientist, 29 January 1987, pp. 55- 57.

[65] Baker, p. 57.

[66] Wayne Biddle, "NASA: What's Needed to Put it on its Feet?" Discover, January 1987, pp. 31-49.

[67] Biddle, p. 32.

[68] Judith H. Dobrzynski, "Morton Thiokol: Reflections on the Shuttle Disaster," Business Week, 14 March 1988, pp. 82-91.

[69] Report of the Presidential Commission on the Space Shuttle *Challenger* Accident, p. 40.

the company’s stock price was barely affected that year, and later stating “Wall Street has pushed Thiokol’s stock price up to around 44, some 22% higher than it was before the accident.”[70]

Finally, from the military perspective, R. Jeffrey Smith contends that the accident created a “lengthy delay [which] could have substantial national security implications.”[71] He cites impacts to military payloads, including photoreconaissance satellites and “Star Wars” experiments. Secretary of the Air Force Edward C. ‘Pete’ Aldridge said that a ‘tragic error’ had been made in the 1970s when the USAF decided to rely on the shuttle as its sole launch vehicle. ‘We have paid, and will continue to pay, dearly for that error. In fact, it will cost the Department of Defense about $10 billion to restore a balance between the shuttle and expendable launch vehicles to recover from the space policy mistake’.” [72]

In an interesting twist on the sphere of interest concept, Charles Perrow has developed a quantitative approach for determining consequences.[73] In his particular consequence of interest, Perrow attempts to quantify the number of “victims,” those who either die or are injured as a result of the failure. In calculating the consequences of system failure, Perrow considers humans as a component in the system and not as the sole variable in the calculation. He asserts “we kill about 5,000 people a year outright in U.S. industry. The vast majority of these "accidents,” however are only "incidents" in our scheme, for no subsystem or system damage is entailed. Only a "part" has been destroyed.[74] Subsequently, he argues that "a group of humans (the flight crew on an airliner) or a single human (the astronaut in a space capsule) may constitute a subsystem."[75]

Perrow’s approach creates a consequence framework that is highly structured. Failures are categorized based on their ultimate impact to society. In a linear process, failures move to increasing levels of severity in a step-wise fashion. Perrow separates the consequences of system failures into four categories of "victims". According to Perrow, first-party victims are those who perform the day-to-day operation of the system such as first-level supervisors, maintenance, and engineering personnel. Second-party victims (e.g., passengers on a ship) are suppliers or system

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[70] Dobrzynski, p. 91.
[71] R. Jeffrey Smith, “A Crimp in the Pentagon’s Space Plans,” Science, Vol. 231, 14 February 1986, p. 666.
[72] Nigel MackNight, Shuttle (3rd ed.), (Osceola, WI: Motorbooks International, 1991), p.92.
[73] Perrow, Normal Accidents.
[74] Perrow, Normal Accidents, p. 66.

users. They have no influence over the system, however. They are not innocent bystanders, because they are aware of their exposure, even though such exposure may not be entirely voluntary. Third-party victims are innocent bystanders who have no involvement in the system. Fourth-party victims are fetuses and future generations.[76]

Perrow considers the consequences of each failure according to their highest level of severity. These higher levels incorporate the effects (or consequences) of the lower levels, resulting in each failure having a single overall consequence. Perrow argues that as we move from operators to future generations, the number of victims rises geometrically.[77] Although public reaction is stronger when the victims are identifiable by name rather than by random statistics, he frames the problem in terms of the catastrophic potential versus the cost of producing the same outputs by alternative methods. For example, Perrow asserts that while space missions are very complex and tightly coupled, the catastrophic potential is small. The victims are primarily first-party and in some cases second-party. In contrast, he identifies other systems where the catastrophic potential is vast and which should be abandoned because the inevitable risks to all parties outweigh any reasonable benefits (e.g., nuclear weapons and nuclear power).[78]

2.1.2.1 The Sum of the Consequences

Like the cause literature, the consequence literature does not dispute the existence of a proximate consequence, and further agrees on the identity of this proximate consequence for a given system failure. For most system failures, the proximate consequence either is obvious or quickly comes to light. The proximate consequence almost always involves technical aspects of the system, its performance, and virtually immediate effects on its surroundings. For example, the consequence of a train wreck is considered by most observers to be the derailment of and damage to the train and any resulting loss of life. Any delay in determining the consequence usually results from delays in determining the extent of the proximate consequence, not its identity.

