## Understanding the Chaos behind Chaos Theory: So What's in it for Managers?

Richard E. Crandall Appalachian State University John A. Walker College of Business CIS Dept, Raley Hall Boone, NC 28608 (828)-262-4093 <u>crandllre@appstate.edu</u>

William "Rick" Crandall School of Business Post Office Box 1510 University of North Carolina at Pembroke Pembroke, NC 28372 (910)-522-5786 <u>rick.crandall@uncp.edu</u>

#### Introduction

A butterfly flaps its wings in Brazil and later, the resulting air currents trigger a series of atmospheric events that eventually cause a tornado in Texas. Down deep, in the uttermost recesses of your brain, do you really believe that? Or, consider this question from Frederick (1998: 369). "Is the corporation a *self-organized complex adaptive system (CAS)* housing an *autocatalytic component*, operating on a *fitness landscape*, and exposed to the risk of *chaotic change* while being held in its niche by a *strange attractor*?" A ridiculous question or a thought-provoking inquiry?

To bring the butterfly phenomenon and the question from Frederick to the practical realm, we must consider this statement: "Increasingly, the quest for accurate prediction of even the short term is difficult. And the reason is that, in spite of how we believe them to be, virtually no social, political, or business systems follow straight-line paths of predictability. Rather, they behave in nonlinear ways because they are chaotic." (Harris and Zeisler 2002: 21).

These statements focus on a radically different way of thinking from many of the "tried and true" paradigms that are used by managers in the practitioner realm. Their origins come from chaos theory and its close sister, complexity theory. Although ideas from this seemingly abstract field may initially seem extreme, they do have applications in business management.

Are managers operating in a chaotic business world? Certainly, open system theory describes the environment in which a business operates as containing various elements that are beyond the control of the business. For example, managers must address external variables (those that exist outside of the organization) such as competitor innovations, volatile economic conditions, government regulations, environmental changes, societal pressures and consumer preferences.

In this paper, we examine the components of chaos theory and their potential application to the managerial practice. We begin by describing the appeal of chaos theory among organizational researchers. Next, the basic components of chaos theory are explained. This paper concludes with potential perspectives that chaos theory can add to the practicing manager's repertoire of tools.

### The appeal of chaos theory

The bestselling book by James Gleick (1987) made chaos theory understandable to those outside the mathematical and physics disciplines. It was not long thereafter that social scientists, organizational scholars and psychologists found an interest in chaos theory. Finally, there was a framework based on nonlinear occurrences that could be used as a lens to understand the complex social and psychological interactions that make up these disciplines.

The past decade has brought an interest in the application of chaos and complexity theories as a lens for viewing the management of organizations (Burns, 2004). Such work has been seen in the fields of strategic management (Dervitsiotis, 2004; Hurtado, 2006), health care management, public management (Farazmand, 2003), marketing strategies (Mason & Staude, 2009; Samli, 2006), entrepreneurship (Mason 2006), product development (Closs et al. 2008), information system design (Dhillon & Fabian 2005), flexible procedures design (Brodbeck 2002), e-commerce (Nelson & Nelson 2004), organization design (Brodbeck 2002; Dolan, Garcia & Auerbach 2003), and the analysis of organizational crises (Crandall, Parnell, & Spillan, 2009; Sellnow, Seeger, & Ulmer, 2002

### Origins of chaos theory

Lorenz (1993) discovered the roots of chaos theory in his attempts to build a mathematical model to forecast weather during the early 1970s. With twelve linear equations containing a number of variables, he found he could predict the weather – but only some of the time. In his research, he found that

sometimes the model came up with very different forecasts, depending on the initial starting point of the forecast period. Even slightly different starting points would result in widely different forecasts. In other words, the results did not follow precisely repeatable cycles, despite the fact that the equations did not change.

At the same time, other scientists - mathematicians, physicists, biologists, social scientists, even economists - were running into similar phenomenon. They discovered the linear equations they were using did not capture the full explanation of what they were trying to predict; consequently, they were forced to conclude the events taking place followed nonlinear patterns. Inasmuch as linear equations were solvable and most nonlinear equations were not, these scientists faced a difficult task. They needed a new way to explain what was happening. Furthermore, they had to convince many in the scientific world that existing theories were not entirely useful. The problem was that they did not account for unexplainable or interfering variations; variations that had been previously regarded as "noise" in earlier studies. When these variations were small, they did not present a problem; however, in some cases, the variations caused major and unexplainable patterns. For example, in weather forecasting, a small variation in an atmospheric condition, can lead to a major change in the weather later on in the week.

