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# Identifying Complex Adaptive Systems Using Quantitative Approaches At A Midsized Biotechnology Firm

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# IDENTIFYING COMPLEX ADAPTIVE SYSTEMS USING QUANTITATIVE APPROACHES AT A MIDSIZED BIOTECHNOLOGY FIRM

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# DEDICATION

To Ashley, who supported me through many late nights, long weekends, and all the ups and downs in between. I love you and could not have done this without you.

To Ted, for constantly reminding me to look at things from a new perspective.
To Steve, for your willingness to listen, words of encouragement, and invaluable counsel.
To Scott, for all of your support, and checking in to help keep me grounded and moving forward.

To Gramma, Elton, John, Callie, and all of my family and friends near and far. Thank you all.

*For my mom and dad.*
*And most of all, for my brother.*

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# ABSTRACT

Rapid technological progress is becoming more challenging for organizations to implement and manage. The traditional, hierarchical leadership models are often inadequate to cope with continuous change, and the inability to keep up with the latest advances can quickly imperil a company. In particular, the field of biotechnology is currently experiencing revolutionary advances. Where hierarchical leadership models lapse, complexity theory and complexity leadership theory may provide an alternative leadership model for successful organizational adaptation. However, much of the research surrounding complexity theory remains academic. Historical data from a biotechnology company was analyzed during a computer hardware and software upgrade to detect the presence of a complex adaptive system, the fundamental component of complexity. Results showed that after the upgrade, animal care technicians did not significantly increase their collective efficiency; instead, they appeared to significantly increase their collective accuracy. This might indicate that the animal care technicians acted as a complex adaptive system in response to an environmental change. Insights into aggregate employee behavior through the lens of complexity theory might be useful to leadership seeking to successfully implement organizational change. Additionally, the adoption of complexity leadership doctrines by management might help create enhanced conditions to cultivate increased innovation and growth.

# CHAPTER 1

# INTRODUCTION

The study of leadership is deeply intertwined with the with the history of human social development. Bass (2008) explains that as relatively simple communities developed into civilizations, the role of leadership evolved in every known ancient culture. Over time, the image of successful leadership tended to center around the single charismatic savior, who either held the power to mobilize their people, or perhaps even had divine favor (Osselaer et al., 2020). For example, the Mongol Genghis Khan, perhaps one of the greatest individual leaders of all time, was endowed with nearly deific status after sweeping across Asia and Europe, creating one of the largest empires in history (Greene, 2000). It is not surprising that modern business organizations mimic this model, given the conditions of the competitive marketplace.

However, during the post-industrial era, this long-standing paradigm has shifted. The rate of innovation and advances in technology is accelerating, and in many cases, the traditional leadership approaches have been inadequate to cope with the necessary rapid adaptation (Regine & Lewin, 2000). The level of organizational sophistication has increased substantially, particularly in the era of globalization, and senior management is struggling to adapt to the near continuous process of change. It is estimated that nearly 70% of organizations have met with varying degrees of failure while undergoing a change initiative (Islam et al., 2020).

The field of biotechnology is currently experiencing a prolonged period of rapid global growth. In the past two decades, the industry has been the recipient of a variety of encouraging drivers, including beneficial government policies, increased private investment, and increasing demand; by 2028, the total market capitalization is expected to exceed $2.44 trillion (Grand View Research, 2021). As a result, the rapid influx of technological advances has created a turbulent environment where effective change management is a necessity to the survival of a business (Clarke, 2013).

Where the traditional, hierarchical based leadership models have lapsed (Regine & Lewin, 2000), there is a necessity to identify alternative methodologies that will provide senior leaders with an effective mechanism for both organizational and change management. If companies cannot successfully cope with increased technical change, leadership will be unable to adequately respond to critical future challenges, threatening the viability of the entire system (Schneider et al., 2017). This is especially critical to those organizations at the forefront of rapid technological and market growth, including the field of biotechnology. Burnes (2005) notes that complexity theory is being increasingly viewed by both academia and in the field as a potential model to effectively understand and govern larger and more diverse organizations.

Advocates of complexity theory propose that, in addition to the influence of formal leaders, organizations are also deeply influenced by a concealed network of “rich interconnectivity” (Uhl-Bien & Arena, 2017, p. 9). However, when faced with increasingly complex problems, many organizations are still attempting to implement simplistic solutions and limit interconnectivity, rendering management less and less effective (Baltaci & Balci, 2017).

Rather than reject the initial chaotic conditions caused by change, proponents of complexity theory argue that this is a natural state, and in fact necessary in order for the overall system to regain equilibrium and achieve growth (Fullan, 2001). Wheatley (2006) argues that during disequilibrium, systems fundamentally reorganize themselves and adapt to the new stimuli in novel ways. This adaptation is both unavoidable and uncontrollable, although it may be possible to “disturb them” in the direction of the desired outcome (Fullan, 2001, p. 108). The idea that complexity may be applied to leadership theory was proposed as complex leadership theory in 2001 (Marion & Uhl-Bien, 2001); and then as complexity leadership theory (Uhl-Bien et al., 2007). While not explicitly using the lexicon of complexity theory, Wheatley (2006) provides a vivid description of the characteristics of complexity, including excellent analogies of how behavioral systems might react under environmental pressure. Therefore, for the purposes of this research, Wheatley's descriptive accounts were utilized for comparison to actual observations.

A mid-sized biotechnology research company, referred to as Biotech X for this study, operates multiple locations across the United States. Growth in scope and innovation has caused the company to expand both in scale and diversity of offerings. The increasing pace of technological change is creating stress on the organization. As previously argued by Regine and Lewin (2000); the conventional, top down leadership strategies may be inadequate for the company to regulate, and alternative methods should be explored.

## Definitions of Key Terms

*Complex Adaptive System:* Networks of interdependent social networks forming a cooperative, dynamic system capable of solving problems and adapting to environmental changes (Uhl-Bien et al., 2007).

*Hierarchical Model:* A stratified leadership model in which the top tiers (management) direct the actions and resources of the bottom tiers (labor) (Osborn & Hunt, 2007).

*Transactions:* For the purpose of this study, the electronically recorded animal care data entered by the animal care technicians throughout the workday.

## Statement of the Problem

Rapid growth of a company creates new layers of complexity, and each additional stratum makes organizational coherence extremely difficult for traditional leadership models to manage (Regine & Lewin, 2000). Bass (2008) notes that there is inherent conflict between long-term ideals of any transformative process and the short-term efficiency of transactional leadership. The introduction of a competing value into an organization, such as the adoption of a new technology, creates tension. Bass (2008) states that this often places mid-level managers or supervisors under heavy stress from both above and below, as they attempt to align the ideals of both scenarios. The failure to reconcile this difference may damage the relationship dynamic between senior leadership and mid-level management. Fullan (2001) argues that, aside from a strong moral purpose, good relationships are the most critical aspects of a healthy organization.

The current prevalent leadership models are top-down, bureaucratic entities largely created in response to the rise of the Industrial Age, emphasizing strict mechanical controls and the attainment of high production (Baltaci & Balci, 2017). However, as the technological frontier continues to evolve at a rapid pace, the hierarchical leadership approach is struggling to find adequate solutions within the expected linear, direct cause-and-effect paradigm (Clarke, 2013). The sophistication required to guide firms through organizational change is becoming too difficult; as a result, companies are “often unable to complete the change process successfully” (Islam et al., 2020, p. 25).

Complexity theory is viewed as a model for the simplification of dynamic, intricate systems (Manson, 2001). While the broad spectrum of organizational interactions may appear to be unpredictable, the entire structure might in fact be governed by a relatively simple set of ordered rules (Burnes, 2005). Leadership, instead of being considered as an implemented command structure, might instead be considered as an emergent property of complexity, the inevitable result of continuous interactions between system components (Tourish, 2019). Marion and Uhl-Bien (2001) propose that the focus of leadership should be guiding and fostering effective interactions within the system, rather than direct control. Complexity leadership theory may be more attractive than the standard complexity theory model, as the latter allows for a reversion into organizational chaos as an acceptable outcome in response to change (Wheatley, 2006). While this may be a satisfactory mathematical consequence, the pragmatic value of this within a company may be limited. Fullan (2001) advises that the role of leadership may be to gently influence the system toward the desired outcome, instead of attempting to dictate a result.

Over the past two decades, the ability to map and sequence novel genes has improved exponentially, and gene editing technology was revolutionized by the discovery of *Clustered Regularly Interspaced Short Palindromic Repeat Sequences* (Vidyasagar, 2018). To remain relevant within the industry, senior management at Biotech X has a vested interest in the ability to successfully introduce technological changes to the organization. The inability to keep up with modifications in the technology may render Biotech X obsolete in a very short period of time, as competitors will move to fill the gap. Reminiscent of Moore’s law of the exponential doubling of computing power, it is quite possible that future technological revolutions will be measured in months, instead of years (Tardi, 2021). If this is in fact the case, the stress levels placed on the animal care division at the company may increase as well.

Additionally, it is difficult to completely homogenize training techniques between multiple geographic locations (Neely, 2015). In the specific case of Biotech X, local operating nuances may create small deviations in standard operating procedures. Without careful monitoring, this introduces the possibility of negative influences on the finished product. Altered methods might create an unwanted divergence of disease expression, which may negatively affect customer research. In the field of research, the faithful reproducibility of an outcome is critical in order to validate precedent studies; indeed, there is already substantial evidence of a growing crisis of “false positive non-replicable results” (Szucs & Ioannidis, 2017, pg. 1). These issues are compounded by the necessity to operate at multiple sites within a high growth environment.

Even under optimum circumstances, those who do not desire change can find numerous ways to impede or undermine the best laid plans (Kotter, 2012). Although Biotech X conducts research, the commercial division is essentially a manufacturing business. In manufacturing, increasing overall efficiency is very highly regarded in order to minimize costs and maximize profitability (Nordmeyer, 2019). The rapid introduction of new methods and processes has created significant stress inside the industrial end of the organization at Biotech X. An in-depth examination of Biotech X from the context of complexity theory may address this issue.

## Purpose of the Study

The purpose of this quantitative correlational study was to examine the relationship between individual employee behaviors and complexity theory within a single business unit of Biotech X. The research sought to determine if animal care technicians, each acting independently, collectively displayed the traits of a complex adaptive system, the fundamental unit of complexity theory (Uhl-Bien et al., 2007). What is unknown is whether the collective behavior of the animal care division of the biotechnology company functions as a single, aggregate unit. The study assessed to what extent the independent transactions of individuals collectively behave as a single overarching social network, a hallmark of complexity, as proposed by Marion and Uhl-Bien (2001). If complexity theory may be considered as a viable leadership model for Biotech X, it should be demonstrated that the organization displays the properties of a complex adaptive system (Uhl-Bien et al., 2007).

The author proposed that a study of technician organizational activities might reveal the underlying network of “rich interconnectivity” described by Uhl-Bien and Arena (2017, p. 9). If this could be affirmed, the complexity theory model might provide an effective tool for Biotech X’s leadership to manage both the daily organizational command and control functions, as well as change initiatives. If it could be demonstrated that the sum of the organization behaves as a single, dynamic system, senior leadership could make effective operating decisions and corrections at a more holistic level.

## Research Questions

The study proposed to examine two research questions:

**Research Question 1:** Can the traits of a complex adaptive system, as described by Regine and Lewin (2000), be detected quantitatively through the analysis of routine data generated by individual employees in the animal care department of Biotech X?

**Research Question 2:** If a complex adaptive system is present in the data, does the complex adaptive system display distinguishable traits of either Wheatley’s (2006) complexity theory or Marion and Uhl-Bien’s (2001) complexity leadership theory?

If the behavior of the employees does act in an interconnected, systemic manner, this may help to provide Biotech X’s management with insights into complex group performance. Returning to the problem of change implementation, if the organization reacts as a collective, viewing the behavior of the group dynamic would be useful when implementing an alteration to procedures. Additionally, Uhl-Bien and Arena (2017) propose that complex organizational systems exhibit emergence, defined as the creation of novel relationships during the return to equilibrium after reorganization. This knowledge may be useful when observing unexpected outcomes throughout the organization.

The implication of this concept is critical. During a change initiative, unintended consequences might not appear proximal to the original change, instead expressing itself in another location, perhaps a separate department. The ability to recognize these events and treat them as an adjunct of the original modification, rather than a detached event, may allow leadership to respond in a more appropriate manner.

The final question may relate to system controllability. Presuming that the complex network does react to external stimuli in the manner described by Wheatley (2006), one possible implication is that there is a level of predictability present. Manson (2001) describes deterministic complexity as the concept that although the total operation of an organization may seem to have infinite variables, in fact the entire order may be regulated by a few key order generating rules. If some of these rules could be identified, they could be useful as a tool for leadership, as they attempt to manage the system.

## Conceptual and Theoretical Framework

The conceptual framework provides both the scaffolding and the scope of boundary for a study (Roberts & Hyatt, 2019). The conceptual framework is typically composed of three components; the researcher’s interest, the relevance of the context in a broader scale, and the theoretical framework (Bloomberg & Volpe, 2019). This researcher has worked at the management level in biotechnology for more than two decades and has a vested interest in improving both the efficiency and capability of operations. An understanding of the work of individuals when viewed as a collective within the company is of interest; however, if the findings can be affirmed, the study may have a more general relevance both across the field of biotechnology and perhaps in other industries.

The theoretical framework is the underlying concept utilized to provide context to the phenomenon that is being observed (Roberts & Hyatt, 2019). It may provide clarity into the relationship between variables and anchors the information into a broader setting (Merriam & Tisdell, 2016). In this case, complexity theory was utilized as the theoretical framework with which to guide this study, although as this research is pertinent to leadership, elements of complex leadership theory as proposed by Marion and Uhl-Bien may also be relevant (Bass, 2008). Modern complexity theory arose within the past few decades as a branch of chaos theory and has a broad application in multiple scientific disciplines (Mason, 2008). Complexity theory incorporates the diversity of all elements within a system and attempts to provide a deeper understanding of how small, linear cause-and-effect models are influenced by external unpredictability (Regine & Lewin, 2000).

## Assumptions, Limitations, and Scope

The study was premised on several initial assumptions. A primary assumption was that while the employees are working toward the same goal, they are not colluding with one another on a large scale to manipulate data. While the dishonesty of individuals cannot be discounted, for the purposes of the research, it was assumed that the employees transact their daily work in good faith and with a reasonable degree of accuracy. It was also assumed that the collected data generated by the employees is maintained with a high degree of integrity, since the transactions are validated by the information technology department daily, and the subsequent information is utilized by other departments routinely.

A major limitation of the study is that it relies on archived historical data. Biotech X’s technicians electronically record their work, and each person records hundreds of transactions during each shift. If there is a question regarding a transaction, it is unlikely that a technician would have a specific recollection about the event. Therefore, it would be difficult to contextualize any larger significance of any one moment. However, as this study was primarily focused on aggregate behavior, the interpretation of discrete events should not be necessary. If it becomes necessary to interpret individual transactions, this might be an indication that complexity is not a good model for Biotech X.

Finally, in order to maintain a narrow focus and remove potential variables, the study was limited to those employees working on a single, genetically homogeneous species. It is possible that the data generated from this study may be representative of only this subset of subjects, and not necessarily applicable to a wider application. If the analysis confirms the research questions, further studies extending the selection may be of interest.

## Rationale and Significance

This importance of this study cannot be understated; the economic survival of an organization might depend on the recognition of an imminent problem at a critical moment. For example, in the early 1990s, Kmart executives attempted to compete with Wal-Mart on price points but failed to recognize the innovation of Wal-Mart’s complex supply chain system, which had been largely developed with the assistance of the rank and file employee base (Power & Mitra, 2016). This failure to recognize complexity contributed to the eventual Kmart bankruptcy (Power & Mitra, 2016). Attending to an issue early saves on human and material resources and prevents the deterioration of morale. With a clearer understanding of the systemic operating rules, it is also possible that they could be utilized as a dashboard metric to gauge the success or failure of a change initiative. This in turn would give leadership more time for a course correction.

Rather than initiating a change, forcing a system to remain in equilibrium over a short period may also be beneficial to the transformational leader who is looking to stabilize a crisis. Alternatively, the presence of equilibrium may indicate a problem. If a change initiative was expected to have an impact, and none is in fact detected, this is a signal that the system did not experience conflict. Prolonged states of equilibrium may be signs of decay, or even the imminent “death” of an organization (Fullan, 2001, p. 74).

In addition, an understanding of these complexities in one organization could have direct applications in other manufacturing environments. The general state of American manufacturing is in turmoil, and this is likely to get worse (Tappe, 2019). The discovery of stress-signaling mechanisms in frontline manufacturing processes could be extremely valuable to unrelated industries. In some cases, it might be possible to directly integrate these indicators to an entirely separate process, as general manufacturing principles have many similarities across business lines. In the current ultracompetitive market environment, teaching middle-level managers to correctly recognize and interpret these signs could save significant remedial time. According to the seminal work of Becker (1965), time is perhaps the most important commodity in capitalist exchange.

## Conclusion

The biotechnology sector has enjoyed extraordinary success over the past few decades; it is likely to continue that trajectory into the foreseeable future. However, these achievements come at a price. Organizations must find ways to constantly balance the relatively static manufacturing processes with the implementation of cutting-edge science. The pace of all business transformation will only increase as new technological advances are routinely adopted (Gest, 2019). Therefore, the survival of the institution depends on the ability to navigate extremely complex issues in short order. This is especially paramount in an expanding industry that depends on both high-volume manufacturing and continuous technological innovation.

The benefits of improved relations between frontline technicians and management must not be overlooked. If more effective, innovative models of management can be identified, the perception of improvement by entry-level technicians may increase their levels of confidence toward leadership. Greater feelings of trust improve the odds of more harmonic interactions among the groups, and perhaps even reduce conflict ideology. Employees who experience greater feelings of trust toward leadership report higher levels of job satisfaction, and increase efforts to innovate (Bass, 2008).

These ideas are not unique to one institution; they may have applications for other interested parties. The ability to rapidly diagnose and treat the maladies of any industry process from a higher level would be very appealing to a variety of constituents and could even potentially salvage an otherwise lost business platform. The cascade effects of staving off the bankruptcy of even one firm could be profound to a local economy. In the highly competitive marketplace where companies like Biotech X operate, every advantage is crucial, and a single element might make all the difference.

# CHAPTER 2

# LITERATURE REVIEW

The hierarchical models of leadership maintain the dominant position in organizational governance, although Baltaci and Balci (2017) argue that these models lack the flexibility required for a turbulent, expanding environment. While there have been alternative concepts developed, many of them still rely on the influence of top-down leadership to stimulate activity. For example, transformative leadership continues to enjoy widespread popularity in the field of organizational research (Islam et al., 2020). For groups undergoing significant change, the ability to model behavior, articulate direction, connect emotionally, and inspire others into positive action are noted by Bass (2008) as being highly regarded by frontline employees.

Likewise, there has been a high degree of interest in the study of complexity theory. The inner workings of complexity can be found in a number of areas, ranging from “multinational corporations . . . mass extinctions . . . ecosystems, or even human consciousness” (Manson, 2001, p. 405). As both traditional leadership and complexity theory relate to the interaction of systems, and in particular to the influence or control of those systems, it is important to critically examine their relationship to one another (Marion & Uhl-Bien, 2003). While there is great promise in complexity, Tourish (2019) suggests that the full theory as it relates to leadership is still significantly underdeveloped. Marion and Uhl-Bien (2003) also posit that both transformative leadership and complexity theories are in fact part of a broader theory of complex leadership; later restated as complexity leadership theory by Uhl-Bien, et al. (2007).

As complexity theory is an integral component of overall systemic function, applying it in the context of organizational development would be of great interest to leadership (Manson, 2001). A mechanism to better understand the intricacies of organizational behaviors beyond those induced by management could be valuable, especially during moments of high stress caused by rapid change. Specifically, this researcher was interested in viewing the events surrounding a change initiative at Biotech X to determine if the behaviors of individual employees, when viewed in the aggregate, adhered to the principles of complexity theory. The study may provide substantive insights into the influences that impact the outcome and establish if utilizing a complexity model could be an appropriate management tool.

Despite the high levels of interest, there appears to be a marked paucity of actual research into complexity theory as it specifically relates to leadership. Tourish (2019) notes that “despite the growing popularity of complexity theory in organization studies, attempts to apply it to leadership are still in their infancy” (p. 2). One reason for this lack of literature may be that complexity theory is so diverse. Many researchers cannot even completely agree on a working definition, as volumes of new concepts are routinely “traded across disciplinary boundaries” (Manson, 2001, p. 405).