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[75] Perrow, Normal Accidents, p. 66.
[76] Perrow, Normal Accidents, p. 67.
[77] Perrow, Normal Accidents, p. 67.
[78] Perrow, Normal Accidents, p. 342.

In the consequence literature, for those few authors who venture beyond the proximate consequence, the path to the remaining consequences is a linear deterministic process. Once the failure event occurs the ultimate consequences unfold in an orderly and predictable fashion. For example, it is taken for granted by many analysts that setbacks to the national space agenda resulted directly from the *Challenger* failure.

In following this path, the authors view consequences based on their predefined interests. Sociologists examine the effects of the *Challenger* failure on society as a whole while space industry executives consider its impact to their profitability. Perrow adopts this approach as well, but takes the additional step of developing a structured quantitative framework. Even here, Perrow has narrowed his framework only to consider the toll on human life.

2.2 The Foundation Upon Which the Classical Paradigm is Built

Social scientists often take advantage of work performed within the physical sciences. Economics, public policy, and organization theories can each trace their lineage to discoveries and findings in the physical sciences. Most reject anecdotal evidence and subjective qualitative measures and instead embrace the use of "scientific" or quantitative measurements. Its view of a totally mechanistic universe leads to the conclusion that, with adequate data and techniques, the failure and its effects can be quantified, understood, and subsequently managed. As Alvin Toffler notes it “led Laplace to his famous claim that, given enough facts, we could not merely predict the future but retrodict the past” and this “simple, uniform mechanical universe…spilled over into many other fields.” [79] Those analysts who exhaustively study the past performance of major stock markets illustrate this idea. In this school of thought, it is their contention that if they can just understand the technical parameters that underlay market trends, they will be able to predict future performance and, to some extent, control swings in the market.

The paradigmatic bases for those looking at system failure are the traditional sciences of Sir Isaac Newton and that branch of classical physics labeled mechanics. Classical mechanics, often referred to as Newtonian Mechanics, is the study of change. "Supported by a barrage of mathematical equations it [classical mechanics] seeks to provide the necessary tools to predict the behaviors of complex systems."[80] The unspoken assumption is that equations are the proper building blocks for creating the tools. Also, classical analysts assume that once developed, these tools provide everything necessary to understand our world and its component systems.

The world of classical mechanics is orderly and predictable. There is no preferred frame of reference -- if the laws of mechanics are valid in one inertial frame of reference, they are valid in any inertial frame of reference. Everything can be described utilizing neatly packaged mathematical equations. To understand the big picture one need only identify the smallest common denominator, and then measure and sum the individual pieces. A particular measurement taken to be used in a variable in one equation can be used in other variables in a series of equations used to explain another phenomenon. This belief that there is no preferred frame of reference influencing the value of a measurement also has another, less explicitly noted, effect. In the classical world, there always is a “correct” measurement for each parameter, the validity of which all parties accept.

The foundation of classical mechanics is composed of three basic principles: reductionism, cause and effect, and determinism. The first principle, reductionism, asserts that everything can be broken down into its smallest individual components which, in turn, can be positively identified and accurately measured. Researchers bound the entire topic, identify the components, and classify each in a logical structure. Beginning with the assumption that one can identify and measure all the individual components within a system, reductionism maintains that the smallest divisible component can be determined. Conversely, if one starts with the smallest divisible component and reconstructs the system, the end result is equivalent to the whole.

For example, when the space shuttle *Challenger* exploded, the search began for the lowest denominator to explain how the failure occurred, whether this failure was management error, a design mistake, or some other factor. Each system and subsystem was analyzed to determine all possible failure modes. These subsystems were further broken down into individual components, and the constituents making up these components each were examined.

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[79] Alvin Toffler, “Forward” to Ilya Prigogne and Isabelle Stengers, Order Out of Chaos: Man’s New Dialogue with Nature, (New York, N.Y.: Bantam Books, 1984), p. xiii.
[80] Linda Huetinck, Physics: Cliff Quick Review, (Lincoln, Nebraska: Cliff Notes, Inc., 1993), p. 1.