### The Characteristics and Components of Chaos Theory

Chaos theory finds its roots in mathematics and the natural sciences; hence, the term chaos must be identified within its proper context. Chaos is a state where phenomena that appear to be unrelated actually follow an unknown or hidden pattern called an attractor. Chaotic systems display two characteristics, sensitive dependence on initial conditions and unpredictability in the long run.

#### Sensitive dependence on initial conditions

Lorenz (1993) noted that a slight change in the initial input of meteorological data could lead to vastly different results. This now famous occurrence led to the popular butterfly effect referred to at the beginning of the paper. This effect states that the flapping of the wings of a butterfly creates tiny air currents that can begin a series of meteorological phenomena that can eventually lead to a larger event such as a hurricane in a specific part of the hemisphere. However, it should be pointed out that it is not so much the occurrence of the hurricane that is important to note; rather, the location of the hypothesized hurricane. In other words, should the butterfly flap its wings in a slightly different variation, the resulting chain of events could lead to a hurricane in a completely different location of the world, or perhaps, to a state of sunshine instead! This important characteristic of a chaotic system, sensitive dependence on initial conditions, thus illustrates that a slight change in initial conditions can lead to a vastly different outcome in the system under study.

#### Unpredictability in the long run

The second characteristic of a chaotic system is that the behavior of the system cannot be predicted in the long run. At best, only short-term predictions are possible. Again, the weather is an example of a chaotic system that defies long-term prediction (Lorenz, 1993). While we can certainly predict seasons and general patterns, we cannot predict the specific weather in terms of temperature and precipitation on a specific day of the year; say one hundred days from now.

A system in chaos thus contains these two characteristics, sensitive dependence on initial conditions, and unpredictability in the long run. The reader should note that such conditions actually describe a number of events that managers must address on a regular basis. Hence, there is some feasibility in stating that managers must manage in a chaotic system. However, we can also add several other components that help describe a chaotic system. These include bifurcations, attractors, nonlinear behavior, and self-organization.

### Bifurcations

A bifurcation is a point in the behavior of a chaotic system where the outcome can actually vary between two possible values in alternating time periods. The biologist Robert May, made the discovery of a bifurcation while conducting a population model experiment (Gleick, 1987). May found, as he increased the parameter value in his model, the population would increase until it reached a bifurcation point. At this bifurcation point, the population would then alternate values on a two year cycle, reaching a certain value the first year, followed by a lower value the next year, then to return to the original value the third year, and so on. As the parameter was increased again, a new bifurcation point was reached. Now the population values alternated within a four-year cycle. As the study variables were increased again, still more new bifurcation points were encountered until the model reached a state where the value of the population could lie almost anywhere between extinction and a very large amount. The system was in chaos because the population did not seem to settle down to any predictable level.

Even while the system was in chaos, May continued to increase the study variable parameter. Interestingly, when a certain parameter value was reached, the system (i.e., the population level) settled back down to a constant three-year cycle. However, increasing the parameter again caused the system to return to chaos. In fact, the system continued to move in and out of chaos as the parameter level increased. Figure 1 illustrates a simplified version of this chaotic system with a series of bifurcations followed by the resulting regions of chaos.

#### Attractors

In chaos theory, an attractor is a pattern that forms when the behavior of a nonlinear system is plotted in phase space (Lorenz, 1993). Phase space depicts the different states of the system through various points in time. Such systems produce plots that can resemble orbits. Thus, the behavior of a chaotic system follows a pattern through time.

Attractors range from being fairly simple to vastly complex. Four types of attractors have been identified: Point, pendulum, torus, and strange. Point attractors depict a simple system that constantly returns to a single point. Pendulum attractors vacillate between two points. The torus attractor is a more complex pattern that forms an orbit. The strange attractor, sometimes referred to as a fractal, is a complicated pattern that exists when the system is in chaos. The most famous strange attractor is the Lorenz butterfly, which resembles the wings of a butterfly when graphed (not to be confused with the butterfly effect described earlier).

#### Nonlinear behavior

Linear systems react in a proportional or linear manner. The concept of linearity implies that a change in one variable will result in a proportional change in another variable. The result is that the relationship among the variables can be depicted as a straight line. Noting this relationship is important to managers because it means there is some degree of prediction possible using linear based models.

