Chaos in the Hospital:
A historical review and case study

Erika Shumate
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Dr. Howie Forman

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Healthcare makes up fifteen percent of the competitive income for services and products in the United States, consuming $1.4 trillion annually and employing seventeen percent of the nation's workforce. Healthcare systems, therefore, are viewed and sometimes treated as commercial enterprises. While supply, clientele, and staff positions are stable and familiar for most businesses, they are more variable for hospitals. Thus, healthcare professionals and patients alike often associate chaos in American hospitals with disorder and unpredictability. The mathematical definition of chaos, however, introduces an alternative way to analyze and define an environment; it states that chaos only occurs in nonlinear, deterministic, dynamical systems that exhibit sensitivity to initial conditions.[7] Can a hospital, therefore, be described as mathematically chaotic, and furthermore should it matter? The benefit of identifying mathematically defined chaos in a system is that it, unlike randomness, can be controlled and utilized if chaotic events are recognized and embraced by system administrators. Characterizing a hospital as chaotic, therefore, should matter to hospital administrators because chaotic systems are hidden by standard analytical business measures.

Most businesses utilize linear graphing tools and functions to analyze the success of a company and to predict its needs, gains, and losses. Linear systems are easy to follow because they can be broken down into parts that each can be solved separately and then reunited to arrive at an answer. Nonlinear equations cannot be solved analytically and even if they are used, they must be transformed into linear approximations. These

processes have proven to work well in business environments where supply, clientele, and staff are stable and familiar. A hospital, however, does not exhibit this type of an environment.

In theory, there are a few ways in which chaos can take form in a healthcare setting. For example, a hospital hosts a variety of patients, each arriving with different needs at different points in time. The patients' conditions and arrival times combined with the readiness of staff and supplies in the hospital make up an environment that is sensitive to initial conditions. In addition to the unpredictability of the initial conditions of a patient and the hospital, the conditions of a discharged patient are just as variable. The cost of the patient to the hospital also varies with the patient's length of stay and the hospital's initial quantity of occupied beds and staff. The sheer inordinate number of interactions that occur between nurses, family members, patients, and doctors within a unit create an environment that in no way could be linear. The list of examples is endless, but in the end, no hospital administrative team can avoid these enigmas. These interactions and variables, however, may not be roadblocks at all. If these issues are embraced rather than ignored or combated, then, perhaps, the chaos could be effectively managed.

These qualitative correlations between chaos and the hospital, however, are not quantifiable indications that chaos is evident in the hospital. Therefore, the first part of this paper will examine the evolution of healthcare management starting in the late-eighteenth century with a focus on complexity. Was the hospital treated as a dynamical system in the past and what were the managerial outlooks for the future of healthcare in

the United States? The emergence of the management team will be traced as well as the creation and adaptation of the current common healthcare management measures that are part of a mechanistic theory of management that is favored by many hospitals. The second part will then include a quantitative case study of a modern American hospital. General admission data, emergency admission data, and Diagnostic Related Groups (DRG) data collected from the hospital will be analyzed for scaling nature, and the Hurst parameter, the fractal dimension will be calculated.

Evolution of Hospital Management

The Almshouse was America's first medical treatment establishment. Each Almshouse was city-owned and served as a hospital, a prison, and an insane asylum. In 1736, the Bellevue opened in New York City; this almshouse was a "public health house and house of correction." The grounds of this institution later served the Bellevue Hospital Medical School of New York University. The hospital eventually separated from the other institutions and the Voluntary Hospital was born.

In the late 18th century, the Voluntary Hospital opened and served only the 'deserving' poor. By 1800, there were two hospitals in the United States, one in New York and the other in Philadelphia. All patients had to go through an application process before they were admitted to the hospital. Patients submitted written applications with letters of recommendation from their employers. All patients had to be evaluated by a doctor to ensure the patient had no communicable diseases, and morally 'bad' people and those with terminal illnesses were not admitted to hospital. The final part of the

application process was an interview with the trustee committee of the hospital. Those people who had a good financial relationship with the trustees were more likely to be accepted even if they did not meet the other acceptance specifications.