Management actions were traced back to the points where decisions were made. Data that led to these decisions were documented and the processes by which the data were derived were reviewed. Finally, the data used were examined to ensure they were correct.

The second principle of classical mechanics, grounded in Newton's laws of motion, which correlate the rate of change with the amount of force exerted, asserts that there is a direct correlation between cause and effect. This principle holds that an object will continue in its current state - of rest or motion - indefinitely unless compelled to change by an external force (Newton's 1st law of motion). However, once an external force is applied, the object's response will be proportionate to the amount of force exerted; for every action there is an equal and opposite reaction (Newton's 3rd law of motion).[81] This second principle further asserts that proximate cause overwhelms all other factors. Other change agents are believed to be insignificant. Actions distant in time or location have little effect and these effects tend to fade away.

Similarly, the cause identified above can be traced clearly to the events that followed it. This interaction includes not only the effects that occurred immediately surrounding the system failure, but also the longer-term effects that result. This principle carries with it the assumption that the total universe of causes that lead to a particular effect or series of effects can be determined by an analyst. Although not all causes may be readily apparent, this failure to uncover them is caused by a lack of sufficient study rather than an inability to determine the complete set of causes.

The third principle of classical mechanics, determinism, holds that change is measurable in advance and as such can be calculated using mathematical equations. Utilizing these mathematical equations, it is possible to accurately measure and predict the impact of change on any object. Small changes produce proportionate effects and large effects are calculated simply by summing the small effects. It also holds that one can measure this rate of change without affecting the end result. Observers and their methods are outside the universe being measured. This principle may be illustrated using Perrow’s work. Perrow argues that we should determine in advance the effects of a particular failure and use the results to balance the value of the system

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[81] Robert Resnick and David Halliday, Physics, (New York, N.Y.: John Willey & Sons, 1960), pp. 66-72

against these effects. This relies on the unspoken assumption that these effects are calculable in advance. Potential long-term effects on fourth party victims, for example, can be determined in advance.

This certainty would allow NASA and its contractors to know in advance the risks being taken in launching the *Challenger* on the STS-51L mission. Any claimed lack of knowledge would not be accepted. This is especially true given NASA's extensive safety analysis and risk management process. As part of the top-level requirements for the shuttle program, NASA developed an extensive set of documentation to record all possible failure modes and their effects on the risks to the shuttle. Systems for which a failure would have dangerous or catastrophic effects were placed on a Critical Items List controlled by senior management. The solid rocket booster O-rings and joint assembly were carried on this list.

This Newtonian universe is unique in that it is extremely ordered. Given enough data and with enough work using the proper methods, all the secrets of the universe are available to man. The analyst's tasks are to understand the underlying structure of the universe and properly apply the tools that have been developed to explain it. Qualitative analysis has no place in this scenario except as a general guide for where to begin the quantitative analysis.

2.3 The Classical Paradigm

Those who analyze systems failure place their findings into a diverse set of categories. These categories vary by subject matter, with findings running the gamut from highly technical matters to sweeping indictments of the past or predictions of the future. For example, the *Challenger* mishap has been called everything from a heinous crime perpetrated by unethical NASA managers to the beginning of the end of human space flight. Others consider the same system failure as the inevitable result of an increasingly complex society that relies on correspondingly complex machines. Still other analysts view the failure as simply an accident, an occurrence from which to learn and to apply to future designs.

These various categories, however, exhibit underlying themes that may be used to group these findings into a logical paradigm. As introduced by Allison, this paradigm provides a useful structure for stating "the basic assumptions, concepts, and propositions employed by a school of analysis."[82] This structure does not, by any means, represent the complete realm of principles, theories, and rules that make up the field of classical mechanics. Nor does it present a complete picture of the manner in which classical mechanics is applied to system failure. However, the paradigm illustrates the common elements found in the classical literature and provides a specific vocabulary for discussing a given system failure and subsequent analyses.