Another possibility is that fully capturing the concept in a meaningful way might be problematic; even the definition of complexity implies a difficulty of understanding (Oxford Learner’s Dictionaries, 2021). Indeed, the available literature appears to be overwhelmingly qualitative, and there are apparently few, if any, quantitative studies at this time (M. Uhl-Bien, personal communication, September 22, 2021). However, Burnes (2005) has argued that while it is likely impossible to calculate the workings of a system with a potentially infinite number of variables, it is possible to demonstrate that the holistic structure may be regulated by a simple set of ordered rules. He cites the work of Edward Lorenz, who successfully reduced the extremely complex behavior of weather patterns into a predictable, deterministic algorithmic model consisting of just a few simple equations (Lorenz, 1993, as cited by Burnes, 2005). Adapting such a model to organizational complexity could have significant potential.

## Organization

The objective of this literature review was to provide a brief outline of complexity theory, and how complexity might be extracted from theoretical perspective to apply in physical leadership situations. A short section provided background into the growth of biotechnology. In addition, this chapter reviews complexity leadership theory, proposed as a stand-alone concept apart from complexity theory (Marion & Uhl-Bien, 2001). The literature review highlights the importance of complexity theory, and ways in which complexity may be utilized. Ultimately, this researcher sought to answer if the foundations of complexity theory can be identified and provide a functional tool for an organizational leader to utilize in real-world scenarios.

## Conceptual Framework

The development of large, industrial organizations over the past century has created significant problems for management theorists (Baltaci & Balci, 2017). Since the industrial revolution of the nineteenth century the pace of technological advance has expanded, rapidly increasing both the scale and complexity of business. As a result, many of the effective traditional structures of organizational management have become obsolete (Bolman & Deal, 2013). Many leadership models are now struggling to develop functional methodologies to cope with the continuous evolution of the new dynamics (Baltaci & Balci, 2017). It is estimated that 70% of organizations experience some form of failure in change initiatives (Islam et al., 2020).

Given the high degree of difficulty experienced by organizations to adequately manage conditions of change, researching the mechanisms by which these failures occur would be of great interest to the field of leadership research. Additionally, the development of functional metrics to measure variations within an evolving environment may have practical value for frontline leadership. Where traditional leadership methods fail to cope with the numerous interactions that occur throughout a large working group, reframing organizational behaviors through the lens of complexity theory may be a promising alternative.

## Researcher's Personal Interest

The field of biotechnology is currently experiencing massive economic growth; the value of the biotech index on the National Associations of Securities Dealers Automated Quotations (NASDAQ) has tripled from 2000 to 2018 (Rudden, 2020). By 2024, the index is expected to more than double once again, with an expected global market capitalization exceeding $729 billion (Ugalmugle & Swain, 2019). This researcher has worked in management at a commercial biotechnology firm for more than two decades. The development and distribution of engineered biologics requires absolute precision, as deviations in production methods can lead to confounding experimental results. The management of production is extremely challenging and requires the daily coordination of hundreds of employees working in numerous vivarium facilities. The constant development of technological innovation requires the company to be extremely adaptable; as a result, change initiatives are frequent. Not surprisingly, the implementation of chronic transformation throughout a large, multilayered organization can be turbulent. In many cases, the expectations of senior leadership cannot be fully realized, there is a significant delay, or management ends up settling for less than expected.

Some issues connected to change initiatives may be anticipated. As with many implementations, there may be some resistance to the requested behavioral alteration. This is not surprising, as employees involved in the process of change often experience negative emotions and attempt to avoid the change (Kearney & Hyle, 2003, as cited by Anfara & Mertz, 2015).

Once these types of problems are identified, remedial steps can typically be taken to help guide employees toward the new process, although sometimes the reaction of leadership is delayed.

In other events, the new change appeared to produce an unexpected consequence. These reactions often occurred in some other area of the organization and did not appear to have any relationship to the original change. Management has historically struggled to identify these novel resistance events and often did not correctly attribute the root cause of the problem. Much time and energy were consumed attempting to fix the unexpected obstacle, only to have another event randomly appear somewhere else within the organization.

## Theoretical Framework

A theoretical framework is a construct that identifies the variables and factors of a study, as well as the potential relationships that may exist among them (Roberts & Hyatt, 2019). A theoretical framework is necessary to a body of research, as it defines the scope of the work to be examined, provides both a scaffolding and anchor point with which to contextualize acquired information and place it into a broader setting (Merriam & Tisdell, 2016). A proper theoretical framework provides clarification into the research problem, guides the direction of the study, and assists in the interpretation of the results (Roberts & Hyatt, 2019).

Research into leadership theory and organizational management has been conducted for millennia. Bass (2008) notes that formal documentation of leadership principles has existed since at least 2300 BCE. However, as previously mentioned, advances in technology and commercial globalization have created larger companies with greater economic reach. Walmart alone employs more than 2.2 million people as of 2019, making it the largest company in the world by population (Duffin, 2020). As more companies reach greater scale, the ability to adapt to rapidly changing conditions become more difficult (Regine & Lewin, 2000).

Curiously, not every unplanned event has a negative consequence. In some cases, an unexpected outcome can also be serendipitous. For example, in 1995, Craig Newmark started an online email list of social events near San Francisco for his friends; however, the site was quickly overtaken by other users promoting good and services, and the Craigslist site is now worth more than $1 billion (Doubek & Kelly, 2020). Unanticipated outcomes can provide a significant boost to an organization under the right circumstances.

Along with increased scale comes amplified levels of organizational complexity. O'Neill and Nalbandian (2018) determined that as organizations become more complex, the leadership of those firms are under increasing pressure to face problems that lie outside of their traditional spheres of expertise. In order to solve these problems, leaders must enlist the aid of experts, increasing the collective scope of the system (O'Neill & Nalbandian, 2018). However, this behavior implies a continuous feedback loop of never-ending, intensifying complexity. Mason (2007) reiterates this, directly stating that as systems increase complexity, adaptation becomes increasing more problematic.

In an examination of the health care industry in the United States, Weberg (2012) found that traditional leadership methodologies were conflicting with the rapid evolution of medicine, causing severe dysfunction to the overall system. Uhl-Bien and Arena (2017) affirmed this, citing health care as the sector most drastically affected by intensifying levels of complexity. In education, Kershner and McQuillan (2016) contend that the increased complexity of school regulation has created a "badly failed 'system'" (p. 4), and reform efforts have fallen miserably short.

Unfortunately, the conditions responsible for the creation of such extraordinary stress are unlikely to abate. Clark (2013) notes that the rapid evolution of social order, technology, and economics are likely to drive ever increasing levels of instability well into the foreseeable future. Baltaci and Balci (2017) argue that the traditional leadership methodologies are no longer relevant. They even dub the new century as “the chaos era,” leaving the information era as a historical footnote alongside the industrial and postindustrial eras (p. 32).

For those organizations that cannot successfully adapt, the unattractive alternative is extinction. Burnes (2005) relates that the key to organizational survival in turbulent times is the implementation of new adaptive rules; if firms retain too much stability, they cannot change, and the entire system perishes. From these exemplars, it is apparent that companies and organizations in a multitude of fields are in crisis. Without the tools to successfully navigate these changes, for many firms the outlook is not good.

There are several modern theories of leadership that may provide at least some assistance to organizations struggling with increasingly complex changes. For example, transformational leadership theory seeks to empower and enable followers to more fully realize their potential (Turnidge & Cote, 2018). However, transformational leadership theory has received significant criticism in recent years, particularly among those in the field of education (Andersen, 2015; Berkovich, 2016). This researcher has selected two potential alternate candidates that might be appropriate for both the remediation of organizational stress, and that could provide a theoretical framework in which to better contextualize the observed instability described above. The two relevant theories are complexity theory and the closely related complexity leadership theory.

## Complexity Theory

Originally developed more or less independently in other fields, such as physics, biology, and economics, complexity theory arose as a branch of chaos theory (Mason, 2008). Complexity theory attempts to illuminate the systematic interactions of large numbers of elements within a dynamic environment, and how these interactions move beyond the linear, simple cause-and-effect models to incorporate the element of unpredictability (Marion & Uhl-Bien, 2001). While complexity theory has received extensive attention in the more physical disciplines, it was relatively unknown to the social sciences until the turn of the twenty-first century (Mason, 2008).

Unlike the hierarchical leadership models, such as great-man theory, trait theory, and transactional leadership, complexity theory integrates the multitude of day-to-day microdynamics that occur within a group setting, instead of just those activities relating to command and control (Bass, 2008). Marion and Uhl-Bien (2003) note that complexity theory is often slightly at odds with established models precisely because the emphasis is placed more on network behavior as opposed to the limitations of leadership initiatives. Wheatley (2006) points out that large organizations display many of the properties of complex, networked systems naturally, sometimes oscillating on the edge of chaotic behavior in order to produce growth.

### ***Strengths of Complexity Theory***

Complexity theory is appealing because it accounts for the totality of the interactions within an organizational system that lie beyond the scope of leadership activity (Bass, 2008). The recognition that group behavior is influenced by more than leadership direction is important. While complexity theory can be complicated to understand (discussed below), there are potential representations that might approximate complex behavior.

Another strength of complexity theory is that it encourages innovative behavior. Most entrepreneurial systems are innovative; however, as they develop, there is a conversion to the constraints of repeatability and efficiency gain (Uhl-Bien & Arena, 2017). This gravitation toward repetition leads to organizational rigidity, and the inability to quickly respond to turbulence and competitive challenge precedes strategic obsolescence (Mason, 2007). Retaining the principles of complexity theory allows for the existence of some disorder, which in turn self-organizes parts of the system into new arrangements of order (Wheatley, 2006). In a vigorous environment, the two philosophies of order and disorder may duel for hegemony, inducing periods of both stability and experimentation (Uhl-Bien & Arena, 2017).

Manson (2001) proposed that small, deterministic mathematical models might provide such an approximation in which to frame organizational behavior. He describes mathematical attractor equations as a possibility, as they utilize a few variables to determine complex systemic behavior. Burnes (2005) expands on this idea, suggesting that large, unpredictable systems may in fact be governed by "a small number of simple order-generating rules" (p. 77).

### ***Weaknesses of Complexity Theory***

One significant weakness of complexity theory is that it can be extremely difficult to appreciate fully. Burnes (2005) recognizes that leaders are struggling to keep up with increasing levels of complexity and are often overwhelmed. As the theory accounts for the innumerable interactions of an organization, it is not surprising that complexity theory is viewed as difficult, often causing a reactionary withdrawal response from leadership (Uhl-Bien & Arena, 2017).

Since complexity theory is focused on the totality of the system, there may be a perceived negligent attitude toward morality. Wheatley (2006) contends that destruction is sometimes a necessary element for the establishment of new order. As complexity seeks to find the most efficient network solution, occasionally this might conflict with the human element. Any gains made in efficiency may potentially be offset by collateral damage to the working relationship between labor and management.

There is often significant disagreement among academics as to the exact definition of complexity theory (Dunn et al., 2016). Turner and Baker (2019) propose that complexity theory may have evolved as a reaction to the observation that increasingly intricate problems may no longer be easily solved by the implementation of the customary reductionist approaches. The previous paradigm of isolating individual parts of a system so as to understand the totality of function is inadequate to explain unpredictability and nonlinear adaptations, resulting in the amalgamation of new concepts derived from several disciplines (Eppel & Rhodes, 2017).

Complexity theory is periodically criticized due to a lack of existing research. While the theory has been around for decades, there have been relatively few studies conducted to elaborate on complexity and leadership (Clark, 2013; Regine & Lewin, 2000; Tourish, 2019). The scarcity of previous data, particularly at the quantum level, makes affirmation of any new research difficult at best. However, existing data for other disciplines may assist in bridging the gaps. For example, the examination of the management challenges in urban water systems through the lens of complexity theory (Dunn et al., 2016) may provide fundamental analogies.

## Complexity Leadership Theory

Complexity leadership theory, not to be confused with complexity theory, attempts to bridge the gap of transformational leadership and complexity theory. Where traditional leadership focuses on leader-follower relationships, and complexity theory concentrates on the interdependent functions of social interactions, complexity leadership theory emphasizes the ability of leadership to encourage the vitality of interconnectivity and influence the system toward a desired state (Marion & Uhl-Bien, 2003). Rather than directing energy, complex leadership theory allows the natural processes of an organization to develop into a robust complex adaptive system.

A distinguishing characteristic between complexity leadership theory and the hierarchical leadership models is the differentiation of leadership. Rather than residing in a person, or appointed office, Lichtenstein et al. (2006) propose that leadership is an “emergent event” arising from the dynamic interactions of the system (p. 3). Leaders may take actions to precipitate action and influence outcomes, but the recognition of leadership is a social construction (Tourish, 2019), and the leaders themselves are not the originating source for change (Lichtenstein et al., 2006).

### *Strengths of Complexity Leadership Theory*

Since complexity leadership theory incorporates a type of middle ground between old-style leadership models and general complexity theories, it may provide new insights that have been traditionally missed. As complexity leadership allows for the nonlinearity and network effects inherent to complexity theory, it may provide for a better representation of real-world scenarios (Marion & Uhl-Bien, 2003). Additionally, the philosophy of fostering the natural processes that encourage the growth of adaptive systems could allow for greater overall organizational resiliency, resulting in the development of new leadership in the ranks (Uhl-Bien & Arena, 2017).

Complexity leadership theory may also provide a kind of safeguard against the possibility of total system chaos, described previously by Wheatley (2006). While destruction may be the most efficient solution, this possibility may not be the most appealing choice for the organization. Rather than permit uncontrolled reactions, complexity leadership theory allows management to gently guide the change in a more desired direction (Fullan, 2001).

Finally, complexity leadership theory tacitly acknowledges the existence of the prevailing hierarchical models. Top-down leadership is nearly the universal norm, firmly embedded in cultural expectations, and “there is no getting around this” (Uhl-Bien & Arena, 2017, p. 11). The implementation of any new model that displaces the existing one would undoubtedly meet resistance, as the decentralization of power would violate Michels' Iron Law of Oligarchies (Tolbert, 2010). The concept of existing authority dynamics working to preserve their power at any cost is elaborated upon in *Leadership as a Function of Complexity*.

### ***Weaknesses of Complexity Leadership Theory***

Complexity leadership theory potentially conflicts with more traditional theories because it discourages bureaucracy, viewing it as a constraint against system growth (Uhl-Bien & Arena, 2017). Given that there are numerous studies confirming that some hierarchical models, such as transformational leadership theory, do appear to have a positive impact on organizations (Bolman & Deal, 2013), any theory that moves away from that model may have difficulty becoming established. The previously mentioned notion that leadership is a socially constructed "emergent event" (Lichtenstein et al., 2006, p. 3) may imply that sources of leadership may arise from systemic interactions, which could potentially conflict with formal centers of power.

Additionally, because complexity leadership theory incorporates elements of complexity theory, it will by necessity become more complicated, owing to the difficulties of complexity theory (Uhl-Bien & Arena, 2017). Because complexity leadership theory focuses on the governance aspects of complexity (Marion & Uhl-Bien, 2003), it may also miss some of the subtle yet critical aspects inherent to general complexity.

One final issue with complexity leadership theory, and perhaps complexity theory in general, is that they are both premised on the foundation that technological advances are moving at an ever-increasing pace; and that this point in history is experiencing change on a scale greater than at any other point in history (Mason, 2007; O'Neill & Nalbandian, 2018; Regine & Lewin, 2000). While this does appear to be the prevailing mood, it is not a unanimous consent. Tourish (2019) argues that "there is little offered to substantiate this declaration of 'unprecedented' change other than assertion” (p. 11). If in fact Tourish is correct, and it is only the perception of each generation that they live in the most complicated times, then the idea that complexity continually creates new systems of novelty may have to be revisited. One refutation to Tourish might be the previously mentioned Moore’s Law, whose 1965 prediction of the exponential doubling of computing power appears to be correct (Tardi, 2021).

## Main Topics of Study

### Complexity

Complexity is not unique to human organizations, it can be found in virtually any collaborative system. In his review of complexity, Manson (2001) provides a reasonable description of the major attributes. Manson notes that the theory is extremely versatile and may be applied to a wide variety of seemingly unrelated topics. The common thread of complexity is that it exists as a result of the relationships within its environment; but “is not beholden to the environment—it actively shapes, reacts, and anticipates” (p. 408).

Fundamentally, complexity theory is all about rich interconnectivity (Uhl-Bien & Arena, 2017). While all functional systems interact, complexity theory provides for much more than just simple transactions. It allows for novelty, nonlinearity, and is the wellspring of innovation (Fullan, 2001). It seeks out new relationships, redefines old ones, and spontaneously creates new, evolving characteristics. It is the inherent order that arises from chaos, as randomly mapped mathematical sequences invariably create the beautiful patterns known as “strange attractors” (Wheatley, 2006, p. 116).

Complexity is found in all interactive systems; it is unavoidable. Under the right conditions, the chance interactions of warm water and thunderstorms begin a chain reaction and become potent hurricanes (National Oceanic and Atmospheric Administration, 2020). Social groups demonstrate complexity through the blending of cultural interactions, and the introduction of new rituals cultivates novel community order (Mesoudi, 2017). Biological organisms, perhaps some of the most complex systems of all, propagate new species diversity through random sequence alterations in their genomes, known as mutations (Rensberger, 1996).

## Properties of Complexity

Manson (2001) describes several features properties of complexity, and these concepts will become a pivotal point when viewing the relationship between complexity and leadership. Complexity is more than the sum of the constituent parts; it possesses emergent qualities that allow the system to self-organize and adapt in new ways when exposed to outside influences (Manson, 2001). Since emergent behavior can often be quite unpredictable, this can tend to place complexity at odds with the expectation of top-down leadership, which often attempts to maintain equilibrium and impose organizational controls (Wheatley, 2006).

### *Unexpected Outcomes*

In their examination of the increased globalization of third-world economies, McMillan et al. (2014) observed that as developing countries move labor from agricultural into technology-based activity, for the most part, rapid economic growth has followed. However, as previously noted, the evolution of complex systems can produce surprising twists. The authors unexpectedly found that several Latin American and Sub-Saharan countries that increased their connectivity to the global economy decreased their overall productivity, making their economic situation worse. This quantitative study included detailed analysis of 38 countries; and is a good demonstration that the evolution of a complex system does not always lead to the desired outcomes, nor is it always benevolent.

Iyer (2020) described the study of a firm that was attempting to increase employee engagement with management. However, only 17% of the people had responded to the engagement survey, and the deadline was drawing close (Iyer, 2020). In an effort to increase the number of responses, the human resources department sent out a fervent email explaining that virtually no one had taken the survey, and how important it was to receive as much input as possible from the staff. Instead of increased participation, the responses ceased entirely, as the employees who had not yet responded realized that they were in the majority (Iyer, 2020).

The Oakland, California, police department introduced a firearm buyback program in 2008, in an attempt to reduce the number of guns on the street (Hartley, 2020). Citizens could return any firearm and receive $250 with no questions asked. However, the Oakland police department received so many weapons that they incurred $170,000 in debt, and it was observed that many enterprising criminals used the incentive money to upgrade to more powerful weapons (Hartley, 2020). The original concept of firearm buybacks to remove guns from the street may be an example of a segmented, linear thought process. However, the possession of weapons is not an independent event, and the incentive failed to account for the adaptation of the complex social system in the Oakland neighborhoods. The appearance of unintended consequences in response to a perceived improvement effort is known as a perverse incentive, or more commonly, the cobra effect (Chollete & Harrison, 2021).

### ***Apparent Irrationality***

Complexity can also provoke what at first appear to be irrational behaviors. Reviewing the work of Lerner and Shankerman (2010) on open source coding, Samuelson puzzled over the seemingly illogical idea that any “rational person would invest time and energy developing computer programs in order to make them freely copyable” (Samuelson, 2012, p. 92). What was perhaps more unusual was that major software companies encouraged their employees to participate in unrelated, external side projects. In some cases, the companies even allowed previously proprietary software to be used. The survey of 2,300 firms in 15 countries appeared to show that, in the long term, comingling of open source and proprietary software benefits all parties, and increases the fitness of the entire coding ecosystem (Samuelson, 2012).

Schneider et al. (2017) observed a similar irrationality in their theoretical paper of the complexity differentials of organizations. The theory of complexity differentials proposes that firms are less complex than their environments, because they draw upon only a limited amount of information available outside of their boundaries, and the magnitude of the difference in complexity between the two is known as the complexity differential. If the external environment increases in complexity, the resulting complexity differential becomes larger. In response, the organization will automatically increase internal complexity, in order to narrow the gap, as failure to do so imperils the firm. Increasing the complexity of the internal systems reduces the differential and actually simplifies the process of handling the external environmental stimuli.

While the research of Schneider et al. (2017) does provide anecdotal physical examples, their publication is principally a conceptual idea of a social systems theory. Therefore, empirical data is unavailable, and their model cannot be verified. Further research is necessary in order to establish or refute the validity of their findings. The irony of increasing the complexity in one system in order to simplify interactions with another has a wide range of potential implications.

