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The Impact of Change on System of Systems Performance with an Application to Small and Medium Multihospital Systems

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I am submitting herewith a dissertation written by Karima Tayeb entitled "The Impact of Change on System of Systems Performance with an Application to Small and Medium Multihospital Systems." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Industrial Engineering.

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The Impact of Change on System of Systems Performance with an Application to Small and Medium Multihospital Systems

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Dedication

This dissertation is dedicated to my loving parents, whose unwavering support and words of encouragement throughout my lifetime has given me the strength to continue my academic endeavors. This work is also dedicated to my siblings and my husband, who have been pillars of support and my cheerleaders.

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ABSTRACT

An entity that functions as a system of systems (SoS) is composed of multiple systems that individually provide various functions which collectively provide a holistic functional capability. It is complex in design and function and tends to become even more complex over time as it evolves and responds to both internal and external changes. These changes might be in the composition or in the interoperability among its system members. Since interoperability affects how well the members work as one system, managing it is critical to the performance of the SoS over its lifespan.

In support of this goal, this dissertation, through research and analysis of small-medium hospital systems, develops a descriptive approach to assist management in determining the impact that changes in membership and interoperability of member systems might have on SoS performance. A modeling approach was used to assess SoS performance before and after changes. This model is part of an analysis framework called Tri-Ex that can be used by managers to evaluate proposed system changes. The procedures and techniques used are recommended for any future investigations into applicability for SoS performance in different domains; designing system structure with future capabilities in mind; and operational assessment during development.

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CHAPTER 1
INTRODUCTION

1.1 Background

The primary goal of an intentional system is to do what it was formed to do, and to do that well. The challenge for that system is to continue to do just that throughout its existence – for however long that might be. The problem is that the expected lifespan might be unknown at initial design and operating conditions might change over that lifespan. Additionally, the purpose of that system might change over time, and, consequently, so might the requirements. The requirements reflect the user's needs based on its current strategy for success in its current environment. As the environment changes, the strategy changes, and so do the system requirements. Making changes to an existing system, however, is no simple task. Resources are consumed in developing and maintaining the system, and additional resources may also be required to make the changes. Management of this change project requires control of costs, time, and scope. Such a management effort may become quite complicated when dealing with a complex system.

Though complex, a System of Systems (SoS) operates as a single entity. It may be a product, an organization, a service, or a program. If that entity is to do what it was formed to do, throughout its lifespan, its overall capabilities must be maintained and must take advantage of its composition and functions. This research attempts to determine a measure of performance of the overall SoS and to assess the resulting performance as the result of changes to its composition and interactions among its member systems. It demonstrates this process with a SoS in an industry that is critical to the well-being of this nation – healthcare. Performance of a system, in this research, is characterized by the degree to which its outputs accomplish the goals of its stakeholders. Hence, in modeling the capabilities of the ever changing system, it is important to ensure that the effects of such changes are positive and that the resulting system maintains the structure needed to optimize the contributions of its members in meeting the user's expectations.

1.2 Problem Statement

Systems are everywhere – in nature and in man-made environments. Many are so complex that traditional techniques of managing them are no longer effective or cease to be effective as their complexity increases over their lifespan. This is primarily because most traditional systems analysis techniques explain the static behavior of systems, rather than their adaptive behavior or responses to changes in requirements or operating environments. What is needed are ways to understand and measure the impact of changes.

A meta-system engineering framework has been constructed under the three major categories of integration engineering, integration management and transition engineering [1] but has not been widely accepted or put into practice [2]. This might be due to many practitioners trying to apply traditional systems engineering approaches to systems of systems and not recognizing the differences. For example, when a simple system is designed, integration concerns are generally about internal processes; however, for systems of systems, external interactions among the member systems must also be considered. Differences between simple and complex systems such as the SoS are also critical during operations and changes that occur to reconfigure or to upgrade. For both, an analysis is needed to ensure that the system remains effective; however, for the SoS, additional concerns call for quantitative analyses to address other system elements like: 1. Impacts; 2. Architecture development; 3. Transition planning; and 4. Preplanned product improvement [2]. Specific tasks of these elements are as follows:

1. Impacts: Comparison of system performance vs. requirements; Assessment of effects of proposed upgrades; and Utilization of modeling and simulation to predict SoS performance.
2. Architecture Development: Defining of top-level functional capabilities; Assurance of intersystem performance; Verification that system of systems is truly an integrated architecture vs. random collection of systems; Overall system optimization.
3. Transition Planning: Develop transition alternatives and strategy; Assess and select; and Document.
4. Preplanned Product Improvement Plans (P3I): Review all component system improvement plans.

5. Identify key areas from system-of-systems perspective; and Feed results and priorities back to system activities.

In order to fully understand complex systems and to make fact-based decisions, these activities need quantifiable results. Examples of such complex systems, often composed of networks of interrelated systems, are found as information systems (the internet); transportation systems (ground - interstates, highways, roads, streets, and rail); healthcare systems (multi-hospital groups), military systems (armed forces and specific initiatives), governing bodies (NATO); utility systems (electrical grids), and manufacturing systems (supply chains). These systems benefit from the contributions of the members, but they also are at risk from potential failures of any of the members. Sometimes the risk response involves making changes to the system's composition, but only after assessing whether the changes are beneficial.

When upgrading a system, the decision maker is generally trying to maximize the system-of-systems' performance subject to a cost constraint. The representation of a system element's performance as a function of cost is referred to as a performance-based cost model (PBCM) [3]. System-of-Systems upgrade decisions may be reviewed annually as part of an organization's strategic planning and budgeting processes or reactively in response to a new demand. There are four general forms of upgrade options, depending on which conditions are most pressing:

1. Adding a new type of system (i.e., additional functionality) to the system of systems
2. Procuring additional numbers of existing component systems (enlarging the scope and capability of the system of systems)
3. Replacing aging or obsolescent component systems (also offering an opportunity to enhance the system-of- systems' performance and functionality)
4. Upgrading existing component systems and subsequently changing the interactions among the systems because of requirements pressures.

In assessing whether to proceed with the development of a new system or a major upgrade, managers usually conduct an analysis of alternatives to determine whether the proposed system is the most cost-effective alternative to meeting a specific user need. A typical analysis approach is to use modeling and simulation to estimate the marginal utility of proposed system designs to a larger mission objective. The system performance is represented by a set of measures of performance (MOPs), and its contribution to the mission is referred to as a measure of effectiveness (MOE). The simulation is run on a carefully selected set of applicable scenarios, with and without the system alternatives, to characterize the hypothesized system alternatives' value-added. A multi-objective metric that combines costs and multiple MOEs into a single scalar metric may be used to compare alternatives [3].

This metric may also attempt to reflect expert opinion as to management's value of the alternatives that are not captured by quantitative analyses. A primary shortcoming of the analysis-of-alternatives process from a system-of systems perspective is that just one component system is considered at a time, in a "stovepipe" fashion. In a cost-constrained environment, this approach will not normally generate the best alternative from the system-of-systems perspective. Quantitative engineering analysis provides information over qualitative decision support methods such as the Analytic Hierarchy Process (AHP). Many managers may find it difficult to convert opinion and judgments into meaningful metrics, creating a real need for modeling and simulation as the basis for decision making.

1.3 Research Question

This research attempts to provide objective, quantitative information to decision makers at the system-of-systems level, thereby minimizing the introduction of subjective judgments at the member system level. Decisions to change the system by modifying membership, contribution of members, or relationships among members (their "interoperability") are important to maintaining the performance of the overall system. This concern has led to the following research questions.

The objective of this research is to develop a framework for measuring and evaluating the impact of changes to member systems on the overall system performance. The specific research question is as follows:

"*Can a framework be developed for assessing the performance of an SoS as its interoperability and/or composition changes?*"

To study the effect of interoperability and composition on performance, the following sub-questions are asked:

- First, given that interoperability reflects the nature of the relationships among members, an answer is needed that responds to

  1. Does a change in interoperability among members have an impact on SoS performance?

  Hypothesis 1: The degree of interoperability directly impacts SoS performance.

- Secondly, given that the SoS is composed of independent systems that contribute to accomplishment of the overall mission, an answer is also needed to respond to

  2. Does change due to addition/removal of a member system affect the SoS performance?

  Hypothesis 2: A change in member composition impacts the SoS performance.

1.4 Scope

The intent of this research is to respond to these questions by developing a framework that can be utilized to evaluate the performance of existing complex systems, such as a system of systems (SoS), and to understand and manage changes due to the emergent behaviors (properties or actions that come forth as a result of the interactions among the system components) and to composition modifications**.** The expected outcome is a systems modeling approach that allows for analysis of alternative system compositions and interactions, while sustaining or improving the system performance. Hence, the first step will be to define the key performance indicator. That will be followed by the development of a quantitative approach for assessing system performance and then determining whether a change is improves performance, relative to the interoperations among the systems, their relative contribution to the SoS performance, and their individual performances values. The methodology will utilize a multi-disciplinary approach including systems analyses, matrix algebra and simulation.

The methodology will be tested in a domain of interest to most Americans – healthcare. Over the last few decades, the hospital industry has seen much activity on acquisitions and mergers into hospital systems. Today, approximately 57 percent of U.S. hospitals are now affiliated with a health system, up from about 50 percent a decade ago [4]. This increase in system creation and expansion has been attributed by some to fear and greed, and by others to sound management. Whatever the reason, the intended outcome seems to be increased market share.

Additionally, health care costs have been rising for many years. In 1970 the United States spent 7% of its gross domestic product (GDP; the value of all the goods and services produced by the nation) on health care. By 1999 health care had risen to 13% ($1.2 trillion) of the GDP; in 2001, health care expenditures reached 14.1% of the GDP ($1.4 trillion); and, in 2008, they surpassed $2.3 trillion or 17% of the GDP [5, 6]. The Bureau of Labor Statistics has highlighted a few significant points about healthcare [6]:

- One of the largest industries and provided 14.3 million jobs for wage and salary workers.
- Ten of the 20 fastest growing occupations are healthcare related.
- Healthcare will generate 3.2 million new wage and salary jobs between now and 2018, more than any other industry, largely in response to rapid growth in the elderly population.
- Most workers have jobs that require less than 4 years of college education, but health diagnosing and treating practitioners are highly educated.
- Employment growth is expected to account for about 22 percent of all wage and salary jobs added to the economy over the 2008-18 periods.
- Projected rates of employment growth for the various segments of the industry range from 10 percent in hospitals, the largest and slowest growing industry segment, to 46 percent in the much smaller home healthcare services.

As important as this industry is to the nation's economical standing, the U.S. fails to achieve better health outcomes than many other industrialized countries (Australia, Canada, Germany, the Netherlands, New Zealand, the United Kingdom), and is the last one on dimensions of access, patient safety, coordination, efficiency, and equity [7].

Cost and quality appear to be the symptoms of the problem. The Institute of Medicine (IOM) identifies four underlying reasons for the inadequacies in health care: 1. the growing complexity of science & technology; 2.increases in chronic conditions; 3. a poorly organized delivery system; and 4. constraints on exploiting the revolution in information technology [8]. This research offers a fifth: failure to design and manage healthcare systems as “systems” that are composed of distributed systems with multiple care-giving environments and a common goal; however, this might also be linked to number three above – delivery systems that are not structured to maximize contributions as part of a system.

1.5 Assumptions, Limitations, and Constraints

The primary assumption under which this research operates is that system characteristics might be different in different domains, but most systems fit the general characteristics required to perform systems analyses based on systems theory. Hence, it is expected that the results of multi-hospital systems may be extrapolated to make statements about other types of SoS.

Another assumption is that, unless the mission is totally aborted, the system survives. Hence, since systems exist to deliver value to the customer, it is assumed that a system change does not negatively impact that value and the system continues to fulfill its mission. This assumption is associated with survivability and robustness of the system. Survivability may be defined generally as the ability of a system to minimize the impact of a change on value delivery; while robustness is defined as the ability of the system to accommodate permanent changes in its mission. Other “ilities” (e.g., flexibility, adaptability, serviceability) are temporal system properties that specify the degree to which systems are able to maintain or even improve function in the presence of change. Although desired attributes of systems that characterize their interaction with uncertainties, there is a great deal of confusion associated with the ility's time value definitions and relationships [9].

The "Ility Space" (Figure 1) is a depiction of how the various ilities relate to one another [9]. The three axes represent sources of change: (1) the physical system which is specified by design variables, (2) stakeholder values which may be articulated as a utility function, and (3) environmental context. A changeable system is able to have its design variables modified by either an internal change agent (adaptability) or by an external change agent (flexibility) to maintain or improve value delivery in the presence of shifting environments and requirements [9]. Changeability may be applied along the physical system axis of Figure 1 as a technique for achieving active value robustness (i.e., maintaining value in the presence of changing contexts through system modifications). Along the environment axis, robustness specifies an unchanging system that is able to accommodate various environments while maintaining value delivery. Along the value axis, versatility refers to an unchanging system that is able to satisfy a variety of needs [9]. Survivable systems leverage a combination of robustness and changeability to remain.

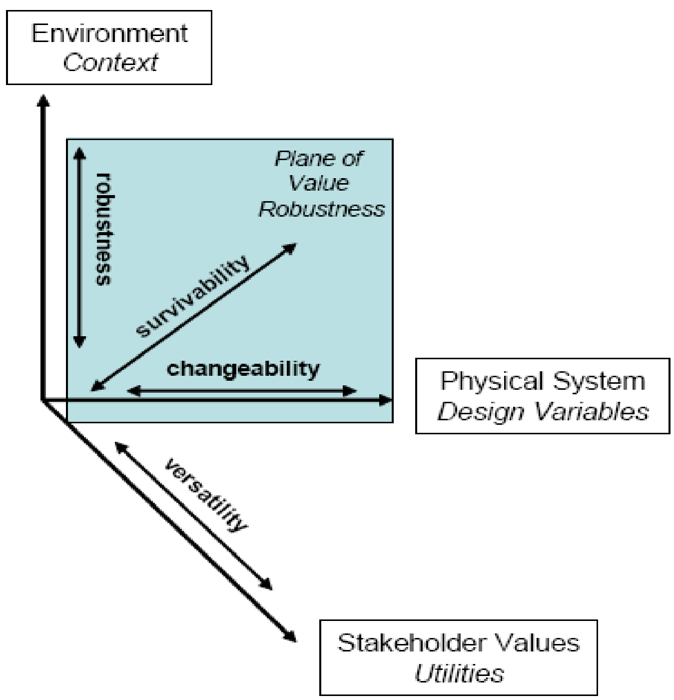

Figure1. The "Ilities" Space [9]

The design principles of survivability are best specified as one of the following verbs [9]:

1) Regenerate – restoration of capability through repair and replacement activities;

2) Evolve – system modification to maintain and possibly extend capability;

3) Relocate – movement in position; and
4) Retaliate – provision of negative consequences to origin of disturbance.

Although these definitions were developed for military systems, they all hold true for most SoS, with the possible exception of "Retaliate".

Additionally, the process of performing this research is bound by certain limitations and constraints. The limitations are primarily due to availability of industry data while the constraints are relative to the nature of a SoS. Specifically, they are:

- This study is limited to the study of a specific type of SoS, multi-hospital systems.
- This study is limited to the study of multi-hospital systems in Tennessee only.
- This study was limited by the availability of hospital-specific financial performance data. Individuals at these facilities were not willing to share much information.
- This study was also limited by the availability and timeliness of available information about the participating systems and their member hospitals on the internet, including their own web-sites and open information of other health-industry organizations.

1.6 Expected Significance of This Study

The need for this research has been stated in the literature by several authors. The model presented in this study is designed to address these needs and to complement the current body of knowledge in the area of systems engineering by providing an efficient, step by step procedure to help management when making decisions concerning the composition or interactions of a system of systems. The desired research contributions, motivated by the research questions, are as follows:

1. A framework for capturing and representing SoS overall performance.
2. A framework for evaluating SoS composition changes relative to multiple objectives.
3. Insight into real world SoS relevance through case applications of hospital systems.

1.7 Research Organization

The remainder of this dissertation, after a description of key terms used, is organized as follows:

- **Literature Review:** This chapter presents a review of relevant sources in systems theory, types of systems, performance, interoperability, healthcare system, and related models to this research.

- **Methodology:** This chapter provides a description of the Tri-Ex framework, the SoS Assessment Performance Model (SPAM), the reduced SPAM model used in health care, the electronic surveys used in this study, and the surveyed population.

- **Results:** This fourth chapter, via case studies to demonstrate the application of various changes, reports the results of applying the framework within multi-hospital systems that serve as models of systems of systems. Provided are descriptions of the Hospital SoS's, and the results of applying the model to determine their performance scores and the assessment to determine the impact of changes on those scores. The sample, the theoretical relation-fraction score, the patient safety performance scores, and stochastic simulation, discusses data collected from the healthcare system and associated statistics are all provided; and the aggregation of these outputs are used to validate the dissertation hypotheses.

- **Conclusions and Recommendations:** summarizes the results and discusses recommendations and future work.

1.8 Definition of the Terms

The following definitions are either formal definitions with sources or author interpretations reflecting operational definitions as used in this research:

Architecture- "The structure of components, their relationships, and the principles and guidelines governing their design and evolution over time." [10]

Capability- "The ability to execute a specified course of action. (A capability may or may not be accompanied by an intention.)" [11]

Flexibility- The ability of a SoS to respond to demand and/or design changes such as when member systems are removed, added, or modified.

Framework- a structure that encompasses specific steps to follow.

Interoperability- the ability of more than one system to exchange resources and/or information and use them after the swap.

Methodology- a set of procedures employed in a particular field.

Performance- the quality of a system's functioning relative to fulfilling its purpose. It includes both effectiveness and efficiency.

System- "An entity which is composed of at least two elements and a relation that holds between each of its elements and at least one other element in the set" [12].

System of Systems- "A complex system involving a collection of task-oriented or dedicated systems that pool their resources and capabilities together to obtain a new, more complex, 'meta-system' which offers more functionality and performance than simply the sum of the member systems." [13]

CHAPTER 2
LITERATURE REVIEW

2.1 Overview

This chapter provides an overview of relevant systems theory needed to provide the foundation of this research and to establish the system perspective of complex organizational systems, such as multi-hospital systems. Also, included is a comprehensive literature examination of previous models used for measuring interoperability and performance of complex systems in general, and specifically in healthcare systems.

2.2 General Systems Theory

There are diverse definitions of a system. The similarity among all is that they have agreed that a system is composed of elements. What differs among them, however, is how and/or why those elements coalesce into a single unit. The International Council on Systems Engineering (INCOSE) defines a system as a collection of components organized to accomplish a specific function or a set of functions [14]. This general definition is often represented as a blackbox as shown in Figure 2.

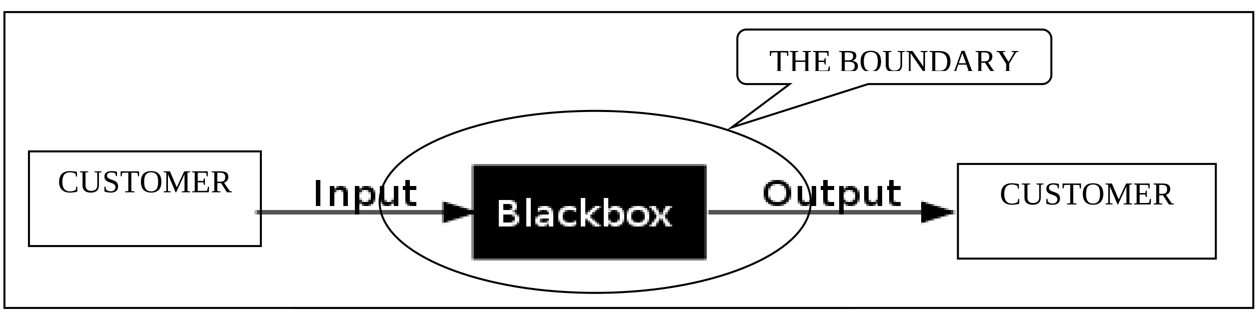

Figure 2. Blackbox Representation of a Simple System

As shown in Figure 2, the purpose of the system is to convert the Input received from its environment (everything outside of its boundary) and to transform it into an acceptable Output that is returned back into the environment. That input is often generated by a customer who determines how well the output met its expectations.

Another common definition of a system in systems engineering is that "a system may be considered as constituting a nucleus of elements combined in such a manner as to accomplish a function in response to an identified need…A system must have a functional purpose, may include a mix of products and processes, and may be contained within some form of hierarchy" [15]. This research will use this definition as a working definition since it relates the necessity of purpose and structure.