The paradigm presented below is purposely abbreviated, providing the key concepts necessary to understand the underlying structure of the classical argument. This approach is advocated by Merton:

> Despite the appearance of propositional inventories, sociology still has few formulae – that is, highly abbreviated symbolic expressions of relationships between sociological variables. Consequently, sociological interpretations tend to be discursive. The logic of procedure, the key concepts, and the relationships between them often become lost in an avalanche of words. When this happens, the critical reader must laboriously glean for himself the implicit assumptions of the author. The paradigm reduces this tendency for the theorist to employ tacit concepts and assumptions.[83]

The paradigm starts with the basic unit of analysis. As with any sorting activity, the analyst must establish up-front the unit by which all other activities are measured. With this yardstick, the structure of the paradigm may be sketched using a series of organizing concepts. These concepts illuminate a dominant inference pattern within the paradigm. Although an analyst may not explicitly call out this pattern, it nevertheless affects the approach used to analyze the system failure. General propositions may be derived from this pattern, describing the basic tenets of the paradigm. These general propositions may be sharpened into a set of specific propositions which may be applied directly to a failure scenario. Finally, the paradigm addresses the veracity of the evidence used by the analyst employing this paradigm.

I. Basic Unit of Analysis

System failure seen as a Newtonian mechanical process. All the events leading up to and following a system failure can be identified and measured. The cause-effect process is linear and deterministic. The resulting findings constitute the analyst's determination of the cause and the

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[82] Allison, p. 32.
[83] Merton, p. 69.

consequence of the system failure that necessarily represent the end of the trail anticipated by this Newtonian process.

II. Organizing Concepts

A. *The System Failure*: System failures result from a discernible cause and have measurable consequences. There is a single cause, a knowable trigger event, and inevitable consequences.

B. *The Proximate Cause*: The proximate cause of the failure is generally seen as the triggering event for the system failure. It is seldom disputed and serves as the constant in the classical equation.

C. *The Root Cause*: Through rigorous investigation, it is possible to determine the one overarching cause which can be identified as the linchpin without which the proximate cause would not have occurred. Other, contributing elements, could have been different or absent but the system failure still would have taken place.

D. *The Proximate Consequence*: The proximate consequence usually is identified as the failure event itself. For example, the loss of the *Challenger* and the crew is cited frequently as the consequence.

E. *The Ultimate Consequence*: The resulting long-term effect of a system failure. The Ultimate Consequence can be calculated in advance or measured postmortem.

F. *System failure follows classical Newtonian principles*:

- All events may be divided into increasingly smaller components to isolate their source. This parsing activity may be continued until the lowest possible level of division is reached. The analyst can determine this level has been reached.
- This source can be linked, through a linear process, to a known set of effects. The source and effect linkage is not variable, but the same for each occurrence.
- This process can be determined, measured, and predicted at any time, including in advance of the event.

III. Dominant Inference Pattern

If a system failure occurred, that failure must have been the result of some root cause. The key to understanding how this cause and its consequence came about is found in the Newtonian analysis of the actions leading to the failure.

IV. General Propositions

The basic assumptions of the classical approach are based on the Newtonian principles that a system failure:

1. Results from a knowable cause.
2. Has a traceable legacy to that cause.
3. Has a consequence that can be adequately determined in advance or documented afterward.

These principles yield three propositions:

1. Decisions are made according to the principles of classical mechanics.
2. Eliminating the cause will prevent future failures.
3. Once the failure takes place, the consequences cannot be altered.

V. Specific Propositions

A. *Knowledge*. By knowing the elements of a system and its possible failure modes, the probability of its failure can be identified and eliminated. A classical analyst would point out that prior to the *Challenger* accident, NASA had the knowledge of problems with the solid rocket boosters and the means to eliminate them.

B. *Prescience*. Our systems and processes, properly developed and maintained, allow us to monitor and prevent future failures. This proposition underscores the lack of attention paid by analysts to the consequences of system failure. Available resources are devoted to understanding a particular failure and preventing future failures. These limited resources cannot be used on the less valuable task of analyzing consequences unless this analysis in turn helps determine the cause.

VI. Evidence:

The analyst attempts to reconstruct the events and insert himself into the failure producing process, the basic tenet being that with enough research one can accurately determine all the facts surrounding the system failure. All analysts bring with them a background of knowledge, experience, and interests that determine the lens through which they view the failure. The alternative lens selected for viewing the failure determines the frame of reference for each analyst. Students of management theory, for example, will place themselves in the position of shuttle program and contractor management and find the failure's cause in their actions.