### *Chaos and Order*

In addition to undesirable outcomes and irrational behavior, complexity can harness substantial chaotic power and create rapid order. In 2008, Satoshi Nakamoto (likely a pseudonym) published a groundbreaking concept of a peer-to-peer electronic cash system, utilizing cryptographic transactions. The concept of a secure, nongovernment-backed currency system was extraordinary, and an entire novel financial ecosystem emerged almost immediately. Although initially condemned by the existing monetary institutions, a 2015 study found that nine of the world's largest banks had already begun to collaborate on standardizing the system, and thirty-two more were making plans (Tapscott & Tapscott, 2018). The fact that most of the world's major financial organizations would both condemn and adopt peer-to-peer transactions, in less than a decade, appears to be an affirmation of Nakamoto's original premise.

## Complexity and Transformative Leadership

With roots in the traditional hierarchical models, transformative leadership tends to focus on how an individual might effectively exert influence on a group. Bass (2008) notes that transformative leadership theory appeals to the follower's sense of self-worth, the importance of their work, and transcending their own self-interest for the sake of the group. In order to do so, the transformative leader must make an emotional connection.

From the mechanical perspective, Wheatley (2006) notes that "all organizations are fractal in nature" (p. 128). In the case of transformative leadership, this is personified by the directives of the leader in shaping the behavior and attitudes of the company. Taken together, all these attitudes and behaviors come together to define the culture of the firm (Wheatley, 2006, p. 128). As new layers of subordinates respond, the entire shape of the system aligns. In the successful transformation, the ethics and attitudes are mimicked down through each level of the system. Just as a snowflake builds smaller and smaller but otherwise identical branches, the transformative leader can induce repeating patterns of behavior and attitude throughout an organization. Discovering areas that do not adhere to these patterns does not necessarily mean that there is a dysfunction, but it might provide an indication of complexity theory at work.

The statistical work of Xu et al. (2015) highlights the necessity of the emotive association of transformative leadership. They found that trust is critical to the alignment of organizational systems, and that building trust is “dependent upon an integrated set of ethically complex leadership behaviors” (p. 1069). Thus, a relational foundation between complexity and transformation begins to emerge.

Islam et al. (2020) studied the impact of trust on organizational transformation in the financial sector. In their quantitative analysis, they concluded that transformational leadership was positively correlated with trust in leadership, and that trust in leadership was positively correlated with higher levels of employee work engagement (p. 29). However, they also noted that approximately 70% of organizations experience some form of failure in their transformative initiatives, “because of the level of complexity related to organizational change” (Islam et al., p. 25). The connection between complexity theory and transformative leadership is quite evident in this statement, and it appears that complexity may play a crucial role in the success or failure of the transformative process.

## Complexity as a Tool

Burns (2005) asserts that complexity theory is being increasingly seen by the academic community and those who are practicing in the field “as a way of understanding organizations and promoting organizational change” (p. 74). This concept supports the notion that complexity theory is now more than just a connection to organizational behavior; it may potentially be utilized as a tool to assist the transformation process. Perhaps paradoxically, Burns (2005) also goes on to suggest that the entire structure and function of complexity may “be underpinned by a set of simple order-generating rules” (p. 81). This hint that an intricate, near-chaotic, nonlinear system can be explained and perhaps even directed by modest laws is a central theme of this paper and will be revisited extensively.

In a qualitative study of a dozen large and small businesses, Regine and Lewin (2000) found that the increasing pace of technological innovation and global commerce has forced the attention of business leaders. They are constantly “preoccupied with change itself; how to generate it, how to respond to it, how to avoid being overcome by it” (p. 5). Senior leadership finds that the old models are no longer adequate. While many of the companies the authors interviewed were already making use of complexity theory, Regine and Lewin also noted that “others reached this place intuitively” (p. 8). It should perhaps not be surprising that there is a natural tendency to gravitate towards complexity, as Wheatley (2006) argues that individuals preserve a clearer sense of self-identity when they are incorporated into a larger network. Further research in this specific area might be very interesting, as it could potentially be a useful tool for organizational management.

### ***Leadership as a Function of Complexity***

In the early 20th century, Robert Michels hypothesized the social rule known as the iron law of oligarchies (Michels, 1911, as cited by Tolbert, 2010). This theory is perhaps best described as the process that “inevitably impelled . . . even the most democratically-committed organizations to become divided into a set of elites, or oligarchs, with their own distinctive interests in the organization” (Tolbert, 2010, p. 4). Not surprisingly, Tolbert (2010) points out that one of the primary forces that would drive this division is an increase in organizational complexity. This might imply that there is not just a relationship between leadership and complexity, but that leadership itself is also in some respects ultimately dependent to the laws of complexity theory.

## Complexity Leadership

That transformational leadership and complexity theory are fundamentally intertwined leads to the possibility that it is more than just relational; they could in fact both be facets of a single system. Marion and Uhl-Bien (2003) address this awareness and propose the novel combined theory of complex leadership. However, the authors also state that the two philosophies often appear to be in opposition. Where the transformative model emphasizes a top-down approach to leadership, complexity theory is most effective through “interdependent, multi-way chains of causality, nonlinear behaviors, and . . . often conflicting feedback loops” (p. 5). To reconcile this, they argue that leaders should seek instead to “influence organizational behavior through managing networks and interactions” (p. 6). As an aside, it is interesting to note their opinion that complexity theory does not appear to be easily defined with simplistic modeling, diverging from Burns’ (2005) previously cited perspective that complicated systems might be governed by minimalism.

### *Decentralization*

Baltaci and Balci (2017) also view complexity leadership as a “bottom up behavior,” emphasizing high degrees of flexibility, interactions, and social structure, rather than the old traditional hierarchy (p. 38). They assert that this dynamic is specifically suited to adjust to the rapid progression of technology and innovation, far more so than older centralized, industrial leadership models. Specifically, the pair describe complexity leadership as possessing exactly the properties of leadership “designed to cope with uncertainty” (p. 40). A built-in ability to operate under near chaotic conditions might make complexity leadership a very attractive selection for leaders operating in turbulent, high-technology sectors. Potential practical applications of this will be examined in more detail shortly, with examples from the work of Weberg (2012) and others.

### ***Adaptivity***

Uhl-Bien and Arena (2017), expand a bit more on complexity leadership theory with their examination of rapidly evolving organizations. They describe a model of how entrepreneurial systems might interact within adaptive spaces, which themselves influence operational systems, and the types of leadership best suited to manage each stage. This visual representation of how the mechanics might work moves complexity leadership away from pure theory and into the diagnoses of pragmatic scenarios. Behavioral models are not particularly helpful to the transformative leader if there is no way to translate them into realistic situations, therefore organizations must learn to implement ideas as a continual “experiment in progress” (Regine & Lewin, 2000, p. 10).

### ***Boundaries of Complexity Leadership Theory***

The characteristics of how leadership might optimally develop in under such a complex system is examined by Clarke (2013). The well-emphasized themes of relational development, communication exchange, and shared leadership are once again present. Here, Clarke hits upon a critical point; under complexity leadership theory, “leadership is the property of relationships, no longer residing in one individual” (p. 136). If Marion and Uhl-Bien (2003) examined the entry point of complexity leadership, Clarke (2013) may have found the outer limits of its usefulness to leadership. He asserts that executive control, disseminated throughout an organization, can only be taken so far. A culture that wades in too deeply without some form of supervision may be abruptly reminded that complexity theory can also be destructive. Perhaps Michels’ iron law

(Michels, 1911, as cited by Tolbert, 2010) exists for this reason; a counterweight to prevent the group from venturing too close to chaos.

### *Differentiation of Complexity and Complexity Leadership Theories*

Whether or not complexity leadership is truly a distinct entity, or that complexity leadership and complexity theory should be considered separately may be a matter of emphasis. It is quite possible that there is no necessity to even make a distinction for this specific study, as evidence of an adaptive network would be equally applicable to both theories. As Efron and Ravid (2019) point out, when attempting to extract meaning from a phenomenological study, it is perfectly acceptable that "multiple interpretations may coexist and no one interpretation is truer than another" (p. 203). The distinction between complexity theory and complexity leadership theory may thus be dependent on the perspective and priorities of the observer.

## Operational States of Complexity

Turning attention away from theory, Hazy and once again the very prolific author on complexity, Mary Uhl-Bien (2015), focus on the physical mechanics behind complexity leadership theory. They analyze both empirical data and theory to identify five specific leadership functions within complexity: Generative, Administrative, Community-Building, Information Gathering, and Information Using. They identify and categorize some of the likely interactions that may occur and begin to contextualize them. Hazy and Uhl-Bien (2017) assign attributes of "fine-grain" or "coarse-grain" properties that emerge naturally from different system interactions (p. 87). Examples of potential real-world scenarios help to bridge the gap of complexity leadership from a purely theoretical state.

Weberg (2012) proposes to implement complexity theory as a proper framework to improve the U.S. healthcare system. He points to healthcare as undergoing an extremely stressful evolution, while also firmly entrenched in antiquated leadership methodologies. These deep-rooted methodologies lead to an overgeneralization of organization function, ultimately breaking down at the microlevel. Complexity leadership would address many of these issues, if not for the resistance of established management.

### ***Friction with Traditional Methodologies***

Weberg's (2012) analysis is a good illustration of the constant evolutionary friction that exists within all dynamic systems. Those who are benefiting from the current status quo are unlikely to wish to see widespread change and may even work to prevent it from happening. Elements on the margins will continue to press inward, until they either gain ground or dissipate. Reorganization will ultimately occur, with the victors themselves eventually being pressed in again by forces in a new cycle. This tension naturally forces complex systems into cultural reinvention. Leaders (and, unfortunately, their attached organizations) that cannot respect and appreciate that fact will inevitably experience significant pains of systemic dysfunction.

O'Neill and Nalbandian (2018) address the evolution of management in their examination of leadership challenges and evolution with complexity theory. Immediately, the two authors acknowledge the "fundamental desire to connect to our identity, an anchor in our lives" (p. 311). The authors assert that this is a central point; humans inherently seek stability, and change is, at best, vaguely uncomfortable for most. Without enough energy, there is an urge to revert to the way things were. But O'Neill and Nalbandian demonstrate three key points regarding modern organizational leadership. First, the vernacular appears to have changed. Instead of calling department heads the "management team," the terminology has changed to "leadership team" (p. 312). Such a minor detail has a slightly deeper meaning; at a minimum, the new concept is beginning to at least create a mental connection.

Second, O’Neill and Nalbandian (2018) also point out that leaders are increasingly forced to face problems that lie outside of their traditional spheres of expertise and influence. This would imply that to solve these issues, leaders would have to enlist the aid of others; thereby expanding the collective capacity of the overall system. Finally, the authors highlight the increasing levels of “citizen engagement” (O’Neill & Nalbandian, 2018, p. 312). New forms of communication, such as social media, have created novel social connections that did not exist before. As a result, ordinary people are changing their behavior, and independently asserting themselves in ways that did not previously occur. Here, O’Neill and Nalbandian are possibly describing manifestations of emergent behavior as a result of novel interactions; in other words, a potential descriptor of complexity theory in physical terms.

## Complexity in Practice

Up until this point, the description and examples of how complexity theory (and, if one considers it separate, complexity leadership theory) could function has largely remained within the boundaries of theoretical research. However, as O’Neill and Nalbandian (2018) have observed, real world examples appear to exist. Murphy et al. (2016) examined six actual cases of urban regeneration projects, and how complexity leadership theory played a part (or did not) in the ultimate successful completion of the case studies. The researchers noted that the distributed leadership properties of complexity theory do not appear to mesh well with the “heroic figure” perspective of traditional thought (Murphy et al., 2016, p. 693). They collected data on each of the jobs, including the overall level of complexity of the project, diversity of the associated populations, and time duration. In addition, Murphy et al. (2016) conducted in-person interviews of participants, using a standardized questionnaire, and also collected available project documents. It was concluded that in the construction involving relatively low complexity, more traditional leadership styles were prevalent; but as the projects increased in difficulty, more adaptive leadership processes became evident, peaking out in the highest complexity cases (Murphy et al., 2016). In other words, as the levels of project complexity increased, observable behaviors of complexity leadership became more apparent in the actors.

It should be noted that the six case studies of Murphy et al. (2016) were evenly split between the Republic of Ireland and Northern Ireland. While the authors were careful to uniformly divide the projects, it is quite possible that cultural differences between the two locations could be a significant factor in the outcome. Many of the neighborhoods surrounding the urban renewal efforts have a long history of sectarian violence, and it is possible that the underlying social tensions could have influenced the outcome of the study (Grattan, 2020).

A potential affirmation of Murphy et al. (2016) may be present in the work of Nooteboom and Termeer (2013). The pair carried out two mixed case studies in the Netherlands to look for evidence of emergent behavior and, therefore, the presence of complexity leadership theory. Both studies could be categorized as complex, each with multiple challenges to overcome. The first was an agricultural project, dedicated to creating a thriving distribution center in the Venlo region; the second was a redevelopment of an abandoned railway junction in Amersfoort. They concluded that in both cases, there was clear evidence of both enabling and adaptive leadership, which in both cases led to the appearance of novel organizations (Nooteboom & Termeer, 2013). While this supports the idea that complexity leadership is a natural consequence of systemic interaction, the authors do concede that the study is more qualitative than quantitative, since the sample size is small.

Kershner and McQuillan (2016) examined how complexity theory affects urban scholastic performance. Their opening remarks reflect on the fact that “longstanding socioeconomic segregation" has severely impacted the student achievement gap, multiple reform efforts have been largely ineffective, and there is essentially a "systemic failure" (p. 4). They conducted a three-year case study of two urban schools in order to assess leadership and change initiatives. They viewed complexity theory as a key aspect of successful leadership, both as a method of analysis and methods, and their leadership subjects had all been through training that supported complexity leadership ideology.

Through observation and interviews, they witnessed the active construction of distributed leadership networks, and the subsequent cultural and organizational shifts. In one case, complexity leadership appeared to make a difference, and there was measurable improvement. In the other study, the efforts of leadership met deep-rooted resistance, and the principal (who was nominally driving the change), from the viewpoint of the authors, hesitated to relinquish central power. At the end of the study, the original school culture remained largely intact (Kershner & McQuillan, 2016).

Perhaps one of the most extensive examples of putting complexity theory to the test is the work by Meek et al. (2007). The authors conducted a qualitative study of various law enforcement agencies affiliated with the Peace Officers Association of Los Angeles County, searching for insights on complexity theory. Law enforcement agencies must be prepared to manage and adapt to ongoing complex situations night after night. One segment of the system might be quiet, while another unexpectedly erupts. In such an environment, top-down leadership exists in name only; distributed power is the norm (Meek et al., 2007). Managers and administrators operating within this system don't just live with complexity; by necessity, actors learn to "watch and understand systemic patterns as well as set goals and priorities for the system" (Meek et al., 2007, p. 26). The occupants of these agencies have learned to utilize the system to create a “conjunctive state” from disarticulation (Meek et al., 2007, p. 27). The study of the law enforcement agencies of Los Angeles are possibly a manifested example of complexity leadership theory functioning in a real-world scenario. These officers are now system level users; complexity works for them.

As a result of their interviews, the authors observed that there appeared to be an ongoing theme of “slow movement away from government towards governing” (Meek et al., 2007, p. 26). Networks showed evidence of higher collaboration, and public input on decision making—all signals of complexity theory. The researchers concluded that the law enforcement agencies studied did display emergent behavioral characteristics consistent with theoretical predictions, although the risk of reversion to central authority remained a continuous presence (Meek, et al., 2007).

## Complexity Theory and Future State Dynamics

It is often convenient to think of evolution as a historical event, something that once happened in the past, without the realization that it is ongoing, ubiquitous, and will continue to happen in the future. The appearance of new states of being within a system inherently changes that system, thereby creating the conditions for yet more emergence order—a continuous feedback process. Mason (2007) provides a good account of this paradox. He writes that “as the system becomes more complex, making sense of it becomes more difficult and adaptation to the changing environment becomes more problematic” (p. 10). Mastering the inner workings of a complex system only leads to the necessity to begin studying an even more complex system. In his exploration of increasing complexity, Mason (2007) interviewed several commercial firms in South Africa and proposed that successful companies in turbulent environments are more likely to make use of self-organizing management and emergent strategies; while successful companies operating in simple, more or less stable environments would be more likely to utilize traditional management and strategies, while struggling examples of each would do the opposite.

While his interviews did not end up supporting the initial premise, they were illuminating. His case studies found that companies adopting a culture of agility, innovation, and distributed leadership were more successful than those who did not in both environments (Mason, 2007). He concluded that a possible reason for this might be that since the overall economic environment in South Africa was turbulent, this had an effect on even relatively stable companies (Mason, 2007). As he researched only four corporations, and his methods were qualitative, further research was recommended in order to validate or refute his initial results.

Mason's (2007) findings suggest the possibility that the complex system of an organization is not working in confinement. It is influenced by forces throughout the entire network, probably even in those spaces where it does specifically operate or compete. As the external world becomes more complex, so will a firm's internal systems, even if their current business is quite static. Perhaps even more importantly, this process will occur regardless of whether leadership is desirous of it or not (Mason, 2007).

Tourish (2019) inquires as to the future of complexity theory. He notes that, due to its increasing popularity, complexity theory is one of the most sought-after topics in the social sciences. It is therefore not surprising to him "that some scholars have also seized upon its theoretical potential in the field of leadership studies" (Tourish, 2019, p. 3). However, he also poses a more questioning view of whether our world really is more turbulent than in the past. Tourish (2019) states that while others often refer to the increasing complexity in today's world, "there is little offered to substantiate this declaration of 'unprecedented' change other than assertion" (p. 11). Perhaps it is the belief of every generation that the current day is always more complex than at any other point in bygone eras.

If this is true, then it is possible that perhaps history repeats itself. Complexity theory might be declared as the new great order of things, only to eventually revert into the old patterns of behavior. Tourish (2019) presents an important point: revolutions of all types have routinely occurred in the past, and in the end, top-down leadership has eventually found a way to reclaim primacy. It is also possible that organizational dominance by centralized leadership (and recalling the reader once again to Michels and his iron law of oligarchy) is a natural and expected emergence of the general schemata of reordering complexity, and the ongoing cycle is inevitable.

Concluding his work, Tourish (2019) provides a slight hedge to his theoretical bets with the reminder that "complexity theory has not been applied consistently to explore how leadership itself emerges as an organizational phenomenon" (p. 27). Our collective understanding of complexity theory is not yet good enough to even fully appreciate what we do not know. Only the passage of time will provide revelations. However, if complexity theory does provide one great insight, it is that any new discoveries will only pose new questions, leading to new connections, and the cycle will begin again, in ever increasing magnitudes of difficulty (Mason, 2007).

## Biotechnology

In 1919, Hungarian Karl Ereky conceived of the notion that technology could be applied to biology, creating a multitude of new possibilities in agriculture, medicine, and general science; in the process, he coined the word biotechnology as an apt descriptor (Fari & Kralovanszky, 2006). Currently, his vision has largely been realized, as thousands of companies as well as research institutions explore new medicines, diagnostic tools, devices, biofuels, and genetically modified organisms (Amgen, n.d.). The total capitalization of the biotechnology market is expected to reach and exceed $2.44 trillion by 2028 (Grand View Research, 2021).

Biotechnology is the manipulation of living organisms in order to create new products or processes (Lone Star College, 2021). While the phrase may invoke the inference of modern scientific pursuits, especially in the field of genetics, the implementation of biotechnology has been utilized by humans for thousands of years (Lone Star College, 2021). For example, the purposeful addition of yeast to wheat and water in order to ferment bread and beer may be considered one of the first uses of biotechnology (Colwell, 2020). For the purposes of this study, biotechnology may perhaps be best characterized as the application of technology to biological material to create useful new products, such as vaccines or novel drug therapies, in order to improve human health (Verma et al., 2011).

## Expansion of Biotechnology

The field of biotechnology is expanding at an increasingly rapid pace. Considering the large influx of resources at a scale estimated to exceed $729 billion by 2024, substantial evolution of the organization is likely to continue (Ugalmugle & Swain, 2019). Both developed and developing economies around the world are “investing massive resources in technological innovation” (Lee & Lee, 2019, p. 1). Food and Drug Administration (FDA) approvals for biotechnology innovations is likely to continue at an accelerated pace for at least the next decade, due to the current “vigorous development pipeline” (Intellisphere, 2017). Specifically, the discovery and development of two recent technologies will provide significant drive for new innovation: clustered regularly spaced short palindromic repeat sequences (CRISPR) and messenger ribonucleic acid (mRNA) vaccines.