Regulating the admittance of patients and overseeing the wellbeing of the hospital and its patients, the trustee committee served as the first type of hospital management team. Trustees met regularly to discuss the state and quality of the hospital and decided how to allocate their funds; they even decided what screens would best suit the patient room windows. The general public had a great suspicion of hospitals at the time because most people were afraid of doctors and most wanted to be treated in the comfort of their own homes. The trustees played an integral role in the doctor patient relationship; the trustees fought for patients against the doctors and med-students in order to maintain the rights of the patients; many doctors and med students performed 'extra' surgeries in order to learn more about the human body and would take the liberty of performing autopsies on patients. The trustees were the 'guardians of the poor.' Not only did they protect the patient, they also monitored the cost of drugs and had total control over the hospital. The trustees hired the attending physicians and then told the doctors when they were spending too much money.

The doctors, however, did have some power in the admittance procedure; each patient was required to be examined and cleared by a physician before hand. Most physicians accepted the division of labor and his or her place as the master of the ward in which he or she worked. These divisions of labor became more specific in the mid-nineteenth century, as noted in the First Decennial Catalogue of the Trustees, Faculty,

Officers, and of the Alumni of the Bellevue Hospital Medical College, of the city of New York from 1861 to 1871; "Previous to 1847, direction of medical affairs of the hospital appears to have been confided mainly to a resident physician, appointed from time to time," and in November of 1847 changes were made to the Medical Board, and the staff was divided into "physicians and surgeons who should hold their positions permanently, and visit wards in alternation." Even with these separations of power, there were many conflicts between laymen and physicians as pressing authoritative decisions became increasingly medical. Thus, trustees had to give up some of there power, and by the middle of the nineteenth century, the admission process was based on medical conditions rather than morals or social standing. However, even as late as the 1890's, trustees questioned the appropriateness of accepting patients with venereal disease and/or patients who were drunk. In addition, trustees hounded the physicians about their personal morals as well. There was a growing need for an intermediary and thus the role of the superintendent emerged.

The superintendent became the executive officer in the hospital, and the trustees slowly handed over their power. The superintendents were expected to be in "supreme relation to every aspect of the hospital." Most superintendents, however, had no training and learned through experience; as a result, most superintendents used the military as an example and tried to run a very tight ship. The roles of authority were still not clear, however, and with an increase in technology and patient admissions into the hospital, the responsibilities grew and the superintendent still had to mediate conflicts between the trustees and physicians. By the turn of the twentieth century, it was evident that the

distribution of executive power was necessary; "in no country is the position of superintendent as difficult as it is in America, since here so much is expected of him."

In 1911, Hospital Management, a compilation of essays by doctors and superintendents, was published and edited by Charlotte Aikens, the former Superintendent of Colombia Hospital in Pittsburg. The essays were lessons in how to organize and run an efficient hospital. There were illustrations of all the furnishings necessary in a 100-bed hospital, explanations on how the engineering department, the laundry service, the dietitian's kitchen, the drug room, the surgical supplies, the training school, and the outpatient department should be organized. Examples of weekly dietary menus were given and pictures of useful moving devices, i.e. the bed truck. This was one of the first manuals created for the executive committee and superintendent, and it covered all aspects of the hospital.

George Ludlam, the former Superintendent of New York Hospital, understood that the hospital must be treated as a dynamical system; "The modern hospital should be recognized as a composite institution or organization, with a definite aim, but with sufficient elasticity to admit of ready adaptation to changing conditions, and an equally ready response to ever-increasing demands." As an educated pioneer in the field of hospital management, he had lived through such changes in the hospital and knew that fluid adaptation was essential to an efficient hospital. Francis T. King, the President of the Board of Trustees at Johns Hopkins Hospital, also recognized the dynamic nature of the hospital. In his address delivered at the opening of the hospital in May of 1889, he noted, "Johns Hopkins did not leave a hospital; what he did leave was a complicated

piece of machinery in the form of various investments capable of evolving the power required to construct and maintain a hospital. This machinery requires constant adjustment and looking after, and for this part of the work the Trustees are solely responsible."

These essays in Hospital Management were written at a time when there was "a growing belief that a hospital is, or should be, a better place for a sick man than his own home, however rich that home." Most of the contributors to the book recognized the need for specialty divisions and wards within the hospital. One executive Superintendent could no longer handle the amount of information and resources he or she was supposed to be responsible for, and therefore recommendations were given as to how to set up an executive committee with each position noted, and how to arrange a medical committee and a training school committee. The role of the Superintendent, however, remained and the Superintendent was expected to arrange all the details of hospital management and was held responsible for the overall management of the hospital. The committees, while helping with some aspects of organization within the hospital, were primarily in place to serve the interest and attention of the trustees.