In contrast, the relationships in nonlinear systems depict variables that are not linear, but instead, may be curvilinear, u-shaped, s-shaped, or any combination of these. Since chaotic systems are nonlinear, they do not possess the predictability that linear systems have. Because much of the natural and social world behaves in a nonlinear fashion, chaos theory offers a suitable perspective in examining these systems (Smith, 2002).

#### **Self-Organization**

This component of chaos theory describes the system's ability to change itself into a new form without intervention from forces outside the system (Loye & Eisler, 1987). The concept posits that a chaotic stage is necessary first in order for a new system to emerge (Butz, 1997). Closely related to this component is the concept of a complex adaptive system (CAS), a term borrowed from complexity theory. This refers to the ability of an organization to adapt to its surrounding conditions in order to survive (Frederick, 1998).

There is another term we must mention at this point, a concept called "the edge of chaos". This concept was not actually part of the original theory on chaos, but one that has been used by complexity theorists who were attempting to distinguish system behavior that was on the verge of, but not in chaos (Brown & Eisenhardt, 1997). Popular writers have found the phrase intriguing because it represents a crucial area of complexity where management creativity can be at its highest. Following this logic, the aim of management is to operate on the edge of chaos, without actually descending into it.

#### So what's in it for Managers? – First, Two Caveats

There has been an abundance of enthusiasm for the use of chaos theory in business applications among those in both the academic and popular business media. However, several cautions are in order. First, some have advocated chaos theory to be a superior framework to more traditional linear models when analyzing organizational problems. Second, a number of writers have been guilty of semantic misunderstandings on the meaning of the term - chaos. Consequently, we offer the following two caveats in reference to these viewpoints.

# Chaos theory has been over-enthusiastically endorsed as a "cure-all" in organizational research applications.

Chaos theory has been offered by some as a superior framework in the analysis of organizational events. The rationale touted is that most organizational problems transpire in a nonlinear manner; therefore, these problems should be analyzed using a nonlinear perspective (Farazmand, 2003). While there is some logic in this perspective, there is also the temptation to downgrade the linear approaches to forecasting and problem solving that have built up our knowledge in the business field over the past several decades. Much of the business and organizational research in management is based on these linear perspectives. To imply that chaos theory is somehow superior or exclusive means we must cast off the significance of previous research that used these linear approaches.

There is however, another problem with advocating the superiority of the chaos theory perspective - little empirical research in the management field is available that validates chaotic conditions. Instead, we must assume organizational life is nonlinear (and hence, capable of chaos) because we say it is. This leaves the management theorist/researcher and the popular press business writer in a bit of a quandary on how to use chaos theory at all. Thus, for the management researcher, the use of chaos theory is usually one of a metaphor, not a strict statistical tool that seeks to plot values in phase space. Indeed, the use of metaphors can be useful in understanding complex organizational systems (Morgan, 1997).

If we downgrade the application of chaos theory to a metaphor, does it mean it is no longer a superior framework to linear approaches to solving problems? Or, put another way, can chaos theory actually tell us much that cannot be explained with existing theories (Kincanon & Powel, 1995)? We believe chaos theory will add "some" unique perspectives to our body of knowledge on business and organizational life. It does provide a useful metaphor, but not necessarily a superior perspective that outclasses all other approaches. We offer that chaos theory is one of a number of tools and perspectives available to the organizational researcher and manager, but it is not one that should be assigned elevated status over any of the other perspectives.

# There are significant misunderstandings of the word "chaos", especially among popular business writers.

The most significant caveat that can be put forth in the context of this discussion is drawing attention to the apparent misunderstanding of the word chaos. Within the context of chaos theory, chaos refers to a system state characterized by sensitive dependence to initial conditions and unpredictability in the long run. However, some have used the more familiar definition, a state of being where events are random or out of control, to signify chaos. This comparison is incorrect (Kincanon & Powel, 1995) although one could see how the two definitions of chaos may be confused.

For others, the concept of chaos carries with it a sense of mystery and excitement about life (Stoppard, 1995). The appeal of chaos theory has been likened to a romantic appreciation of disorder that accompanies a corresponding reaction against the scientific appreciation for order and symmetry. One could further extrapolate that such a viewpoint advocates liberation from the constraints and bondage of a world obsessed with trying to bring order to every issue imaginable (Friedrich, 1988; Smith & Higgins, 2003). As we have pointed out though, this perspective is not consistent within the context of chaos theory.