The classical analyst must establish that the particular vantage point chosen for studying the failure is the correct one for explaining it. It supplants the approaches taken by other analysts, and applies the Newtonian principles correctly. In doing so, the analyst develops a world that is congruent with his or her view of reality. This lens becomes the correct approach for collecting and analyzing the data, and for organizing it to explain the failure.

2.4 The Classical Paradigm Illustrated

The classical paradigm, a five step linear deterministic process, is illustrated in Figure 2-1. This structured illustration incorporates the events prior to a system failure, those surrounding it and those processes resulting from the failure. It accommodates actions taken remotely in time either before or after the failure and demonstrates the interactions of the various processes surrounding a system failure. Further, this structure accommodates the theories of virtually all the proponents of the classical paradigm. Specific conclusions reached by analysts may differ, but their approaches fall within the structure of this paradigm.

In the first step, a number of factors contribute to constructing the cause of the failure. Depending on the opinion of the analyst, these factors contribute in varying degrees to the composition of the cause. For example, an analyst whose expertise is communications theory might emphasize the breakdown in communications as the primary contributing element to the *Challenger* accident. This analyst would recognize that other factors, such as the management structure or the technical constraints surrounding the shuttle, affect the communications paths, but still would focus on communications as the root cause of the failure.

Finding the single root cause of the failure is the second step in this process. This step is the focus of classical research into system failure. Although the authors of the cause literature differ in their interpretation of the record and come to sometimes conflicting conclusions, this step is common to each argument. Illustrating all three of the classical paradigm principles of reductionism, cause and effect, and determinism, analysts sift through mountains of data, speculate on the motives of those who dealt with the failed system, and search for outside influences which could have had a bearing on the failure. All still seek a single root cause.

In step three, the root cause triggers the proximate cause of the failure. Once determined, the proximate cause is seldom debated. In the case of the *Challenger* accident, the failure of the O-rings is the proximate cause. In the ValuJet crash, it was the ignition of the oxygen cylinders creating a fire in the aircraft's cargo hold. As shown by its position in Figure 2-1, classical analysts view the proximate cause as the fulcrum in the analysis of a system failure. It acts as the central departure point from which to review either the cause or consequence of a given failure. Additionally, this point provides a common element in discussing analyses that might otherwise be in conflict. While one analyst may believe a failure to have occurred because of operator error and another because of technical flaws, both would agree on the proximate cause.

As illustrated in the fourth step, the authors in the classical literature tend to describe the failure event and the proximate consequence as one and the same. The explosion of the space shuttle and the loss of the crew are labeled both ways. This isolated approach to viewing the consequences is seen in other system failures. Airplane malfunctions lead to crashes that are viewed as isolated events. Even the public does not seem to think otherwise, continuing to log miles without interruption in the days following a crash. Flights remain full on aircraft of the same model as the one that failed, even though the root cause of the failure may be under investigation.

In the final step, most analysts tend to seize on the consequence as they define it. This definition is highly dependent on the sphere of interest that the analyst brings to the analysis of the failure. In so doing, as with the cause, they effectively exclude other consequences from consideration. In the recent Titan IV explosion, for example, the U.S. Air Force spokesperson focused on the loss of a valuable intelligence asset worth billions of dollars. The spokesperson also stressed the loss of surveillance capability in a period of regional unrest across the world. In contrast, the Lockheed Martin Company, which makes the rocket, is reviewing the impact of the failure on their future competitiveness in the lucrative expendable launch vehicle market. This last aborted flight of the Titan IV rocket, which had experienced only a five percent failure rate, places a strain on the company as it attempts to recruit payloads for its new rocket model.