In the field of genetic research, the discovery of CRISPR has ushered in a “new era in genetic engineering” (Kwon, et al., 2019). The use of CRISPR allows for more precise gene editing on a far more reliable scale than was previously available, resulting in the exponential increase of its use over the past decade (Ishino, et al., 2018). Ironically, the original discovery of CRISPR was an unexpected side effect of a project, spanning several months, to map an unrelated genetic region; the same region may now be mapped using CRISPR in one day (Ishino, et al., 2018). CRISPR technology has revolutionized the speed at which innovation may progress by many magnitudes.

The rediscovery and increased use of vaccines starting in the eighteenth century have transformed human health; through the use of vaccination, diseases such as polio and smallpox have either been nearly eliminated or completely eradicated (Centers for Disease Control and Prevention, 2021). Likewise, the relatively recent development of mRNA vaccines has demonstrated significant promise as an alternative to the conventional methodologies. The use of mRNA technology is highly effective, low cost, and therapies may potentially be deployed against a wide array of diseases, including cancer and infectious agents (Pardi, et al., 2018). However, it may be the remarkable success of experimental mRNA vaccines against the SARS-CoV-2 (COVID-19) virus that will transform the mRNA paradigm from a mere intellectual curiosity into the principal philosophy of future vaccinology (Kim, et al., 2020).

## Biotechnology as a Complex Organization

In such a high growth environment, many biotechnology companies have evolved to be quite large. For example, the pharmaceutical giant Johnson & Johnson employs more than 134,000 individuals, operating in consumer health, pharmaceutical, and medical device business segments (CNN Business(b), 2021). Even the relatively small Incyte retains over 1,700 workers

(CNN Business(a), 2021). Such large numbers of people simultaneously working on research, logistics, compliance with federal regulations, and safety divisions require extensive effort, close coordination and oversight. The development of a single new drug may take more than a decade to fully complete, and may cost more than $2.6 billion (Anderson, 2020). Additionally, there are many opportunities for things to go wrong. From 2006 to 2015, out of 7,455 experimental therapies, less than 10% were deemed to be safe and effective for market consumption (Alteri & Guizzaro, 2018).

## Leadership in Biotechnology

While many small biotechnology companies start out avoiding the multiple levels of bureaucracy in their organization, as they experience rapid success and the accompanying growth, these firms typically begin to mimic the hierarchical-based leadership models (Kleinman, 2017). The eventual imposition of a stratified leadership standard is viewed as a necessity for the healthy growth of an evolving biotech company, according to Foller (2002). Although this viewpoint may be slightly dated, it appears that the cultural attitude may remain. In their article for the *Harvard Business Review,* Banta and Karp (2020) observe that the research and development departments of the big life science companies are still being severely hampered by the rules, structure, and layers of management. Some of the larger firms are attempting to adapt their leadership models, but the transitions can be difficult, especially in middle-management; as some individuals leave and other resistors are moved out by the company (Kleinman, 2017).

# Laboratory Animals in Biotechnology

## Laboratory Animal Medicine

Animal models are widely used in laboratory research and have significantly contributed to the discovery of new insights that have "led to improvement in human and/or animal well-being" (National Research Council, 2011, p. 4). The field of laboratory animal science has directly contributed to advances in vaccines, antibiotics, and other therapies that have improved the lives of multitudes (American Association for Laboratory Animal Science, 2019). While exact industry figures may be difficult to determine, a survey of both academic and nonacademic scientists indicated that 74% of respondents (*n = 367*) were involved in research that currently included animal models (Bressers et al., 2019). At the same time, it is recognized that the use of animals in research carries a strong ethical responsibility, and as such it is strictly regulated by numerous state and federal regulations (American Association for Laboratory Animal Science, 2019). The development of laboratory animal medicine as a specific field began in 1915 with Dr. Simon Brimhall at the Mayo Clinic, and was followed by federal regulation, including the Laboratory Welfare Act of 1966 (Alvarado & Dixon, 2013).

## Animal Care Technicians

Animal care technicians are critical members of any research team. In addition to the daily maintenance of the animal vivarium, animal care technicians monitor the welfare of animals, and observe for even the smallest disturbance that might negatively affect research data (American Association for Laboratory Animal Science, 2019). Animal care technicians should be appropriately trained for their tasks, including both formal and on-the-job education (National Research Council, 2011). The accuracy of their work is essential, as even the smallest variation to a standard operating procedure could impact research data, creating a false or misleading result, damaging the validity of a study (American Association for Laboratory Animal Science, 2019).

## Conclusion

Whether one regards traditional leadership paradigms, such as transformative leadership, as separate entities from complexity theory, or they are part of one continuous complexity leadership model, or if in fact they are both things simultaneously, the two themes appear to share at least a fundamental, quantum connection (Uhl-Bien & Arena, 2017). Complexity theory is scalable, affecting top level executives and frontline managers alike. Leaders direct their energies to influence the system toward a desired end; in turn, the system reflects energy back, influencing the evolution of leadership (Wheatley, 2006).

Complexity is not simply theoretical; there have been several real applications presented. In some cases, it was a straightforward demonstration of function; in others, the participants developed the capacity to understand and take advantage of complexity theory in action. If a leader can learn to make use of complexity theory as a tool, or adopt the full model of complexity leadership theory, they may find that this provides a competitive edge. In the modern economic environment, even the smallest advantage can make the difference between success and failure.

# CHAPTER 3

# METHODOLOGY

The ability for organizations to adapt to continuous states of change is critical. There is widespread consensus that the pace of change is accelerating worldwide and will continue to do so in the foreseeable future (Burnes, 2005). The traditional static, top-down leadership approaches are struggling to cope with increasingly intricate problems of systemic governance (Baltaci & Balci, 2017); therefore, research into alternative approaches is necessary. Complexity theory may provide a substitute mechanism for executive leadership to adapt and thrive in a chaotic, competitive environment (Baltaci & Balci, 2017).

However, even as recently as 2019, it is noted that research into the application of complexity theory to leadership theory is still in the early stages (Tourish, 2019). While there have been some studies, much of this work is still conceptual. The demonstration of complexity theory within a live work environment may help to both provide a better understanding of its pragmatic value and stimulate interest for further research.

If it can be established that the collective activity of multiple employees behaves as a single complex adaptive system, it may be possible to develop tools that allow leadership to monitor the larger organization for undesirable disturbances. Additionally, the predictability of the system may be enhanced, establishing more efficient management methods. Any initial success could begin to create a cascade effect and allow for more widespread acceptance and adoption of complexity and complexity leadership theories.

## Purpose of Proposed Study

The purpose of this quantitative correlational study was to examine the relationship between the behavioral patterns of a subset of animal care technicians and complexity theory within a biotechnology organization. It is not known if the aggregate behavior of the organization functions as a single, adaptive network; therefore, it is also unclear to what extent the work of individuals, each acting independently, collectively behave as a single overarching social network—a hallmark of complexity—as proposed by Marion and Uhl-Bien (2001).

If the presence of an adaptive network could be affirmed through a statistical analysis, this concept could be effective as a tool for managers in both daily organizational command and control activities, as well as during change implementation. Every day, the animal care technicians at Biotech X work autonomously and are responsible for the upkeep and maintenance of a subset of the breeding colonies at the institution. In doing so, the employees record hundreds of data transactions pertaining to animal care and reproductive performance into an enterprise resource planning (ERP) system. Additionally, the animal care technicians record the expected observable physical (phenotypical) characteristics of the animals. This information is collected into a data warehouse and archived for future analysis. Historical records have been collected for more than the past decade; as a result, there are millions of data points captured and time stamped. Since it is difficult to fully predict the behavior of a single individual (Fennell et al., 2019), it is impractical for a company’s leadership structure to attempt to manage at this level, particularly with a large worker base. However, if the combined conduct of the employees can be reasonably predicted, the collection of the animal care information may provide insights for leadership into complex group performance.

If this is in fact the case, the behavior of the collective may also be relevant when examining the implementation of a change initiative to the environment. Measurable changes in group dynamics could be useful for members of leadership in order to detect the unintended consequences of organizational transformation. Addressing the actions of each single employee within an organization is less efficient than managing the collective, as large groups tend to naturally self-organize, and adhere to simple rule structures (Mason, 2007). This in turn may allow management to more appropriately respond to potential deviations and provide for a more effective change management process.

## Research Questions

This study proposed to answer two central research questions:

**Research Question 1:** Can the traits of a complex adaptive system, as described by Regine and Lewin (2000), be detected quantitatively through the analysis of routine data generated by individual employees in the animal care department of Biotech X?

**Research Question 2:** If a complex adaptive system is present in the data, does the complex adaptive system display distinguishable traits of either Wheatley's (2006) complexity theory or Marion and Uhl-Bien's (2001) complexity leadership theory?

To determine the answer, it is necessary to establish that the structure mimics the expected behavior of complexity theory in action. One method might be to observe the collective reaction of the animal care technicians in response to a new environmental stimulus, such as the introduction of new computer hardware. Uhl-Bien and Arena (2017) describe the appearance of spontaneous emergent events as a hallmark of an adaptable complex system. If the individual transactions of employees do collectively form a cohesive complex system, a reasonable way to detect it would be to discover one such event. Therefore, if the aggregate output of the animal care technicians generates spontaneous new relationships as stimuli are introduced, this might provide some evidence that the cumulative reactions generated by employees, each working independently, obeys the overarching laws of complexity theory.

Burnes (2005) also describes complex systems as being fundamentally governed by a “set of simple order-generating rules” (p. 74). For example, certain species of social insects, such as bees and ants, utilize simple rules of behavior to govern highly complex and adaptive colony networks (Uhl-Bien & Arena, 2017). This implies that the management of a complex adaptive system does not necessarily have to be overly complicated or energy exhaustive in order to be successful. A deeper understanding of these tenets might be very beneficial to leadership when examining proposed future changes.

## Hypothesis and Research Design

It was hypothesized that the independent transactions of the individual technicians in the animal care department at Biotech X, when viewed in the aggregate, will behave according to the rules of a complex adaptive network. These rules include self-reorganization in response to external stimuli, and the emergence of novel behaviors, as defined by Wheatley (2006). If this in fact the case, the collective behaviors of the animal care technicians should react to external change stimuli as predicted by complexity theory, demonstrating a temporary reversion to chaotic conditions, creating new, nonlinear relationships, and the spontaneous appearance of unanticipated novel events (Wheatley, 2006). In the case of Biotech X, there was a computer hardware and software upgrade affecting all animal care facilities. This event should be adequate to represent a sudden ubiquitous change in the environment. This researcher proposes that the simultaneous emergence of unexpected behavior by the animal care technicians following this specific change event might be reflected in the daily animal care data (Figure 1).

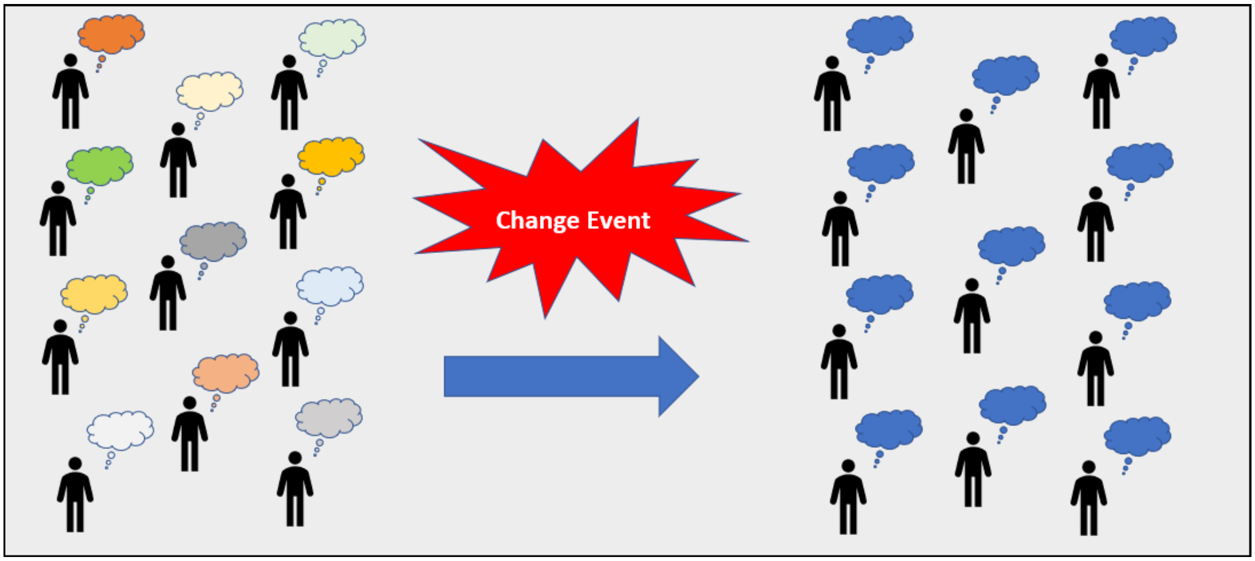


**Figure 1. A complex adaptive response to an environmental stimulus. Differing individual behaviors align into a coordinated, novel arrangement not present prior to the event.**

While most of the available literature surrounding complexity theory appears to be qualitative (M. Uhl-Bien, personal communication, September 22, 2021), there are quantitative studies that may serve as precedent models. For example, some species of social insects form decentralized, highly adaptive complex networks; however, the entire structure appears to operate largely on a set of simple, order generating rules (Mizumoto & Bourguignon, 2020). A study by Greenwald et al. (2018) utilized quantitative analysis to measure the communal behavior of foraging ants. They found that collective food regulation for the entire colony was achieved efficiently, despite the absence of any centralized control network (Greenwald et al., 2018). Individual foragers knew when to stop, despite having no knowledge of the state of the colony's total food supply, implying a collective system regulation (Greenwald et al., 2018).

In order to verify if independent activities of individuals at Biotech X will behave as a single complex adaptive system, the daily animal care transactions of the employees were examined prior to and after a significant organizational change implementation, in this case a computer hardware and software upgrade. The data was analyzed for statistically significant correlations with a commercially available software package. Presuming that there is little or no correlation between the animal care technicians prior to the change implementation, the sudden appearance of a novel, unanticipated correlation after the event might provide evidence of an adaptive group response during the change initiative.

These data were originally gathered to monitor the animal care, breeding, and phenotypic performance of the research animals. However, since the information is collected and entered by people, it was theorized by the author that at least some of these statistics may also reflect a component of human behavior. For example, where the animal census of each breeding unit for the same species is likely have a relatively stable average, the animal care technicians may be subject to subconscious anchoring behavior. Anchoring is the human tendency to “rely too heavily on one piece of information when making decisions” (Wu & Chen, 2014). Individuals or even groups may remain irrationally attached to an anchoring point even in the presence of contrary information (Meub & Proeger, 2018).

Thus, anchoring theory would imply that a minor environmental change causing confusion or disruption may cause the animal care technicians to adhere more closely to the established anchored position, regardless of the actual conditions. However, if the change is strong enough, the employees may anchor around a new position. In the latter case, the introduced change to the work environment may affect the animal care transactions, and the behavioral responses to the environmental change may be detectable through a quantitative analysis of the meta-data. While it is possible that some of this data is the result of human error, Galton’s work demonstrates that the accuracy of aggregate data can be high even when the majority of individuals is incorrect (Wallis, 2014). Further specifics of Galton’s experiment are discussed in Limitations and Delimitations of the Research Design.

Since the data already exists at Biotech X, an ex post facto quantitative analysis was an appropriate choice for this study. An ex post facto analysis is a research design by which the investigation begins after the facts have occurred, and without manipulation by the researcher (Salkind, 2010). In the specific case of this proposal, the independent variable was identified as the animal care data collected by the animal care technicians after the computer upgrade, and the dependent variable would be the animal care data collected prior to the change event. One of the strengths of an ex post facto design is that the environment is “real” and not likely to have been manufactured or manipulated by the subject population (Giuffre, 1997). In the case of this study, it was important to observe the natural behaviors and reactions of the animal care technicians.

For example, Itani et al. (2020) utilized ex post facto analysis to examine the impact of the Lebanese banking system prior to and after the social upheaval known as the Arab Spring, and the COVID-19 outbreak. While this is not exactly analogous to the collective actions of animal care technicians, it does demonstrate the viability of ex post facto analysis of specific change events on a complex system. Similarly, Turiel et al. (2021) examined past social media posts and compared them with the rate of COVID-19 mortality in Italy, Spain, and the United States. They quantified the numbers of COVID-19 related tweets by geographic region and found the aggregate number of tweets was a superior predictor of COVID-19 mortality rates for the following month than any official data (Turiel et al., 2021). This work provides a clear demonstration that ex post facto data of individuals can be aggregated into a pragmatic diagnostic tool.

The archived animal care data was collected and paired with the date of a historical change initiative within the organization, in this case the replacement of computer hardware. Information was categorized into two groups: the first data set six months prior to the change introduction, and the second data set to follow six months after the event. The time period of six months for each data set has been selected for two reasons. First, it should provide enough data points to establish statistical significance; and second, the time period must be short enough that it does not overlap with other potential change initiatives, as this could confound the study. Each group was double checked to ensure that enough data was collected to provide adequate statistical power for the study. A $p$-value of no greater than 0.05 was established as the appropriate level of significance, as this is the commonly accepted standard (OpenStax, 2013).

In addition, data from multiple geographic sites was compared. Technicians from each campus do not normally interact frequently. Therefore, the sudden appearance of novel behaviors simultaneously at each site may serve to augment the study design. This component of the study would be critical to determine if any introduced change is creating a systemic reaction or is the result of individual changes at a single location. If the group dynamics happen at a large scale, this may provide further affirmation of the hypothesis.

## Population

Biotech X is a biotechnology research institute, located over several campuses across the United States. The company houses colonies of laboratory animals for therapeutic study. The firm employs several thousand workers across the United States. The animal facilities on each campus are segregated from one another so as to minimize the risk of cross-biocontamination. Technicians are allocated to small teams for individual rooms, and typically remain assigned within their own workspace. Employees from separate campuses rarely interact, and whereas all teams are dedicated to the maintenance and welfare of the animal colonies, each person works on their own assignment. There are small teams of specialized float technicians on each campus, typically less than five, who do move between areas from week to week to cover for vacations or other unexpected labor shortages among the general staff. These employees are selected for their advanced capabilities to handle multiple or particularly complex assignments. For the purposes of this study, these specialized float technicians will be excluded from the data.

## Sampling Methods

Archived data was retrieved from the data warehouse and downloaded into a spreadsheet. Permission to use this data for the purpose of this research study has been granted by Biotech X, under the conditions that the organization, the species, and the individuals are deidentified (Appendix B). As a member of management, this author has direct access to the data warehouse and is authorized by the company to extract information for analysis on a routine basis. Management also gave permission for the researcher to directly extract the data (Appendix B), provided the specific dates are not publicly published. Appendix A outlines the permissions, with specific details redacted as requested by Biotech X. Individual employee names were not used in the data set and individuals were not identified. This information was then loaded into a commercial statistical analysis software JMP 16 (SAS, 2021).

In order to maintain validity, the sampled transactions were limited to one specific, genetically homogeneous animal species at each campus of Biotech X. Colonies for this species exist at all sites, and because the animals are genetically uniform and housed under identical conditions, theoretically, the animal care transactions should be similar. As the colonies are maintained at scale, large numbers of technicians are required on a weekly basis ($n > 400$). Only technicians who specifically work on this species were included in the study.

The selected employees represent a subset of the entire company-wide population. Since the technician group selected was not completely random, but instead based on their association with a specific category of animal, the study relied on nonprobability sampling. Nonprobability sampling is a statistical methodology by which the sampled population is chosen in a nonsystemic way, and therefore does not guarantee that any subject had an equal chance of selection (Elfil & Negida, 2017). As the selected species does represent the largest colony population at the institution, this method may be best categorized at modal instance sampling (Glen, 2021). Modal instance sampling is a statistical method that specifically selects the most typical, or frequent, appearance of a test population (Etikan & Bala, (2017). No part of the study included material from identifiable subjects, nor was any of the data regarding specific persons provided to the management of the company.

## Instrumentation

The meta-data is routinely collected through a company-wide enterprise resource planning system. Every night, the daily animal care transactions from all worksites are downloaded and permanently archived in a data warehouse system. In-house servers are kept secure via commercial firewall software. As a member of the company management, this author has routine access to the data warehouse, and is authorized to retrieve data as necessary. The relevant data subsets were downloaded and stored in a spreadsheet (Microsoft Excel).

As the data warehouse is preconfigured to be compatible with Excel, raw information does not have to be manipulated prior to analysis. The JMP (SAS, 2021) statistical software package is also compatible with Excel and does not require editing during data transfer. If the column headers retrieved into Excel contained identifiable information, the headers were edited to reflect anonymity of both subjects and the institution prior to loading them into JMP.