Other general characteristics of a system are that it is usually part of a larger system, called the super-system and its constituents may be independent elements or systems, themselves. Systems receive inputs from its entities in its environment, process those inputs in order to transform them into outputs, and then send those outputs back into the environment to the entities who demanded them. The transformation processes also receive inputs from the environment in order to perform their work (e.g., raw materials, information, etc.) and often produces outputs not requested (e.g., by-products, wastes, etc.). These relationships are depicted in Figure 3.

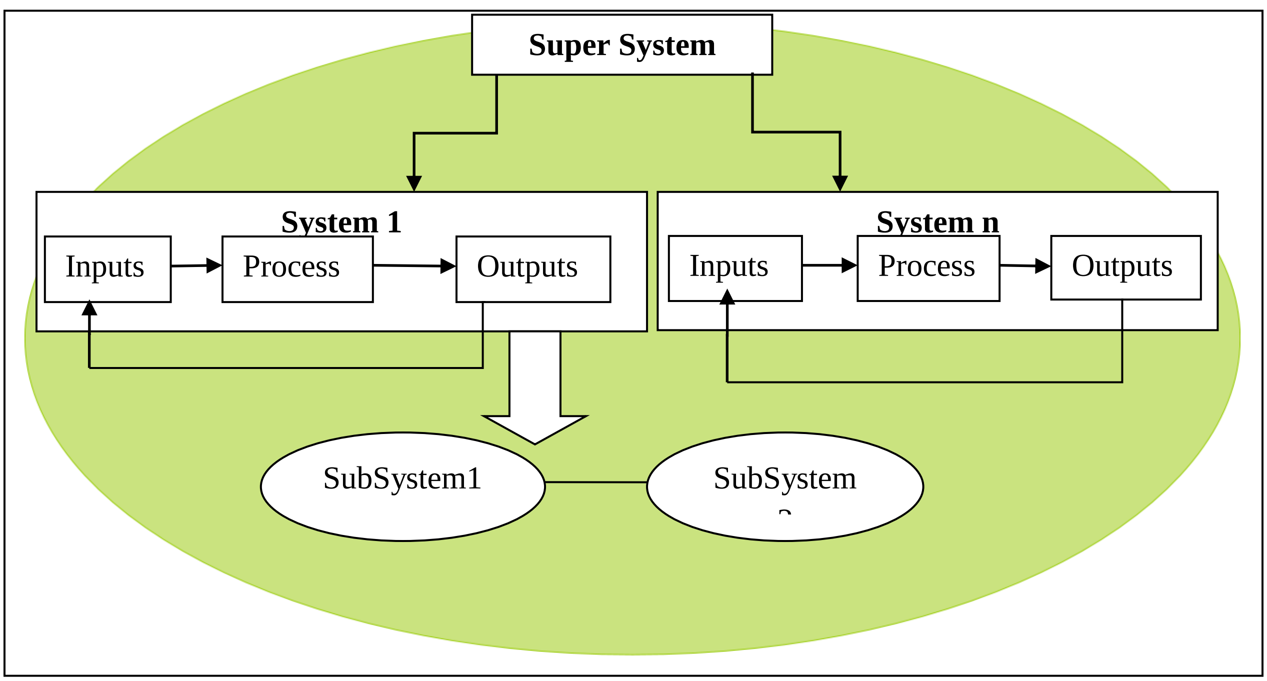

Figure 3. Detailed System with Feedback

A system must have at least one input, one output, and a cause-effect relationship between them [14]. Each system has three properties which are the elements, the attributes, and the relationships that occur between elements and attributes [14]. The number of elements, the diversity of their attributes, and the complexity of the relations may result in more types of systems. Discussion of some of these other types of systems follows.

2.3 Types of Complex Systems

2.3.1 Family of Systems (FoS)

A Family of Systems also known as (a federation of systems, a system family, or a coalition of systems) is a coalition of partners having decentralized power and authority and potentially differing perspectives of situations [16]. According to the Department of Defense, an FoS is a set or arrangement of independent systems that can be arranged or interconnected in various ways to provide different capabilities and the mix of systems can be tailored to provide desired capabilities, dependent on the situation [17]. An example of a FoS used by DoD would be an anti-submarine warfare system consisting of submarines, surface ships, aircraft, static and mobile sensor systems and additional systems. Although these systems can independently provide militarily useful capabilities, in collaboration they can more fully satisfy a more complex and challenging capability: to detect, localize, track and engage submarines [17].

2.3.2 Complex Adaptive Systems (CAS)

A Complex Adaptive System consists of inhomogeneous, interacting adaptive agents. These agents are the components that are capable of learning and changing their behavior in response to environmental stimuli. "A CAS behaves/evolves according to three key principles: order is emergent as opposed to predetermined (neural networks), the system's history is irreversible, and the system's future is often unpredictable [18]". Some examples of complex adaptive systems are the stock market, the biosphere and the ecosystem, and manufacturing businesses. The human body has several complex adaptive systems such as the immune system and the brain [19].

2.3.3 System of Systems (SoS)

System of Systems (SoS) is a mix of multiple systems capable of independent operations but interact with each other to meet a need or set of needs [20]. Jamshidi [20] defines system of systems as meta-systems that are themselves comprised of multiple autonomous embedded complex systems that can be diverse in technology, context, operation, geography and conceptual frame. There are other definitions of System of Systems depending on the application area and focus [21]. A sample of these application-specific definitions follows [21]:

Definition 1: Systems of systems exist when there is a presence of a majority of the following five characteristics: operational and managerial independence, geographic distribution, emergent behavior, and evolutionary development. Primary focus: Evolutionary acquisition of complex adaptive systems. Application: Military [22].

Definition 2: Systems of systems are large scale concurrent and distributed systems that are comprised of complex systems. Application: computer system [23].

2.4 Comparison of Different Types of Systems

System characteristics may be described according to structure, behavior, and interconnectivity. System structure is defined as "the arrangement of parts, or of constituent particles, in a substance or body" [24]. Hence, the structure of a system is its component parts and the relationships among them; and a description of a system's structure must include:

- A list of all the components that comprise it.
- How the components are interconnected.
- What portion of the total system behavior is carried out by each component.

The system's behavior is defined by its actions or reactions, and it involves the inputs, processing, and outputs, and suggests that there is information transfer between its components. System behavior results from the effects of reinforcing and balancing processes and the use of feedback [25]. A reinforcing process leads to the increase of some system component, and a balancing process tends to maintain equilibrium in a particular system

[26]. Feedback may be used to adjust processes for future improvements. Simulation modeling is often used to model a system's behavior in response to various conditions of operation [27].

A system's interconnectivity is the interconnection or exchange beyond its boundaries. It might involve sending or receiving entities such as data/information, materials, or even people. If that interconnection contributes to the overall operation of a larger system, then the two systems are interoperating. Hence, for simple systems, the interconnections might be interfaces at the component boundaries; but for larger, more complex systems, it might involve creating a synergy needed for overall fulfillment of its purpose. Tables 1- 3 provide a summary of the differences in behavior, structure, and connectivity, respectively, among the different types of systems previously described.

Table 1-Differences in Behavior

Simple System	SoS	CAS	FoS
Simple systems have static behavior.	Meta-system behavior cannot be derived by analyzing the behavior of the component systems. System of systems has dynamic /evolving behavior	System level behavior can not be deduced from the behavior of lower level components of the system. Coherent behavior of the system arises from competition and cooperation among the agents. Emergent behavior of the system is the result of implicit and explicit collaboration of its independent systems. CAS has adaptive dynamic /evolving behavior.	System family change over time.

Table 2-Differences in Structure

Simple System	SoS	CAS	FoS
General components: inputs, processes, outputs and outcomes, processing input, processing output, environment, stakeholders, and boundaries.	Constituent independent systems, subsystems, environment, boundaries, connectivity, components and parts, stakeholders.	Collection of independent systems (agents), changing environment.	Independent constituent systems, boundaries, changing environment.

These different types of systems, and experiences with any combination of them in an organization, create problems for managers who must make decisions about ensuring their effective and efficient operation. A discussion of some of these concerns is provided in the following section.

Table 3- Differences in Connectivity

Simple System	SoS	CAS	FoS
Designed systems require relationships between elements to be designed simultaneously with the design of the elements themselves. Connectivity is between the components.	The internal connectivity of the SoS is not initially designed but emerges as a property of present interactions among constituent systems. Enables full connectivity by supporting interactions and connections between all elements and it is adapted as constituent systems enter or exit the SoS.	Each element in the system is independent and interacts with other elements. The degree of effect of the interaction depends on the connectivity among the elements. Connectivity is not static and changes over time. As result, connectivity, along with interdependence, creates new order and coherence [28]. Interactions and the strength of connectivity make it difficult to predict the system behavior [29].	FoS interoperability issues are greater than those of a SoS.

2.5 Systems Management

Decision-makers in government and industry (manufacturing and service) and many other areas are facing problems that are becoming more difficult to solve because of increased complexities in the structure of the systems in which they operate and the demands placed on them by multiple stakeholders. At a 2006 workshop held by SEI researchers, systems engineers, designers, and managers from various U. S. Army (Army) organizations identified several issues pertaining to managing SoS. Several of the more general issues are listed below [30]:

1. System-of-systems requirements are not clearly documented, nor are configurations controlled /managed.

2. There is no method for validating and adjudicating interoperability requirements; interoperability requirements are not defined early or identified as a common development goal.
3. There is no ownership of system-of-systems requirements; there is no follow-up for their explanation or verification.
4. There is no single funding line for system of systems, making it difficult to bring personnel, resources, and priorities together sufficiently to develop the common requirements.
5. The general system-of-systems currently in place do not produce effective results; there is a need for a process that is comprehensive, to include time frame, management structure, definition of terms, results, and responsibilities.
6. The Army (and few other organizations) have no tools (more automated than Excel or a protocol checker) to adequately model interoperability; must wait until done to achieve interoperability by trial and error.
7. There is a lack of application of system engineering capability in development and gap analysis (science and technology); multiple organizations (uncoordinated) working on multiple solutions to solve either the same problem or similar problems.
8. DoD (and few other organizations) maintain multiple systems with independent users, requirements, and timelines with no single authority; there is no coordinated end product.
9. There is no comprehensive system-of-systems description available to all developers to determine interfaces and ensure designs achieve interoperability.
10. The incentives for successful management do not support sacrificial resource distribution; system-of-systems interoperability will only be as good as its weakest proponent.
11. Joint system-of-systems requirements are not clear; interoperability is not guaranteed and joint testing results are questionable.
12. There is a lack of tradeoff analysis; acquisition is not efficient, effective, and timely.

These issues indicate that both technical and organizational factors require management for system success. Success can be defined either narrowly in terms of meeting performance, cost, and schedule expectations, or more broadly in terms of stakeholders perceiving benefit given the generalized costs of realizing the system [31]. Given that systems often have multiple stakeholders, often with multiple and conflicting expectations, and that these expectations may change over time, requiring system reconfigurations, obtaining and maintaining their overall performance is not trivial. Research shows that assessing performance of today's complex systems has become an increasingly challenging problem for most organizations.

This is true for service organizations as well as for those in manufacturing. In addition to meeting requirements in a static context, the performance of system architectures is increasingly defined by an ability to deliver value to stakeholders in the presence of changing operational environments, economic markets, and technological developments. Research on system changeability and uncertainty management has been conducted as a first step towards the achievement of value robustness, or maintaining customer value through changes [9].

For example, several researchers have developed a theory of the time-based, system property called changeability, which is a subset of the "ilities" (i.e., flexibility, adaptability, rigidity, robustness, scalability, and modifiability) and identifies tradespace metrics to operationalize the theory [9]. These "ilities" are the general system characteristics that are used to define system performance. (Note that most of them end in "ility".) In an attempt to improve and build upon this theory of changeability, ongoing research on system survivability is focused on challenges posed by dynamic events in the environment that impact system survivability. Much attention has been given to how survivability might be better addressed during the conceptual design of engineering systems. This research is not considering design of new systems, but improvement of existing systems. Hence, this theory was not considered to be applicable. Of concern in this research is events in the operational environment of engineered systems that may degrade performance, particularly for systems with networked structures.

In fact, the literature indicates that existing criteria and systems architecting methodologies for evaluating highly survivable systems and networks are “incomplete and inadequate” [32]. Furthermore, it is noted that there is “almost no experience in evaluating systems having a collection of independent criteria that might contribute to survivability” nor in examining the interactions among different criteria. These shortcomings make it difficult to specify, develop, procure, operate, and maintain systems with critical survivability requirements.

Survivability at the architecture level is further complicated when issues extending beyond design of the technical system are internalized, such as operational behavior, human factors, and supporting infrastructures [32]. Although survivability is an emergent system property that arises from interactions among components and between systems and their environments, conventional approaches to survivability engineering are often focused only on selected properties of subsystems or modules in isolation, and not on the overall system. This leads to sub-optimization of performance. Hence, optimization of the system’s performance requires survivability of the constituents and the ties among the constituent systems; it calls for managing the interoperability of the system.

2.6 Interoperability

The interaction or interoperability of a SoS is defined fundamentally by the Institute of Electrical and Electronics Engineers (IEEE) as “the ability of two or more systems or components to exchange information and to use the information that has been exchanged” [33]. This definition represents only the most general expression of interoperability and only reflects the exchange of information. However, interoperability is not only about information exchange but also about the type of relations between systems which can be represented in terms of shared resources. For example, in multihospitals systems, the types of resources shared between facilities are technologies, workforce, and market share [34]. Frequent exchanges lead to greater transfer of information and technical competence across networked organizations, more frequent interaction among them, and a greater involvement of personnel [35].

The notion of interoperability has emerged in many publications, especially in the military. Some of these definitions follow:

- "The ability of alliance forces and, when appropriate, forces of partner and other nations to train, exercise and operate effectively together in the execution of assigned missions and tasks" [36].
- "The ability of systems, units or forces to provide services to and accept from other systems, units or forces and to use the services so exchanged to enable them to operate effectively together" [36].
- "Ability to provide services and information to and accept from other systems and to use the services and information so exchanged to enable them to operate effectively together" [37].
- "Interoperability is a measure of the degree to which various organizations or individuals are able to operate together to achieve a common goal. From this top-level perspective, interoperability is a good thing, with overtones of standardization, integration, cooperation, and even synergy" [38].

This last definition is considered to be a more comprehensive definition that is appropriate in many applications. These definitions indicate that interoperability has two basic characteristics: 1. a relation, a mutual capability between/among two or more objects; and 2. a functional capability strongly connected with, and supporting cooperation [39]. Cooperation includes existence of a common goal, consciousness, deliberateness, and agreement; however, interoperation may not always include co-operation. It might also include competition. Effective interoperability then depends on the recognition of interdependencies and interfaces between and among the constituent systems in whatever form they might take.

Effective interoperability depends on the recognition that interoperability is about interdependencies and interfaces between and among system (i.e., it is about families-of-system or systems-of-systems) in a mission-area context [40]. Also, some authors [39, 41] stress discussions about the types of interdependencies/interfaces. For example, Ford [41] presents the types of interoperability as semantic, operational, and technical; and he describes their nature as either being collaborative or confrontational. Munk [39] also describes their nature as either being cooperative or competitive.

In this research, a general definition was refined to at least bind interoperability to the concept of SoS in service domain. This definition follows:

> *SoS Interoperability is the ability of constituent systems to collaborate (positive interactions) or compete (negative interactions) with each other at varied degrees to achieve the SoS intended goals and objectives.*

The above statement will be the working definition of SoS interoperability used for the remainder of this research. Also, based on this definition, interoperability is expected to take several forms:

- Collaborative Interoperability- implies that there is interaction among systems with a positive effect. In other words, the systems engage, concur, and help each other toward better performance.
- Competitive Interoperability: signifies that the systems compete with other over a certain things such as resources. Correspondingly, the systems try to improve their performance based on outperforming the others.
- No interoperability: denotes that the systems neither collaborate nor compete with each other. More specifically, the systems have neutral relationships among each other.

Another view of different types of interoperability, the Organizational Interoperability Maturity Model (OIM) [42], was developed by the Australian Defense Science and Technology Organization (DSTO) to identify problems and evaluate interoperability in a coalition operation [42]. The OIM has five levels which are independent; they are Ad hoc/cooperative, collaborative, combined, and unified [42]. These levels, building in degree of achievement, are defined as follows [43]:

- **Independent-** describes the interaction between independent organizations. These are organizations that would normally work without any interaction other than that provided by personal contact. They are likely to be organizations that do not normally share common goals or purpose but that may be required to interoperate in some scenario that has no precedent. Essentially the arrangements are unplanned and unanticipated.
- **Cooperative/Ad hoc-** cooperative interoperability support shared purpose with general guidelines but with separate reporting lines of responsibility [43].
- **Collaborative-** collaborative organizational interoperability level is where recognized frameworks are in place to support interoperability and shared goals are recognized and roles and responsibilities are allocated as part of on-going responsibilities however the organizations are still distinct.
- **Integrated/Combined-** integrated level of organizational interoperability is one where there are shared value systems and shared goals, a common understanding and a preparedness to interoperate, for example, detailed doctrine is in place and there is significant experience in using it.
- **Unified-** a unified organization is one in which the organizational goals, value systems, command structure/style, and knowledge bases are shared across the system. The organization is interoperating on continuing basis.

The OIM model is similar to the Architecture Maturity Model of the Systems Enterprise Institute (SEI) where each of the 5 levels of the maturity model (initial, repeatable, defined, managed, and optimized) represents an increased ability to control and manage the enterprise architecture. The independent level of OIM model is essentially parallel to the initial level where there is no interoperability between entities but, there is a limited shared purpose among them. Additionally, the repeatable level and the cooperative levels are alike since at this stage the entities' shared purposes are identified. Furthermore, at the collaboration level and the defined levels, shared values are identified, communicated, and used. Moreover, integration and managed levels are identical since at this stage entities have shared culture that is managed to improve the organization. Last, but not least, is the resemblance of the optimization and unified levels where standardization within the organization is satisfied.

Since the OIM describes the degree of system interoperability, but not the impact of change on the interoperability or the influence that change might have on moving it from one level to another, it is not applicable for this study.

2.7 Performance

All of the types of interoperability are defined according to their impact on performance. Hence, this research is aimed at quantifying that impact. To begin, a working definition of performance is required. The Merriam-Webster Dictionary defines performance as “the execution of an action or the fulfillment of a claim or request, or the manner in which a mechanism performs” [44]. Another definition found includes accomplishment of a given task measured against preset standards of accuracy, completeness, cost, and speed [45]. The working definition of performance in this study is the degree to which a system accomplishes what it was intended to perform. This definition is primarily a definition of effectiveness. This is a measure at the system level, and is viewed as an aggregation of what goes on at the constituent-system level.

2.8 Measures of Performance (MoPs)

A measure of performance, MoP, is used to measure task performance at the constituent-system level and the measure of effectiveness (MoE) is used to “determine progress of an operation toward achieving objectives” [42]. According to US Joint Forces Command Glossary, Measures of Performance (MoP) are objective metrics of the "outcomes" of "tactical actions," and are assessed at the component level as a result of the "tactical actions" performed to achieve a desired effect, i.e., were the targets hit and what level of damage was achieved [46]. The US Air Force defines MoPs as qualitative or quantitative measures of system capabilities or characteristics, indicating the degree to which that capability or characteristic performs or meets the requirement under specific conditions [47]. Measures of performance are derived from specifications and selection is based on the stakeholders’ ability to discriminate between levels of “good” performance. Gentner, however, points out that MoPs are components, or subsets, of MoEs; i.e., the "degree-to-which" a system performs is one of a number of possible measures of "how well" a system's task is accomplished [48]. Therefore, MoPs can be accumulated to assess a MoE that is not directly measurable [49]. However, the performance of the constituent systems in a SoS are not independent, and cannot simply be aggregated because of their interoperability.

2.9 Applicability to Multihospitals Systems

In the early 1980s, the healthcare system experienced a profound transformation [50]. New healthcare care organizations resulted from the integration, through ownership or contractual relationships, of previously separate entities [51, 52]. Also, other new facilities emerged by filling roles that had not previously existed in the health care system such as physician-hospital organizations, administrative-services-only organizations, and practice management associations [53]. The new healthcare system category formed goes by two names, integrated healthcare system or multi-hospitals system. Multi-hospitals system is defined by both the American Hospital Association (AHA) and Modern Healthcare as "nonfederal and non-state hospitals that are either leased, under contract management, legally incorporated, or under the direction of a board that determines the central direction of two or more hospitals" [54]. A multi-hospitals system may also be defined as having 2 or more general acute care hospitals [55]. Based on these definitions, a multi-hospital system may be viewed as a system of systems (a hospital of hospitals).