#### So what's in it for Managers? - Three Perspectives to Consider

# 1. Managers should operate from the mindset that their organizations already exist within a chaotic system.

Open systems theory taught managers that their organizations exist within a larger system that exerts influences on the business, some of which are good, many of which are bad. We recommend this line of thinking be continued and not abandoned. However, chaos theory maintains that the organization exists within a system that ALSO has these two characteristics, sensitivity to changes in the initial conditions that the organization finds itself in, and, an inability on the part of the organization to make long-term predictions. Given this mindset, the application of a chaos theory perspective seems feasible.

What this means is that the organization continually finds itself within a system that is similar to meteorological phenomenon. Some days are certainly good days for the organization and life can be very nice, particularly when revenues are high, profits are being realized, and the economy is good. But all of that can change, and change substantially, with just a small jolt in the system. Certainly, the sub-prime mortgage crisis is an example of an initial condition in the economy that changed, causing a worldwide economic collapse. The point to remember is this – the system itself was already a chaotic system, even when times were good. A small change in initial conditions that produces big results is simply a characteristic of this system. Hence, the sensitivity to initial conditions.

Perhaps this example though is too familiar and simple to understand. Let's take another one that is less known. Industrial fires offer an example of events that are subject to sensitive dependence to initial conditions. In many of these accidents, a small, almost insignificant factor can serve as the trigger event that causes the fire to erupt. For example, under the right conditions, a concentration of dust can serve as a trigger event. Warner Lambert experienced such an event in November 1976, when a fire and explosion shook its chewing gum manufacturing plant in New York, culminating into a crisis that left six employees dead and 54 injured. The trigger event for the fire was thought to have been a stray electrical spark in the presence of magnesium stearate, a powdered lubricant used in the manufacturing of chewing gum (Sethi & Steidlmeir, 1997).

The concept of sensitive dependence on initial conditions maintains that the outcome of this event could have been dramatically different had something in the initial conditions been slightly different. For example, the stray spark was thought to have originated from a machine that was operating beyond its designed capacity, and, in close proximity to high levels of magnesium stearate dust (Sethi & Steidlmeir, 1997). Had the dust levels been lower, or had the machine been operating at its designed capacity, the explosion itself may have never occurred (Crandall, Parnell, & Spillan, 2010).

Examples abound of industrial accidents that were associated with sensitive dependence on the initial conditions of the system. The Exxon Valdez oil spill would have never occurred if the tanker had been on a course just a few meters away from the reef that it hit. In the tragic 1996 ValuJet Flight 592 crash, oxygen canisters were improperly loaded on the aircraft, which lead to a fire in the cargo compartment. Unfortunately, even though cargo compartments are not supposed to have air available to feed a fire, the oxygen containers themselves provided the fuel necessary to escalate the fire, sending the airliner uncontrollably into the Florida Everglades (Greenwald & Hannifin, 1996). Aircraft successfully take off and land every day, but when an accident does occur, it is often because of a slight change in the initial conditions that sends the event into the accident case files.

A second assumption of operating within a chaotic system is that long-term forecasts are difficult, if not impossible. This is a hard assumption for managers, who, let's face it, are in the business of planning and controlling. Nonetheless, their job requires that they make forecasts, define goals and implement action plans, all in an environment in which they often have little control.

Consider this example to illustrate the problem in making long-term forecasts in a chaotic system. Many managers face a dilemma related to management by objectives (MBO). In theory, MBO sounds good - line managers and their superiors work together to arrive at operational goals. However, what often occurs is that their supervising managers tell the line manager what bottom line profits goals should be by the end of the fiscal period. The line managers must then "figure out" how to hit that goal. Because slight changes in the working environment can occur, the line manager may not be able to hit certain goals, even though the variables that have changed have nothing to do with the line manager's interventions. For example, raw material prices can escalate during the fiscal period. This raises product cost, which raises cost of goods sold, and suddenly, the forecasted budget is out of sync. In reflection, this observation is not an indictment against MBO, but simply recognizing that small changes in the initial state of the organization and its environment can make longer term planning difficult – a fact that practitioners already know from years of operating experience.