### Validation of Instruments

Animal room transactions are verified by the Information Technology department. Additionally, the records are utilized on a routine basis by the Planning department. Unusual data points are investigated for potentially corrupt data migration. In the event of incorrect data migration, the Information Technology department works to correct the information the following day. In rare cases, information that cannot be corrected is permanently deleted from the daily files. To maintain the integrity of this study, incomplete or missing data points were not included in either the collection or the analysis.

It should be noted that while the data warehouse is validated, initializing new records are dependent on human entry. As such, there is always the potential for some level of error that cannot be detected during the verification process. For example, if an employee forgets to enter an animal care transaction into the system, this mistake will not be corrected during validation. Alternatively, it is also possible that all or some of the data could be erroneous, intentionally or otherwise, simply because “people can be repeatedly wrong” (Merriam & Tisdell, 2016, p. 251).

## Data Collection

Complexity theory predicts that ongoing disorder naturally organizes itself into systemic behavior, and that as new changes are introduced into the system, there will be an automatic response toward disorder and back into reorganization (Mason, 2007). More specifically, as a system returns to equilibrium, unintended novel arrangements should appear spontaneously (Fullan, 2001; Wheatley, 2006). An upgrade of the animal care computer hardware and software system was implemented in all animal facilities at Biotech X several (>3) years ago. This unique event affected the entire company on all campuses simultaneously. The implementation date of the project is precisely known; therefore it is possible to segregate the animal care data to identify the transactions prior to the event, and the transactions appearing after the event. This upgrade will serve as the environmental change event.

Historical technician transactions are available at will from the internal data warehouse, which are stored on servers within the company Information Technology department. Archival data were retrieved and stored on a spreadsheet. In addition to the animal care transactions created by the staff, the weekly census of animals was captured. Each week, a census of all breeding units is taken to ensure that the population control is strictly regulated per the Institutional Animal Care and Use (IACUC) policies. The IACUC is the internal governing body for Biotech X, and no project may be initiated or continued without their explicit approval. This census provided a baseline of a per-animal ratio for each transaction type, to ensure that the magnitude of categories can be accurately reflected. All collected data subsets for the study, including change implementation project information, were stored on a password protected personal computer. Transactions identifiable to the individual employees, the institution, or the animal species was not selected for retrieval, or anonymized, per the request of Biotech X.

## Data Analysis

If there was a system-wide reaction to a change event, it should be detectable by a Pearson’s product-moment correlation coefficient (Pearson’s correlation coefficient) test. In the case of a positive result, the Pearson’s correlation coefficient will indicate a rise in correlation for the animal care transactions at each site after the event, in comparison to the correlation measurements prior to the change implementation. This study is not directed at expected outcomes in response to change; instead it focused on unanticipated behaviors that may emerge. Emergent events within a system are an indicator of an adaptive system at work (Uhl-Bien & Arena, 2017). Since this data is historical, and there is an implied expectation that the information will be utilized by the company, it was unnecessary to recruit volunteers to participate in the study.

The collected meta-data was analyzed using the commercial statistical analysis software JMP 16 (SAS, 2021). These transactions reflect the ongoing weekly animal census, breeding performance, and phenotypic measurements, as they are entered by the animal care technicians. As the collecting transactions between two sites are measured over time, a Pearson correlation coefficient was utilized to detect significant changes in correlations between them, both before and after the change event. The Pearson correlation coefficient is a statistical measure to determine the linear association strength of two variable data sets (Lund Research Ltd., 2018(c)). If the technicians do indeed change their behavioral patterns in accordance with complexity theory, this test should detect a statistically significant difference in their aggregate transactions.

In addition to the Pearson correlation coefficient, the large sets of research animal care and phenotypic data were categorized and compared for differences. A one-way analysis of variance (ANOVA) is an appropriate choice to determine statistically significant changes. The ANOVA is a statistical test to determine if at least three unrelated groups are significantly different (Lund Research Ltd., 2018(b)). For comparisons between only two data sets, an independent t-test was an appropriate measure. An independent t-test is a statistical assessment to infer significant differences between the means of two unrelated data sets (Lund Research Ltd., 2018(a)).

## Limitations and Delimitations of the Research Design

All research studies are inevitably subject to limitations and at least some type of assumption (Ellis & Levy, 2009). Limitations reflect a potential weakness or other type of problem that might be inherent in a study (Creswell, 2005). Likewise, assumptions form the foundation of a study, thus creating a starting point (Leedy & Ormrod, 2005). Since the assumptions are so basic, incorrect or incomplete assumptions may become extremely problematic for a study. Identifying the limitations and assumptions of a study allows the researcher to provide a more open acknowledgement for others that there could be alternate explanations for findings (Ellis & Levy, 2009).

Because the subjects of the study were chosen based on their work assignments to a single species, it is possible that the final data collected may represent only that species and cannot be extended to a more general application. However, the inclusion of other species will likely introduce new variables that must be accounted for, which may also confound the data. Therefore, limiting the scope of the study to the single, genetically homogeneous species is appropriate. If the original hypothesis is confirmed, further studies extending the range of the research may be of interest.

It is possible that during the course of their work, some technicians enter incorrect information, either through simple error or, possibly, dishonesty. As a result, any data collected will include some measure of inaccuracy due to human limitations. However, as the data was collected and analyzed in the aggregate, this may remediate any potential problems within the analysis. In 1907, Francis Galton demonstrated that although individuals ($n = 787$) who attempted to guess the weight of an ox were almost invariably wrong, the mean of their collective totals was extremely accurate to within 99.2% (Wallis, 2014).

A delimitation of a study is perhaps most aptly described as what a researcher will not do (Leedy & Ormrod, 2005). Delimitations provide clear borders to research, so that the investigator may remain within a manageable scope of interest. Additionally, this provides the audience with a clear sense of boundaries (Ellis & Levy, 2009). For this study, there were two primary delimitations. The company ERP software collects and tracks other information in addition to animal care data. For example, customer service and inventory logistic records are also maintained in the archives. While this data may contain useful information, for the purposes of this study, only transactions directly entered by the animal technicians was examined.

In order to limit the amount of information collected, data surrounding the scrutiny of an organizational change implementation occurrence was limited to a maximum of six months prior to and six months after the event. Analysis extending beyond this time frame may risk being influenced by a separate and unrelated change implementation event, increasing the potential for confounding any findings.

## Validity

Validity is a necessary component to ensure that a subject is measured accurately and appropriately in a study (Heale & Twycross, 2015). In order to confirm that collected transactions have sufficient validity, the collected data sets were analyzed for the presence of outlier data and evidence of normal distribution. As the research question is limited to addressing only whether members of a group collectively change behavior in response to a new environmental stimulus, data sets may not be normally distributed for a period after a change implementation. For example, if there is a detectable change in the data after the change implementation, but the results do not conform to normal distribution patterns, this might indicate that the results are impacted by a few outliers, rather than a systemic, and therefore complex adaptive, response. Outlier data could be caused by a number of factors, including carelessness, the desire to conform to expectations, or even intentional sabotage (Widhiarso & Sumintono, 2016).

## Ethical Issues in the Proposed Study

The general process of research provides the foundation for the advancement of knowledge; however, the attainment of knowledge must be tempered with a concern for the value of good ethical conduct (Ryan et al., 1979). Currently, the recognized ethical philosophies binding any study involving humans include: a respect for the individual, the protection of subjects from harm, and the prevention of undue burden as a result of research (Ryan et al., 1979). Therefore, in accordance with good ethical conduct, this study must not violate these principles.

The study was conducted using historical data. Because the generated statistics are utilized to continuously monitor animal care performance, it is expected that this information is not exclusively private to the employee. However, to guarantee employee anonymity transactions from specific individuals was de-identified, and no employees were interviewed during the study. Additionally, no information gathered during the research that identifies the work performance of one person was shared with members of company management.

It is recognized that the general use of animals in research may be the subject of ongoing moral debate (Peryer, 2019). To protect the identity of the institution, no information was utilized that can identify either the company or the species. No live animals were utilized in this research at any time. Therefore, there should be no ethical conflicts with the subjects under study. The company’s Institutional Review Board is aware of and has formally approved the use of the data to conduct this research.

## Minimizing Bias

It is extremely difficult to completely eliminate bias in research. At a minimum, there are inherent preconceptions carried by the human researcher prior to beginning the research, and the selected theoretical lens can influence this even further (Merriam & Tisdell, 2016). Rather than an issue of presence or absence, it may be more practical to consider that some degree of bias will always be present in any study design (Pannucci & Wilkins, 2010). However, there are several methods that may be used to reduce the possibility of bias. For example, simply remaining aware that bias may be present, along with continual monitoring, may help to minimize the possibility for bias influence (Merriam & Tisdell, 2016).

The use of statistical models may be useful to remove the potential for human bias in a data set, although even this may not discount the possibility for all error (Szucs & Ioannidis, 2017). Additionally, it is possible to create a statistically significant result after the fact by the selection of specific data pre-fitting the desired criteria, known as *p-fishing* or *p-hacking* (Marin-Franch, 2018). In order to reduce the potential for human bias, the study utilized historical quantitative data, rather than live interviews or other qualitative data. Statistically significant results will be measured at $p <= 0.05$, the commonly held standard (Open Stax, 2013). Additionally, in order to prevent *p-fishing*, this researcher examined data from a discrete, previously selected time period, rather than search for statistically significant data sets at random time points.

### Conflict of Interest

While the animal care data is collected by technicians, none of the employees were identified. Additionally, the animal care data is historical, rather than current (>3 years). In the event of outlier data for a single individual, this researcher did not investigate into the details of the data or notify management at Biotech X. None of the animal care technicians report to this researcher. No identifiable data was or will be provided to employees or management at Biotech X.

## Conclusion and Summary

The aim of this chapter was to discuss the specific methodologies proposed to explore whether the behavior of large numbers of individuals functions as a single dynamic, adaptive system. Additionally, to what degree does this behavior conform to the tenets of complexity theory, and if so, what level of predictability is inherent? The collection and analysis of historical data from hundreds of employees, acting independently, may provide insights to answer these questions.

Given the availability of meta-data, quantitative analysis should be an appropriate measure for this research, and the standard assessment of $p = 0.05$ should adequately reflect any significant findings. The scope of the study should provide for both reasonable limitations and delimitations, and the validation of both data collection and instrumentation has been considered. Finally, the guidelines of the Belmont Report (Ryan et al., 1979) have been utilized to provide attention to the ethical implications of human study.

Any enhancement to the collective understanding of how complexity theory may be taken from a largely academic realm into a real-world application would be very important to the senior leadership of a company. The ability to demonstrate that complexity theory is not just academic, but that it can be physically detected within the daily interactions of a large organization will provide the foundation for practitioners to begin to move complexity from a theoretical concept toward a pragmatic tool set. In turn, increased adoption of complexity leadership theory may stimulate further research and provide firms with a greater ability to cope with the increasingly competitive and rapidly changing global environment.

# CHAPTER 4

# RESULTS

The purpose of this quantitative analysis was to explore the collective behavioral patterns of individuals working in the animal care department of Biotech X. Specifically, this study was interested in how groups of employees collectively respond to a systematic hardware and software change affecting multiple geographic work sites and within multiple facilities at each location. There were two original research questions:

> **Research Question 1:** Can the traits of a complex adaptive system, as described by Regine and Lewin (2000), be detected quantitatively through the analysis of routine data generated by individual employees in the animal care department of Biotech X?
>
> **Research Question 2:** If a complex adaptive system is present in the data, does the complex adaptive system display distinguishable traits of either Wheatley's (2006) complexity theory or Marion and Uhl-Bien's (2001) complexity leadership theory?

To explore these research questions, the historical animal care data transactions were extracted from the data warehouse at Biotech X immediately prior to and after a computer hardware and software upgrade. This data was then analyzed for statistically significant differences.

## Analysis Method

To detect the presence of a complex adaptive system, a specific change event was identified. For the purposes of anonymity to Biotech X, the exact date of the computer upgrade will not be identified in this analysis. The change involved an upgrade from alpha-numeric data entry using small screens to touch-screen data entry on larger tablets. This change was implemented simultaneously to all animal care facilities within the same week. Animal care technicians received extensive training in a simulation program during the weeks prior to the rollout. It was theorized by this researcher that a sudden, ubiquitous experience might stimulate a detectable complex adaptive response by the animal care technicians. In this case, the sudden experience of the computer hardware/software rollout to the animal care facilities was selected.

During the course of the workday, the animal care technicians in each workspace electronically record the data surrounding the care and maintenance of the animal colonies. This data includes the census, breeding, and phenotype information of the colonies. The historical data sets are maintained by the Information Technology department at Biotech X and are readily available for extraction into Microsoft Excel. For the purposes of this study, and to reduce the possibility of confounding data, only a single species was selected for analysis.

Although Biotech X operates at multiple sites, two campuses were selected for this study. For purposes of anonymity to Biotech X, neither the exact location nor the number of animal facilities at each campus were identified. Sites are referred to as “Location 1” and “Location 2.” The two locations are geographically distant from one another (>1000 miles), and the animal care staff at each site do not routinely interact with animal care employees at the other location in person. The single selected species is housed within multiple animal facilities at each site, under similar environmental conditions.

The number of breeding units serviced per day for the twenty-four weeks prior to the change event was extracted from the data archives for each location and stored in Microsoft Excel. Additionally, data sets for breeding transactions for the same time period were extracted. Definitions of breeding units serviced per day and breeding transactions per breeding unit are found in the corresponding sections below (**Breeding Units Serviced Per Day** and **Breeding Transactions Per Breeding Unit**, respectively). The names of individuals were not obtained in the data sets, in accordance with the request of Biotech X for individual anonymity. While the hardware/software change occurred during the appointed week, it is unknown if the rollout happened on the first workday. Therefore, it is impossible to determine the exact transition point of the data; as a result, the actual week of the computer change was not selected for analysis in either data set. The number of breeding units serviced per day for the twenty-four weeks after the change event was extracted from the same data archives for each location and stored in Microsoft Excel, along with the corresponding breeding transactions. Any features within the data that could potentially identify Biotech X were changed. The number of breeding transactions per week was divided by the number of breeding units serviced per week to establish the weekly rate of breeding transactions per breeding unit for each location. A weekly rate was selected for breeding transaction data, as it is possible that an animal care technician might service a breeding unit, but record breeding data at a different time during the week. Therefore, a daily rate may not be an appropriate measure in this case.

For this study, the individual data points were downloaded from Biotech X’s internal data warehouse into Microsoft Excel. In addition, the statistical software JMP 16 was then used to generate the summary results. JMP 16 is a commercially available software program commonly used for advanced statistical analysis and data visualization (SAS, 2021). The statistics used included:

- A one-way analysis of variance (ANOVA) by location for the events prior to and after the hardware/software change event.
- A pooled t-test to determine if the means of two data sets are statistically different.
- A Pearson product-moment correlation coefficient to determine the strength and direction (if any) of aggregate responses to the hardware/software change.

- Significance was determined using a measure of $p <= .05$, as this is the commonly accepted standard for statistical analysis (OpenStax, 2013).

## Presentation of Results and Findings

### Breeding Units Serviced Per Day

One of the major tasks of animal care technicians is to service the animals in each breeding unit. All breeding units must be checked by the end of the week, so each day the animal care technicians service a subset of the breeding units. The breeding unit is cleaned, food and water are replenished, and the animals are checked for general health and well-being. For this study, the number of breeding units serviced per day was analyzed at each location and was examined before the upgrade and after the upgrade. The total number of days analyzed for Location 1 was 259, approximately representing the six months prior to and after the upgrade. The total number of days analyzed for Location 2 was 254, approximately representing the six months prior to and after the upgrade.

#### ***Breeding Units Serviced Per Day: Location 1***

The one-way analysis of the breeding units serviced per day for Location 1 before and after the upgrade produced the following results. These results indicate that there is no significant difference ($n = 259$, $p = .701$) between the number of breeding units serviced per day for Location 1 before and after the upgrade (Figure 2):

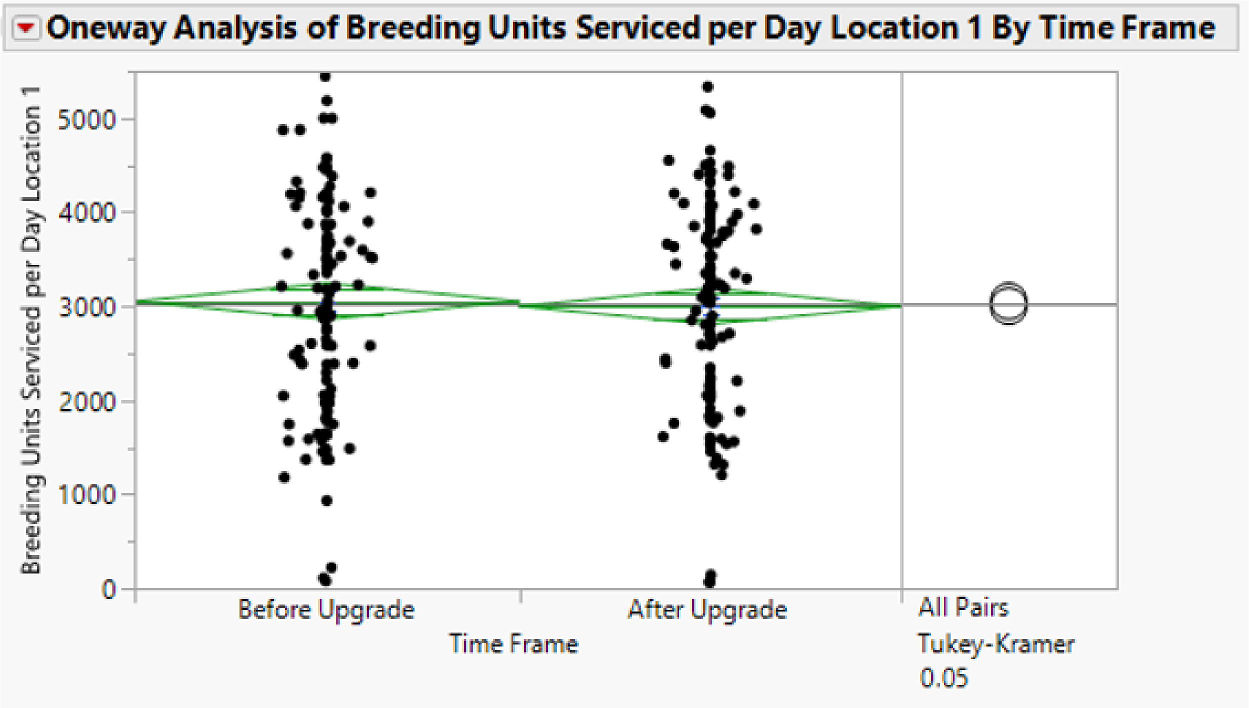
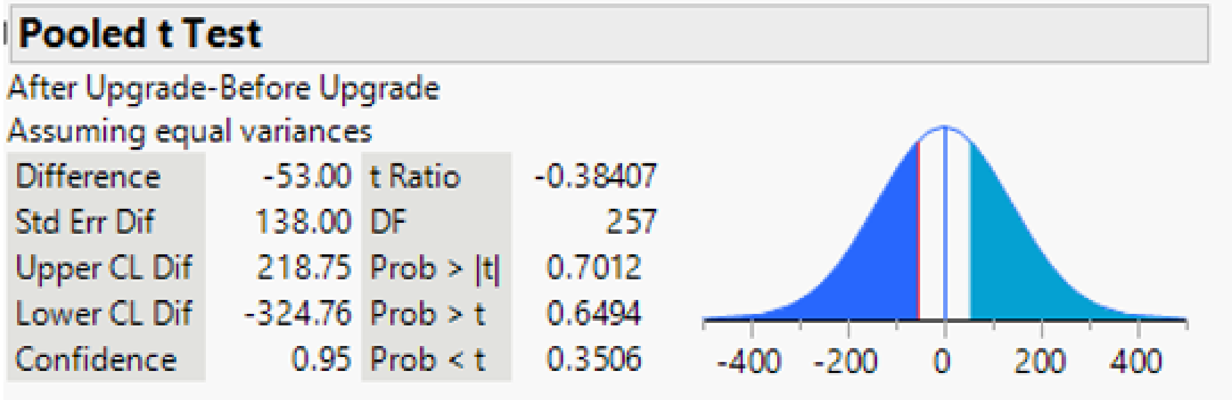


**Figure 2. One-way analysis for Breeding Units Serviced per Day before upgrade and after upgrade for Location 1.**

The t-test analysis for the same data at Location 1 produced the following results. These results indicate that there is no significant difference (*n* = 259, *p* = .701) between the number of breeding units serviced per day for Location 1 before and after the upgrade (Figure 3):



```
Pooled t Test
After Upgrade-Before Upgrade
Assuming equal variances
Difference       -53.00   t Ratio      -0.38407
Std Err Dif      138.00   DF                257
Upper CL Dif     218.75   Prob > |t|     0.7012
Lower CL Dif    -324.76   Prob > t       0.6494
Confidence         0.95   Prob < t       0.3506
```