By the end of the First World War, a school of hospital administration was formed that graduated medical specialists who understood the financial and administrative happenings in the hospital; they knew enough about medicine to work with the physicians instead of against them, unlike most uneducated superintendents who believed the medical profession had an exploitative relationship with the hospital. Before the 1920's, however, this was partly true. There was not a large amount of cash flow in and

out of the hospital and therefore, doctors saw the hospital as a place to practice on and learn from the bodies of poor patients while the patients and nurses took advantage of the room and board available. The trustees most likely enjoyed the position of power and the feeling of benevolence.

In 1873, America reportedly had one hundred seventy-eight hospitals, and by 1923, there were almost five thousand hospitals across the country. The poor were no longer the only patients. With the sanitation movement, there was a large increase in awareness of public health; open-air schools and open-air hospital wards were initiated and children took health classes in school. As Germ Theory became more widely accepted, more Americans were willing to go to the hospital. Bureaucracy within the hospital helped to organize the institution and the nurses, physicians, and administrators were properly trained. However, there was a divide in the more favorable private hospital and the public hospital. This is a divide that still exists almost a century later.

Between 1950 – 1975, there was an explosive expansion of information, specialization, sophisticated facilities, and costs in the hospital. Healthcare costs were on the rise and complexity within the hospital was growing. By 1975, the basic assumption that trends would continue in the future was not "as tenable" in the "period of rapid change as it might have been two decades ago [1950s]." Although contagious diseases were a problem of the past, there were unexpected and unpredictable changes in human values and attitudes. Faster computers stored larger data sets and multivariable analysis was possible. The data that was collected, however, from complex healthcare facilities was "seriously deficient in quantity, specificity, scope, and relevance." There was no

way to measure the quality of health care. Therefore, by the 1980's researchers at Yale University created a system that classified and weighted the costliness of each patient diagnosis on the hospital called Diagnosis Related Groups (DRG's). These DRG weights were then used to calculate the case mix index for the hospital. The hospital receives funding based on its case mix index number. This method is still widely used today in America.

A hospital's quality and performance are no longer evaluated by the trustees or by the management teams, but rather by the Joint Commission on Accreditation of Healthcare Organization (JCAHO) and the National Committee for Quality Assurance. These organizations ensure that quality healthcare is delivered across the nation. In addition, hospitals cannot receive Medicare or Medicaid unless they are accredited by one of these groups. While these measures set a minimum level of healthcare performance across the country, they assume similar contexts throughout the country. Management teams must ensure that their hospital will receive accreditation, and thus the focus of the management teams is not entirely on the ideal atmosphere for the hospital staff or the patient, but rather on producing the extensive performance data that is required for accreditation. JCAHO recently distributed information on the importance of data collection and management for the year 2005; "managing information is an active, planned activity. The critical access hospital's leaders have overall responsibility for managing information, just as they do for managing the critical access hospital's human, material, and financial resources."

In the 1960's, patient's relied on and trusted their doctor's diagnosis and selected

form of treatment, but recently with the expansion of the internet and an increase in alternative medical treatments, patients want to hear their doctor's diagnosis and then make their own decisions regarding treatment. According to David Lawrence, in his book From Chaos to Care, changing expectations of patients, expanding pace and scope of discovery in medical science and technology, an increasing number of Americans with chronic illnesses, new laws and regulations on hospitals, an increasing demand for transparency of a hospital's accreditation rating, the nation's growing diversity, and external threats on American public health are adding to the complexity of today's healthcare.

From the evolution of disease in America and the dramatic changes seen in the recent data from an American hospital, it can be assumed that elastic healthcare facilities will be more successful over the long-term and the short-term. In the first half of the twentieth century, infectious diseases were the leading causes of death in America because people did not live long enough to develop cancer or other diseases of aging. At the turn of the twenty-first century, however, chronic illnesses such as heart disease, cancer, and Alzheimer's were the leading cause of death. The increasing number of Americans with chronic illness requires a change in healthcare services and hospitals need to be prepared for the other changes in public health that will arise in the future. It was believed that the era of contagious diseases ended in the 1960's during the golden years of antibiotics. However, AIDS shocked the world in the early eighties, and who's to say that another such epidemic will not emerge in years to come? The evolution of man and disease requires the evolution of healthcare facilities and practices. Elastic healthcare facilities

will prove more efficient as new problems and situations arise in the future.