In 1980, sixty percent of the for-profit system hospitals were located in four states: California, Texas, Florida, and Tennessee" [54]. Over the years, the number of multi-hospitals systems and the number of beds in these systems have grown rapidly. Currently, more than half of all U.S. hospital admissions occur in the 200 largest multi-hospital systems and about 60 percent of all hospital admissions occur in system hospitals [55]. There is still the question, however, whether these system hospitals guarantee better performance; or if a specific type of system is better.

Yonek [55] states in the Health Research and Educational Trust (HRET) report that "no one system type was most associated with high performance". The authors of the HRET report examined the relationships of many system characteristics to an overall composite measure of quality as well as to more specific measures, such as overall patient satisfaction, and a combined, risk-adjusted readmission rate and mortality rate [55]. From the HRET analysis report, it was evident that high quality scores were achieved by a variety of different system types- large or small systems, geographically regional or multi-regional systems, systems from all regions of the country, and systems with differing levels of teaching components [55]. The conclusion drawn was that the size, type, and location of the integrated healthcare systems are not indicators of high performance.

Additionally, hospital acquisitions and mergers are a source of concern for policymakers because of the potential to increase medical spending. Recent evidence suggests that prices for services are higher for system hospitals and prices at system hospitals increase faster than at non-system hospitals [56-60]. Higher prices are typically thought to result from greater market power. However, they could also reflect higher quality of care.

[61] Found no relationship between hospital acquisitions and inpatient mortality looking at hospitals in California between 1992 and 1995. Several other studies [62-64] look at the relationship between hospital market concentration and quality. Those studies find that higher concentration leads to no significant quality improvement or even deteriorating quality. With price increasing and no apparent improvement on quality, an important question is whether there is an upside to hospital acquisition. In particular, do multiple hospital systems help save costs by improving coordination and reducing duplicate technology? Another question might be whether adding another hospital is a sound management decision; and sometimes, it might be whether dropping a non-productive hospital is a sound management decision. Maybe these answers depend on how and why changes to a system are being made.

The industrial organization literature argues that horizontal integration can generate gains in production efficiency. However, the evidence on efficiency gains in hospital markets is mixed. Concentration is usually measured by the Herfindahl-Hirschman Index (HHI), and it might tell the whole story. This measure is often used by the U.S. Department of Justice for evaluating mergers to make sure that it does not create a monopoly. It is calculated by squaring the market share of each organization competing in a market, and then summing the resulting numbers. The HHI number can range from close to zero to 10,000. The closer a market is to being a monopoly, the higher the market's concentration (and the lower its competition).

[65, 66] compared true system hospitals with pseudo systems in high-tech services, cost per admission and administrative costs in California. Their conclusion was that hospitals are motivated to join systems to enhance their reputation. However, [67] found that system hospitals in Florida had lower costs (around 17 percent lower) as a result of technological efficiency gains. A more recent study, [68], found that small localized multi-hospital systems have higher adoptions of clinical health information technologies than independent hospitals, while it is not the case for large or geographically dispersed systems.

Thus, the recent trend of local acquisitions provides an interesting setting where efficiency gains may be very important. By joining local systems, hospitals may achieve higher production efficiency gains than geographically dispersed systems cannot. Therefore, it seems that location is just as important as size. Perhaps this is due to logistical benefits when hospitals are closer. Hence, the realized benefits of joining a system might not meet the pre-joining expectations provided in the literature [45]:

- Hospital systems can exploit economies of scale and scope, for example, by eliminating duplicative equipment.
- Hospital systems can reduce administrative costs and realize purchasing economies. Independent hospitals also can achieve these economies, by unilateral elimination of services or by collaboration with other independent hospitals.
- System membership may confer marketing benefits. Employers and insurers may prefer "one-stop shopping," which minimizes purchasers' transaction costs. Hospital systems can offer stability-purchasers can expect to gain access to the same providers year after year. Hospital systems also can reduce purchasers' uncertainty about quality of care,

geographic access to hospitals and specialists, availability of technology, referral patterns, and so forth.

If the overall expectation is improved performance, knowing whether that expectation was met or the degree to which it was met is critical to management. The International Standards Organization (ISO) has developed different dimensions for health system performance and their indicators. These are summarized in Table 4 [69].

Table 4- ISO Health System Performance Dimensions and Indicators [69]

Dimension	Definition	Indicators
Acceptability	All care/services provided meet the expectations of the client, community, providers and paying organizations, recognizing that there may be conflicting or competing interests between stakeholders, and that the needs of the clients/patients are paramount	Patient satisfaction
Accessibility	The ability of clients/patients to obtain care/service at the right place and the right time, based on established standards	Waiting times, availability of physicians.
Appropriateness	Care/service provided is relevant to clients'/ patients' needs and based on established standards	Appropriate use of Ace Inhibitor at discharge for heart failure
Competence	An individual's knowledge and skills are appropriate to the care/service being provided.	
Continuity	The ability to provide uninterrupted coordinated care/service across programs, practitioners, organizations, and levels of care/service, over time.	
Effectiveness	The care/ service, intervention or action achieves the desired results.	Survival rate; admission rates
Efficiency	Achieving the desired results with the most cost-effective use of resources .	Avoidable hospitalizations, Cost per case mix-adjusted separation
Safety	Potential risks of an intervention or the environment are avoided or minimized.	Hospital-acquired infection rate

In this study, performance measures for the participating systems were obtained from the Joint Commission Healthcare organization. This data did not contain the exact same metrics such as survival rate and admission rates, but they did provide a comprehensive assessment of performance based on effectiveness. The specific measures, for each participating hospital, that are provided by the Joint Commission include values for performance relative to Heart Failure, Heart Attack, Pneumonia, Pregnancies, and Infectious Diseases. This data is for improvement at the system level.

The literature cites many early efforts focused on improvements at the operational level, such as reducing waiting and delays in primary care [70] or reducing travel required in the process of chemo-radiation treatment [71]. Often these are not integrated with other enterprise processes and do not lend themselves for aggregation up to system-level measures. Operational-level challenges in measuring performance relative to delivery of health care services and how they affect outcomes include the following [53]:

- Measures must be developed for each characteristic. To do this properly (i.e., ascertaining the measures' validity and reliability) is an expensive and time-consuming process.
- Another challenge is to develop better measures of outcomes and have to adapt as data systems improve.
- Research on the impact of health care system characteristics requires collaborating with the health care players being studied.
- New strategies must be developed that recognize the importance of engaging health care organizations in the research process.

Because of these challenges, and due to the scope of this study, no effort was made to collect operational performance measures to aggregate into effectiveness measures. Instead, industry-accepted measures of system-level performance were used.

2.10 Summary

In summary, current literature documents that there is a need for quantitative assessment of system-level performance of complex systems such as the SoS – partly because they are an extension of traditional systems with enough differences to justify their own approaches for designing, operating, and improving; that SoS are found across many domains and multi-hospitals systems is a critical one to understand and manage. This research offers one approach to document the performance benefits espoused by designers of SoS by taking advantage of theories and techniques for measuring and improving the performance of systems complicated by their structure, size, and interactions.

CHAPTER 3
METHODOLOGY

3.1 Introduction

The approach taken for this research is to apply a structured technique for optimal decision-making in process improvement. The framework used is a hybrid of commonly applied methods – including Deming's Plan-Do-Study-Act Cycle (PDSA) and Six Sigma's Define-Measure-Analyze-Improve-Control (DMAIC). This hybrid consists of three steps because psychological studies, such as the Brown-Peterson procedure [72], demonstrated that people can remember three items even if being distracted by another task. The name of the framework, "Tri-Ex", was selected because other foundational psychological studies, such as those conducted by[68], indicate that people tend to recall with greater frequency those things they see or hear more often – for example, words that start with the same letters. In Tri-Ex, the three phases all start with the letters "EX".

3.2 The Tri-Ex Framework

This framework has been designed for use by those who have expert knowledge (know interoperability and performance measures) in the domain of the SoS and experience with analysis and improvement tools and techniques (spreadsheets and simulation). Since one individual might not meet both requirements, it is recommended that this effort be conducted by a team. The Tri-Ex framework is based on three phases which are **Ex**plain, **Ex**plore, and **Ex**perience, and they are related as shown in Figure 4. A description of each phase follows.

3.2.1 Explain Phase

The first task is to fully describe the SoS. This includes a description of its purpose so that all stakeholders might have a common point of reference. Everything done in the system should be done in support of that purpose. The objective(s) describe the intended results; and it may consist of several smaller goals that support it. The objective serves as the basis for policy and performance appraisals and act as glue that binds the entire system together. System objectives specify what the system will be able to do, or perform to be competent. The stakeholders are those entities (internal and external) that have a vested interest in the system. They include internal employees and managers and external customers and regulators.

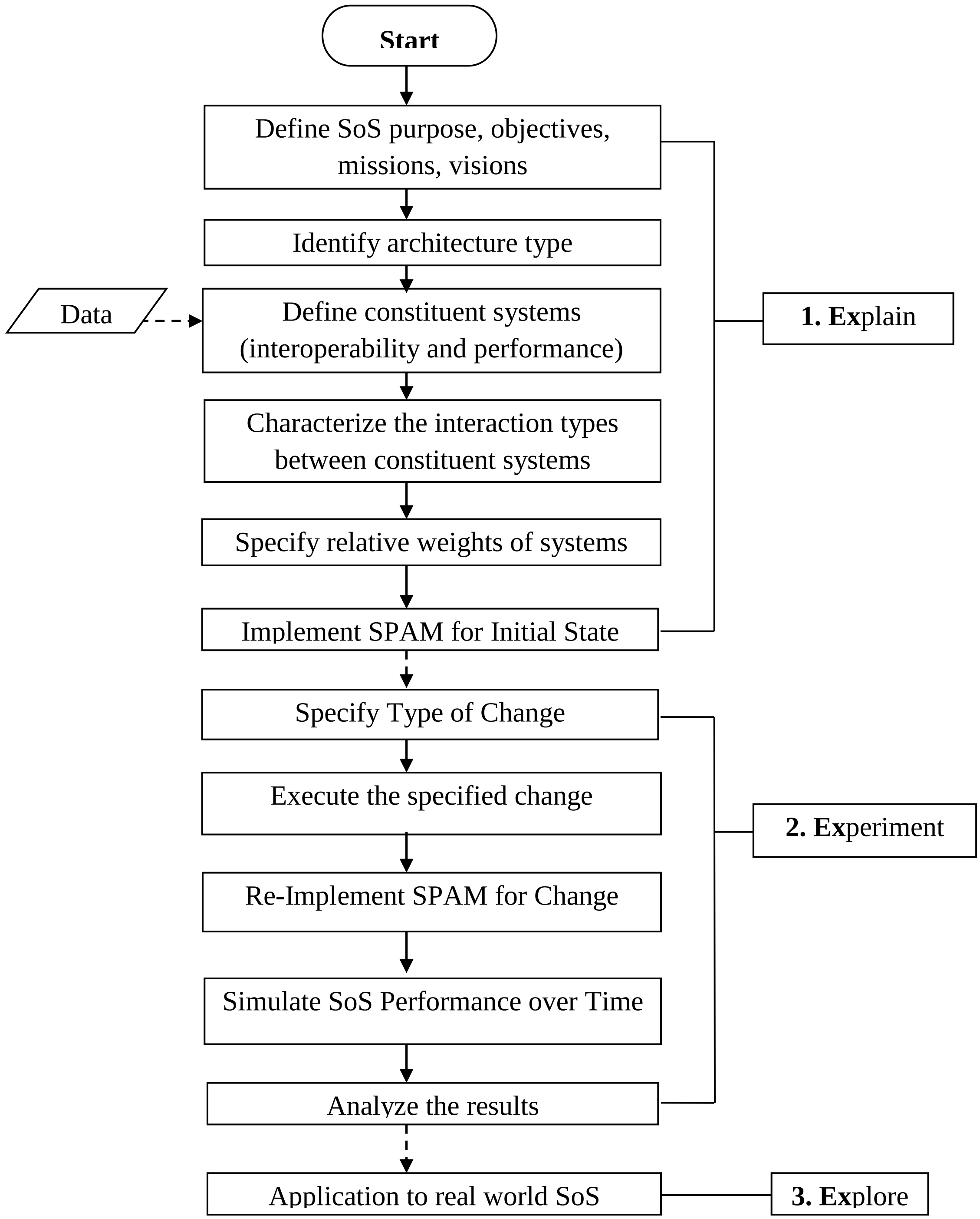

Figure 4. TriEx Performance Framework

All the stakeholders of the systems and the system of systems should be listed. According to Buehler [73], stakeholders include those who provide data for the system and those who use the information generated by the system (e.g., public health practitioners; health-care providers; other health-related data providers; public safety officials; government officials at local, state, and federal levels; community residents; nongovernmental organizations; and commercial systems developers). The stakeholders are different from one system to another and they change as the system alters. Listing stakeholders helps define who the system is intended to serve and provides context for the evaluation results [73]. Detailed system descriptions also will facilitate evaluation by highlighting variations in system operation that are relevant to variations in system performance. Therefore, such conceptual model can facilitate the description of the system.

The environment represents everything that is important to understand the functioning of the system, but is not part of the system. It includes competition, people, technology, capital, raw materials, data, regulation and opportunities [74]. The environment is a part of the world that can be ignored in the analysis except for its interaction with the system. There are two types of environments, internal and external. Internal environment is made up of the system's resources, its capabilities and competencies. The external environment is divided into two parts: those elements which are directly interactive with the systems (like competitors and suppliers) and those which interact indirectly (like the economy and new technologies).

Other characteristics described during this phase include the purpose, goals, and objectives [73]. The purpose(s) of a system or system of systems should be clearly described and the intended usage of the system. In case of adding a system to the SoS, the purpose should indicate the period of time, context, and type of interactions with other systems in which the system operates. The objective(s) should be clearly stated and describe the intended results. A clearly described objective allows stakeholders to find how successful their system has been. The objective of a system may have several goals; and it serves as the basis for policy and performance appraisals and act as glue that binds the entire system together [74]. System objectives specify what the system will be able to do, or perform to be competent.

In addition to a description of the system's context, a description of its structure is also required. This description builds upon the system and its component descriptions to define and quantify the relationships among the systems and with the meta-system. Specifics needed are as follows:

- The interaction types and degrees between constituent systems;
- The relative weights of system-mission contribution provided by each of the constituent systems; and
- A measure of the current performance of the SoS.

The approach taken to quantify these system parameters is described in the next section.

3.2.1.1 Quantification of Parameters for System Performance Assessment Model (SPAM)

Other studies as discussed in the literature section have designed models to measure performance of individual members, but not to measure their contribution to the system performance. However, the objective of the **System Performance Assessment Model (**SPAM) in this research is to assess the SoS performance by taking into account the effect of interoperability on the contribution of the members to the system. This research uses a matrix vector multiplication approach to assess the SoS performance given the individual system performances, relative weights, and interoperability parameters.

Consider a system of systems, S_{sos}, which is defined by its *n* different constituent systems with the following characteristics:

1. $S_{sos} = \{S_1, \ldots, S_n\}$

2. Each system has interoperability values m_{ij} , and the interoperabilities among the constituent systems of S_{sos} are defined by M, where

$$M = \begin{pmatrix} 1 & m_{12} & m_{13} & \ldots & & m_{1n} \\ m_{21} & 1 & m_{23} & \ldots & & m_{2n} \\ . & & 1 & & & \\ . & & & 1 & & \\ . & & & & 1 & \\ m_{n1} & m_{n2} & m_{n3} & \ldots & & 1 \end{pmatrix} = \begin{pmatrix} M_1 \\ M_2 \\ . \\ . \\ . \\ M_n \end{pmatrix}$$

The element m_{ij} represents the degree of interoperability between system *i* and system *j* or the effect on system *i* caused by system *j*. However, the effect of system *i* on system *j* may not be the same as the effect of system *j* on system *i*. Therefore, the relationship between systems i and j may be such that $m_{ij} \neq m_{ji}$. The size of m_{ij} represents the strength of the interactions. The sign represents the direction of the interaction, positive indicating a strengthening of the receiving system and negative representing a diminishing of the receiving system. The diagonal of the matrix has ones and represents self interoperability. In general, the values of m_{ij} are assumed to be -1, 0, or 1indicating that the systems either compete, have no relationship, or collaborate with each other.

These types of interactions might differ across domains, as was learned with this research. A director of quality at one of the participating systems claimed that interoperability in healthcare systems is not viewed as competitive but only as collaborative interactions. Subsequent research confirmed this statement. Consequently, a decision was made to determine the interoperability within the multi-hospital systems as a function of the patient transfers and receipts between facilities as reported from the surveys. The rates were determined from the percent of patients, and the degree was determined from the frequency.

Therefore, the interoperability vector elements in the healthcare system were calculated using Equation 1 such as:

$$\mathrm{M_i} = (1 + \mathrm{R_i} * \mathrm{D_i}) \,/\, \textstyle\sum_1^n \mathrm{W_i} * (1 + \mathrm{R_i} * \mathrm{D_i}) \qquad \textit{Equation 1}$$

Where,

M_i is the interoperability for system *i*;
R_i *Di is calculated using $((R_C*D_C) - (R_T*D_T))$ where,
R_C is the rate for receives,
D_C is the degree for receives,
R_T is the rate for transfers,
D_T is the degree for transfers, and
W_i is the relative weight for system *i* (the number of treated patients).

3. Each system has a relative weight W_i or degree of contribution to accomplishment of the mission of the SoS where, $W_{SoS} = \{W_1, \ldots, W_n\}$
4. Each constituent system has a Measure of Performance (MOP) called P_i and the SoS performance is represented by P_{SoS} such that $P_{SoS} = \{P_1, .., P_n\}$
   Performance is characterized as a set of individual performance measurements P_i, where P_i is the performance of system i where, $i = 1, 2, \ldots, n$.
5. Then, the SoS performance, P_{SoS}, is represented in Equation 2 as follows:

$$P_{SoS} = \sum_{i=1}^{n} P_i * W_i * M_i \quad \textit{Equation 2}$$

3.2.2 Experiment Phase

This phase involves testing the impact at the SoS level of a change made at the constituent system level within the overall system. This framework may be used to evaluate the soundness of an existing change or the feasibility of a proposed change – if needed data are available or if there is confidence in the estimates. The application described in the next chapter involves an assessment of existing changes. For this analysis, the following scenarios will be used as demonstrations of system changes:

- **Scenario 1-** The first scenario is about the change of the rate of interoperability. This which means a change in the frequency of exchanges between systems, either increasing or decreasing.
- **Scenario 2-** The second scenario is about the degree of interoperability where a change in the size of transfers between systems either becomes stronger of grows weaker..
- **Scenario 3-** Remove one of the constituent systems from the SoS.
- **Scenario 4-** Add a new system to the SoS.

No scenarios involving changes with a combination of relationship (Scenarios 1 and 2) with SoS composition (Scenarios (3 and 4) have been considered.

After the selection of the appropriate scenario, the Experiment phase continues following these steps:

- Reassess SoS performance after change using SPAM model.
- Simulate the average SoS performance.
- Analyze the SoS results.

3.2.3 Explore Phase

At this phase, the decision maker applies only changes that indicated an improvement in the SoS. It is the Explore phase during which management delves into options for fulfilling the SoS goals that can help keep its strategy on course. During this phase, management can map out "what-ifs" — the scenarios, priorities and choices that they'll build into their strategy for continuous positive performance. This framework, with the three phases of Explain, Experiment, and Explore, may help the decision maker to develop a clearer picture about the performance of the SoS being managed in the midst of change.

3.3 SPAM Assessment Tool

The objective of measuring the overall performance is to study the relationships among the individual systems and the effect of changes to those relationships, as well as changes in the composition due to adding or deleting systems on the SoS performance. These activities are based on the assumption that the system survives the change. The logic used in assessing the performance of each SoS is shown in Figure 5.