**Figure 3. T-test for Breeding Units Serviced per Day before upgrade and after upgrade for Location 1.**

The analysis of variance for the same data produced the following results. These results indicate that there is no significant difference (*n* = 259, *p* = 0.701) between the number of breeding units serviced per day for Location 1 before and after the upgrade (Table 1):

**Table 1**

**Analysis of Variance for Breeding Units Serviced per Day before upgrade and after upgrade for Location 1.**

**Analysis of Variance**

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Time Frame | 1 | 181888 | 181888 | 0.1475 | 0.7012 |
| Error | 257 | 316904328 | 1233091 | | |
| C. Total | 258 | 317086216 | | | |

### *Breeding Units Serviced Per Day: Location 2*

The one-way analysis of the breeding units serviced per day for Location 2 before and after the upgrade produced the following results. These results indicate that there is no significant difference (*n* = 254, *p* = .844) between the number of breeding units serviced per day for Location 2 before and after the upgrade (Figure 4):

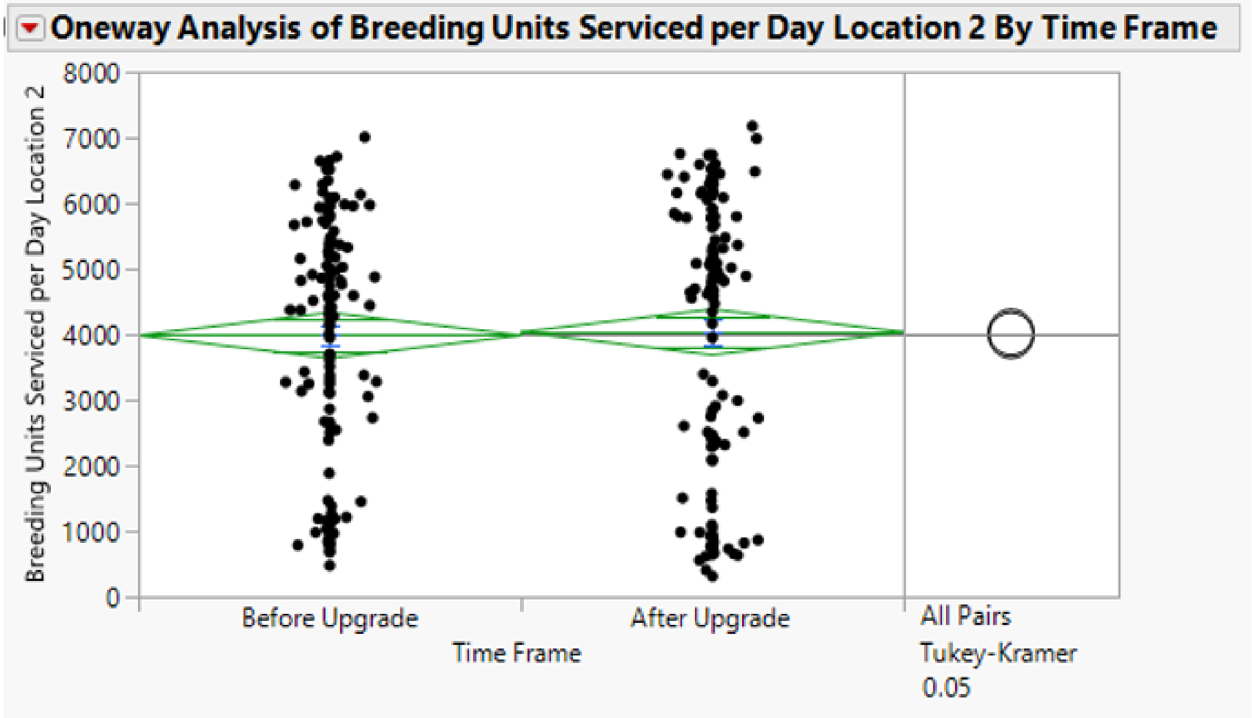
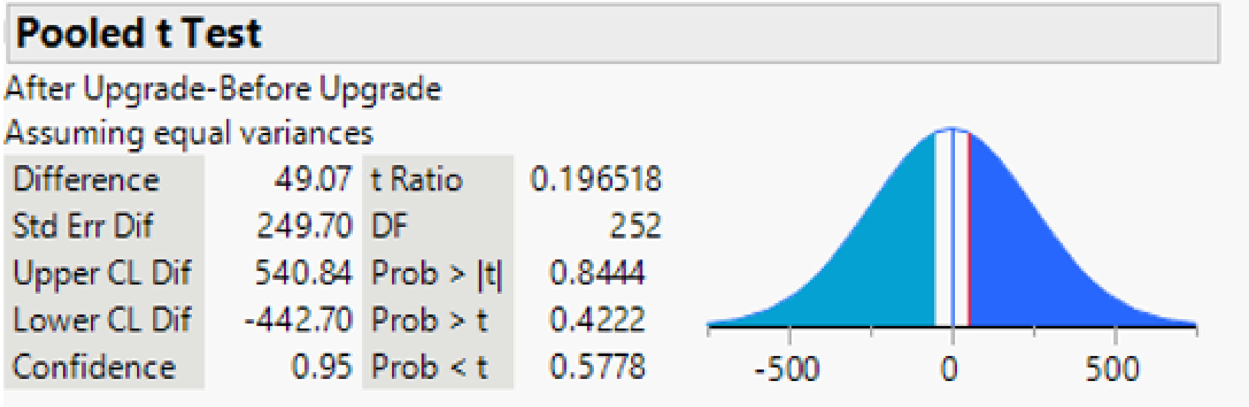


**Figure 4. One-way analysis for Breeding Units Serviced per Day before upgrade and after upgrade for Location 2.**

The t-test analysis for the same data produced the following results. These results indicate that there is no significant difference (*n* = 254, *p* = .844) between the number of breeding units serviced per day for Location 2 before and after the upgrade (Figure 5):



```
Pooled t Test
After Upgrade-Before Upgrade
Assuming equal variances
Difference        49.07  t Ratio    0.196518
Std Err Dif      249.70  DF              252
Upper CL Dif     540.84  Prob > |t|   0.8444
Lower CL Dif    -442.70  Prob > t     0.4222
Confidence         0.95  Prob < t     0.5778
```

**Figure 5. T-test for Breeding Units Serviced per Day before upgrade and after upgrade for Location 2.**

The analysis of variance for the same data produced the following results. These results indicate that there is no significant difference (*n* = 254, *p* = .844) between the number of breeding units serviced per day for Location 2 before and after the upgrade (Table 2):

**Table 2**

**Analysis of Variance for Breeding Units Serviced per Day before upgrade and after upgrade for Location 2.**

**Analysis of Variance**

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Time Frame | 1 | 152905 | 152905 | 0.0386 | 0.8444 |
| Error | 252 | 997738752 | 3959281 | | |
| C. Total | 253 | 997891657 | | | |

## Breeding Transaction/Breeding Unit

In addition to servicing breeding units, another major responsibility of the animal care technicians is to track breeding performance. Each day, as the animal care technicians service each breeding unit, they also record the breeding performance for each set of breeding animals.

In this case, the daily transactions per breeding unit may not be an appropriate measure, because it is possible that an animal care technician may service a breeding unit but return to it later in the week to record a breeding transaction. Therefore, for this study, the number of weekly breeding transactions per breeding unit was analyzed. For both Locations 1 and 2, the breeding transactions per breeding unit for the 24 weeks before and 24 weeks after the computer upgrade was selected, for a total of 48 weeks for each site.

***Breeding Transaction/Breeding Unit: Location 1***

The one-way analysis of the weekly breeding transactions per breeding unit (*n* = 48) for Location 1 before and after the upgrade produced the following results. These results indicate that there is a significant difference (*n* = 48, *p* < .001) between the number of breeding transactions per breeding unit for Location 1 before and after the upgrade (Figure 6):

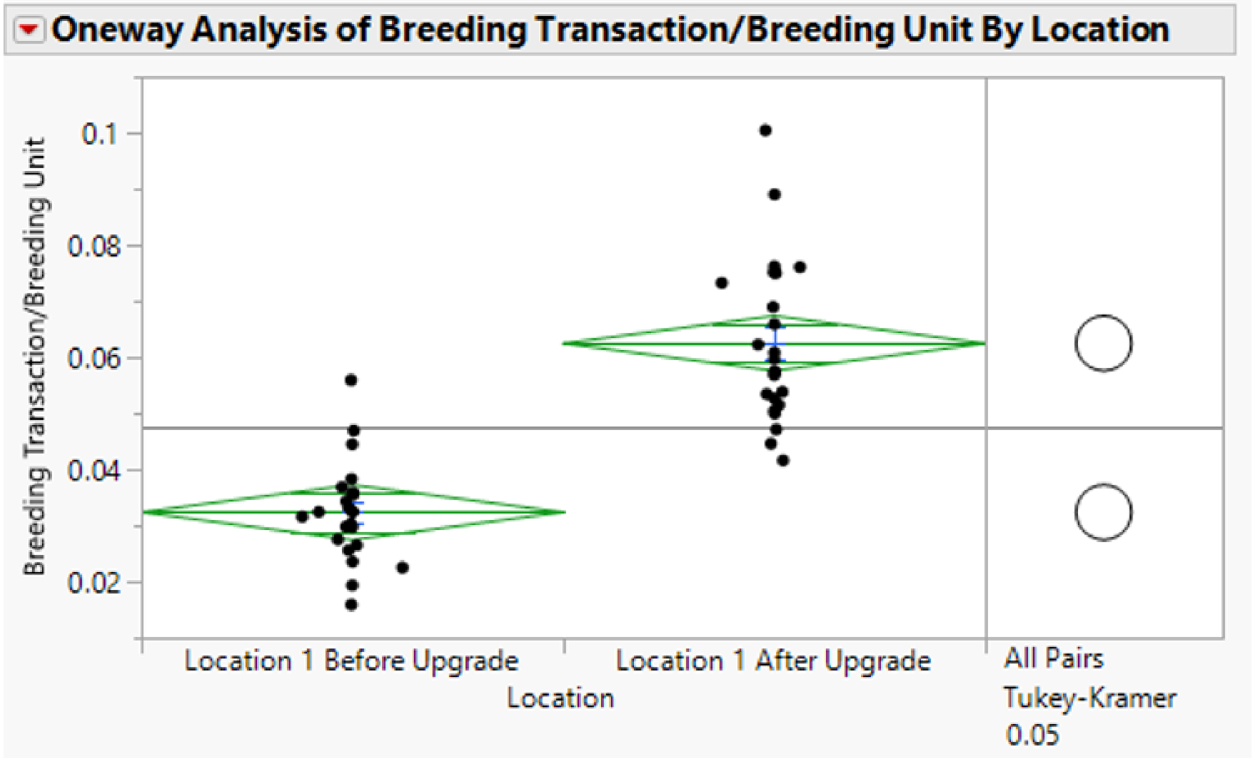
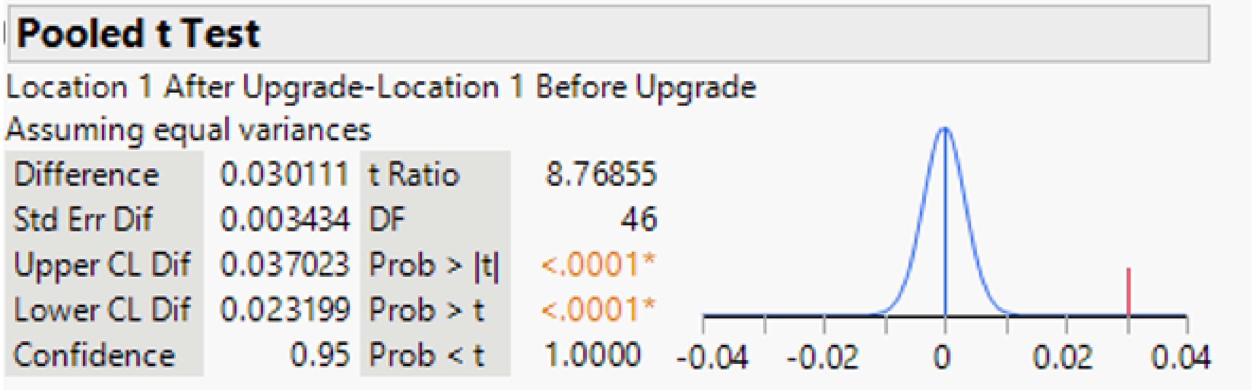


**Figure 6. One-way analysis for Breeding Transactions per Breeding Unit before upgrade and after upgrade for Location 1.**

The t-test analysis for the same data produced the following results. These results indicate that there is a significant difference (*n* = 48, *p* < .001) between the number of breeding transactions per breeding unit for Location 1 before and after the upgrade (Figure 7):



```
Pooled t Test
Location 1 After Upgrade-Location 1 Before Upgrade
Assuming equal variances
Difference      0.030111  t Ratio     8.76855
Std Err Dif     0.003434  DF               46
Upper CL Dif    0.037023  Prob > |t|  <.0001*
Lower CL Dif    0.023199  Prob > t    <.0001*
Confidence          0.95  Prob < t     1.0000
```

**Figure 7. T-test analysis for Breeding Transactions per Breeding Unit before upgrade and after upgrade for Location 1.**

The analysis of variance for the same data produced the following results. These results indicate that there is a significant difference (*n* = 48, *p* < .001) between the number of breeding transactions per breeding unit for Location 1 before and after the upgrade (Table 3):

**Table 3**

**Analysis of Variance for Breeding Transactions per Breeding Unit before upgrade and after upgrade for Location 1.**

**Analysis of Variance**

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Location | 1 | 0.01087996 | 0.010880 | 76.8875 | <.0001* |
| Error | 46 | 0.00650923 | 0.000142 | | |
| C. Total | 47 | 0.01738918 | | | |

***Breeding Transaction/Breeding Unit: Location 2***

The one-way analysis of the weekly breeding transactions per breeding unit for Location 2 before and after the upgrade produced the following results. These results indicate that there is a significant difference (*n* = 48, *p* < .001) between the number of breeding transactions per breeding unit for Location 2 before and after the upgrade (Figure 8):

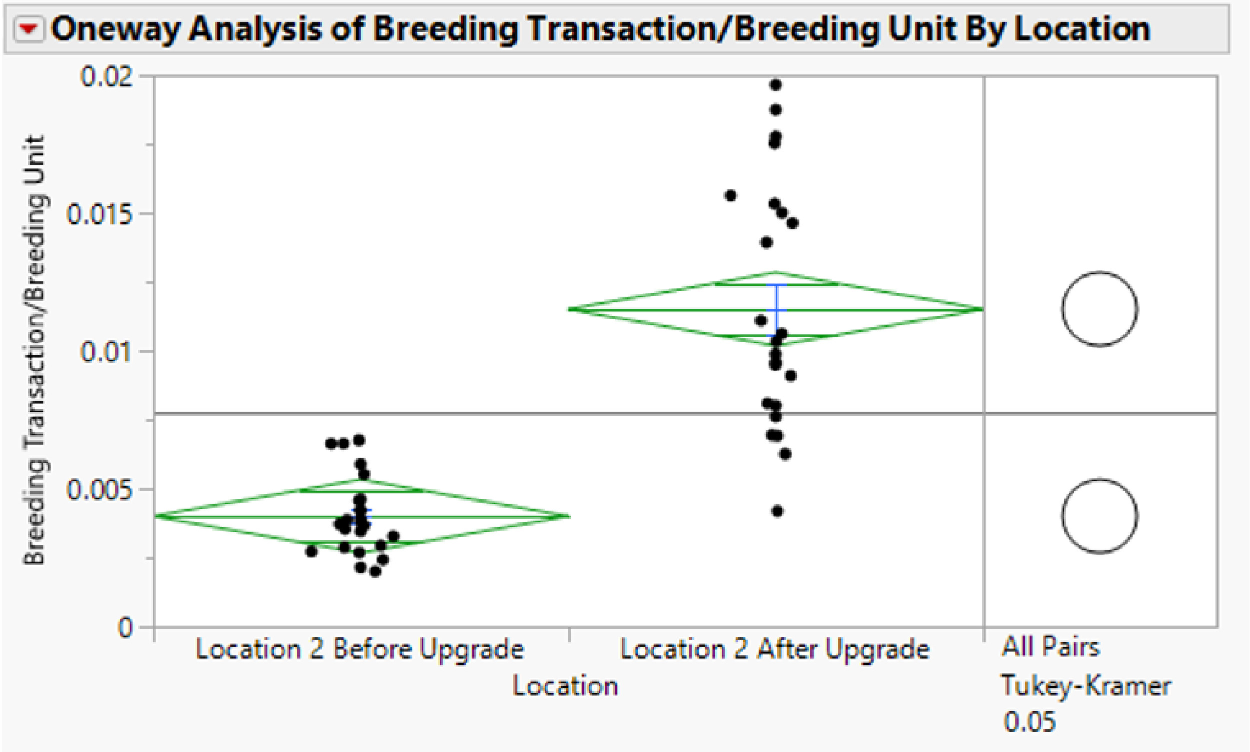
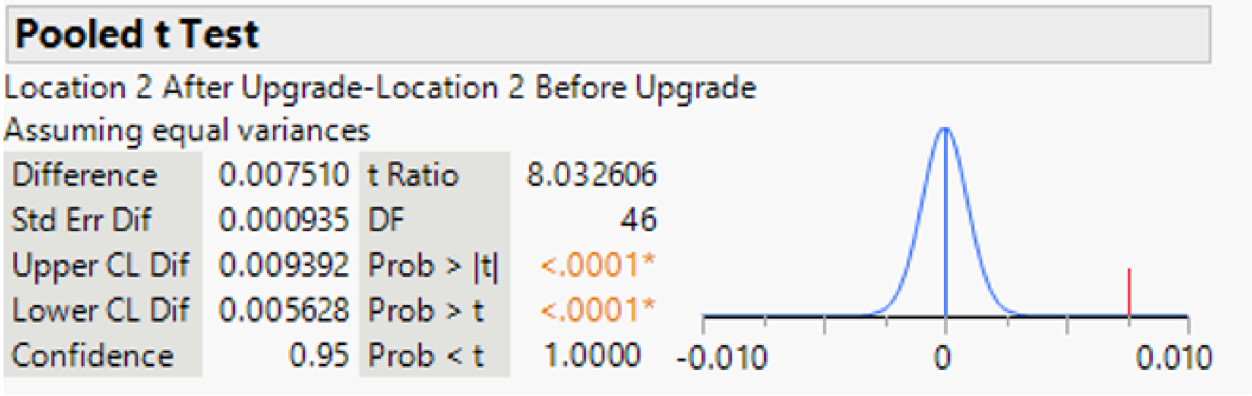


**Figure 8. One-way analysis for Breeding Transactions per Breeding Unit before upgrade and after upgrade for Location 2.**

The t-test analysis for the same data produced the following results. These results indicate that there is a significant difference (*n* = 48, *p* < .001) between the number of breeding transactions per breeding unit for Location 2 before and after the upgrade (Figure 9):



**Pooled t Test**

Location 2 After Upgrade-Location 2 Before Upgrade

Assuming equal variances

| | | | |
|---|---|---|---|
| Difference | 0.007510 | t Ratio | 8.032606 |
| Std Err Dif | 0.000935 | DF | 46 |
| Upper CL Dif | 0.009392 | Prob > \|t\| | <.0001* |
| Lower CL Dif | 0.005628 | Prob > t | <.0001* |
| Confidence | 0.95 | Prob < t | 1.0000 |

**Figure 9. T-test analysis for Breeding Transactions per Breeding Unit before upgrade and after upgrade for Location 2.**

The analysis of variance for the same data produced the following results. These results indicate that there is a significant difference (*n* = 48, *p* < .001) between the number of breeding transactions per breeding unit for Location 2 before and after the upgrade (Table 4):

**Table 4**

**Analysis of Variance for Breeding Transactions per Breeding Unit before upgrade and after upgrade for Location 2.**

**Analysis of Variance**

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Location | 1 | 0.00067686 | 0.000677 | 64.5228 | <.0001* |
| Error | 46 | 0.00048255 | 0.000010 | | |
| C. Total | 47 | 0.00115941 | | | |

## Correlation of Location 1 and Location 2 Before and After Upgrade

To determine if the significant differences for the breeding transactions per breeding unit affected both locations in a similar manner, a Pearson product-moment correlation test was applied to the data for both locations. It was theorized by this researcher that if a new, positive correlation appeared between the two locations directly after the change event, this might indicate that a behavioral change in the animal care technicians is the result of the hardware/software upgrade. However, if no new correlation appears between the two locations after the upgrade, or if a negative correlation is detected, this might suggest that any observed behavioral changes are local, and not systemic.