Quantitative Case Study of Complexity in an American Hospital

Introduction

Fractal geometry is a one way to observe a dynamical system; "fractals are to chaos what geometry is to algebra. They are the usual geometric manifestation of the chaotic dynamics." A fractal is a set of points that has a fractal dimension that is larger than its topological dimension. Fractal dimension describes the space filling properties of the perimeter, whereas the topological dimension describes how points on the perimeter are connected. When the fractal dimension is larger than the topological dimension, the edge, surface, or volume of an object has more finer pieces than expected of an object with its topological dimension; therefore, when the object is examined at finer resolutions, ones sees smaller and smaller pieces of the same situation. The observation of this type of event in a nonlinear system is termed scaling behavior or self-similarity and from now on will be referred to as scaling behavior.

Scaling behavior is found in graphs of chaotic systems like trend lines of the stock market where data is plotted on graphs with different time series. For example, data is plotted for one month on one graph, one year on another, and ten years on another graph. The jumps or "bursts" in the trend for the smallest time scale are similar to the bursts in

the trend for the larger time scale. This is an example of scaling behavior that is found in chaotic systems; a pattern exhibits scaling behavior if a zoomed-in piece of a graph appears to be the same as the entire graph. If a graph has scaling behavior, then the ratio increases as scale increases and the 'burstiness' is not smoothed out. This behavior implies that the dynamical process is also scale invariant meaning that there is no characteristic scale length. In non-chaotic non self-similar systems, a trend line flattens out as the time scale is increased.

Hurst R/S (or rescaled range) Analysis measures the smoothness of a time-series. Hurst developed this test while studying the flow of water in the Nile River in order to quantify the correlation between points in a time series. The graph of a data set that has independent time units does not represent anything intrinsic about the time series because the dimension of the graph depends on the choice of units. Therefore, R/S Analysis is used to observe the true behavior of the data. This analysis gives the evolution of the range of the data (the maximum minus the minimum). R is the range of cumulative sums and S is the standard deviation, . The ratio R/ increases with a power of time R/ n^H. H is the Hurst exponent that describes the smoothness or noisiness of the time-series.

If $0 < H < 1$, then, the data set exhibits fractal Brownian motion, or fBm, and the data set shows scaling beehavior. If $H = .5$, then an uncorrelated sequence of values produced Brownian motion which implies that the data is totally random and the future does not depend on the past. The data has independent increments and zero correlation. If $H > .5$, then there is persistence or positive correlation in the data set; the trend continues in its current direction and there is considerable long-term memory. If $H < .5$,

then there is anti-persistence or negative correlation in the data set; the trend tends to return to the point from which it came, which suppresses diffusion. Data sets with $H < .5$ have graphs that appear to be very 'noisy' in that they seem to oscillate more erratically, and they have local noise of the same order of magnitude as the total excursions of the record. The Hurst parameter can then be used to calculate the fractal dimension of the graph of the data set from $D = 2 - H$. The fractal dimension, D, is somewhere between the first and second dimensions, between a line and a surface.

A scatter plot tests the independence of the data points in a given set. For example, for a given set (A_1, A_2,…, A_N), the points on the scatter graph would be (A_1, A_2), (A_2, A_3), etc…. If the data is independent, then the points will form a circular pattern. Clumped points indicate that the data is not totally independent or random like Brownian Motion.

To predict the size or magnitude of fluctuations in the data, a log-log is used with the Log (magnitude of occurrence) on the x-axis and the Log (Frequency of the occurrence) on the y-axis. This type of analysis follows the Gutenberg-Richter Relation used to determine the frequency of earthquakes. The relation shows that the log-log plot is a line with a negative slope and that it is more likely that a larger number of small earthquakes will occur than large ones.

Data Collected and Data Source

Daily patient admission (admit) data from January 1998 to June 2004, emergency admit data from January 1997 to June 2004, and DRG data for each patient from January

2004 through February 2004 were collected from an American hospital.