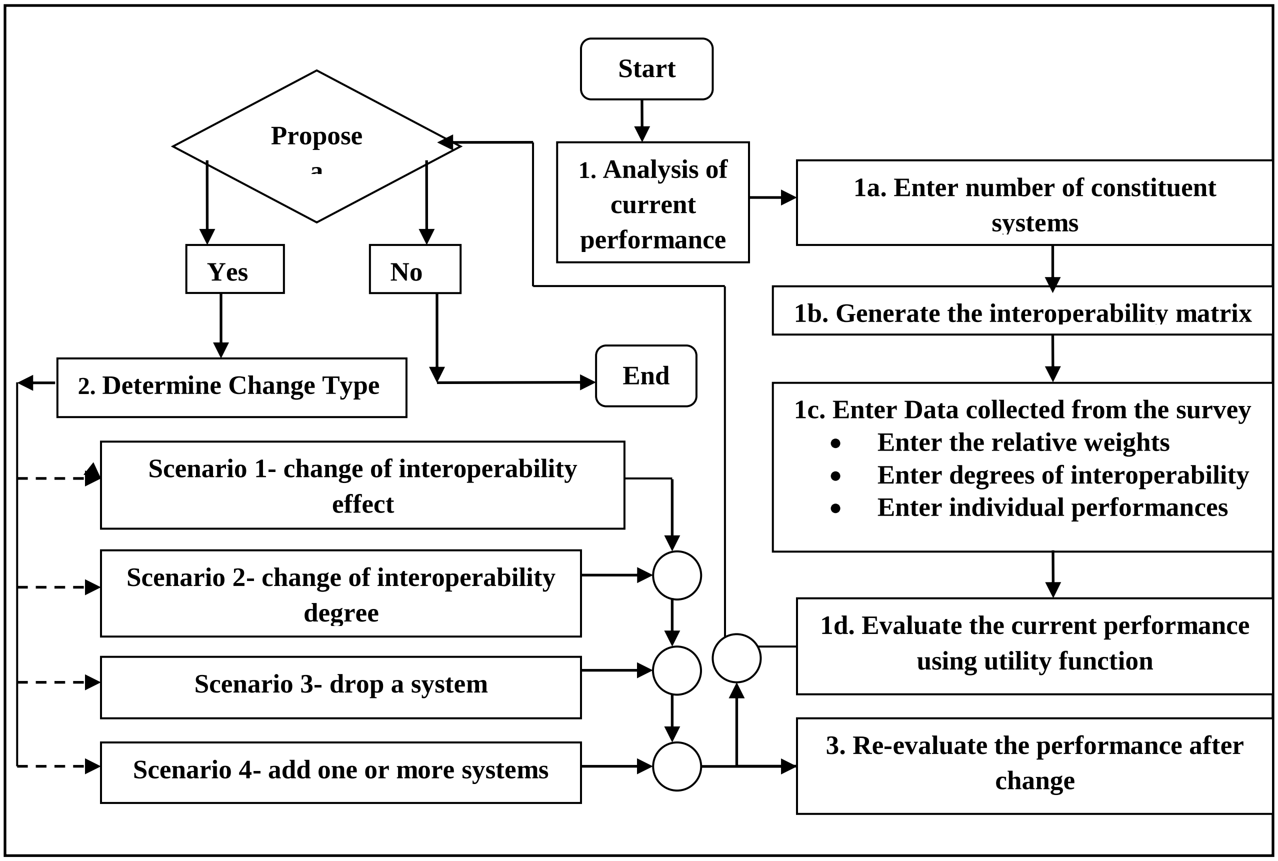

Figure 5- SoS Performance Assessment Model (SPAM) Flowchart

This SPAM tool was designed using MatLab, a product of Mathworks. MatLab is used throughout this research for the optimization modeling because it was found to be more pliable to the mathematical approach taken (matrix operations). MatLab was used to design a model that calculates the current SoS performance and the reevaluated SoS performance after change; it was also used to simulate average SoS performance using a stochastic model. The same software was also used to calculate the confidence levels for each of the participating systems to prove the assumption made in this research that the patients' transfers and receives between facilities is based on specialties' availabilities.

The SPAM tool was designed to determine SoS performance based on inputs about the constituent systems – namely, their interoperability, individual performances, and relative weight values. The SPAM program is initiated by entering the total number of systems followed by the rate and degree for each system. Next, the relative weights for each system are entered followed by the individual performances for each entity. Using Equations 1 and 2 that were previously defined, the program outputs the SoS performance before change.

The user is walked through the program with a series of prompts. The first prompt "Propose a Change?" waits for the user to select either Yes/ No. The No option exits the program. However, the Yes alternative prompts another pop-up window which is called "Scenario" that contains three options which are "Change Interoperability", "Change Composition", or "Change Performance/Relative Weight". The "Change Interoperability" selection prompts another pop-menu that has two sub-scenarios which allow the user to select either a change in rate or a change in degree. The selection of either rate or degree options ask for the change to be entered and that allows for the program to recalculate the SoS performance after the change. The "Change Composition" option prompts another pop-menu that asks whether the user wishes either to add a new system or to drop one of the existing systems. For the "Add "option, the program asks to enter 1 to add a system and -1 to exit this option. Afterward, rate and degree values are entered in the program and followed by reentering new rates, degrees, relative weights, and individual performances for all constituent systems. Then, the program outputs the reevaluated SoS performance after change. In the case of the "Drop" selection, the program inquires the user to enter the system that need to be dropped from the SoS. Subsequently, new relative weights and individual performance for the remaining systems have to be reentered. Consequently, the program outputs the Reevaluated SoS performance. In the case of "Change Performance/Relative Weight", new performances and relative weights are required to reassess performance after change. Note, that for each scenario, it is assumed that the user is familiar enough with the SoS that he/she has access to the required inputs.

3.4 Data Needed to Answer the Research Question

To answer the research questions and affirm the hypotheses, certain parameters are needed to assess the SoS performance scores before and after proposed changes. The parameters employed to calculate the SoS performance scores are relative weights, individual system performances, and interaction scores for each constituent system of the SoS.

3.5 SPAM Parameters

All the parameters are retrieved from the data survey except relative weights and individual performances which are publically published in the Joint Commission quality report. To obtain the exact performance score, it was impossible due to the confidentiality of the information and the high competition among healthcare systems. Therefore, a decision was made to use patient quality care scores which are available at the Joint Commission website. The relative weights used in this study were decided to be measured by the number of patients who received care per facility from the total treated patients within the multihospital system. The interoperability values are considered to be a function of the rates and degrees. The rate parameter is the total number of other facilities that have transfers/receipts of patients with a certain facility. However, the degree is explained as the average relationships strength between entities which is in this case the frequency of patients' transfers/receipts.

3.6 Data to Test the Framework and the Model

Due to strict confidentiality and high competition in the healthcare domain, performance scores were not made available by facility managers. Therefore, based on a recommendation from one of the surveyed healthcare system experts, information was obtained from public healthcare sources like The Joint Commission, the American Hospital Association (AHA), the Agency for Healthcare Research and Quality (AHRQ), or Health Grades. These sites have current and archived information on patient safety, quality care, and efficiency for each of the healthcare systems' facilities. Since the most commonly available information among them all is quality care and was listed as one of the performance measures listed by ISO as shown in Table 4, this measure was used in this research to measure performance. Also, quality care was deemed to be comprehensive because the specific information was provided about care relative to heart failure, heart attacks, pneumonia, infectious diseases, and pregnancies.

This researcher obtained permission from the Joint Commission to download the current quality care report, and the Joint Commission later sent this information for 2005 after a contract signature. Data from these two time periods allowed assessment of performance at different points in time. The relative weight score for each constituent system, in this case, were obtained from the Joint Commission reports whereas the rates and degrees were attained from the data survey.

3.7 Data Collection Method

This research required both current and historical data on performance and system composition. Data was obtained from healthcare informational organizations via searches of their web sites and agreed sharing of selective reports, and via surveys of healthcare managers at various levels within their facilities. The University of Tennessee Statistical Consulting Center assisted in creating electronic surveys with the help of market-research, interview software offered by the university.

Two detailed electronic surveys were designed and sent to a local healthcare system expert for feedback. Based on that feedback, the surveys were simplified to ensure that the responses would not reveal facility identity to other experts. Next, the two redesigned and simplified surveys were sent to a director of quality improvements in a local healthcare system for feedback; and based on those suggestions, the surveys were corrected and made available to facilities' directors of quality improvement, directors of nursing, case managers, healthcare systems' chief of quality officers, facilities' chief of executives officers, facilities' administrative chief officers, health systems vice presidents, and facilities' chief of operations officers. The surveyed individuals were targeted randomly to administer the surveys depending on their availability and time to answer the questionnaire.

To assess change in performance due to interoperability and composition changes, a facility survey was conducted at the individual facility level to act as a check on the information provided by the system-level survey. For each facility, information was also obtained from their websites. Contact persons at each facility were identified based on organization charts on the websites and general phone calls asking for the Quality Management Department. Individuals were initially contacted by phone and then sent e-mails that contained the links to the surveys. Each facility had a unique password that provided access to a survey intended specifically for it. A copy of this survey may be found in the Appendix C.

The facility survey had four parts as shown in Appendix C. First of all, the facility survey starts with two questions to identify the respondent; these are job title and facility name. The first part of the survey is “Transfer To” section. This section has questions on number of current and past transfers to other facilities in their healthcare system; the number of current transfers that did not occur in the past and vice versa; and the current and past degrees of transfers from their facility to other facilities in their healthcare system. The second part of the survey is “Receive From” section. This section has questions on the number of current and past receipts from other facilities in their healthcare system; the number of current receipts that did not occur in the past and vice versa; and the current and past degrees of receipts from other facilities in their healthcare system to their facility. The third part of the survey is the “Performance” section. This section has questions on current performance relative to the past performance. Questions on current performance were not questioned since they were retrieved from the Joint Commission site. The fourth part of the survey was “Functions Shared Across System” section which had a question on the different types of functions (information technologies, accounting, purchasing, pharmacies, transportation, workforce, etc) shared between their facility and other facilities in their healthcare system.

The healthcare system-level survey was also made available electronically. This survey was designed specifically for each of the healthcare systems in the state of Tennessee. The expected system-level respondents held such positions as Chief Quality Officer, Chief Administrative Officer, and Vice President; if no system-level respondent was available, the Director of Quality at the flagship facility was requested. Individuals were initially contacted by phone and then sent e-mails that contained the links to the surveys. Each system had a unique link that provided access to a survey intended specifically for it. A copy of this survey may be found in the Appendix D.

The health system survey has six parts. The header identifies the respondent (not by name, but by position). The first part of the health system survey starts with a question regarding job title of the surveyed individual. The second part, “Current Transfer”, seeks to determine current patient transfers among its constituents. The third part, “Change in Relationships”, seeks to determine changes in patient transfers over the last five years. The fourth part, “Removals”, seeks to identify system losses. The fifth part of the survey is the “Performance” section. This section seeks to determine how performance behaved after change. The sixth part, “Additions”, seeks to identify system gains. The last part, “Shared Resources”, seeks to identify other interactions/interfaces such as information technologies, accounting, purchasing, pharmacies, transportation, and workforce among the system’s hospitals. This part provides validation of the information retrieved from the facility level surveys about their interactions.

3.8 Description of the Surveyed Population

The population for this study consisted of directors of quality improvement, directors of nursing, case managers, lead case managers, and chief quality officers in the local integrated healthcare systems. However, it was hard to convince most of the directors of quality to participate in this study. The survey and participants were approved by my advisor Dr. Denise Jackson, the Industrial and Information Engineering Department Head, and the Office of Research Internal Review Board (IRB). The packet sent to the IRB included a permission letter, form A, and a consent form which are in Appendices A and B, respectively.

3.9 Description of the Sample

A list of healthcare systems with top management based in the state of Tennessee was gathered using sites from two organizations: Tennessee Center for Performance Excellence (TNCPE) and Tennessee Hospital Association (THA) as shown in Table 6. Each of those healthcare systems was confirmed through their websites. According to the THA, a total of 11 healthcare systems are based in the state of Tennessee (TN), and they include three to fourteen inpatient facilities. Four of these systems had facilities not located in Tennessee, but they are headquartered in Tennessee and kept in the sample. In addition to inpatient facilities, many of them had other types of facilities, such as: physicians’ clinics, restorative care, rehabilitation clinics, homecare, nursing homes, hospice, palliative care, pain management center, and fitness centers. In investigating interfaces, only transfers among acute care, inpatient facilities were considered.

For confidentiality reasons, the real names of these healthcare systems are not stated in this study and are only known to this researcher who has assigned random numbers for the healthcare systems and random alphabetical letters for each of their facilities. Since researchers have indicated that system characters impact performance, some characterization was performed. Specifically, Coyne claimed that the size and ownership type make a difference in the efficiency and cost results of hospitals [75]. Also, he added that during periods of economic difficulty, it is reasonable for boards of directors to explore merging hospitals to accumulate assets and increase size [75]. Therefore, a decision was made to categorize the systems to compare the effect of interoperability and composition changes on performance for different size categories. Hence, the first effort was to categorize the systems by size.

The systems were categorized into four groups. The first group is “Small”, and it contains systems that have no more than four inpatient facilities. The second group is “Medium”, and it holds systems that have between five and seven inpatient facilities. The third group is “Large”, and it encloses systems that have between eight and ten inpatient facilities. The fourth group is “Mega” and it includes systems that have more than ten inpatient facilities. This size classification is shown in Table 5.

Table 5. Classification of TN integrated healthcare Systems

System Classes	Number of Required Facilities
Small “S”	2 < N_F <= 4
Medium “M”	4 < N_F <= 7
Large “L”	7 < N_F <= 10
Mega “G”	N_F > 10

Coincidentally, several of the systems described themselves as small, medium or large; and they fit into the selected ranges.) The result for the healthcare systems follows: 3 Small, 4 Medium, 2 Large, and 2 Mega healthcare systems.

Attempts were unsuccessful to survey SoS6, SoS8, SoS9, SoS10, and SoS11. Hence, the six participating systems are SoS1 through SoS 5 and SoS 7. Note that Mega and Large systems declined to participate, and these both had facilities outside of the state. Therefore, the results provided in this research are applicable only to small and medium-sized multi-hospital systems. The larger, multi-state systems are a remaining challenge as the recent news reveals that current small-medium systems are beginning to turn to them for economic survival.

Table 6. Number of Facilities for Integrated Healthcare Systems by Locations

		Number of Inpatient Facilities by Locations					
System	**Classification**	***Tennessee***	***Virginia***	***Mississippi***	***Georgia***	***Arkansas***	***Kentucky***
SoS 1	S	3					
SoS 2	S	4					
SoS 3	S	4					
SoS 4	M	6					
SoS 5	M	7					
SoS 6	M	7					
SoS 7	M	7					
SoS 8	L	5	3				
SoS 9	L	5	5				
SoS 10	G	9			4		1
SoS 11	G	6		5		1	

3.10 Theoretical Rate

Interoperability was designed in this research to be a function of rates and degrees. A conjecture was made that rate may be closely measured using specialties' availability. The rate values were determined as the proportion of specialties a facility has that the others within the system do not. For simplicity, an assumption was made that a facility transfers its patients to other facilities within the same healthcare system to receive treatment only if that facility lacks a certain specialty that one of the other facilities has.

A decision was made to calculate theoretical rate values based on specialties listed on the healthcare systems' websites. The information presented in these websites was updated regularly and confirmed through the information published in the Joint Commission site. The main reason behind these calculations was to examine if patients' transfers and receives are based on the availability of specialties and sharing of these specialties among the constituent facilities. Therefore, Excel spread sheets were created for each of the participating healthcare systems where inpatient facilities were placed in the first column and all the specialties offered by the healthcare system are positioned at the top row. For each facility, values of ones were entered to indicate the availability of certain specialties and values of zeros were placed in the cells if there is a lack of others. It was assumed that if two facilities had values of ones under the same specialty then they were least likely to have patients' transfers or receives taking place between them. However, if one facility has a value of 1 while the other one has a value of 0, then that may indicate that the facility lacking that certain specialty transfers its patients for treatment to the one that has it available.

The implicit receives/transfers rates for each participating facility were calculated using Equation 3:

$\text{Rate}_i = \sum(\text{number of specialties facility } j \text{ has that facility } i \text{ does not})_{ij} / \sum(S)_i / N\text{-}1$ *Equation 3*

Where,

S is the total number of specialties and N is the number of constituent facilities

3.11 Comparison of Predicted and Actual Rate Scores

After the facility surveys were administered, the current transfers and receives values which are used to calculate the rates, were compared to the calculated predicted rates. First, the facilities were ranked in descending order using their rates for current transfers and receive values. The same process was performed to rank the facilities using the predicted rates calculated based on the specialties. Facilities with the same rate values can have more than one possible rank. In the case of the predicted rates, facilities that have very close rate values were given the same possible ranks. The differences between the actual and predicted ranks were calculated. Results with values of zeros support the hypothesis that transfers and receives of patients is based on the availability of certain specialties.

To assure the significance of agreement between the predicted and the actual ranks, a confidence level was calculated. In general, there are n*(n-1) possible interoperations between n systems. Therefore, a vector of 0s or 1s of length n*(n-1) were used to represent all possible combinations of interoperation between systems. Consequently, there were 2 ^ (n*(n-1)) of such vectors. In this case, all the different combinations using 0s and 1s were generated to calculate the transfers and receive rate values that are possible. Next step was to rank each of those values and match them with the ranks of the predicted values. Then, a count of the number of matching ranks among all the combinations was outputted to calculate next the confidence level.

3.12 Manipulation and Analysis of Survey Data

Both the facility and healthcare electronic surveys for each of the participating healthcare systems were administered during the period of October 21, 2010 and May 5, 2011 and completed by quality management, case management, and management engineering directors. One of the benefits of utilizing electronic surveys is that survey answers for each healthcare system were automatically and separately summarized and exported to Excel. The first step was to sort the retrieved data by facilities in ascending order. This ordering provided a clear visual for determining "reported" inter-relationships among the facilities so that the presence and degree of the relationships could be calculated. This was done for current and past relationships. Next, the performance data was aggregated for each SoS and that value was compared to the actual scores retrieved from the Joint Commission reports. To calculate the individual performances, current and past quality care measures for each of the participating facilities were retrieved from the Joint Commission quality care reports and weighted by the number of treated patients. The number of treated patients were gathered from the same reports and weighted to obtain the current and past relative weights for each of the participating facilities except for facility D in SoS3 which was calculated based on averaging the other facilities since no values were published for facility D in the report.

3.13 Analysis Methods and Tools

The Statistical Package for Social Sciences (SPSS) software was used to create the surveys electronically, to assign passwords for each survey, and to activate the generated links for each of the participating healthcare systems. To export and manipulate the data from the survey, Excel was chosen because of ease of computation. Formulas and macros were embedded for calculations. These calculations included the relative weights, individual performances and the interoperability scores. Additionally, to verify the assumption that transfers and receipts of patients between facilities could be based on specialties/services offered, Excel was utilized to rank the actual and the predicted relationship degrees. Hence, Excel supported analysis of the data obtained from the on-line surveys to calculate performance values whereas MatLab was used to provide descriptive statistics about the data such as mean, variance, skewness, and kurtosis.

3.14 Potential Threats to Validity and Limitations

Several threats to the validity of this research as well as research limitations exist in the areas of data precision, sample sizes, and general engineering variance. The following describes these threats and limitations, the potential impacts it will have on this research, and the steps that have been taken to mitigate these potential threats.

- *Availability of Data.* Publicly available data was sparse, at best. Public data was general about the healthcare industry. Therefore, it was necessary to create the surveys to collect data needed. However, no specific information about the hospitals was permissible to be shared.
- *Performance Measures Precision:* Because the performance is not defined the same across systems and data is often not precise, approximate performance values were calculated using quarterly published care measures.
- *Interoperability Measures Precision:* Because interoperability does not have a common definition and is not commonly measured, the frequency and intensity of patients' transfers and receipts were used as an approximate quantitative measure of interoperability.
- *Sample Size:* Because a decision was made to include only Tennessee hospital systems, the numbers are small. That decision was made because of the initial plan to also do interviews. Not only was it difficult to get "people" to participate; it was also difficult to identify the "right" people to complete the survey. Additionally, not all of the multi-hospital systems based in Tennessee chose to participate.
- *General Variances:* The hospitals were different in many ways, such as governance approaches and membership. There are even cases with mixed ownership types within the system.