The Pearson product-moment correlation of the Breeding Transactions per Breeding Unit between Location 1 and Location 2 for the twenty-four weeks before the upgrade produced the following results. These results indicate that there is no significant correlation (*r(22)* = .18, *p* = .390) between the number of breeding transactions per breeding unit for Location 1 and Location

2 before the upgrade. This would imply that weekly fluctuations in the breeding transactions per breeding unit for Location 1 display no correlation to the weekly breeding transactions per breeding unit at Location 2 prior to the change event (Table 5):

**Table 5**

**Pearson product-moment correlation of Breeding Transactions/Breeding Unit between Location 1 and Location 2 before upgrade.**

**Correlations**

| | **Location 1 Breeding Transaction/Breeding Unit Before Upgrade** | **Location 2 Breeding Transaction/Breeding Unit Before Upgrade** |
|---|---|---|
| **Location 1 Breeding Transaction/Breeding Unit Before Upgrade** | 1.0000 | 0.1839 |
| **Location 2 Breeding Transaction/Breeding Unit Before Upgrade** | 0.1839 | 1.0000 |

**Correlation Probability**

| | **Location 1 Breeding Transaction/Breeding Unit Before Upgrade** | **Location 2 Breeding Transaction/Breeding Unit Before Upgrade** |
|---|---|---|
| **Location 1 Breeding Transaction/Breeding Unit Before Upgrade** | <0.0001 | 0.3896 |
| **Location 2 Breeding Transaction/Breeding Unit Before Upgrade** | 0.3896 | <0.0001 |

A Pearson product-moment correlation of the Breeding Transactions per Breeding Unit between Location 1 and Location 2 for the twenty-four weeks after the upgrade produced the following results. These results indicate that there is a significant positive correlation ($r(22) = .68$, $p < .001$) between the number of breeding transactions per breeding unit for Location 1 and Location 2 after the upgrade. This would imply that weekly fluctuations in the breeding transactions per breeding unit for Location 1 display a correlation to the weekly breeding transactions per breeding unit at Location 2 after the upgrade. In this case, both locations experienced a simultaneous rise in the total number of breeding transactions per breeding unit after the hardware and software upgrade (Table 6):

**Table 6**

**Pearson product-moment correlation of Breeding Transactions/Breeding Unit between Location 1 and Location 2 after upgrade.**

**Correlations**

| | **Location 1 Breeding Transaction/Breeding Unit After Upgrade** | **Location 2 Breeding Transaction/Breeding Unit After Upgrade** |
|---|---|---|
| **Location 1 Breeding Transaction/Breeding Unit After Upgrade** | 1.0000 | 0.6794 |
| **Location 2 Breeding Transaction/Breeding Unit After Upgrade** | 0.6794 | 1.0000 |

**Correlation Probability**

| | **Location 1 Breeding Transaction/Breeding Unit After Upgrade** | **Location 2 Breeding Transaction/Breeding Unit After Upgrade** |
|---|---|---|
| **Location 1 Breeding Transaction/Breeding Unit After Upgrade** | <0.0001 | 0.0003 |
| **Location 2 Breeding Transaction/Breeding Unit After Upgrade** | 0.0003 | <0.0001 |

## Summary

The analysis of the data indicates that there was no significant difference between the number of breeding units serviced per day at Location 1 prior to and after the hardware/software upgrade. Similarly, there appears to be no significant difference between the number of breeding units serviced per day at Location 2 prior to and after the hardware/software upgrade. In the case of the number of breeding transactions per breeding unit for Location 1, there was a significant increase in the reported data per breeding unit after the upgrade. Likewise, the data for Location 2 also shows a significant increase during the same time frame. Finally, the Pearson product-moment correlation shows that there was no correlation ($r(22) = .18$, $p = .390$) for breeding transactions per breeding unit between the two locations for the twenty-four weeks prior to the upgrade. However, there was a significant correlation ($r(22) = .68$, $p < .001$) for breeding transactions per breeding unit between Locations 1 and 2 for the twenty-four weeks post upgrade.

# CHAPTER 5

## CONCLUSION

The intent of this quantitative study was to examine the potential for observed collective behavioral changes in response to stimuli within the animal care department at Biotech X. If detected, the collective behaviors of the animal care staff may indicate the presence of a complex adaptive system, the fundamental unit of complexity theory (Uhl-Bien at al., 2007). The research investigated how groups of employees aggregately responded to a ubiquitous upgrade in the hardware and software utilized within two separate animal care facilities at Biotech X. It was proposed by this researcher that the analysis of the historical data transactions entered by the animal care technicians at the time of the computer upgrade might demonstrate a quantitative adaptive response.

The observation of a complex adaptive system would support the argument for the relevance of complexity theory within Biotech X. Where hierarchical leadership models struggle to adapt to rapid growth and technological change, the properties of complexity theory, described by Wheatley (2006), may provide an alternative governance model. Additionally, if complexity theory is affirmed, complexity leadership theory has relevance, as it provides a guide for the reconciliation of complexity and the existing hierarchical leadership theories that are unlikely to decline (Uhl-Bien & Arena, 2016).

This study was designed to address the two original research questions:

**Research Question 1:** Can the traits of a complex adaptive system, as described by Regine and Lewin (2000), be detected quantitatively through the analysis of routine data generated by individual employees in the animal care department of Biotech X?

**Research Question 2:** If a complex adaptive system is present in the data, does the complex adaptive system display distinguishable traits of either Wheatley's (2006) complexity theory or Marion and Uhl-Bien's (2001) complexity leadership theory?

The investigation followed two primary lines of inquiry. First, the number of breeding units serviced per day at each site was examined for the six months prior to and six months after the hardware and software upgrade. A statistical analysis of the data indicated that there was no significant difference between the number of breeding units serviced per day for either location. Second, the number of breeding transactions per breeding unit at each site was examined for the twenty-four weeks before and twenty-four weeks after the upgrade. A statistical analysis of the data indicated that the number of breeding transactions per breeding unit rose significantly at both sites after the change was implemented. Additionally, a Pearson product-moment correlation of the two sites indicated no significant correlation of the breeding transactions per breeding unit for the twenty-four weeks before the upgrade, but a significant, positive correlation for the twenty-four weeks after the upgrade.

## Interpretation and Importance of Findings

To consider the results of this study as a possible affirmation of the research questions, two criteria should be met. First, to support the thesis for the presence of a complex adaptive system, there must be a discernable (or, in this case, quantifiable) aggregate macro-level response to the environmental change (Marion & Uhl-Bien, 2003; Regine & Lewin, 2000). Second, to consider complexity theory, there should be an unexpected or emergent outcome (Fullan, 2001; Wheatley, 2006). After an analysis of the data, three key findings have been identified.

### Finding 1: No Significant Change in Breeding Units Serviced Per Day

The results of the analysis indicate that there appeared to be no significant change in the number of breeding units serviced per day by the animal care technicians as a result of the upgrade. It is therefore inferred that the computer upgrade had no detectable effect on the speed of the animal care workers as they service the breeding units each day.

### Finding 2: A Significant Change in Breeding Transactions Per Breeding Unit

The results of the analysis show that there appeared to be a significant change in the recorded breeding transactions per breeding unit directly after the upgrade. This change was detected at both locations following the change event. This finding suggests that there was an aggregate response, as the difference was observed at both Location 1 and Location 2 after the event. The observation of the aggregate response is favorable to Regine and Lewin’s (2000) explanation that when the environment changes, so does the “behavior of the system as a whole” (p. 6). Additionally, the apparent bias of the animal care technicians toward breeding transactions per breeding unit, but not toward breeding units serviced per day after the upgrade may support the concept of Burnes’ (2005) adherence to simple systemic rules. It might also potentially fulfill the expectation for the emergence of “new forms and repertoires” (Fullan, 2001, p. 108).

### Finding 3: A Significant Correlation Between Locations After Upgrade

The results of the analysis indicate that prior to the upgrade, there was no significant correlation between the locations for the breeding transactions per breeding unit. However, after the upgrade, a significant, positive correlation appeared. In Wheatley’s (2006) description on the properties of complexity, she describes fractal behavior by organizations. If Biotech X has successfully instilled a fractal culture, this would suggest that separate divisions of the firm should display similar reactions when disturbed. This finding suggests that the direction and magnitude of the aggregate response to the change was similar for both locations, supporting the case for Wheatley's (2006) fractal behavior.

### Interpretation: Findings 1 and 2

The number of breeding units serviced per day did not change after the upgrade. However, the breeding transactions per breeding unit increased significantly after the upgrade. The observation that the breeding transactions per breeding unit changed following the hardware and software upgrade is interesting, as it implies that the breeding performance of the animals has changed after the upgrade. The implementation of new data recording devices should not affect the reproductive biology of the animals; although it is known that some laboratory animals are sensitive to the ultrasounds emitted by some electronic equipment, so this cannot be completely ruled out (Sales, et al., 1988).

One possible explanation is that, prior to the upgrade, the animal care technicians were collectively underrepresenting the breeding performance of the animals, and that the hardware and software change allowed for a resolution to this issue. This apparent collective response is in line with the commentary of Mason regarding complexity theory, that "stimulating one part of the system can have unexpected effects in other, unanticipated, parts of the system" (2007, p. 12). An interpretation of this outcome might be time compression. If, prior to the change event, the animal care technicians were pressed for time to complete their daily tasks, it is possible that they were collectively less accurate in their breeding transactions, instead favoring efficiency.

The computer upgrade involved a change from alpha-numeric text data entry to touch screen data entry. In a study by Mitsubishi Electric Research Laboratories, a touch screen input was demonstrated to increase the speed of data entry by up to 20% over other conventional methods (Kazmeyer, 2022). If this upgrade allowed for more efficient data collection, then the staff of the animal care facilities would have suddenly found themselves with more available work time during their day. This might suggest that when time compression was relieved at Biotech X, at the moment of bifurcation between choosing increased efficiency (breeding units serviced per day) or increased accuracy (breeding transactions per breeding unit), the animal care technicians at Biotech X collectively chose accuracy (Figure 10).

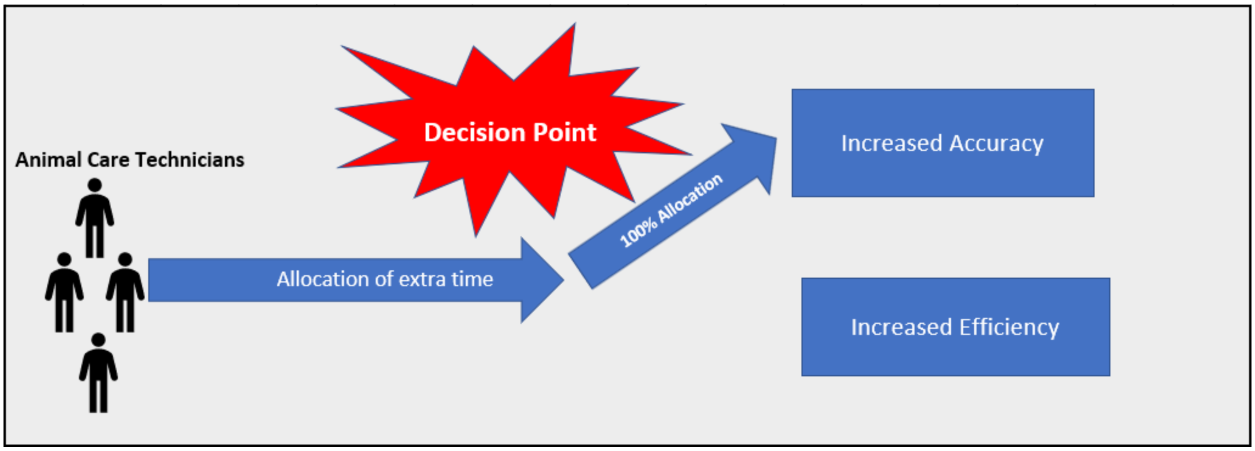


**Figure 10. Animal care technician allocation of extra time to only increased accuracy, suggesting a collective response.**

If the interpretation that the animal care technicians at Biotech X collectively chose accuracy is correct, this could indicate a complex adaptive response, since a noncollective reaction would likely show a random dispersal of the time relief in both efficiency and accuracy (Figure 11). As the response of the animal care technicians in this case was strongly influenced toward breeding transactions, and not pens serviced per day, there is the possibility that the system has an element of determinism. Burnes (2005) does argue that dynamic complex systems, while unpredictable, might be “governed by a set of simple order-generating rules” (p. 74). If this can be affirmed, perhaps it is possible to create deterministic models that could increase the predictive capabilities of senior leadership. It would also suggest two critical implications, described in more detail below (see **Deterministic Modeling**).

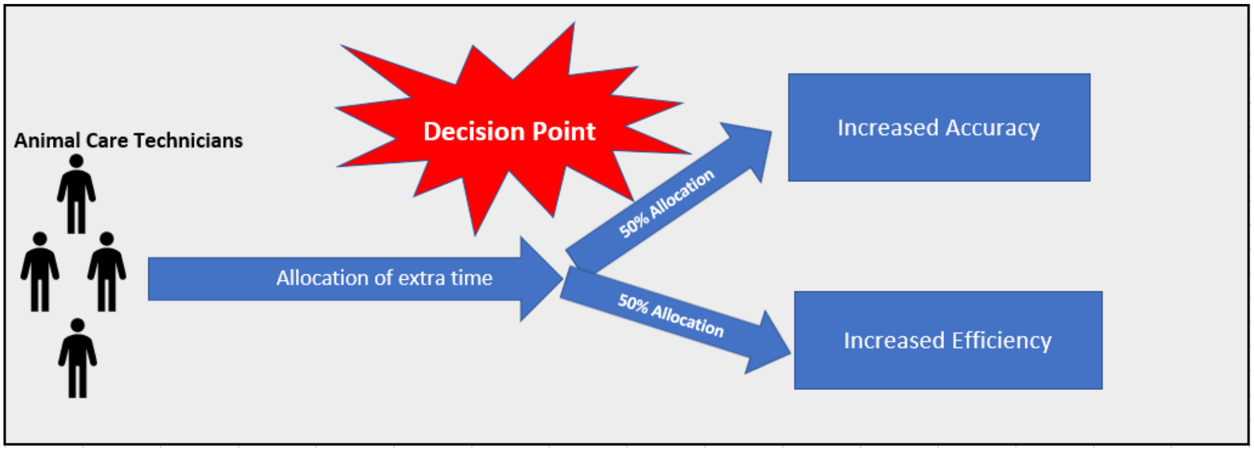


**Figure 11. Animal care technician allocation of extra time to both increased accuracy and increased efficiency, suggesting a random, noncollective response.**

The positive identification of unexpected or emergent conduct may be more ambiguous than the detection of aggregate behavior, as the precise definition of either term may be highly dependent on the observer. For example, a relatively simple behavior such as laughter in the workplace is considered typical by Western standards but is deemed to be unexpected behavior in Japanese companies (Stadler, 2018). However, the observation that the number of breeding transactions per breeding unit significantly increased after the computer upgrade, but breeding units serviced per day did not is of interest and may provide support for the unexpected behavior criteria.

In business, especially in a highly competitive market, the senior leadership often vocalizes a balance between speed and quality; however, in practice, the overwhelmingly accepted top industry value is speed (Brooks, 2015). For instance, Amazon, a top distributor of retail goods, has been criticized for allegedly using algorithms to maximize the efficiency of their workers beyond the limits of reasonable employee health and safety (Selyukh, 2021). In the case of the animal care technicians at Biotech X, increased data entries around breeding transactions, but not toward breeding units serviced appears to be contrary to this ideal. This may support the premise that some other factor besides the expectations of efficiency is driving the behavior of animal care technicians at Biotech X, suggesting the presence of a complex adaptive system. Alternately, perhaps there is a natural optimum efficiency equilibrium point inherent to the system, and when this value is surpassed, further time allocations are automatically redirected toward increased accuracy.

It is possible that the senior leadership of Biotech X has successfully proliferated a culture of prioritizing high-quality products over throughput at the company. Wheatley (2006) describes all organizations as “fractal in nature” (p. 128); if leadership maintains a higher regard for quality, this philosophy would likely trickle down throughout the rest of the firm. If this is in fact the case, when faced with an opportunity, the animal care technicians at Biotech X might naturally be more inclined to make quality improvements over quantity improvements. For the animal care technicians, while there may be a willingness to adhere to ideology, they also face the daily pressures, as transactional leaders must continually attempt to resolve the conflict between long term ideals and short-term efficiency at the local level (Bass, 2008). This could explain the unusual response of the animal care technicians as time pressures are relieved.

Even if Biotech X has successfully instilled a culture of high quality, there must still be some pressure on the animal care technicians to maximize efficiency, and therefore service as many breeding units as possible during their workday. Otherwise, the economic law of supply and demand would predict that another, more efficient competitor would enter the market (Asmundson, 2020). As there must be some time pressure on the animal care technicians to perform, it is surprising that the apparent extra time in the workday was allocated to increased accuracy (breeding transactions per breeding units) and not increased efficiency (breeding units serviced per day). If this is the correct analysis of the data, then observation of the animal care technicians’ collective response may qualify as an unexpected outcome. This aligns with

Fullan’s (2001) description of complexity theory, as he notes when “excitation takes place . . . new forms and repertoires *emerge*” as a result (p. 108). Wheatley (2006) provides a similar portrayal, arguing that “order emerges as elements of the system work together . . . inventing new capacities” (p. 111). This interpretation would therefore offer support for the affirmation of Research Question 2, as there do appear to be at least some observable, quantifiable properties of complexity present, as described by Wheatley (2006). Specifically, it would appear that properties of complexity were present at Biotech X when the animal care technicians reacted in the aggregate after the upgrade. Additionally, the significant response toward accuracy but not efficiency would support Burns’ (2005) argument that the system is following simple rules in response to external stimuli.

### Interpretation: Finding 3

Prior to the change implementation, there was no significant correlation for breeding transactions per breeding unit between Location 1 and Location 2. After the change, there was a significant, positive correlation for breeding transactions per breeding unit between the two locations. If a response was observed at one location but not the other, this might imply that the change did not affect the entire system, or that the observation was the product of some other environmental stimuli. Since the correlation appeared directly after the hardware/software upgrade, but was not present prior to the change, this would support the argument that the computer change produced a systemic, aggregate response.

One possibility is that the reaction of the animal care staff is a collective shift to a new anchoring behavior. As discussed in Chapter 3, humans tend to gravitate to an idea, and over-rely on it to make decisions, even to the point of irrationality (Meub & Proeger, 2018). However, if a strong enough environmental influence occurs, individuals or groups may reduce their attachment to the original anchor point, opening themselves to the possibility of a new anchor (Nagtegaal et al., 2020). Anchoring behavior can also be influenced (or purposefully manipulated) by the presence of suggestive information or visual cues, even if these cues are “impossibly extreme” (Adomavicius et al., 2013, p. 960). In this case, the computer hardware and software change may have been a significant enough disruption that the animal care technicians collectively moved to a new anchoring position surrounding the expected average breeding performance of the animals.

The idea that the animal care technicians may organize themselves around an anchor point is similar to the previously mentioned deterministic work of Lorenz on weather systems (Burnes, 2005). These patterns, known as “strange attractors,” allow for an enhanced level of system predictability in a field of apparent chaos (Wheatley, 2006, p. 118). While the decisions of individuals within the system are unpredictable, the group as a whole tends to remain inside a fixed boundary, remaining in close proximity to one or more static points. This interpretation would support Burnes’ (2005) argument that the behavior of complex systems is controlled by relatively simplistic operating rules, and that qualitative anchor points are possibly analogous to quantitative strange attraction orbits (see **Deterministic Modeling**).

The display of similar emergent behavior in both locations after the hardware/software upgrade also appears to corroborate Wheatley’s (2006) description of fractal organizational behavior. The observation that the animal care technicians appeared to collectively increase the accuracy of their work, but not their efficiency, may possibly be interpreted as unusual behavior, since there is a strong bias of most organizations to increase efficiency (Brooks, 2015). The idea that behavioral anchor points are analogous to strange attractor orbits would also support the argument that at least some elements of the organization are displaying complex adaptive behavior. Thus, under this interpretation of the results, Research Question 2 may also be tentatively affirmed. By extension, the presence of a complex adaptive system implies that both complexity and complexity leadership theories may have relevance for senior leadership at Biotech X, since complex adaptive systems are the fundamental building block of complexity (Uhl-Bien et al., 2007). An increased level of determinate predictability within the system may also have a pragmatic value for senior leadership, as they monitor the ongoing performance of the organization. A recognition of complexity by management and the decision to allow it to operate more freely under less limited constraints conforms with the ideals of complexity leadership theory, which seeks to "integrate complexity dynamics and bureaucracy" (Uhl-Bien et al., 2007, p. 304).