The data was collected for a hospital that is not-for-profit and was recently named in 'America's Best Hospitals 2004' in "U.S. News and World Report reviews 177 top Medical Centers." The hospital has 271 licensed beds and in 2003, there were 15,857 inpatient admissions. Between 1998 and 2004 when the data was collected, the number of beds did not increase substantially. However, a new Cardiac Unit opened in Spring 2004. In respect to the demographics of the town that the hospital serves, the population in the town grew from 52,978 to 61,607 between 1990 and 2000. It should also be noted that the hospital used in this report has a twin hospital in a town nearby that has 3 more beds, but had 3000 less inpatients in 2003.

Objective

To test for the presence of chaotic behavior in the collected data using scaling behavior analysis, Hurst R/S Analysis, fractal dimension analysis, data independence analysis, and variance vs. time analysis.

Procedure

I. Scaling Behavior

General Hospital Admits January 1998 to May 2004. Three graphs were constructed at three different time scales. Each graph contained 77 entries. Graphs were compared to look for scaling nature. The same was done with the Emergency Admits data collected from January 1997 to May 2004.

II. Hurst Analysis

The daily admit data collected from January 2003 to May 2004 for both the General Hospital Admits and the Emergency Admits was used to find the Hurst parameter of each set. Graphs of the log (time interval) vs. log (R/S) were made for each data set and the slope of the best-fit line was determined as the approximate Hurst parameter. The Hurst parameter was also found for the first 535 entries in the January 2004 DRG data and for the first 535 entries in the February DRG data.

III. Fractal Dimension

Using the determined Hurst values, the fractal dimension, D, was calculated using the equation $D = 2 - H$.

IV. Scatter Plot Test for Independence

Scatter plot tests were performed on the General Admit Data from January 1998 to May 2004 and on the Emergency Admit Data from January 1997 to May 2004. The graphs were constructed as outlined in the Introduction.

V. Log-Log plot (Gutenberg-Richter Relation)

A log-log frequency vs. magnitude plot was constructed for the General Hospital Admit data from January 2003 to May 2004. The number of admits per day were binned and then the frequency recorded in each bin was calculated. Then a log-log plot was constructed with log(# admits/day) on the x-axis and the log(# of occurrences) on the y-axis.

Data Analysis

Figure 1. Monthly Hospital Admits over 77 months

Figure 2. Weekly Hospital Admits over 77 weeks

Figure 3. Daily Hospital Admits over 77 days

Figures 1-3 show the scaling nature found in the Hospital Admits over 3 time scales. Figure 1 shows a general trend upward, but there are still spikes within the general trend. Figures 2 & 3 show bursts as well. The graph does not flatten out as the time scale grows.

Figure 4. Monthly Emergency Admits over 77 months

Figure 5. Weekly Emergency Admits over 77 weeks

Figure 6. Daily Emergency Admits over 77 days

Figures 4-6 show the scaling behavior of the Emergency Admits over three scaled time periods. Figure 4 shows a trend increasing and then decreasing. If tracked over a longer time span, this activity may be a burst. There are many spikes in the graph of Figure 4. Figures 5 and 6 also show bursts. Figure 5 has one large spike and Figure 6 has a wide spike on the left, which is similar to the one in Figure 4. This is an example of self-similarity.

Figure 7: Hurst Analysis of General Hospital Admits January 2003-May 2004

slope = H = 0.0841 Fractal Dimension = 2-H = 1.9159

Figure 8: Hurst Analysis Emergency Admits from January 2003-May 2004
slope = H = 0.117 Fractal Dimension = 2-H = 1.883

Figures 7 & 8 show the Hurst R/S analysis for the general and emergency admits. Both

have a Hurst parameter greater than .5 and both exhibit a fractal dimension.

Figure 9: Hurst Analysis of 535 DRG weights from January 2004

slope = H = 0.1409 Fractal Dimension = 2-H = 1.8591

Figure 10: Hurst Analysis of 535 DRG weights from February 2004

slope = H = 0.1044 Fractal Dimension = 2-H = 1.8956

Figures 9 & 10 show the Hurst R/S value for the DRG weights. These curves are a tighter fit than the Admit data curves. Both have a Hurst parameter greater than .5 and both exhibit a fractal dimension.