3.15 Verification, Validation, Documentation

Model verification and validation (V&V) are essential parts of the model development process if models are to be accepted and used to support decision making [76]. Model verification and validation (V&V) are essential parts of the model development process if models are to be accepted and used to support decision making [76]. Verification is concerned with building the model right. It is utilized in the comparison of the conceptual model to the computer representation that implements that conception. Verification asks the questions: Is the model implemented correctly in the computer? Are the input parameters and logical structure of the model correctly represented? Is the model programmed correctly? Does the model contain errors, oversights, or bugs. Verification ensures that the specification is complete and that mistakes have not been made in implementing the model. Verification does not ensure the model solves an important problem, meets a specified set of model requirements or correctly reflects the workings of a real world process.

Validation is concerned with building the right model. It is utilized to determine that a model is an accurate representation of the real system. It ensures that the model meets its intended requirements in terms of the methods employed and the results obtained [76]. The ultimate goal of model validation is to make the model useful in the sense that the model addresses the right problem, provides accurate information about the system being modeled, and to make the model actually useful [76]. To validate the model built in this research, surveys data on the progress of SoS performance were used and compared to the results obtained by the SPAM model.

Documentation on model verification and validation is critical in convincing users of the “correctness” of a model and its results, and should be included in the simulation model documentation. Both detailed and summary documentation are desired. The detailed documentation should include specifics on the tests, evaluations made, data, results, etc. The summary documentation should contain a separate evaluation table for data validity, conceptual model validity, computer model verification, operational validity, and an overall summary.

3.16 Simulation

Once the system and its components have been clearly identified, an analysis environment must be created. As previously stated, the primary objective is "quantification". In order for the decision maker to analyze the system effectively, the results of the analysis must be presented as quantifiable metrics. Mathematical modeling allows the user to understand and make informed decisions at various levels within the system hierarchy. With the "System of Systems" concept comes an appreciation of the potential complexities and interactions involved. Mathematical modeling offers significant benefits: "There are many interrelated elements that must be integrated as a system and not treated on an individual basis. The mathematical model makes it possible to deal with the problem as an entity and allows consideration of all major variables of the problems on a simultaneous basis.

It must be recognized that system knowledge has an associated uncertainty with it. This lack of certain knowledge could be based on missing, unavailable, or incomplete information, or even an uncertainty in the modeling tools used in the analysis. The question becomes how to accommodate this uncertainty into the mathematical modeling and subsequent analysis. The answer to this is to incorporate basic probabilistic elements into both the modeling and the analysis, and, by extrapolation, the overall system effectiveness methodology.

Understanding the sources of the uncertainty helps determine why a probabilistic approach is useful. Referring back to the "System of Systems" hierarchy, it is clear that each subsystem level will have its own inputs. Perfect knowledge about these inputs is rare, and the decision maker often must make assumptions based on available data and personal experience. Using probabilistic inputs would allow the user to account for variation in his assumptions. Analysis based on these probabilistic inputs could provide useful information about the sensitivities of the inputs, which in turn could translated into requirements definitions. By allowing the inputs to vary, the decision maker could play "what if" games, using the models as a computationally and economically inexpensive way to explore the boundaries of the problem. And finally, variable inputs would allow an investigation of the robustness of a solution (i.e. that solution whose performance parameters are invariant or relatively invariant to changes in its environment.

Overall, the presence of uncertainty in most complex systems points to the use of probabilistic elements. Coupled with a mathematical modeling capability, an analysis environment can be created for incorporation into a system of systems effectiveness methodology.

Simulation usually is performed to mimic the behavior of the real systems over time. Simulations (and models, too) are abstractions of reality [77]. A simulated mathematical model is a representation of a process that designed to initiate the system elements, functions, and attributes. Models are created from a mass of data; equations and computations that mimic the actions of things represented and may include a graphical display that translates all this number crunching into an animation [77]. Models can be complex, carrying all the characteristics of the object or process they represent. A complex model will simulate the actions and reactions of the real thing [77]. In this study, a simulated model is used to predict the behavior of the past and the current SoS performance over specific period of time.

3.16.1 Stochastic Simulation of Performance Measurement

A System of Systems is most often continuously changing in time. Any measurement of its performance would be expected to change as the SoS changes. To measure average performance, one observation of performance would typically not be enough to estimate average performance. Instead, performance can have rises and falls when evaluated at certain times. An estimate of performance taken at a given time could be either higher, lower, or roughly the same as the true mean performance of a System of Systems.

SoS can be measured using a stochastic model which requires parameters such as defining states, current individual performances, and probabilities per unit time of transitions. The probabilities can be represented either by relative frequencies of physical events or uncertainty of occurrence. Therefore, the stochastic model can be modeled with n possible states such as $\{St_1, St_2, ..., St_n\}$. Then, each system S_k have n_k possible states for both rates and degrees such as: $St^k_1, St^k_2, ..., St^k_{nk}$ and associated with performance measurements and relative weights such as: $p^k_1, p^k_2, ..., p^k_{nk}$ and $w^k_1, w^k_2, ..., w^k_{nk}$ respectively.

Parzen [78] stated that a Markov process is similar to Markov chain and can be thought of as a directed graph of states of the system. Also, he added that the only difference is rather than transitioning to a new state, the system remains in the current state for some random amount of time, particularly exponentially distributed, then transition to a different state. Markov process is presented by Equation 4 which is as follow:

$$q_{ii} = \sum q_{ij} \quad \text{with} \quad j \neq i$$ *Equation 4*

Where, q_{ij} is the transition rates between states i and j.

Let $X(t)$ be the random variable describing the state of the process at time t, and assume that the process is in a state i at time t. q_{ij} (for $i \neq j$) measures how quickly that $i \rightarrow j$ transition happens. Precisely, after a tiny amount of time h, the probability the state is now j is given by Equation 5 [78]:

$$\Pr(X(t+h) = j \mid X(t) = i) = q_{ij}\, h + o(h), \quad i \neq j$$ *Equation 5*

Where, o(h) represents a quantity that goes to zero faster than h goes to zero, and

q_{ij} are called transition rates.

The probability that no transition happens in some time r is represented by Equation 6 [78]:

$$\Pr(X(s) = i \;\forall s \in (t, t + r) \mid X(t) = i) = e^{q_{ii}\, r}$$ *Equation 6*

Suppose that the following assumptions hold that a system when in state i can make a transition to another state j at a random time, or it remains stable at the same state i. In an interval of time dt, the probability of the process making a transition from state *i* to state *j* is given in Equation 7 by the theory of continuous time Markov process:

$$Pr\ (St=j/St=i) = r_{ij} * dt + o(dt) \qquad \textit{Equation 7}$$

Where, the r_{ij} are positive rate parameters and o(dt) means $o(dt)/dt \to 0$ as $dt \to 0$

For this model, the assumption made was that for each possible transition from state i to state j there is an exponential waiting time with rate parameter r_{ij}. The transition which has the minimum waiting time is the one that occurs. The distribution of such waiting times is the distribution of the first order statistic of n-1, exponentially and independently distributed random variables with rate parameters r_{ij}, $j \neq i$.

Each System S_k makes random transitions between states St^k_i according to probability law. As described in the description above of a stochastic process. Hence, for each System S_k some collection of transition rate parameters r^k_{ij} exists. Also, for this model, the transition times are considered to be independent exponentially distributed random variables.

3.16.2 The Simulation Model

Due to the limited knowledge about the system of systems, a stochastic simulation model is needed to understand its overall behavior. While studying the behavior of the SoS, only a few assumptions were made about the SoS such as its interoperability, systems performances, and weights, to understand its behavior and mechanism. The stochastic model in this research was designed to show the variation in the behavior of the System of Systems in past and the present. Time was indicated as 0 being the time beginning 5 years ago, and time 5 is the current time.

A general stochastic simulation model was designed to show the SoS performance as systems transit from 5 years ago to present. A text file was created which contained a description of the SoS. The file has, respectively, the number of member systems of the SoS, their relative weights, number of states for rate, number of transitions to simulate, past rate, current rate, the starting state, exponential transition rates for each transition of state. Same parameters were created for degree and performance. These parameters are created for each member system as shown in Sim_SoS.txt (Appendix F). The simulation models each of the relation-fractions, degrees, and performances as separate stochastic processes.

A stochastic process is modeled by first assigning a starting state. Then, at each stage, random exponential waiting times are generated. For each possible state to which it may make a transition to, one time is assigned to it. The rate parameter for each transition from a state *i* to state *j*, λ_{ij}, is used according to the Equation 8:

$F(x) = 1-e^{-\lambda x}$,

$F(x) = u$,

$x= -\ln(1-u)/\lambda$, *Equation 8*

Where,

u is uniformly distributed on [0,1] , and
x is the random waiting time.

Due to lack of past data availability and uncertainty, the principle of insufficient reason was applied in this study [79]. Therefore, an assumption was made that the mean transition time was at the half way point of the 5 years. The rate for an exponential distribution is 1/μ where μ is the mean. Therefore, the rate in this case is equal to 0.4.

3.16.3 Average Performance using Monte Carlo Method

For any statistical measurement that has random variations in its values, a mean and standard deviation are usually calculated. Due to the difficulty of calculating a formula for the mean and standard deviation of the stochastic model used in this study, a Monte Carlo method was used instead.

The Law of Large Numbers says that if the simulation is run for large number of times, the mean of the results will be close to the expected value [80]. Therefore, a MatLab code was designed to approximate the mean and the standard deviation of the simulated average performances over time. The program uses Monte Carlo technique to calculate the mean, standard deviation, skewness, and kurtosis of the average performances over a time interval.

3.17 Summary

SPAM model was designed based on the Tri-Ex framework to answer the main research question. Two electronic surveys for each the participating healthcare systems were designed and answered by their managers top management experts within their organizations. The SPAM model uses these parameters, interoperability, individual performances, and relative weights. The interoperability is calculated based on rates and degrees and which were collected using the facility survey. However, the individual performances and relative weights were retrieved from the Joint Commission website. The model was verified using Excel software and validate through the SoS survey questions.

CHAPTER4
RESULTS

4.1 Introduction

The purpose of this chapter is to investigate the effect of change in interoperability and composition on the SoS performances for small and medium-sized, acute care, multihospital systems that are based in the state of Tennessee. This chapter treats each of the participating healthcare systems as an independent case study and draws conclusions about the effect of change. Also, each of the scenarios discusses general information regarding the healthcare system and draws conclusions on the size, ownership, and location dependency.

In the previous chapter, it was hypothesized that patients transfers and receives between healthcare system's facilities is based on the availability of specialties. To affirm this hypothesis, it was necessitated to calculate predicted facility contribution (Receives) and facility need (Transfers) scores for each healthcare system using the available web information on specialties. Tables were created using the member facilities and counts were outputted in each row to represent the number of specialties offered by that facility but not offered in the others. The facility contribution scores are calculated for each row by dividing each of the row weighted counts by the number of specialties offered at that location. The facility need scores are calculated for each column by dividing each of the weighted column counts by the number of specialties offered at that facility. These scores were ranked from the highest to the smallest and compared to the current transfers and receive ranked survey data to confirm the hypothesis by calculating deltas. Generated combinations using the ranks from predicted data for transfers and receives were used to calculate the significance level.

To calculate the past and current rates for patients transfers and receives, the retrieved values from the data survey were weighted by the total number of facilities within the healthcare system. Whereas, the data survey on degrees was divided by the highest number of the 5 scale likert scale.

This chapter also presents the results and discusses the findings regarding the completed surveys of acute care hospitals in integrated healthcare systems. The quality care data reports retrieved from the Joint Commission website and specialists (Appendix G) contained Joint Commission Organization IDs, names, addresses, programs, measure set name, nationwide symbols, nationwide footnotes, statewide symbols, statewide footnotes, measure names, nationwide hospital result symbols, nationwide hospital result footnotes, actual rates, expected rates, number of eligible patients, nationwide rate, nationwide top 10% scored, Nationwide Top 50% scored, statewide rate, statewide top 10% scored, Statewide top 50 % scored, statewide top 10 % footnote, statewide top 50% footnote for each facility. However, only actual rates and number of eligible patients were used in this study.

These results provide past and current SoS performances based on the change that has occurred in the healthcare system for the last 5 years. This chapter also represents a discussion of the findings for each of the scenarios. Also, statistical properties such as mean, standard deviation, skewness and kurtosis were calculated for each healthcare system using average SoS performance program which was run for 4000 repetitions for time between 0 and 5 years. Then, it summarizes with a discussion of the findings for each of the scenarios.

4.2 Scenario 1- Change in Rate of SoS1

SoS1 is a Small system characterized as a 100 percent not-for-profit-secular healthcare system. SoS1 is based in the state of Tennessee and comprised of 3 facilities located in two different regions where 67 percent of them are rural and only 33 percent are in urban area. SoS1 facilities have different sizes and facility A is the largest among all since its represents 72 percent of SoS1 total number of beds. However, facilities B and C symbolize only 7 percent and 21 percent of the total respectively as seen in Figure 6. Therefore, we may conclude that the size of facilities is dependent on their locations and number of specialties and independent on the ownership.

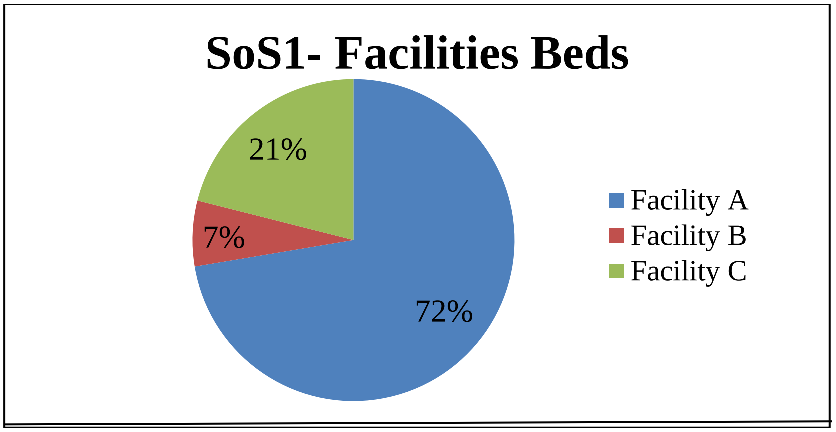

Figure 6- SoS1 Number of Beds

The theoretical rates were calculated for SoS1 as shown in Table 7 which indicates that 77 percent of the specialties offered by facility A are not offered by facility B or C thus, indicating that there may be patients' transfers from facility B or C to facility A. However, for facility B, 68 percent of specialties accessible by this facility do not exist in facility A or C and this means that there may be patients' transfers from facility A or C to facility B. Also shown is that 43 percent of specialties obtainable at facility C are not offered by facility A or B, so patients' transfers may occur from facility A or B to facility C. In Addition, 27 percent of specialties offered by B or C are not offered by A. Therefore, this may signify that facility A may transfer its patients to facility B or C.

Table 7- Assumed Receive/Transfer Rates for Each Facility Based on Specialties for SoS1

(Receive /Transfer)	Facility A	Facility B	Facility C	Sum	Total Specialties	Contribution Rate
Facility A		17	17	34	22	0.77
Facility B	9		10	19	14	0.67
Facility C	3	4		7	8	0.43
Sum	12	21	27			
Need Rate	0.27	0.75	1.68			

The actual and theoretical rates were compared to affirm the hypothesis stated in Chapter3. The actual and predicted transfer and receives ranks shown in Table 8, were compared and found not to be different. Generated rates using the predicted ranks were used to find that 15 out of 64 combinations matched. Therefore, the significance level for transfers and receives for this system was 15/64 with a confidence level of 1-0.24 which equals to 0.76. As a result, we conclude that transfers and receives are based on specialties for this system.

Table 8- SoS1 Actual and Predicted Ranked Transfers and Receives

Facility	Current Transfers Data	Current Receives Data	Actual Transfer Rank	Actual Receive Rank	Predicted Transfer Rank	Predicted Receives Rank	Delta Transfer	Delta Receive
A	0	2	3	1	3	1	0	0
B	1	0	1,2	2,3	2	2	0	0
C	1	0	1,2	2,3	1	3	0	0

The transfers and receives degree values retrieved from the data surveys for each facility were summarized in Tables 9a and 9b. Comparing the values, no changes in degree have occurred which means that the number of patients transfers and receives has been consistent.

Table 9a- Past Transfers and Receives Degree Values

Facility	Past Transfer Degree Data	Past Receive Degree Data	Past Transfer Degree Ratio	Past Receive Degree Ratio
A	1	4	0.2	0.8
B	4	1	0.8	0.2
C	4	2	0.8	0.4

Table 9b- Current Transfers and Receives Degree Values

Facility	Current Transfer Degree Data	Current Receive Degree Data	Current Transfer Degree Ratio	Current Receive Degree Ratio
A	1	4	0.2	0.8
B	4	1	0.8	0.2
C	4	2	0.8	0.4

The current and the past rate values from the data surveys were summarized in Tables 10a and 10b consecutively. Comparing the current and the past rate values indicates that there was a change in values for facility C. The past rate for receives has dropped from 0.33 to 0. This may be due to removal of certain specialty(s), or adding those specialties to facility B.

Table 10a- Past Transfers and Receives Rate Values

Facility	Past Transfer Rate Data	Past Receive Rate Data	Past Transfer Rate	Past Receive Rate
A	0	2	0	0.66
B	1	0	0.33	0
C	1	1	0.33	0.33

Table 10b- Current Transfers and Receives Rate Values

Facility	Current Transfer Rate Data	Current Receive Rate Data	Current Transfer Rate	Current Receive Rate
A	0	2	0	0.66
B	1	0	0.33	0
C	1	0	0.33	0

SoS1's individual performance before and after change are summarized and presented in Tables 11a and 11b respectively. Comparing the before and after change performances, facilities A and C performances increased from the past to the current. However, facility B's performance decreased between these two periods.

Table 11a- SoS1 Calculated Individual Performance Scores Before Change

	Sum_ Yearly Actual Rate_ Calculation	Total Treated Patients	Performance Scores
Facility A	2416	2830	0.85
Facility B	994.9	1130	0.88
Facility C	456	528	0.86

Table 11b- SoS1 Calculated Individual Performance Scores After Change

	Sum _Yearly Actual Rate Calculation	Total Treated Patients	Performance Scores
Facility A	2300	2378	0.96
Facility B	314	367	0.86
Facility C	184	204	0.90

Relative weights before and after the change for SoS1 are summarized in Tables 12a and 12b correspondingly. Comparing the two of them, it was concluded that number of treated patients increased for facilities A and B have increased. Though, the number of treated patients has dropped for facility C.

Table 12a- SoS1 Relative Weights Before Change

Facilities	Relative Weights
A	0.63
B	0.11
C	0.25

Table 12b- SoS1 Relative Weights After Change

Facilities	Relative Weights
A	0.80
B	0.12
C	0.06

The results from the SPAM may be found in Appendix E. Comparing the resulting past and current SoS performances; it was concluded that SoS performance increased from 0.85 to 0.95 as a result of a decrease in the rate value of Facility C. This represents an 11.46% SoS performance increase between the two periods. Therefore, we may conclude that an internal change in one of the interoperability parameters (rate) of a member system, performances, and weights had increased the SoS performance.

Following the verification procedure discussed in Chapter 3, the calculated SoS performances, before and after change, using Excel are displayed in Tables 13a and 13b. Comparing the Excel and SPAM results, the outcomes are identical.

Table 13a- SoS1 Performance Model Verification Before Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive-Transfer)	(1+(Receive-Transfer))*w	M	U
A	0	0.53	1.53	0.96	1.20	0.65
B	0.26	0	0.73	0.08	0.57	0.05
C	0.26	0.13	0.86	0.21	0.68	0.15
SoS1 Performance Score Before Change						**0.85**

Table 13b- SoS1 Performance Model Verification After Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive -Transfer)	(1+(Receive-Transfer))*w	M	U
A	0	0.53	1.53	1.23	1.11	0.86
B	0.26	0	0.73	0.09	0.53	0.06
C	0.26	0	0.73	0.05	0.53	0.03
SoS1 Performance Score After Change						**0.95**

The statistical properties such as the mean, standard deviation, skewness, and kurtosis for simulated SoS1 performance are calculated as shown in Table 14, and an average SoS performance histogram was plotted and is shown in Figure 7. The plot and the outputted skewness value of -0.55 designated that the average performance distribution is skewed to the left which means that the distribution is not normal. Figure 7 represents the simulated average SoS performance where the red graph is the normal distribution and the blue graph is the simulated average SoS performance histogram for 4000 repetitions. This histogram shows that average performances are either overestimated or underestimated with regard to the mean.