To compensate for this lack of ability to make long-term forecasts, some management theorists and practitioners advocate contingency planning. Contingency theory advocates moving away from simple point targets, to exploring a realistic range of possibilities that could occur – possibilities that we say are likely in a chaotic system. However, even contingency planning can suffer from its own problems with long-term planning. For example, should we plan for a range of contingencies 20% higher or 20% lower? But is 20% right, or should it be 25%? This type of thinking can cause managers to regress back to a point target mentality instead of thinking in terms of true range possibilities. Point targets (one number) are seldom correct; therefore, it appears that the targets should cover a reasonable range.

One other response to recognizing that the manager's world resides in a chaotic system is to devote more time to the practice of scenario planning. This type of planning allows for a range of possibilities, and often aims at planning for crisis events. For example, oil companies plan for interruptions of oil in case a war breaks out in a region of the world. This type of planning focuses more on a range of potential events, as opposed to a range of potential outcome targets, such as sales, expenses, and profit margins.

# 2. Operating in a chaotic system is a unique mix of stability (strange attractors) and flexibility (adaptation to the changing environment).

Technically, the strange attractor is a quantifiable phenomenon found in phase space, However, among management writers, the strange attractor is usually discussed as a metaphor when analyzing organizational life. Management researchers have assigned various descriptive to the strange attractor. Murphy (1996) relates several studies that identify organizational culture as a strange attractor, particularly when an organization experiences a crisis. Organizational culture generally refers to a set of beliefs and values embedded within an organization. For example, Johnson & Johnson's strong belief in a focus on the consumer has been identified as an example of a strange attractor during the Tylenol poisoning crisis in 1982 (Murphy, 1996).

In the organizational realm, Dervitsiotis (2004) identifies unique styles of management as attractors. Likewise, Frederick (1998) ascribes an organization's values as its strange attractor. From this perspective, values can be likened to an organization's culture discussed previously. In other words, it is the organization's values that hold it together while it is going through the turmoil of a crisis.

From the crisis management literature, Sellnow and associates examined the 1997 Red River flood in Minnesota and North Dakota from a chaos theory perspective. They proposed that the United States National Guard and Federal Emergency Management Agency (FEMA) were the strange attractors since both agencies were instrumental in bringing order to a situation that was in the midst of a crisis. Thus, Sellnow's viewpoint maintains that the strange attractor can literally bring stability to a situation that is in chaos (Sellnow, et. al., 2002).

The implication for managers is this; some stability is needed to maintain the integrity of the organization during difficult times. However, the stability implied by a strange attractor is not the same as maintaining the status quo. The status quo usually implies that a change is needed in order for the organization to move forward. Furthermore, there are times management must move the organization through the change process so it can re-adapt to its new environment.

For example, changes to the organization are usually inevitable when a crisis hits. From a manager's perspective, the concept of self-organization asks the question: how does the company look different from what it was before the crisis? The 1997 Red River Valley flood resulted in an array of self-organization for the political units involved in disaster relief for that area. Murphy (1996) maintains that within a chaotic system, changes will also occur in the organization's system, changes that create a new order with positive dimensions. Sellnow and colleagues discussed how the 1997 Red River Valley flood prompted a reorganization of emergency services between the adjacent cities of Moorhead, Minnesota and Fargo, North Dakota (Sellnow, et. al., 2002). On the positive side, the two cities were formerly rivals, but after the flood, cooperative structures emerged whereby crisis communication was centralized through Fargo's City Hall.

#### 3. Operating on the edge of chaos is the norm, not the exception.

If we (as managers) assume that we are always operating in a chaotic system, then we no longer seek equilibrium as our goal, but instead, adaptation. With this assumption, we realize we are always operating on the edge of chaos. (Remember, chaos is simply that region within the chaotic system where we cannot make an accurate prediction, at all).

From a psychological viewpoint, the ability to function at the edge of chaos can spawn creativity and problem solving (Richards, 1996). Managerial writers have advocated that operating at the edge of chaos can be a good thing. The pressure it puts on organizations causes management to change the organization for the better or else die in the process. In fact, some note that organizations seeking to operate at a comfortable equilibrium may actually be in danger of failing in the long run (Pascale, 1999; Singh & Singh, 2002). Certainly, this is not a new observation by any means, as those in the strategic management field have been saying this very thing for years. What chaos theory does is to help us understand why this observation is true.