Figure 11. Scatter Plot Test for Independence in General Admit Data from January 1998 to May 2004 using Monthly Averages

Figure 12. Scatter Plot Test for Independence in Emergency Admit Data from January 1997 to May 2004 using Monthly Averages

Figures 11 & 12 show the scatter plot test for independence. Neither scatter forms a circular pattern, which is characteristic of independence. Therefore, there must be some relationship between the past and the future. Both graphs exhibit a similar trend.

Figure 13: Log # of Occurrences vs. Log of Admits/ day General Admission 1998-2004

Figure 13 shows the frequency vs. the magnitude of the number of admits. This is a line with an increasing slope, unlike that of *Gutenberg-Richter Relation.* In this case, the graph reveals that the larger number of patients admitted per day occured more frequently than the smaller number of patients admitted per day.

Discussion

The purpose of this case study was to examine data collected from an American Hospital for the presence of chaotic trends. Five tests were used to view the data: scaling behavior, Hurst R/S Analysis, fractal dimension analysis, scatter plot analysis, and log-log Gutenberg-Richter Analysis. The general admit graphs exhibited scaling behavior. They were not exactly self-similar, but all three graphs at different time scales showed spikes

and bursts in the data. The three emergency admit data graphs exhibited scaling nature. The spikes and bursts in the emergency graphs were larger and more frequent. Figures 4 and 6 are very similar and are a good example of scaling and self-similarity.

The Hurst Analysis showed that H < .5 for all four approximated lines. The R/S curves for the general and emergency admit data (Figures 7&8) were fairly wavy, but the fitted lines gave a fair approximation and the H was very small and definitely less than .5. The R/S curves for the DRG weights (Figures 9&10) were a tighter fit with the approximated line. The slopes, and thus the Hurst parameters, for both these graphs were much less than .5 as well. Since the estimated Hurst parameters are far from H=1, the degree of self-similarity is genuine and is not a result of shifting or differencing. With four Hurst parameters less than .5, it can be inferred that the environment is not random and does not exhibit Brownian Motion. Rather, there is a negative correlation between the past and the future. The system is anti-persistent and therefore noisy and not very smooth. This is beneficial for hospitals because it means that the data is not random and instead contains an ordered system, even though it may not be immediately obvious or long-term dependent. Rather, the data analysis reveals that the order of the system must be very sensitive to the initial conditions of the environment.

The fractal dimension was calculated using each Hurst parameter. All four dimensions were between 1.8 and 1.9, between a line and a surface. The scatter plots also showed that the data was not totally independent and not random. There was a correlation between the past and the future. This also confirms that the Hurst parameter is not .5 for either the admit data sets. Again, chaos is observed.

The final test of frequency versus magnitude of admits was completed to demonstrate conditions that this hospital should prepare for. Unlike the *Gutenberg-Richter Relation,* the log-log plot in Figure 13 had an increasing slope, and therefore days with more patients admitted were more frequent than days with a lesser number of patients admitted. Thus, hospital administrators can see that it is more likely for a surge in the number of patients admitted to occur than there is for a decline. However, it is important to remember that both situations occur. In the future, more data points should be used in the Hurst R/S analysis in order to determine a better approximation of the Hurst parameter. In the future, all of the DRG weights from January and February will be analyzed using Hurst R/S Analysis. For now, it can be concluded that the hospital environment exhibits chaos, specifically in patient admits and in the diagnoses of each patient.

Where to go from here?

It has been both qualitatively and quantitatively observed that the American hospital can be defined as chaotic. But what does this mean to managers and hospital employees? The good news is that the environment is not random or disordered. Chaos can be managed as long as the initial conditions of the environment are understood and are used to plan for the future. The sensitivity to initial conditions in chaos is due to many unstable cycles, and in order to manage a chaotic environment for a short period of time, the parameter must be set to force the system toward a desired cycle. Since cycles are unstable, the system will not stay on track, i.e. it will wander away from the cycle, and

the parameter of the system must be changed frequently in order to keep the system on track with the cycle. The parameters based on the past must be updated repeatedly in order to predict the immediate future because the initial conditions are always changing.

Therefore, it makes sense that the best way to problem-solve in the hospital is to do so when the problem occurs so that the initial conditions are understood. Many times, the hardest part of problem solving is identifying the root-cause of the problem. First-order problem solving is common in hospitals with high-paced activity; a problem is identified and quickly fixed, but the root-cause of the problem is never addressed. Usually when a problem arises, a staff member goes through first-order problem solving in order to continue with the days' tasks. Although the 'quick-fix' appears to nullify the problem, the solution is merely a temporary measure.