Table 14- SoS1 Statistical Properties

Healthcare System	Mean	Standard Deviation	Skewness	Kurtosis
SoS1	0.91	0.03	-0.55	1.98

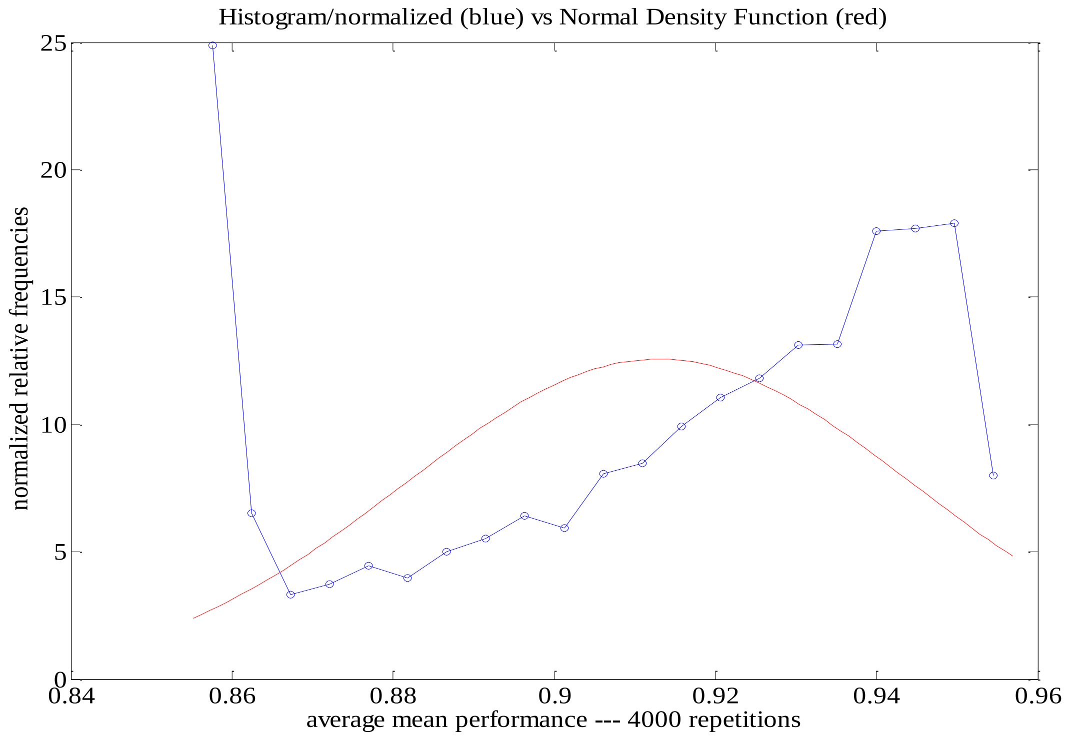

Figure 7- SoS1 Average Performance Histogram

Based on the survey answers on the shared resources section, 100 % of the facilities in SoS1 share information technologies among them, 33 % of the facilities share accounting, 67% of the facilities share purchasing, and 33 % of its facilities have some type of sharing between their pharmacies.

4.3 Scenario 2- New System Added to SoS2

SoS2 is a Small system with 75 percent of its facilities characterized as not-for-profit-secular while the remaining 25 percent are for-profit. SoS2 is based in the state of Tennessee and comprised of 4 facilities which are all located in an urban district. SoS2 facilities have different sizes and facility A is the largest among all since its represents 45 percent of SoS2 total number of beds. However, facilities B, C, and D symbolize 35, 19, and 1 percent of the total respectively as shown in Figure 8. In this case, it has been noticed that number of beds is independent of the facility ownership and location since facility A has the highest number of beds but it is located at an urban region. Moreover, it has been concluded that the number of beds is dependent on number of specialties, in this case, since facility 1 had more specialties than the rest of SoS2 facilities.

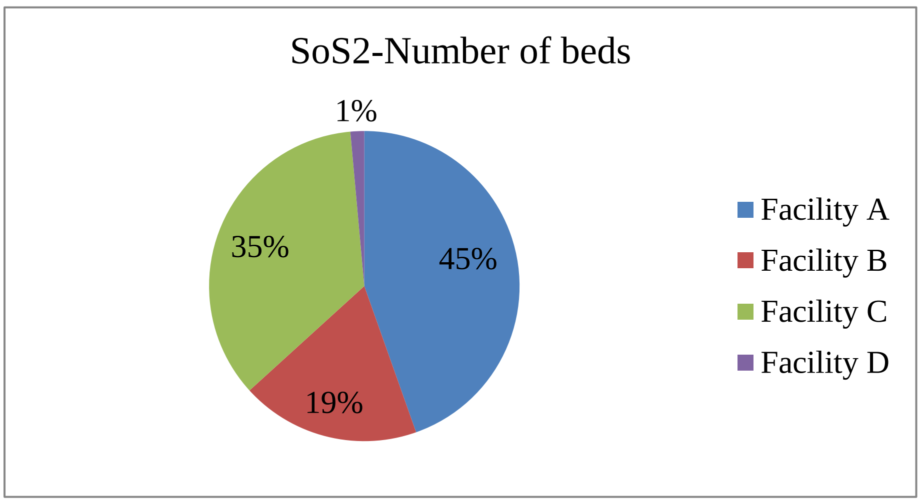

Figure 8- SoS2 Number of Beds

The theoretical contribution rates calculated for SoS2 as shown in Table 15 show that 55 percent of the specialties offered by facility A are not offered by facility B, C, or D. This indicates that there may be patients' transfers from facility B, C, or D to facility A. However, for facility B, 48 percent of specialties accessible by this facility are not in facility A, C, or D and this means that there may be patients' transfers from facility A, C, or D to facility B. Also, 43 percent of specialties obtainable at facility C are not offered by facility A, B, or D, this signifies that patients' transfers may occur from facility A, B, or D to facility C. While 100 percent of specialties offered by facility D are not offered by facility A, B, or C indicates that patients' transfers may take place from facility A, B, or C to facility D. Instead, the need rate for facility A means that 18 percent of specialties offered by B, C, or D are not offered by facility A. This signifies that facility B, C, or D may receive patients from facility A. Also, 33 percent of specialties offered by A, C, or D are not offered by facility B. Therefore, facility A, C, or D may receive patients from facility B.

Table 15- Assumed Receive /Transfer Rates for Each Facility Based on Specialties for SoS2

(Receive/ Transfer)	Facility A	Facility B	Facility C	Facility D	Sum	Total specialties	Contribution Rate
Facility A		9	9	27	45	27	0.55
Facility B	4		6	22	32	22	0.48
Facility C	2	4		20	26	20	0.43
Facility D	9	9	9		27	9	1
Sum	15	22	24	69			
Need Rate	0.18	0.33	0.4	2.55			

These actual and theoretical rates are compared to actual rates to affirm the hypothesis stated in Chapter 3. The actual and predicted transfer and receives ranks shown in Table 16 were compared and came out to be the same. Generated rates using the predicted ranks were used to find that 299 out of 4096 combinations matched. Therefore, the significance level for transfers and receives for this system was 299/4096 with a confidence level of 0.92. As a result, we conclude that transfers and receives are based on specialties for this SoS.

The current and the past degree values from the data surveys are summarized in Tables 17a and 17b consecutively. The healthcare data survey indicated that this system had only 3 facilities but added a new one over the past 5 years. Comparing the past and current degree values, no change has been indicated which means that the number of patients' transfers and receives has been consistent even after adding a new facility D.

Table 16- SoS2 Actual and Predicted Ranked Transfers and Receives

Facility	Current Transfers Data	Current Receives Data	Actual Transfer Rank	Actual Receive Rank	Predicted Transfer Rank	Predicted Receives Rank	Delta Transfer	Delta Receive
A	1	3	3,4	1	4	1	0	0
B	2	2	2	2,3	2,3	2	0	0
C	1	2	3,4	2,3	2,3	3,4	0	0
D	3	0	1	4	1	3,4	0	0

Table 17a- SoS2 Past Transfers and Receives Degree Values

Facility	Past Transfer Degree Data	Past Receive Degree Data	Past Transfer Degree Ratio	Past Receive Degree Ratio
A	2	3	0.4	0.6
B	4	4	0.8	0.8
C	2	4	0.4	0.8

Table 17b- SoS2 Current Transfers and Receives Degree Values

Facility	Current Transfer Degree Data	Current Receive Degree Data	Current Transfer Degree Ratio	Current Receive Degree Ratio
A	2	3	0.4	0.6
B	4	4	0.8	0.8
C	2	4	0.4	0.8
D	2	1	0.4	0.2

The current and the past rate values are presented in Tables 18a and 18b consecutively. Comparing the current and the past rate values shows that new transfers and receives rate values for facility D are added to SoS2. Also, the receive rate for facility A has increased between these two periods.

Table 18a- SoS2 Past Transfers and Receives Rate Values

Facility	Past Transfer Rate Data	Past Receive Rate Data	Past Transfer Rate	Past Receive Rate
A	1	2	0.33	0.66
B	2	2	0.66	0.66
C	1	2	0.33	0.66

Table 18b- SoS2 Current Transfers and Receives Rate Values

Facility	Current Transfer Rate Data	Current Receive Rate Data	Current Transfer Rate	Current Receive Rate
A	1	3	0.25	0.75
B	2	2	0.5	0.5
C	1	2	0.25	0.5
D	3	0	0.75	0

The past and current SoS 2 individual performances are summarized in Table 19a and 19b. In this case, no measures are reported for facility D, therefore the investigator decided to approximate a performance value for facility D. To calculate a performance value for D, performance scores for facility A, B, and C are first multiplied by their total number of patients then summed and divided by the total number of patients for facility A, B, and C. Comparing the past and current values, the performances has augmented between these two periods.

Table 19a- SoS2 Calculated Individual Performance Scores Before Change

	Sum _Yearly Actual Rate Calculation	Total Treated Patients	Performance Scores
Facility A	4711	5962	0.79
Facility B	9591	11961	0.80
Facility C	4110	5182	0.79

Table 19b- SoS2 Calculated Individual Performance Scores After Change

	Sum _Yearly Actual Rate Calculation	Total Treated Patients	Performance Scores
Facility A	9267	9711	0.95
Facility B	9662	10128	0.95
Facility C	14400	14934	0.96
Facility D	-	-	0.95

The past and current relative weights are summarized in Tables 20a and 20b. Comparing the values between the two periods, an enhancement in the number of treated patients has occurred for all facilities except for facility C that had a relatively small decrease in the number of treated patients.

Table 20a- SoS2 Relative Weights Before Change

Facilities	Relative Weights
A	0.25
B	0.22
C	0.51

Table 20b- SoS2 Relative Weights After Change

Facilities	Relative Weights
A	0.27
B	0.28
C	0.42
D	0.01

The results from the SPAM can be found in Appendix E. Comparing the resulting past and current SoS performances; SoS performance has increased in these two states from 0.80 to 0.96 as a result of adding Facility D. Therefore, we may conclude that the addition of the new system to SoS2 and change in the relationship-fraction (rate) of one of its member systems, individual performances, and relative weights had increased its performance by 20 percent. Following the verification procedure discussed in Chapter 3, the SoS performance values calculated using Excel are presented in Tables 21a and 21b matched the SoS performance values using the SPAM program.

Table 21a- SoS2 Performance Model Verification Before Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive-Transfer)	(1+(Receive-Transfer))*w	M	U
A	0.13	0.4	1.26	0.32	0.99	0.21
B	0.53	0.53	1	0.22	0.78	0.14
C	0.13	0.53	1.4	0.72	1.09	0.45
SoS2 Performance Score Before Change						**0.80**

Table 21b- SoS2 Performance Model Verification After Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive -Transfer)	(1+(Receive-Transfer))*w	M	U
A	0.1	0.45	1.35	0.37	1.11	0.28
B	0.4	0.4	1	0.28	0.82	0.22
C	0.1	0.4	1.3	0.55	1.07	0.44
D	0.3	0	0.7	0.01	0.57	0.01
SoS2 Performance Score After Change						**0.95**

The statistical properties such as the mean, standard deviation, skewness, and kurtosis for SoS2 are calculated as shown in Table 22 and an average overall performance histogram was plotted as shown in Figure 9.

Table 22- SoS2 Statistical Properties

Healthcare System	Mean	Standard Deviation	Skewness	Kurtosis
SoS2	0.88	0.03	-0.3	2.46

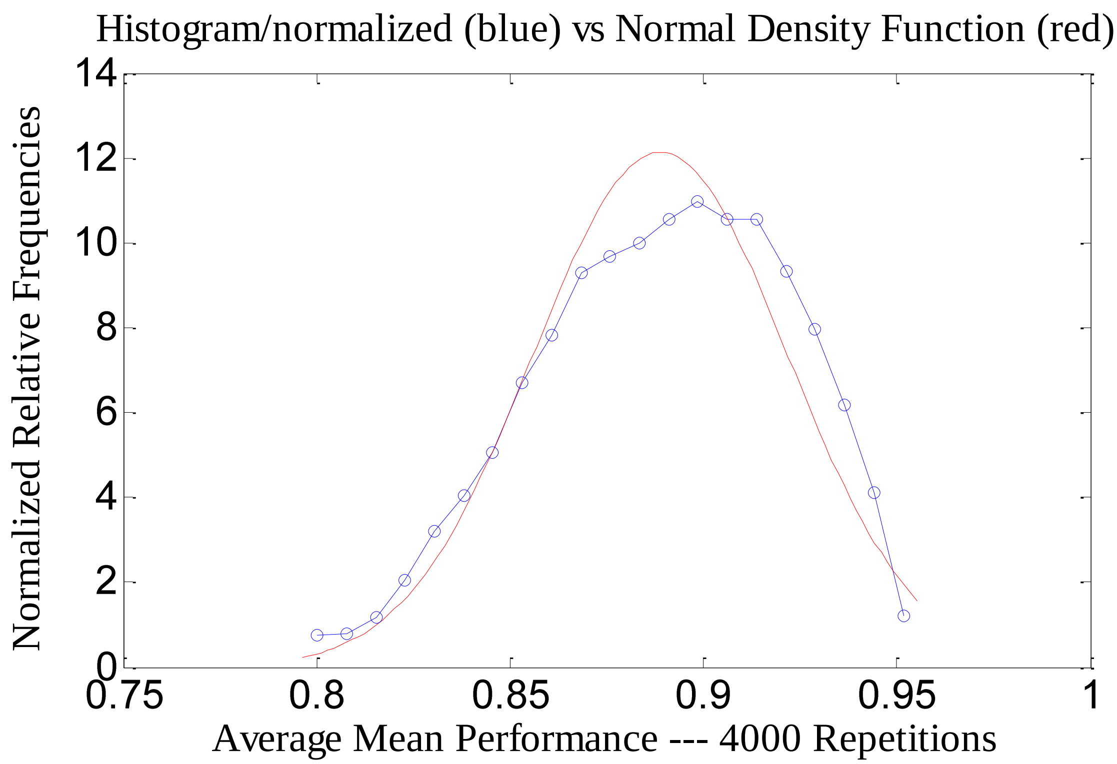

Figure 9- SoS2 Average Mean Performance Histogram

The plot and the outputted skewness value of -0.3 indicated that the average overall performance distribution is close to normal with some skewness to the left. Figure 9 represents the simulated average SoS performance where the red graph is the normal distribution and the blue graph is the simulated average SoS performance histogram constructed using 4000 repetitions. This histogram shows that average performances are either overestimated or underestimated with regard to the mean.

Based on the survey answers on the shared resources section, 100 % of the facilities in SoS2 share information technologies among them, 75 % of the facilities share accounting, 75% of the facilities share purchasing, 100 % of its facilities have some type of sharing between their pharmacies, 25 % of the facilities share transportation, and 100 % share workforce among them.

4.4 Scenario 3- Addition of New Facility to SoS3

SoS3 is a Small system characterized as being 100 percent for-profit. SoS3 had initially 3 facilities but added a new facility in the past 5 years. SoS3 facilities are dispersed, with 75 percent based in rural areas and 25 percent in urban regions. SoS3 had different facility sizes where facility C is the largest and represents 58 percent of the total number of beds as shown in Figure 10. However, facilities A, B, and D represent respectively 24, 9, and 9 percent of the total number of beds. Therefore, it has been indicated that the number of beds is dependent on the number of specialties since facility C had the largest number of beds and the highest number of specialties. Also, it appears in this case that locations, sizes, and ownerships are independent of each other.

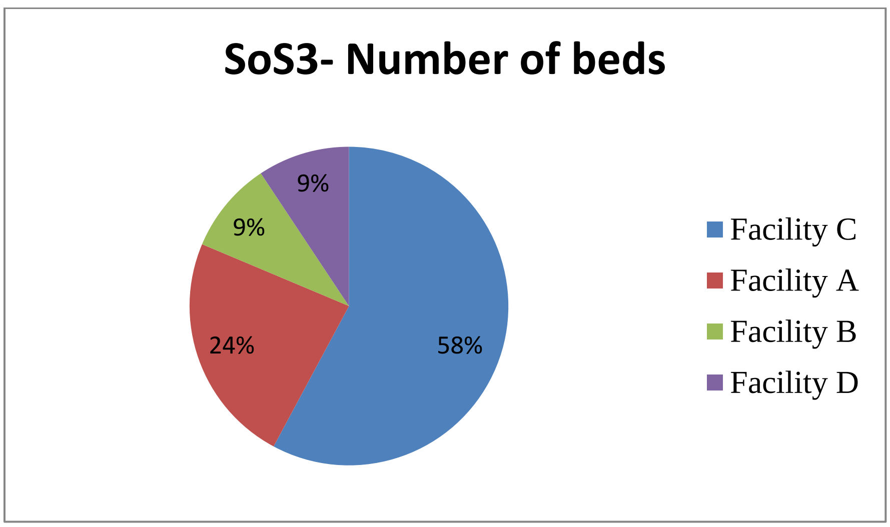

Figure 10- SoS3 Number of Beds

The facility contribution and facility need rates are calculated and summarized in Table 23 and shows that 62 percent of the specialties offered by facility B, C, or D are not offered by facility A, indicating that there may be patients' transfers from facility A to facility B, C, or D. However, for facility B, 42 percent of specialties accessible by facilities A, C, or D are not in facility B and this means that there may be patients' transfers from facility B to facility A, C, or D. Also, 76 percent of specialties obtainable at facility A, B, or D are not offered by facility C, this signifies that patients' transfers may occur from facility C to facility A, B, or D. While 50 percent of specialties offered by facility A, B, or C are not offered by facility D, patients' transfers may take place from facility D to facility A, B, or C. However, the need rate for facility A signifies that 43 percent of specialties offered by facility B, C, or D are not available within facility A. Therefore, patients transferred by facility A may be received by facility B, C, or D. For facility B, its corresponding need rate means that 75 percent of specialties offered by facility A, C, or D are not offered by B. Consequently, facility A, C, or D may receive patients transferred from B.

Table 23- Assumed Receive /Transfer Rates for Each Facility Based on Specialties for SoS3

(Receive/ Transfer)	Facility A	Facility B	Facility C	Facility D	Sum	Total specialties	Contribution Rate
Facility A		15	20	17	52	28	0.61
Facility B	3		10	7	20	16	0.41
Facility C	17	19		21	57	25	0.76
Facility D	5	7	12		24	16	0.5
Sum	36	36	36	36			
Need Rate	0.42	0.75	0.48	0.75			

Table 24- SoS3 Actual and Predicted Ranked Transfers and Receives

Facility	Current Transfers Data	Current Receives Data	Actual Transfer Rank	Actual Receive Rank	Predicted Transfer Rank	Predicted Receives Rank	Delta Transfer	Delta Receive
A	2	1	1,2	4	1	3,4	0	0
B	1	2	3,4	1,2,3	4	1,2	0	0
C	2	2	1,2	1,2,3	2,3	3,4	0	0
D	1	2	3,4	1,2,3	2,3	1,2	0	0

These actual and theoretical rates are compared to actual rates to affirm the hypothesis stated in Chapter 3. The actual and predicted transfers and receives ranks shown in Table 24 were compared and found to be the same. Generated rates using the predicted ranks were used to find that 378/4096 combinations matched. Therefore, the significance level for transfers and receives for this system was 299/4096 with a confidence level of 0.91. As a result, we conclude that transfers and receives are based on specialties.