Brown and Eisenhardt (1998) have this to say about competing on the edge of chaos:

"Intense, high-velocity change is relentlessly reshaping the face of business in fledgling high-tech ventures and Fortune 500 giants, in steel and silicon alike. Everywhere, and in every industry, markets are emerging, closing, shrinking, splitting, colliding, and growing – and traditional approaches to business strategy are no longer adequate. To thrive in these volatile conditions, standard survival strategies must be tossed aside in favor of an entirely new paradigm: *competing on the edge.* 

Competing on the edge is an unpredictable, uncontrollable, often even inefficient strategy, yet a singularly effective one in an era driven by change. To compete on the edge is to chart a course along the edge of chaos, where a delicate compromise is struck between anarchy and order. By adroitly competing on these edges, managers can avoid reacting to change, and instead set their own rhythmic pace for change that others must follow, thereby shaping the competitive landscape – and their own destiny."

In his classic bestseller, Christensen (2000) suggests successful companies may be the most reluctant to change, because they believe what they are presently doing is what made them successful. As a result, they may suffer when their entrenched or "sustaining" technology is replaced by "disruptive" technology from a new competitor. He suggests that disruptive technologies rarely make sense during the years when investing in them is most important; consequently, conventional managerial wisdom at established firms becomes an entry and mobility barrier that entrepreneurs and investors can count on (Christensen, 2000).

Operating at the edge of chaos implies that with no equilibrium to retreat to, management must assign themselves the task of adapting and working through critical points in the organization's history. Andrew Grove, CEO of Intel, strongly supports the need to manage in turbulent times in his book *Only the Paranoid Survive, How to Exploit the Crisis Points that Challenge Every Company and Career* (1998). He describes how strategic inflection points must be confronted and managed during the life of a company. If managed correctly, strategic inflection points can be an opportunity for growth and success (at least until the next strategic inflection point occurs); if managed incorrectly, it can mean the demise of a company. He recalls the crisis faced by Intel during the 1980s when they struggled with the decision to vacate their strong position in memory chips and move more aggressively into microprocessors. Grove points out other strategic inflection points – superstores replacing neighborhood stores, talkies replacing silent movies, shipping containers replacing stevedores, and wireless communications replacing landlines. He stresses that strategic inflection points are difficult to identify ahead of time, especially for successful companies and suggests that top management listen carefully for early warning signs of change, both from within their company and from external sources.

Toyota's current experience with recalls is evidence that situations change dramatically, often seemingly arising from a small change in initial conditions that was not initially considered to be a major event.

#### Conclusion

As we write this paper, we can't help but think of its possible relationship with chaos theory. If we had written it a week ago, or a week from today (initial conditions), would it have been almost the same or would it have been significantly different? Would our thought patterns (unpredictable but within a given framework) have led to a somewhat different emphasis? Also, let's ask the obvious question, would this same exact paper, be rejected (or accepted) if sent to another meeting, where a different set of reviewers are utilized? (Note the change in initial conditions.) Most certainly, we have all experienced that; papers rejected at one meeting, were later accepted at another meeting, with the only change being a different set of reviewers.

As for the fate of THIS paper, we leave that in the hands of our current capable reviewers, who no doubt, are themselves operating on the edge of chaos, confronted with the potential bifurcation of accept or reject, (within the parameter of some undisclosed strange attractor of course).

#### References

Brodbeck, Peter W., (2002). Complexity theory and organization procedure design. *Business Process Management Journal*, 8(4), 377-402.

Brown, Shona L., & Eisenhardt, Kathleen M. (1997). The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations. *Administrative Science Quarterly*, 42, 1-34.

Brown, Shona L. & Eisenhardt, Kathleen M. (1998). *Competing on the Edge, Strategy as Structured Chaos*, Boston, Massachusetts: Harvard Business School Press.

Burns, B. (2004). Kurt Lewin and complexity theories: Back to the future? *Journal of Change Management*, 4(4), 309-325.

Butz, M. (1997). Chaos and complexity. Washington, DC: Taylor & Francis.

Closs, David J., Jacobs, Mark A., Swink, Morgan, & Webb, G. Scott (2008). Toward a theory of competencies for the management of product complexity: Six case studies, *Journal of Operations Management*, 26(5), 590-610.

Crandall, W.R., Parnell, J., & Spillan, J. (2010). *Crisis Management in the New Strategy Landscape*. Thousand Oaks, CA: Sage Publishing.

Christensen, Clayton M., *The Innovator's Dilemma*, Collins Business Essentials, Harper Collins, New York, 2000.

Dervitsiotis, K. (2004). Navigating in turbulent environmental conditions for sustainable business excellence. *Total Quality Management*, 15(5-6), 807-827.