The worker, however, feels as though the problem is taken care of and this feeling of self-sufficiency decreases the chances that the worker will involve his or her superiors as needed for second order problem solving. Therefore, the number of problems does not decrease and in many cases, the quick fixes compound problems in other areas of the hospital. For example, if a nurse on Unit II does not have clean bed linens for her patient, the nurse may 'borrow' linens from Unit III. However, this leaves Unit III with a smaller supply than allocated, and the problem continues when the missing linens are not accounted for. Most workers prefer first order problem solving because it is quick and easy, and the worker is capable of solving the problem without the help of a supervisor. However, managerial intervention is essential for second-order problem solving; managers and workers should think together about what can be done in the future to prevent similar

problems.

Chaos only occurs in nonlinear systems. It is impossible, however, to exactly measure a nonlinear system, and instead linear approximations are used in math as close predictions; the smaller the linear segment used, the closer the approximation to the real measurement of the nonlinear system. Therefore, a nonlinear system can be approached and treated in very small steps. Therefore, it might behoove a hospital to address the 'small' problems that keep recurring, especially when these small problems have compound larger effects on the overall system. With smaller steps, the outcome will be more accurate. In addition, chaotic systems may exhibit the butterfly effect where a small change may have huge effects on the overall system. Bringing together sensitivity to initial conditions and smallest linear approximations, staff members should be encouraged to identify 'small' annoying problems when they occur in order to avoid larger problems down the road.

For example, the Kenagy Method of hospital management recognizes chaos in the hospital and thus encourages a staff member to embark on first-order problem solving when an issue arises so that the patient receives what is needed. After the patient is cared for, the staff member notifies the manager of the problem so that second-order problem solving can be implemented. The Kenagy Method of hospital management uses second-order problem solving to identify the problem at its root cause and then formulates a solution based on the ideal target condition and the initial conditions when the problem arose. The solutions are hypotheses and they are tested only for failures. The staff creates a test for the solution, and if the test fails, then another solution is created and

tested. This way, the solutions are malleable and dynamic, and the solutions are always sensitive to the initial state of a problem.

This may seem like another chore for a staff member, but in the long run it may make life much easier and make the work environment more enjoyable. All these improvements are directed towards creating ideal conditions for the healthcare worker and so that he or she may deliver ideal patient care. Because hospitals are institutions that serve people, the hospital employees should be given ideal conditions in order to provide ideal patient care. Ideal patient care is delivering exactly what the patient needs, when and where they need it; therefore ideal employee care would be an environment that allows the staff to access their needs when and where they need it. This focus on the welfare and the success of the employee stems from the Toyota system of management where the working environment is constantly being improved by creating more efficient team interactions between employees and managers.

More interactions between humans are encouraged especially because the current quantitative analyses of performance in the hospital do not represent the inherent chaos in the system. For example, one measure of productivity is FTE / CMI * AOB where FTE is the number of Full Time Equivalents, CMI is the Case Mix Index (the measurement of resources needed to treat a mix of patients over a period of time and is determined by an average of DRG weights over a period of time) and AOB is Adjusted Occupied Bed which is equal to the total average daily census * the adjustment factor for outpatients. AOB does not account for the frequency of admit and discharge in one day, thus work done is not accounted for. The adjustment factor is equal to the total gross

revenue / inpatient gross revenue. The amount of division and averaging that occurs to create this one measurement of productivity greatly hides any complexity in the system. This measurement, therefore, should not be relied on to predict the nature of the system in the future. Instead, the pure DRG weights should be looked at monthly and quarterly to plan the budget. Since DRG weights are split into ranges, hospitals can plan according to demands in certain ranges. The complexity of the system must be embraced and the system must not be averaged into a poor linear approximation by one productivity figure.

The beauty of chaos is that once it is identified, management is not a lost cause. In fact, if chaos is embraced and understood, it can be managed according to its mathematical definition. Chaos in the hospital is not new, nor has it been overlooked. However, it is evident that implementing change in the healthcare system is becoming more difficult as time goes on. It seems as though the forefathers of hospital management understood the need to treat the hospital as a dynamical system. Even though the framework of the hospital is now set and understood, Francis T. King was correct in saying that "this machinery requires constant adjustment and looking after."