SoS3 current and past transfers and receives degrees are calculated and summarized in Tables 25a and 25b simultaneously. Comparing the transfers and receives degrees, the transfers degree for facility D has increased. Also, for the past 5 years, new transfers and receives degrees were added to SoS3 since a new facility B has been added.

Table 25a- SoS3 Past Transfers and Receives Degree Values

Facility	Past Transfer Degree Data	Past Receive Degree Data	Past Transfer Degree Ratio	Past Receive Degree Ratio
A	4	3	0.8	0.6
D	2	3	0.2	0.6
C	3	5	0.6	1

Table 25b- SoS3 Current Transfers and Receives Degree Values

Facility	Current Transfer Degree Data	Current Receive Degree Data	Current Transfer Degree Ratio	Current Receive Degree Ratio
A	4	3	0.8	0.6
B	3	3	0.6	0.6
C	3	5	0.6	1
D	4	3	0.8	0.6

The current and the past rate values are calculated and summarized in Tables 26a and 26b consecutively. Comparing the current and the past rate values shows that there was an increase in transfers and receives values for facility C. Also, it was verified that facility B was not part of this SoS five years ago.

Table 26a- SoS3 Past Transfers and Receives Rate Values

Facility	Past Transfer Rate Data	Past Receive Rate Data	Past Transfer Rate	Past Receive Rate
A	2	1	0.5	0.25
C	0	1	0	0.25
D	1	2	0.25	0.5

Table 26b- SoS3 Current Transfers and Receives Rate Values

Facility	Current Transfer Rate Data	Current Receive Rate Data	Current Transfer Rate	Current Receive Rate
A	2	1	0.5	0.25
B	2	2	0.5	0.5
C	1	2	0.25	0.5
D	1	2	0.25	0.5

Current and past performance scores for SoS3 are calculated and summarized in Tables 27a and 27b below. During the current state, the quality care measures values for facilities A and B were reported jointly. Therefore, a decision was made to regard the performance values for these two facilities to be the same. To calculate current performance value for facility D which was not provided in the quality report, performance scores for facility A, B, and C were first multiplied by their total number of patients then summed and divided by the total number of patients for facility A, B, and C. By comparing the past and current values, we conclude that the individual performances augmented between these two states.

Table 27a- SoS3 Calculated Individual Performance Scores Before Change

Facilities	Individual Performances
A	0.91
C	0.23
D	0.45

Table 27b- SoS3 Calculated Individual Performance Scores After Change

Facility	Sum _Yearly Actual Rate_ Calculation	Total Treated Patients	Performance Scores
A	616	661	0.93
B	616	661	0.93
C	1467	1636	0.89
D	-	-	0.63

Current and past relative weights for SoS3 are calculated and summarized below in Tables 28a and 28b. Comparing the past and current relative weights, the addition of a new facility led to a minimal change to the rest of the other facilities' relative weights even though the same numbers of treated patients are used for the past and current relative weights.

Table 28a- SoS3 Relative Weights Before Change

Facilities	Relative Weights
A	0.28
D	0.61
C	0.10

Table 28b- SoS3 Relative Weights After Change

Facilities	Relative Weights
A	0.18
B	0.07
C	0.64
D	0.09

Comparing the past and current resulting SoS performances, a conclusion was made that there was an amplification from 0.40 to 0.87 as result of adding Facility B to SoS3 as indicated in Appendix E. Therefore, the addition of a new system with a increase in rates and degrees of two member systems, relative weights, and a noticeable increase in the performance of the "Lead" system have improved the SoS performance with a 117 percent increase. Following the verification procedure discussed in Chapter 3, the SoS performance values calculated using

Excel as shown in Tables 29a and 29b matched the SoS performance values using the SPAM results.

Table 29a- SoS3 Performance Model Verification Before Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive-Transfer)	(1+(Receive-Transfer))*w	M	U
A	0.4	0.15	0.75	0.21	0.70	0.19
C	0	0.15	1.15	0.70	1.08	0.16
D	0.15	0.5	1.35	0.13	1.27	0.05
SoS3 Performance Before Change						**0.40**

Table 29b- SoS3 Performance Model Verification After Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive-Transfer)	(1+(Receive-Transfer))*w	M	U
A	0.4	0.15	0.75	0.14	0.75	0.13
B	0.2	0.3	1.1	0.08	1.10	0.07
C	0.3	0.3	1	0.64	1.0	0.59
D	0.15	0.5	1.35	0.12	1.35	0.08
SoS3 Performance After Change						**0.87**

The statistical properties such as the mean, standard deviation, skewness, and kurtosis for SoS2 are calculated as shown in Table 30 and an average overall performance histogram was plotted as shown in Figure 11. The plot and the outputted skewness value of -0.47 indicated that the average overall performance distribution is skewed to the left. Also, it represents that the simulated average SoS performance where the red graph is the normal distribution and the blue graph is the simulated average SoS performance histogram constructed using 4000 repetitions. This histogram shows that average performances are either overestimated or underestimated with regard to the mean.

Table 30- SoS3 Statistical Properties

Healthcare System	Mean	Standard Deviation	Skewness	Kurtosis
SoS3	0.66	0.14	-0.47	1.87

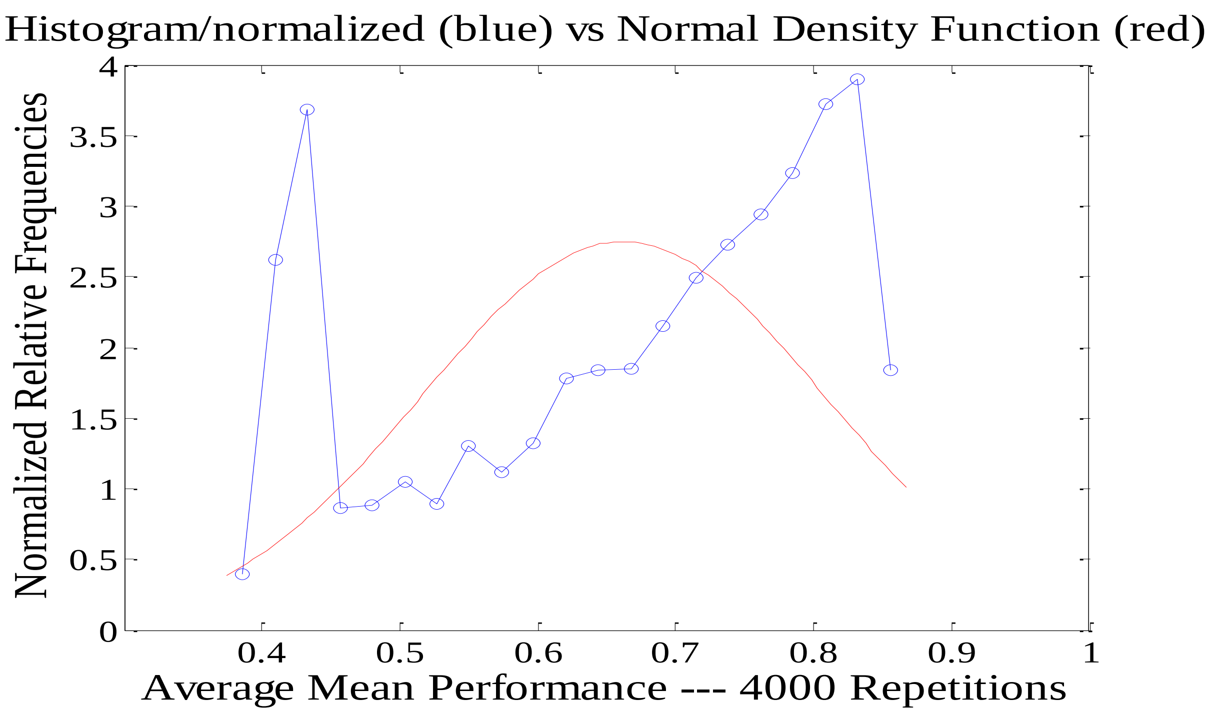

Figure 11- SoS3 Overall Average Mean Performance Histogram

Based on the survey answers on the shared resources section, 100 % of the facilities in SoS3 share information technologies among them, 100 % of the facilities share accounting, 100% of the facilities share purchasing, 25 % of its facilities have some type of sharing between their pharmacies, and 50 % share workforce among them.

4.5 Scenario 4- No Change in SoS4

SoS4 is a Medium system which contains 6 facilities located in the rural regions of the state of Tennessee and characterized as 100 percent not-for-profit-secular healthcare system. SoS4 has different facilities' sizes and facility E is the largest among all as seen in Figure 12 since it represents 69 percent of the total number of beds. The remaining facilities which are A, B, C, D, F and G only represent 5, 3, 8, 7, and 8 percent of the total number of beds respectively. These results imply that the locations, size and ownerships are independent of each other. In addition, in this case it appears that the facility size is independent of number of specialties.

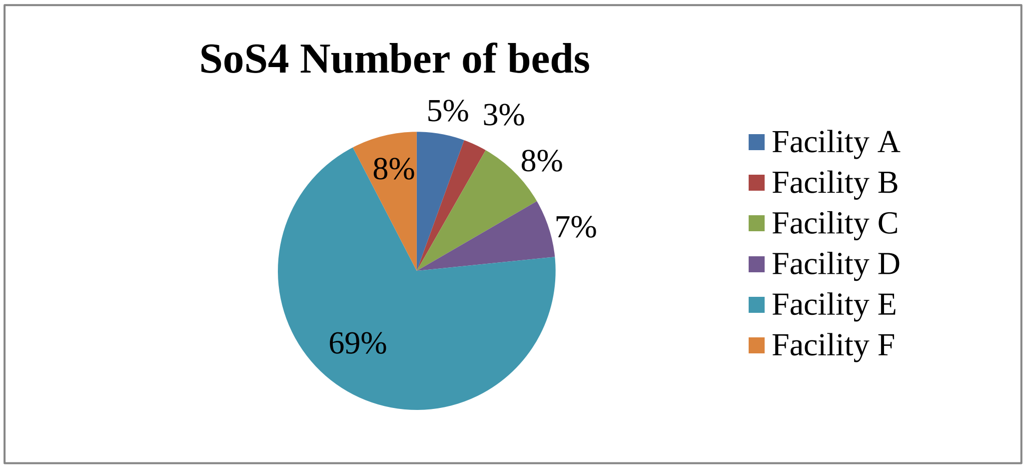

Figure 12- SoS4 Number of Beds

The facility contribution and facility need rates are calculated for SoS4 as shown in Table 31 and indicate that 18 percent of the specialties offered by facility A are not offered by facility B, C, D, E, or F; thus, this explains that there may be patients' transfers from facility B, C, D, E, or F to facility A. However, for facility B, 26 percent of specialties accessible by this facility do not exist in facility A, C, D, E, or F and this means that there may be patients' transfers from facility A, C, D, E, or F to facility B. Six percent of specialties obtainable at facility C are not offered by facility A, B, D, E or F; this signifies that patients' transfers may occur from facility A, B, D,E or F to facility C. However, the facility need rate for facility A means that 98 percent of specialties offered by B, C, D, E or F are not offered by A. therefore, this may signify that facility A may transfer its patients to facility B, C, D, E or F.

Table 31- Assumed Receive /Transfer Rates for Each Facility Based on Specialties for SoS4

(Receive/ Transfer)	A	B	C	D	E	F	Sum	Total Specialties	Contribution Rate
A		2	7	2	0	5	16	17	0.18
B	4		8	5	2	6	25	19	0.26
C	2	1		0	0	1	4	12	0.06
D	7	8	10		3	7	35	22	0.31
E	34	34	39	32		35	174	51	0.68
F	37	36	38	34	33		178	49	0.72
Sum	84	81	102	73	38	54			
Need Rate	0.98	0.85	1.7	0.66	0.14	0.22			

These actual and theoretical rates are compared to actual rates to affirm the hypothesis stated in Chapter 3. The actual and predicted transfer and receives ranks are presented in Table 32. All of the actual and predicted ranks matched except facility C transfer rank. The total number combination in this case is (2^30) and since it is a very large number of combinations, the investigator chose a number of 1000000 random combinations to be used in this case. Therefore, the significance level for transfers and receives being based on specialties for this system was 18927/1000000 with a confidence level of 1- 0.018297 which equals to 0.9817. As a result, we conclude that transfers and receives are based on specialties.

Table 32- SoS4 Actual and Predicted Ranked Transfers and Receives

Facility	Current Transfers Data	Current Receives Data	Actual Transfer Rank	Actual Receives Rank	Predicted Transfer Rank	Predicted Receives Rank	Delta Transfer	Delta Receive
A	1	1	4,5	3,4,5,6	2,3,4	3,4,5	0	0
B	5	1	1,2	3,4,5,6	2,3,4	3,4,5	0	0
C	2	1	3	3,4,5,6	1	6	2	0
D	1	1	4,5	3,4,5,6	2,3,4	3,4,5	0	0
E	0	5	6	1	6	1,2	0	0
F	5	4	1,2	2	2,3,4	1,2	0	0

The current and past degree data survey values are calculated and summarized in Tables 33a and 33b simultaneously. Comparing the current and the past degree values for SoS4, no changes in degree have occurred which means that the number of patients' transfers and receives has been consistent.

Table 33a- SoS4 Past Transfers and Receives Degree Values

Facility	Past Transfer Degree Data	Past Receive Degree Data	Past Transfer Degree Ratio	Past Receive Degree Ratio
A	4	3	0.8	0.6
B	4	2	0.8	0.4
C	4	2	0.8	0.4
D	4	2	0.8	0.4
E	2	4	0.4	0.8
F	4	4	0.8	0.8

Table 33b- SoS4 Current Transfers and Receives Degree Values

Facility	Current Transfer Degree Data	Current Receive Degree Data	Current Transfer Degree Ratio	Current Receive Degree Ratio
A	4	3	0.8	0.6
B	4	2	0.8	0.4
C	4	2	0.8	0.4
D	4	2	0.8	0.4
E	2	4	0.4	0.8
F	4	4	0.8	0.8

The current and the past rate survey data values are calculated and summarized in Tables 34a and 34b consecutively. Comparing the current and the past rate values shows that there was no change in values. This means that the interaction between the facilities and the composition of SoS4 has been constant throughout the last 5 years.

Table 34a- SoS4 Past Transfers and Receives Rate Values

Facility	Current Transfer Rate Data	Current Receive Rate Data	Current Transfer Rate	Current Receive Rate
A	1	1	0.16	0.16
B	5	1	0.83	0.16
C	2	1	0.33	0.16
D	1	1	0.16	0.16
E	0	5	0	0.83
F	5	4	0.83	0.66

Table 34b- SoS4 Current Transfers and Receives Rate Values

Facility	Past Transfer Rate Data	Past Receive Rate Data	Past Transfer Rate	Past Receive Rate
A	1	1	0.16	0.16
B	5	1	0.83	0.16
C	2	1	0.33	0.16
D	1	1	0.16	0.16
E	0	5	0	0.83
F	5	4	0.83	0.66

Performance values for SoS4 are calculated and summarized in Table 35a and 35b. Comparing the past and current individual performances, an augmentation has occurred between these two periods for most of the facilities except for facilities A and C. Also note that and facility F had the highest performance over the 5 years period.

Table 35a- SoS4 Calculated Individual Performance Scores Before Change

Facilities	Performance Scores
A	0.81
B	0.72
C	0.81
D	0.78
E	0.72
F	0.88

Table 35b- SoS4 Calculated Individual Performance Scores After Change

Facility	Sum _Yearly Actual Rate_ Calculation	Total Treated Patients	Performance Scores
A	82	135	0.6
B	84	100	0.84
C	117	153	0.76
D	158	191	0.82
E	22362	25188	0.88
F	182	191	0.95

Relative weights are calculated using treated patients and summarized in Tables 36a and 36b. Based on these results, all the facilities had less treated number of patients between the two periods except for facility E which had an increase in the number of treated patients. Note that the reason for these changes was not investigated.

Comparing the past and current resulting SoS performances; it has been concluded that there was an augmentation in the SoS performance scores from 0.73 to 0.88 and which indicate 21percent increase in SoS performance between the past and present. Following the verification procedure, the overall performance values calculated using Excel as shown in Tables 37a and 37b matched the overall performance values using the SAPM program.

Table 36a- SoS4 Relative Weights Before Change

Facilities	Relative Weights
A	0.02
B	0.01
C	0.02
D	0.04
E	0.87
F	0.02

Table 36b- SoS4 Relative Weights After Change

Facilities	Relative Weights
A	0.005
B	0.003
C	0.006
D	0.007
E	0.97
F	0.007

Table 37a- SoS4 Performance Model Verification Before Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive -Transfer)	(1+(Receive-Transfer))*w	M	U
A	0.13	0.10	0.97	0.02	0.62	0.01
B	0.67	0.07	0.40	0.00	0.26	0.002
C	0.27	0.07	0.80	0.02	0.51	0.008
D	0.13	0.07	0.93	0.04	0.60	0.02
E	0.00	0.67	1.67	1.45	1.07	0.67
F	0.67	0.53	0.87	0.02	0.55	0.01
SoS4 Performance Score Before Change						**0.73**

Table 37b- SoS4 Performance Model Verification After Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive-Transfer)	(1+(Receive-Transfer))*w	M	U
A	0.13	0.10	0.96	0.005	0.59	0.002
B	0.67	0.07	0.4	0.002	0.24	0.0008
C	0.27	0.07	0.8	0.005	0.49	0.002
D	0.13	0.07	0.93	0.007	0.57	0.003
E	0	0.67	1.6	1.61	1.02	0.87
F	0.67	0.53	0.867	0.006	0.53	0.003
SoS4 Performance Score After Change						**0.88**

The statistical properties such as the mean, standard deviation, skewness, and kurtosis for SoS2 are calculated as shown in Table 22 and an average overall performance histogram was plotted as shown in Figure 13. The plot and the outputted skewness value of -0.52 indicated that the average overall performance distribution is skewed to the left. Figure 13 represents the simulated average SoS performance where the red graph is the normal distribution and the blue graph is the simulated average SoS performance histogram constructed using 4000 repetitions. This histogram shows that average performances are either overestimated or underestimated with regard to the mean.

Table 38- SoS4 Statistical Properties

Healthcare System	Mean	Standard Deviation	Skewness	Kurtosis
SoS4	0.81	0.05	-0.52	1.94

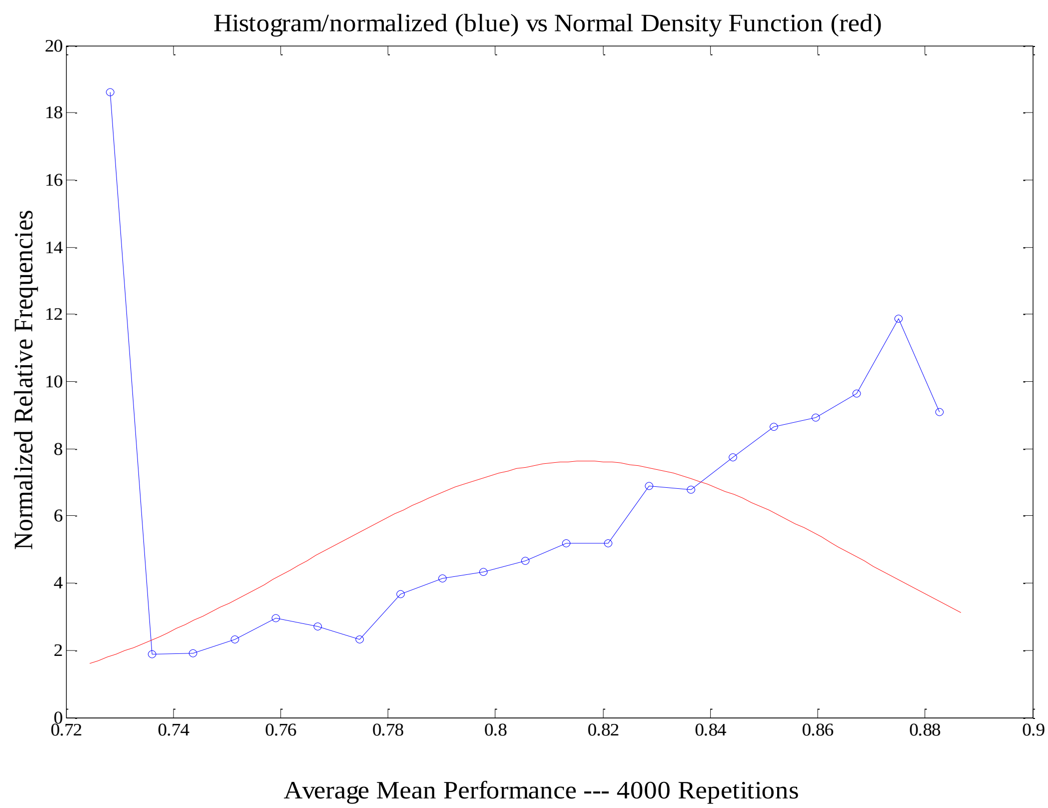

Figure 13- SoS4 Average Performance Histogram

Based on the survey answers on the shared resources section, 100 % of the facilities in SoS4 share information technologies among them, 100 % of the facilities share accounting, 83% of the facilities share purchasing, 83 % of its facilities have some type of sharing between their pharmacies, 50 % of the facilities share transportation, and 100 % share workforce among them.