Dhillon, Gurpeet, & Fabian, Frances (2005). A fractal perspective on competencies necessary for managing information systems, *International Journal of Technology Management*, 31(1,2), 129-139.

Dolan, S. L., Garcia, S., & Auerbach, A. (2003). Understanding and managing chaos in organizations, *International Journal of Management*, 20(1), 23-36.

Farazmand, A. (2003). Chaos and transformation theories: A theoretical analysis with implications for organization theory and public management. *Public Organization Review*, 3, 339-372.

Frederick, W. (1998). Creatures, corporations, communities, chaos, complexity: A naturological view of the corporate social role. *Business and Society*, 37(4), 358-389.

Friedrich, P. (1988). Eerie chaos and eerier order. *Journal of Anthropological Research*, 44(Winter), 435-444.

Gleick, J. (1988). Chaos: Making a new science. New York, NY: Viking Penguin.

Greenwald, J., & Hannifin, J. (1996). Tragedy retold. Time, 148(25), 57.

Grove, Andrew S., (1998). Only the Paranoid Survive, How to Exploit the Crisis Points that Challenge Every Company and Career, New York, NY: Currency Doubleday.

Hurtado, Pedro (2006). Will the real complexity in strategic management please stand up? *Competition Forum*, 4(1), 175-182.

Kincanon, E., & Powel, W. (1995). Chaotic analysis in psychology and psychoanalysis. *The Journal of Psychology*, 129(5), 495-505.

Lorenz, Edward N., (1993). *The Essence of Chaos*, Seattle, Washington: University of Washington Press.

Loye, D., & Eisler, R. (1987). Chaos and transformation: Implications of nonequilibrium theory for social science and society. *Behavioral Science*, 32 (January), 53-65.

Mason, Roger B., Staude, Gavin (2009). An exploration of marketing tactics for turbulent environments, *Industrial Management + Data Systems*, 109(2), 173-190.

Mason, Roger B. (2006). Coping with complexity and turbulence – An entrepreneurial solution. *Journal of Enterprising Culture*, 14(4), 241-266.

McDaniel, R., Jordan, M., & Fleeman, B. (2003). Surprise, surprise, surprise! A complexity view of the unexpected. *Health Care Management Review*, 28(3), 266-278.

Morgan, G. (1997). Images of Organization (2nd ed.). Newberry Park, CA: Sage.

Murphy, P. (1996). Chaos theory as a model for managing issues and crises. Public Relations Review,

22(2), 95-113.

Nelson, William H. M. III, & Nelson, Anne (2004). Re-evaluating the business sourcing model in electronic commerce initiatives. *Journal of Applied Management and Entrepreneurship*, 9(2), 34-56.

Pascale, R. (1999). Surfing the edge of chaos. Sloan Management Review, 40(3), 83-94.

Richards, R. (1996). Does the lone genius ride again? Chaos, creativity, and community. *Journal of Humanistic Psychology*, 36(2), 44-60.

Samli, A. Coskun (2006). Surviving in Chaotic Modern Markets: Strategic Considerations in Turbulent Times, *Journal of Marketing Theory and Practice*, 14 (4), 315 -322.

Sellnow, T., Seeger, M., & Ulmer, R. (2002). Chaos theory, informational needs, and natural disasters. *Journal of Applied Communication Research*, 30(4), 269-292.

Sethi S., & P. Steidlmeir, P. (1997). *Up Against the Corporate Wall* (6<sup>th</sup> ed.). Upper Saddle River, NJ: Prentice Hall.

Singh, H., & Singh, A. (2002). Principles of complexity and chaos theory in project execution: A new approach to management. *Cost Engineering*, 44(12), 23-33.

Smith, A. (2002). Three scenarios for applying chaos theory in consumer research. *Journal of Marketing Management*, 18, 517-531.

Smith, W., & Higgins, M. (2003). Postmodernism and popularization: The cultural life of chaos theory. *Culture and Organization*, 9(2), 93-104.

Stoppard, T. (1995). Extract from Acadia in John Carey (Ed.). *The Faber Book of Science,* London: Faber and Faber, 502-503.



Figure 1 – A Bifurcation Diagram illustrating the Onset of Three Regions of Chaos

X-Axis: System Parameter that is adjusted

Adapted from Crandall, W.R., Parnell, J., & Spillan, J. (2010). *Crisis Management in the New Strategy Landscape*. Thousand Oaks, CA: Sage Publishing, page 222.