The totality of the findings indicates that there did appear to be a collective reaction in both locations directly following the hardware/software upgrade. The reaction was similar in both direction and magnitude for Location 1 and Location 2, as quantified by the correlational analysis. Additionally, the overall response appeared to significantly favor a quantifiable increase in animal care technician accuracy, but not efficiency. These conditions satisfy the requirements of Regine and Lewin's (2000) description of complex adaptive systems, as they note that "when a system's environment changes, so does the behavior of its agents, and . . . the behavior of the system as a whole" (p. 6). Therefore, the findings provide a reasonable affirmation of Research Question 1, in which there did appear to be an intuitive, aggregate response to a system-wide disturbance (Regine & Lewin, 2000) and simple rule following (Burnes, 2005; Uhl-Bien & Arena, 2017).

## Limitations to Findings

There are important limitations to this study. As the research data is historical, it would be difficult to answer peripheral questions surrounding the rollout, such as logistical issues, individual employee opinions, and acceptance or resistance to the change. Specific modifications to the software architecture are also unknown. If the hardware and software upgrade somehow forced or otherwise incentivized the animal care technicians to provide more breeding transactions, this could have a profound effect on the interpretation of the results. The simulation training, while utilizing identical software in both locations, may have been influenced at the local level by human training methodologies and concentration on areas of specific focus. Alternatively, by definition, complexity is filled with “rich interconnectivity,” permeating the entire system with myriad visible and invisible influences (Uhl-Bien & Arena, 2017, p. 9). Any one or more of these unseen system effects could be at least partially responsible for the observed results, and it might be very difficult, if not impossible, to retroactively establish a firm connection.

## Implications

While Biotech X must certainly have a high degree of interest in maintaining efficiency, it should also have a high level of attentiveness in the accuracy of employee work, since the end products must be precise. Presuming that the upgrade did not alter the reproductive biology of the animals, the inference that may be drawn is that prior to the change, the animal care technicians were somehow underrepresenting the breeding performance of the animals. If the change did, as the data suggests, relieve some of the time pressure on the animal care technicians, and they collectively allocated their extra time to increased accuracy, this may be an indication that there was originally too much time pressure to complete their daily assignments.

Additionally, if there are indeed “simple order-generating rules” (Burnes, 2005, p. 74) governing complex behavior, this study may have defined one: In this specific context, when faced with time compression, animal care technicians will collectively sacrifice accuracy in favor of efficiency.

Other industries may also have an interest in this outcome, as most manufacturers also face the constant dilemma between speed and accuracy (Bigham, 2017). To take advantage of this particular methodology, organizations would have to identify the relevant employee behaviors that are important to the business, as well as have the means to monitor and analyze historical data sets. Depending on the type of work, this may or may not be a practical solution.

## Deterministic Modeling

While not an explicit finding in this research, the observations from the study may help to provide some insight into deterministic modeling. After the upgrade, the animal care technicians appeared to cohesively respond and collectively gravitate to a new behavioral anchor point. Uhl-Bien and Arena (2017) argue that social insect colonies adapting to environmental changes by utilizing simple rules are complex adaptive systems. The animal care technicians at Biotech X may have been reacting in a similar fashion. The idea that the collective behavior of animal care technicians may be governed by a set of simple rules may also have several important consequences. Systemic behavior that follows a set of prearranged guidelines may be a sign of a deterministic model, analogous to the mathematical equations created by Edward Lorenz to predict complex weather patterns (Burnes, 2005). If the behavior of animal care technicians is obeying the laws of determinism, then two important deductions can be established. First, during a change implementation, any small deviation in the initial starting conditions will result in a drastic divergence of individual behaviors (Burnes, 2005). Therefore, prior to integrating something new into the workplace, leadership might wish to closely examine how accurately each affected department can undertake the implementation.

Second, while the system may appear to be turbulent and unpredictable, there might be an underlying order, where the activities of the animal care technicians eventually converge and settle into orbit around one or more fixed axes, previously described as “strange attractors” (Osborn & Hunt, 2007). If the organizational leadership of Biotech X could identify one or more of these attractors, they could be periodically monitored in case there is a shift in the attractor state. In the case of the events at Biotech X, under this scenario, it is possible that the hardware and software upgrade caused a shift away from the previous attractor. The actions of the animal care technicians after the upgrade may have been the manifestation of that event.

In addition, the apparent aggregate reaction of the animal care technicians may be comparable of Wheatley’s (2006) previous assertion that organizations operate like fractals. Within a fractal, each division of the smaller layers mimics the one above it, and therefore each individual subdivision should exhibit similar patterns of behavior (Wheatley, 2006). The fact that both Location 1 and Location 2 reacted in a very similar manner to the upgrade may be an affirmation of this argument. If this is the case, it could imply that the senior leadership of Biotech X has instilled a deep-rooted, organizationally pervasive culture, since the subdivisions of fractals are direct reflections of the higher strata within the organization (Wheatley, 2006). As fractals are essentially repeating patterns, and are generated by a series of predictable rules, this concept could also fit into the criteria of a deterministic model.

## Recommendations for Action

The apparent reaction of the animal care technicians after the upgrade demonstrates that seemingly routine changes to the environment can provoke a significant aggregate response. In this specific case, if the outcome was favorable or unnoticed by the leadership at Biotech X, this might be viewed as a successful change implementation. However, if the aggregate reaction had been in an undesirable direction, the senior leadership may have had difficulty in correctly diagnosing and managing the outcome. One recommendation for action might be to implement further changes in a more controlled manner at Biotech X. Future upgrades could be tested in a smaller live environment, with management observing for unusual responses, prior to a full-scale rollout. Fullan (2001) argues that complex systems cannot be directed but can instead be guided towards the approximate desired state. Along these lines, Complexity Leadership Theory might provide some relevance. Instead of acting to limit networks and information flow, Uhl-Bien and Arena (2017) argue that leadership should seek to open more network conditions and allow for increased communication, especially between disparate components of the organization. This fostering of favorable environmental conditions provides a mechanism to “manage the entanglement” between the goals of the administrative elements of the organization and the attempts of complex adaptive systems to spontaneously adapt to environmental tension (Uhl-Bien, et al., 2007, p. 305).

Alternatively, perhaps there is no true action required on the part of Biotech X. It may not be necessary or cost-effective to investigate the minutia of complexity theory to benefit from it, just as it is not necessary to fully understand internal combustion to enjoy the utility of an automobile. A relatively simple perception of complexity might be enough, along with a monitoring process of awareness that change processes will periodically deviate from the intended outcome. This alone may be enough to prevent a more severe reactionary response from senior leadership when unexpected outcomes appear. In some cases, the end result might even be welcome; for example, increased accuracy on the part of the animal care technicians might be desirable to Biotech X.

## Recommendations for Further Study

Replicating the study would be challenging, as it would be difficult to recreate the exact original environmental conditions. However, if other organization-wide change events could be identified at Biotech X, the data surrounding that initiative could be collected, analyzed, and compared to this study. If this could be accomplished, it might also be of interest to examine the demographics of the employee base, to determine in what way the results are influenced by factors such as gender, education level, or age. For example, females account for nearly 60% of all animal care technicians at the national level (Zippia, 2021).

The fact that Biotech X has historical data available is fortuitous, as it allows for large scale analysis of group responses to environmental change. Other companies may not have this capability, which might limit their capacity to detect potential variations in employee performance. It should be noted that further research studies involving the behavioral responses of staff should be carefully considered, particularly if they identify individuals. Employees may feel compelled to provide information, or otherwise suffer harm as a result of a study, which could breach the basic ethical principles of respect for persons and beneficence (Ryan et al., 1979).

It might be interesting to replicate a simple experiment in a controlled setting. However, by reducing the number of elements, a smaller trial would also remove the other influences inherent to complexity theory, the original foundation of this research paper. This would potentially diminish the original problem to a more simplistic “cause-effect relationship” scenario more inherent to a reductionist approach rather than complexity theory (Clarke, 2013, p.

137). Nonetheless, a self-contained experiment might have some pragmatic value, and provide more insights into the choice of animal care technicians to collectively select accuracy over efficiency when time constraints are relaxed. The experiment might have volunteers count and record simple shapes from a series of computer screens (serving as proxies for breeding transactions and breeding units, respectively), where time pressure is modulated, in order to see if the original results can be duplicated.

## Conclusion

The paradigm of effective top-down leadership is being continually challenged by the constant advance of technology and the increasing complexity of rapid organizational change (Regine & Lewin, 2000). Firms that cannot adapt to the shifting environmental conditions face the real threat of losing market position, or even perhaps the loss of the entire business model. Biotech X is at the forefront of this issue, as it relies on cutting-edge technological innovations to increase market share. Environmental impacts continually influence the organization, creating the potential for significant deviations.

Complexity theory may provide Biotech X with some insights into coping with and managing the evolution of the change process, and the potential relationship to unintended consequences. Additionally, complexity leadership theory can give senior management a framework with which to reimagine the organizational culture, providing encouragement to the conditions that will allow the company to harness complexity, rather than resist it. To determine if the influences of complexity theory can be observed within the organization, this quantitative research study sought to identify the presence of a complex adaptive response to an environmental change, in this case a computer hardware and software upgrade.

If the presence of a complex adaptive system can be observed reacting to an environmental stimulus, this might affirm that the collective activity of the animal care technicians working at Biotech X behave as a single, adaptive network. To determine this, two research questions were explored:

> **Research Question 1:** Can the traits of a complex adaptive system, as described by Regine and Lewin (2000), be detected quantitatively through the analysis of routine data generated by individual employees in the animal care department of Biotech X?
>
> **Research Question 2:** If a complex adaptive system is present in the data, does the complex adaptive system display distinguishable traits of either Wheatley's (2006) complexity theory or Marion and Uhl-Bien's (2001) complexity leadership theory?

It would be challenging to positively conclude that the results of this study unequivocally affirm the two original research questions, as there are other alternatives that might also explain or influence the observed phenomenon. However, the analysis of the data does appear to reflect an aggregate response to the upgrade, with the animal care technicians significantly increasing the number of breeding transactions per breeding unit in both locations, while the total number of breeding units serviced per day did not materially change. This might suggest the presence of a complex adaptive response, which in turn could support a tentative affirmation of the two research questions.

Additionally, since the reaction of the animal care technicians appears to be strongly biased towards increased accuracy but not increased efficiency, it is possible that the group behavior of the employees follows an established order. This might imply that the aggregate group response adheres to a deterministic model, similar to the Lorenz weather representations, and the observation of the response is simply a collective shift to a new attractor state. This might be of some use to Biotech X, as senior leadership could monitor the current attractor state for unexpected shifts in the future. Even if Biotech X does not have the capacity to fully investigate complexity theory, an awareness of the impact that complexity theory has on the organization might still be of some utility. In addition, the adoption of some aspects of complexity leadership theory might provide the organization with the ability to promote the growth of increased complexity, driving innovations forward.

This study found three key findings to support the proposal for the presence of a complex adaptive system. First, there was an observed aggregate response by the animal care technicians at Biotech X directly after the change, fulfilling the requirements of a macro-level response to a stimulus (Marion & Uhl-Bien, 2003). Second, the response could be interpreted as unusual, since the significant change was directed toward increased accuracy but not efficiency gains, as would be predicted by economic theory (Asmundson, 2020), supporting Fullan’s (2001) argument for emergent behavior. Finally, there was a significant, positive correlation in the responses of both Location 1 and Location 2 after the change, aligning with Wheatley’s (2006) description of organizations behaving like fractals. Additionally, the totality of the observations, while not definitive, allow for the possibility of a rule-following deterministic model, as proposed by Burnes (2005).

Further studies to attempt to replicate this effect would be interesting, bearing in mind that isolated experiments would reduce the number of complex variables, possibly altering the results. Inquiries focusing specifically on the compression and relaxation of time pressure may provide insights into the mechanics of how and when accuracy is forfeited in favor of efficiency. Other identified historical change events and the accompanying data sets at Biotech X could provide additional understanding and help to confirm or refute the initial findings of this research. Finally, supplementary investigation must carefully consider the effect on employees, so as not to violate the principles of good ethical conduct.

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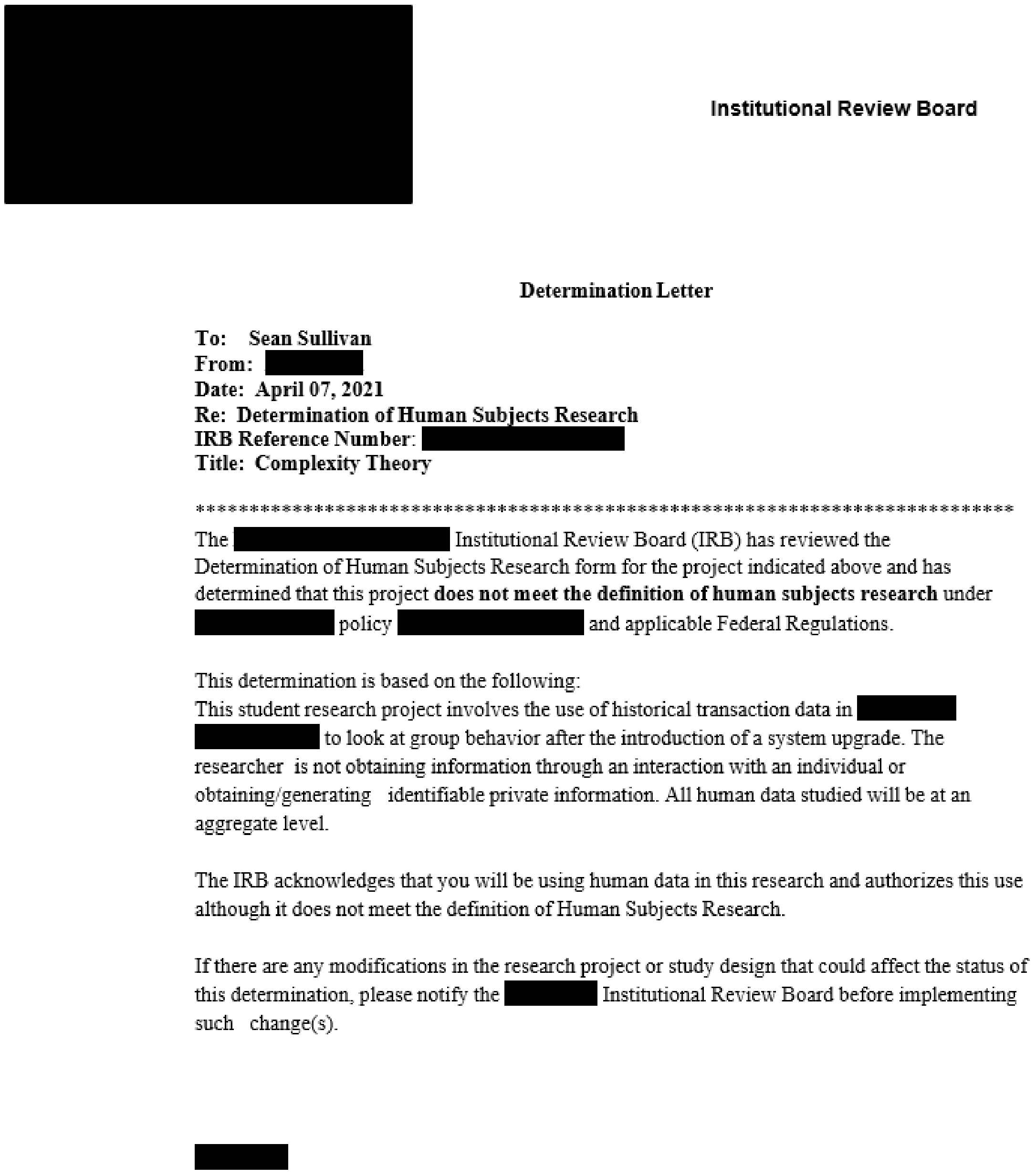
# APPENDIX A

# INFORMED CONSENT DOCUMENT



[redacted]

**Institutional Review Board**

**Determination Letter**

**To: Sean Sullivan**
**From:** [redacted]
**Date: April 07, 2021**
**Re: Determination of Human Subjects Research**
**IRB Reference Number**: [redacted]
**Title: Complexity Theory**

***********************************************************************************

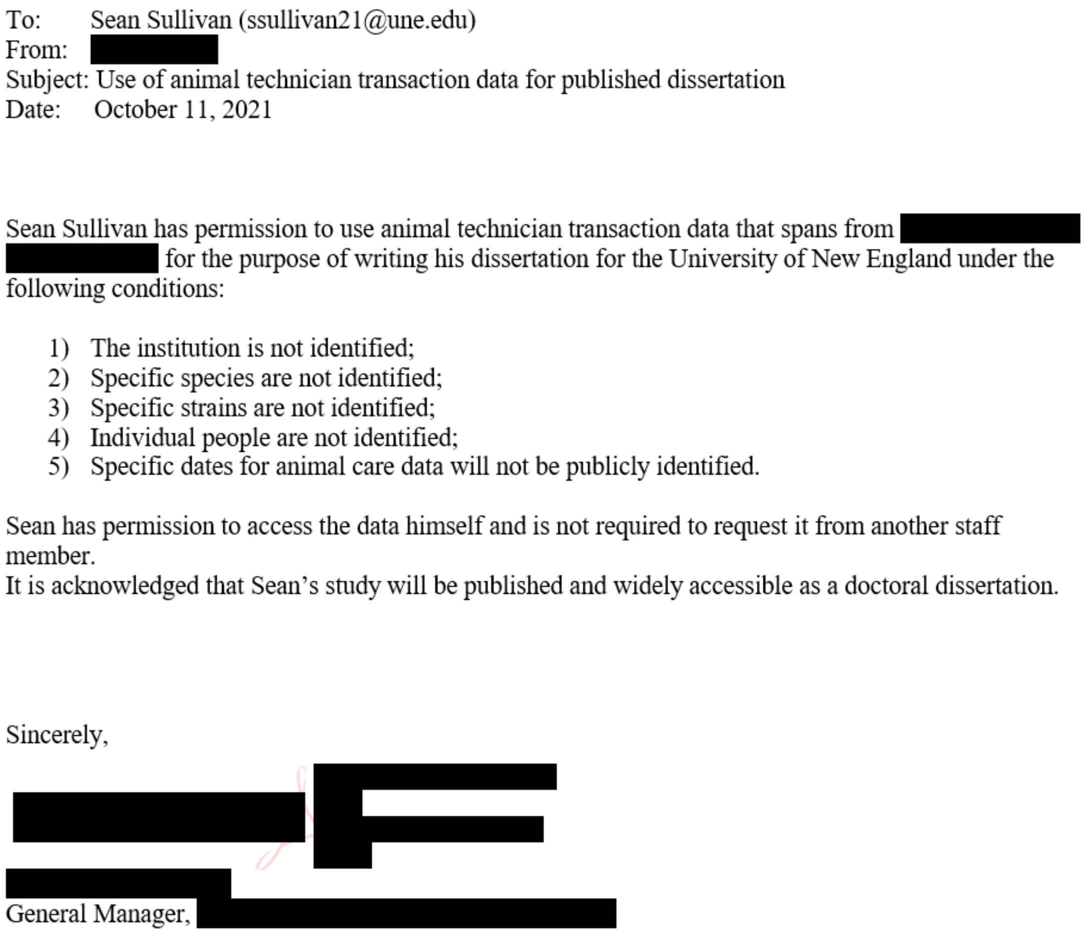
The [redacted] Institutional Review Board (IRB) has reviewed the Determination of Human Subjects Research form for the project indicated above and has determined that this project **does not meet the definition of human subjects research** under [redacted] policy [redacted] and applicable Federal Regulations.

This determination is based on the following:
This student research project involves the use of historical transaction data in [redacted] [redacted] to look at group behavior after the introduction of a system upgrade. The researcher is not obtaining information through an interaction with an individual or obtaining/generating identifiable private information. All human data studied will be at an aggregate level.

The IRB acknowledges that you will be using human data in this research and authorizes this use although it does not meet the definition of Human Subjects Research.

If there are any modifications in the research project or study design that could affect the status of this determination, please notify the [redacted] Institutional Review Board before implementing such change(s).

[redacted]



To: Sean Sullivan (ssullivan21@une.edu)
From: [redacted]
Subject: Use of animal technician transaction data for published dissertation
Date: October 11, 2021

Sean Sullivan has permission to use animal technician transaction data that spans from [redacted] for the purpose of writing his dissertation for the University of New England under the following conditions:

1) The institution is not identified;
2) Specific species are not identified;
3) Specific strains are not identified;
4) Individual people are not identified;
5) Specific dates for animal care data will not be publicly identified.

Sean has permission to access the data himself and is not required to request it from another staff member.
It is acknowledged that Sean's study will be published and widely accessible as a doctoral dissertation.

Sincerely,

[redacted]

[redacted]
General Manager, [redacted]