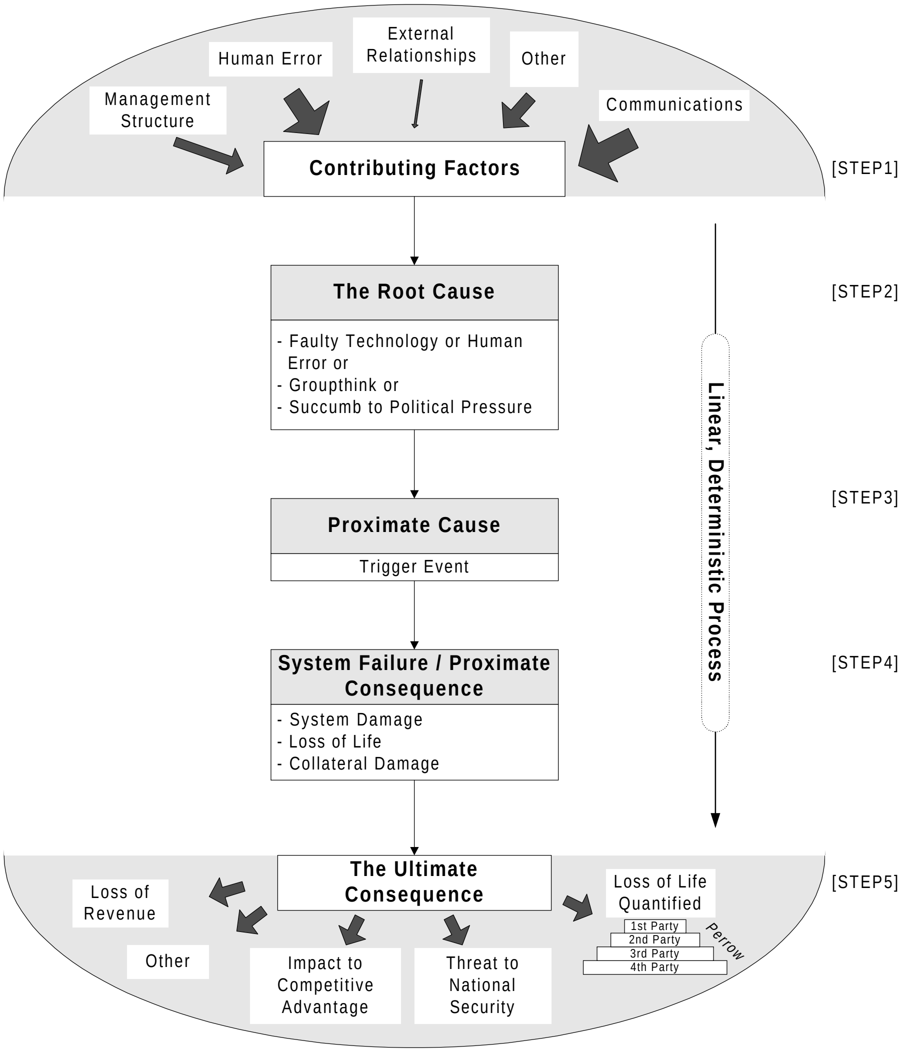

Figure 2-1 - Classical Paradigm Structure

This paradigm has been used countless times by analysts attempting to understand system failure. Though not always explicitly, these analyses have embodied one or more of the five steps described above. In some studies the focus has been on the abstract nature of system failure and the importance of this field of study. Other analysts review these failures in order to assist practitioners in preventing or minimizing future failures.

In analyzing the sequence of events one can move back and forth in either direction, much like a sliding scale, depending on the analyst's objective. For example prior to a system failure, those within the organization will concentrate energies on identifying and tracking contributing factors which might combine to produce the root cause and, subsequently, a system failure. After a failure, analysts will retrace the course of events seeking first to discover the proximate cause and then working backward to the root cause. This path of discovery can be seen with the August 12, 1998 failure of a Titan IV rocket carrying a U.S. spy satellite. When it exploded 40 seconds into the flight, the immediate reaction of all involved was to determine the cause of the failure. Technical experts were rushed to the scene and the industry and popular media speculated as to the cause. Many suspected that the solid rocket boosters, which are similar in design to those used by the shuttle, were the culprits. The investigation team began to generate a tree showing the possible causes of the failure identified down to the component level within the systems. They are attempting to link this cause to its effect, the proximate cause that actually made the vehicle explode. For classical analysts seeking to determine the contributing factors and root cause after a system failure has occurred, it is essential to absolutely determine this step before moving to the next step in the paradigm.

In both approaches, the analysts frequently use examples to illustrate their methods and conclusions. The *Challenger* accident provides the ideal situation for many analysts because it is well known and contains the complexity necessary to prove the utility of a certain approach. In addition, the analyses of one observer can be compared to many other observers - the *Challenger* failure is cited by those in all schools of thought. The story of this accident, as seen by the classical analysts is told in Chapter 3.