4.6 Scenario 5- Change in Composition of SoS5

SoS5 is a Medium system which consists of 7 facilities located in the state of Tennessee. SoS5 has different locations with 57 percent of them being located in rural areas, 29 percent of its facilities are located in urban district, and 14 percent being located in suburban region as shown in Figure 14. SoS5 is characterized by 71 percent being not-for-profit-religious facilities while 29 percent are for-profit locations. SoS5 has different facilities sizes where facility A is the largest and represents 46 percent of the total number of beds where the remaining 54 percent is spread out between facilities B, C, D, E, F, and G as shown in Figure 15. These results suggest that there is no dependency between the locations, sizes, and ownerships. However, the number of beds is dependent of the number of specialties.

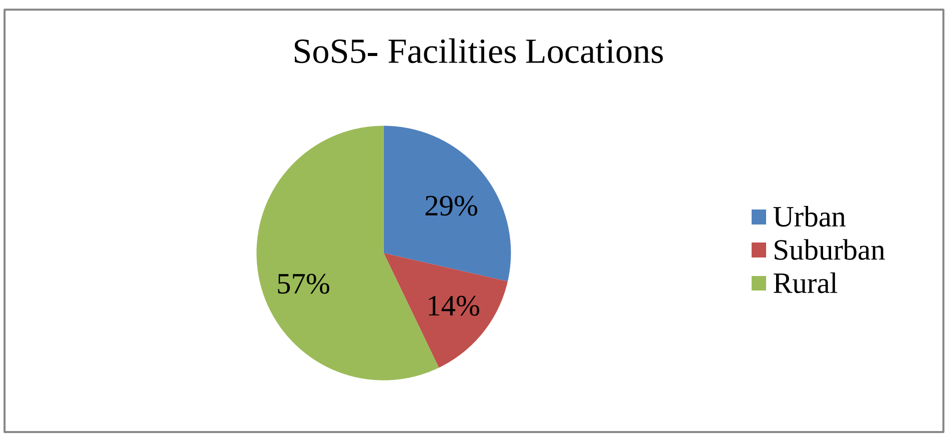

Figure 14- SoS5 Locations

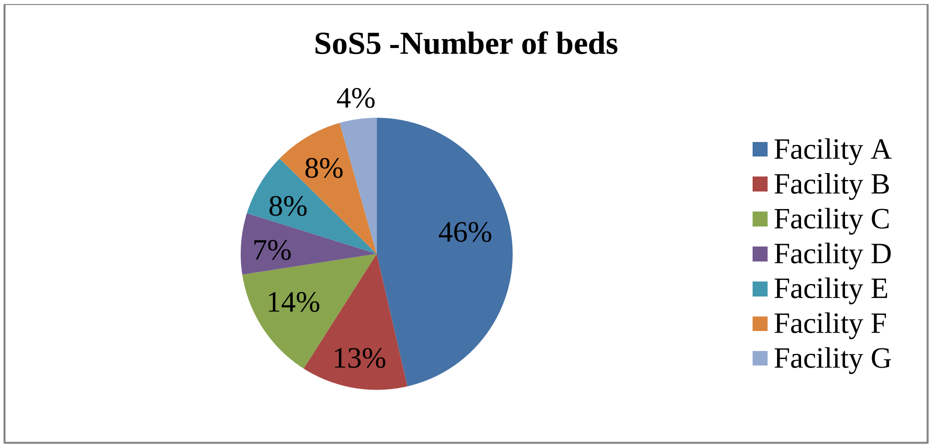

Figure 15- SoS5 Number of Beds

The facility contribution and facility need rates are calculated for SoS5 as shown in Table 39 and show that 59 percent of the specialties offered by facility A are not offered by facility B, C, D, E, F, or G; thus, there may be patients' transfers from facility B, C, D, E, F, or G to facility A. However, for facility B, 26 percent of specialties accessible by this facility do not exist in facility A, C, D, E, G, or F and this means that there may be patients' transfers from facility A, C, D, E, G, or F to facility B. Also, 35 percent of specialties obtainable at facility C are not offered by facility A, B, D, E,G, or F; this signifies that patients' transfers may occur from facility A, B, D, E, G, or F to facility C. The facility need rate for facility A indicates that 4 percent of specialties offered by B, C, D, E, G, or F are not offered by A. Hence, facility A may transfer its patients to facility B, C, D, E, G, or F.

Table 39- Assumed Receive /Transfer Rates for Each Facility Based on Specialties for SoS5

(Receive/ Transfer)	A	B	C	D	E	F	G	Sum	Total specialties	Contribution Rate
A		23	35	27	29	27	29	170	48	0.59
B	3		14	5	7	6	9	44	28	0.26
C	4	3		6	7	7	9	36	17	0.35
D	2	0	12		2	1	4	21	23	0.15
E	2	0	11	0		1	3	17	21	0.13
F	1	0	12	0	2		3	18	22	0.13
G	0	0	11	0	1	0		12	19	0.10
Sum	12	26	95	38	48	42	57			
Need Rate	0.04	0.15	0.93	0.27	0.38	0.3	0.5			

These actual and theoretical rates are compared to actual rates to affirm the hypothesis stated in Chapter 3. The actual and predicted transfer and receives ranks are presented in Table 40. All of the actual and predicted ranks matched except facility B transfer rank and facilities A and C receive ranks. The total number of combination in this case is (2^42) and since it is a very large number of combinations, the investigator chose a number of 1000000 random combinations to be used in this case. Therefore, the significance level for transfers and receives being based on specialties for this system was 42915/1000000 with a confidence level of 0.95. As a result, we conclude that transfers and receives are based on specialties.

The data survey regarding current and past transfers and receives degrees of this system are summarized in Tables 41a and 41b simultaneously. Comparing the current and the past degree values, changes occurred in both transfers and receives degree values for all facilities except facilities D and E values. The current and the past rate values are calculated and summarized in Tables 42a and 42b consecutively. Comparing the current and the past rate values shows that there was a change in values for all facilities except facility E which had the same transfers and receives rate values.

Table 40- SoS5 Actual and Predicted Ranked Transfers and Receives

Facility	Current Transfers Data	Current Receives Data	Actual Transfer Rank	Actual Receives Rank	Predicted Transfer Rank	Predicted Receives Rank	Delta Transfer	Delta Receive
A	2	3	5,6,7	2,3	7	1	0	1
B	3	3	2,3,4	2,3	6	2,3	2	0
C	6	6	1	1	1	2,3	0	1
D	4	1	2,3,4	4	2,3,4,5	4	0	0
E	2	0	5,6,7	5,6,7	2,3,4,5	5,6,7	0	0
F	3	0	2,3,4	5,6,7	2,3,4,5	5,6,7	0	0
G	2	0	5,6,7	5,6,7	2,3,4,5	5,6,7	0	0

Table 41a- SoS5 Past Transfers and Receives Degree Values

Facility	Past Transfer Degree Data	Past Receive Degree Data	Past Transfer Degree Ratio	Past Receive Degree Ratio
A	1	1	0.2	0.2
B	1	1	0.2	0.2
C	1	3	0.2	0.6
D	3	2	0.6	0.4
E	4	2	0.8	0.4
F	4	1	0.8	0.2
G	3	3	0.6	0.6

Table 41b- SoS5 Current Transfers and Receives Degree Values

Facility	Current Transfer Degree Data	Current Receive Degree Data	Current Transfer Degree Ratio	Current Receive Degree Ratio
A	4	2	0.8	0.4
B	2	4	0.4	0.8
C	3	3	0.6	0.6
D	3	2	0.6	0.4
E	4	2	0.8	0.4
F	5	1	1	0.2
G	3	2	0.6	0.4

Table 42a- SoS5 Past Transfers and Receives Rate Values

Facility	Past Transfer Rate Data	Past Receive Rate Data	Past Transfer Ratio	Past Receive Ratio
A	0	0	0	0
B	0	0	0	0
C	0	0	0	0
D	1	0	0.14	0
E	2	0	0.28	0
F	1	0	0.14	0
G	3	0	0.42	0

Table 42b- SoS5 Current Transfers and Receives Rate Values

Facility	Current Transfer Rate Data	Current Receive Rate Data	Current Transfer Ratio	Current Receive Ratio
A	2	3	0.28	0.42
B	3	3	0.42	0.42
C	6	6	0.85	0.85
D	4	1	0.57	0.14
E	2	0	0.28	0
F	3	0	0.42	0
G	2	0	0.28	0

Current and past performance values for SoS5 are summarized in Tables 43a and 43b. Current performances for facilities A, B, and C were grouped under one name in the quality care reports; therefore, the same performance score was used for all three. To calculate the current performance value for facility G, performance scores for facilities A-F were first multiplied by their total number of patients then summed and divided by the total number of treated patients for facilities A-F. During the past 5 years, SoS5 added two facilities, B and E. Comparing the past and current performance values, all the individual performances have been enhanced during this time period.

Table 43a- SoS5 Calculated Individual Performance Scores Before Change

Facilities	Performance Scores
A	0.87
C	0.66
D	0.88
F	0.92
G	0.89

Table 43b- SoS5 Calculated Individual Performance Scores After Change

Facility	Sum _Yearly Actual Rate Calculation	Total Treated Patients	Performance Scores
A	5740	5954	0.96
B	5740	5954	0.96
C	5740	5954	0.96
D	902	959	0.94
E	862	1445	0.59
F	1765	1803	0.97
G	-	-	0.94

Current and past relative weights for SoS5 are calculated and summarized in Tables 44a and 44b. The unpublished current relative weight for facility G was calculated by using the weighted sum of the beds for facility G multiplied by the total number of treated patients divided by one minus weighted sum of the beds for facility G. Comparing the past and current relative weights, a decrease in the number of treated patients has been noticed among all SoS5 facilities.

Comparing the resulting past and current overall performances; SoS performance scores increased from 0.84 to 0.92 as result of adding two new facilities, and change in interoperability parameters, performances, and relative weights. Therefore, all these changes have resulted in a 10 percent increase during this time period. Following the verification procedure, the overall performance values calculated using Excel as shown in Tables 45a and 45b matched the overall performance values using the SPAM program.

The statistical properties such as the mean, standard deviation, skewness, and kurtosis for SoS2 are calculated as shown in Table 46 and an average overall performance histogram was plotted as shown in Figure 13. The plot and the outputted skewness value of -0.35 indicated that the average overall performance distribution is close to normal with some skewness to the left.

Table 44a- SoS5 Relative Weights Before Change

Facilities	Relative Weights
A	0.38
C	0.13
D	0.17
F	0.21
G	0.11

Table 44b- SoS5 Relative Weights After Change

Facilities	Relative Weights
A	0.36
B	0.1
C	0.1
D	0.09
E	0.14
F	0.17
G	0.04

Table 45a- SoS5 Performance Model Verification Before Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive-Transfer)	(1+(Receive-Transfer))*w	M	U
A	0	0	1	0.38	1.33	0.45
C	0	0	1	0.13	1.33	0.12
D	0.08	0	0.91	0.15	1.22	0.18
F	0	0	1	0	1.33	0
G	0.25	0	0.74	0.07	0.99	0.09
SoS5 Performance Score Before Change						**0.84**

Table 45b- SoS5 Performance Model Verification After Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive-Transfer)	(1+(Receive-Transfer))*w	M	U
A	0.22	0.17	0.94	0.33	1.1	0.38
B	0.17	0.34	1.17	0.11	1.36	0.13
C	0.51	0.51	1	0.10	1.16	0.12
D	0.34	0.05	0.71	0.06	0.83	0.07
E	0.22	0	0.77	0.10	0.89	0.07
F	0.42	0	0.57	0.09	0.66	0.11
G	0.17	0	0.82	0.03	0.96	0.04
SoS5 Performance Score After Change						**0.92**

Table 46- SoS5 Statistical Properties

Healthcare System	Mean	Standard Deviation	Skewness	Kurtosis
SoS5	0.88	0.01	-0.35	2.69

Figure 13 represents the simulated average SoS performance where the red graph is the normal distribution and the blue graph is the simulated average SoS performance histogram constructed using 4000 repetitions. This histogram shows that average performances are either overestimated or underestimated with regard to the mean.

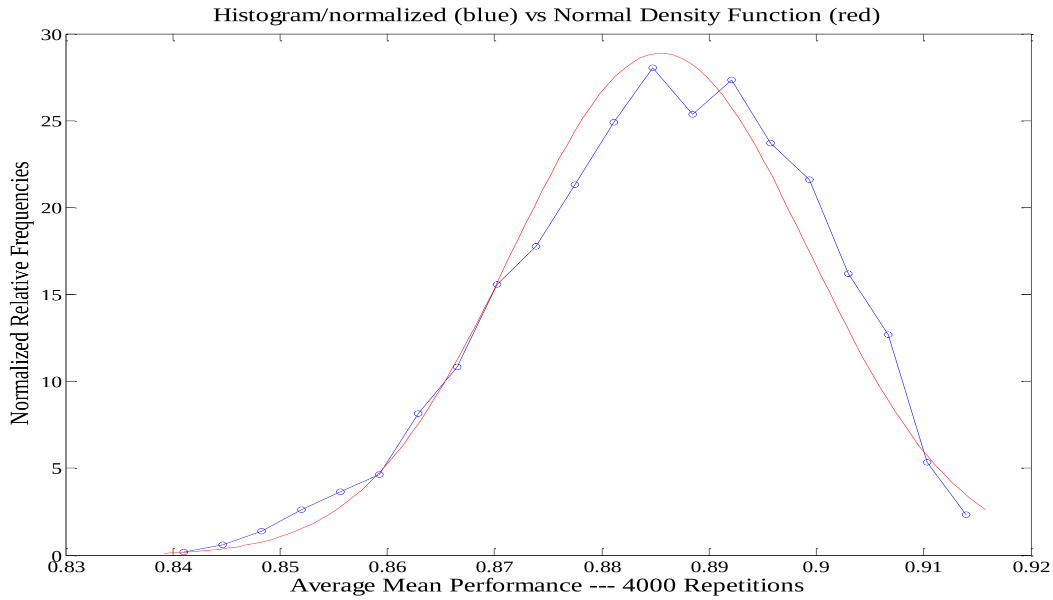

Figure 16- SoS5 Average Performance Histogram

Based on the survey answers on the shared resources section, 88 % of the facilities in SoS5 share information technologies among them, 88 % of the facilities share accounting, 88% of the facilities share purchasing, 88 % of its facilities have some type of sharing between their pharmacies, 50 % of the facilities share transportation, and 63 % share workforce among them.

4.7 Scenario 6- Change in Composition of SoS6

SoS6 is an "M" type system which contains 7 facilities located in the state of Tennessee. SoS6 has different locations with 57 percent of them being located at urban areas and 43 percent being located in rural regions. SoS6 is characterized as not-for-profit-secular facilities and has different facilities sizes where facility A is the largest and represents 39 percent of the total number of beds where the remaining 61 percent is spread out between facilities B, C, D, E, F, and G as shown in Figure 17. These results suggest that there is no dependency between the locations, sizes, and ownerships. However, the number of beds is dependent of the number of specialties.

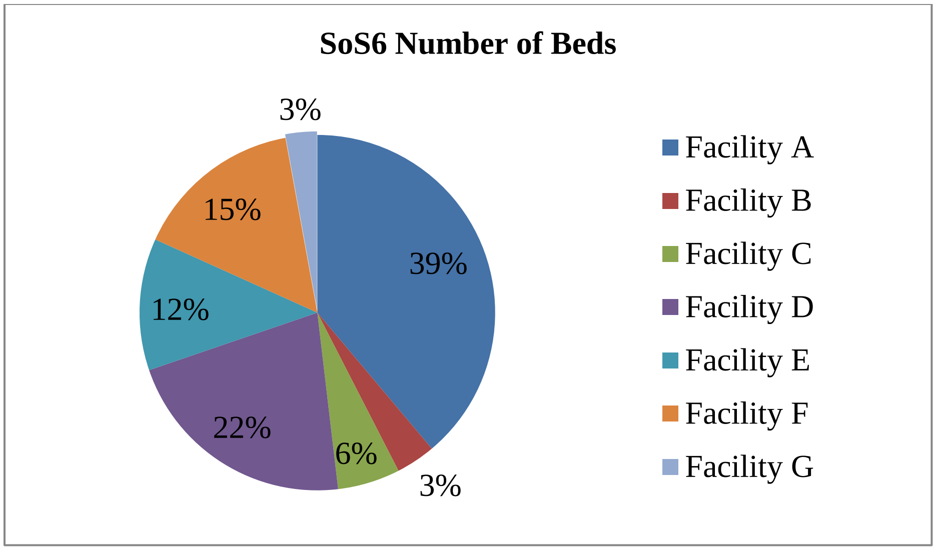

Figure 17- SoS6 Number of Beds

The facility contribution and facility need rates were calculated for SoS6 as shown in Table 47 and which represented on the average that 77 percent of the specialties offered by facility A are not offered by facility B, C, D, E, F, or G thus, this explains that there is may be patients' transfers from facility B, C, D, E, F, or G to facility A. However, for facility B, 64 percent of specialties accessible by this facility do not exist in facility A, C, D, E, G, or F and this means that there is may be patients' transfers from facility A, C, D, E, G, or F to facility B. Though, 61 percent of specialties obtainable by facility C are not offered by facility A, B, D, E,G, or F this signifies that patients' transfers may occur from facility A, B, D, E, G, or F to facility C. the facility need rate for facility A signifies that 43 percent of specialties offered by B, C, D, E, G, or F are not offered by A. therefore, this may signify that facility A may transfer its patients to facility B, C, D, E, G, or F.

Table 47- Assumed Receive /Transfer Rates for Each Facility Based on Specialties for SoS6

(Receive/ Transfer)	A	B	C	D	E	F	G	Sum	Total specialties	Contribution Rate
A		20	19	28	23	25	25	140	30	0.77
B	11		10	17	14	15	14	81	21	0.64
C	12	12		17	14	13	16	84	23	0.61
D	14	12	10		10	8	13	67	16	0.69
E	10	10	8	11		6	11	56	17	0.54
F	17	16	12	14	11		14	84	22	0.63
G	14	12	12	16	13	11		78	19	0.68
Sum	78	82	71	103	85	78	93			
Need Rate	0.43	0.65	0.51	1.07	0.83	0.5	0.8			

These actual and theoretical rates were compared to actual rates to affirm the hypothesis stated in Chapter 3. The actual and predicted transfer and receives ranks are presented in Table 48. The actual and predicted receive ranks all matched except for facility D. However, transfer ranks did not match as the receive ranks where facilities C, D, E, F had different predicted and actual ranks. The total number combination in this case is (2^42) and since it is a very large number of combinations, the investigator chose a number of 1000000 random combinations to be used in this case. Therefore, the significance level for transfers and receives being based on specialties for this system was 57125/1000000 with a confidence level of 0.94. As a result, we conclude that transfers and receives are based on specialties.

Table 48- SoS6 Actual and Predicted Ranked Transfers and Receives

Facility	Current Transfers Data	Current Receives Data	Actual Transfer Rank	Actual Receive Rank	Predicted Transfer Rank	Predicted Receives Rank	Delta Transfer	Delta Receive
A	2	6	5,6,7	1	5,6,7	1	0	0
B	3	0	2,3,4	5,6,7	3,4	2,3,4,5	0	0
C	3	1	2,3,4	4	5,6,7	2,3,4,5	1	0
D	2	2	5,6,7	3	1	6,7	4	3
E	2	0	5,6,7	5,6,7	3,4	6,7	1	0
F	6	5	1	2	5,6,7	2,3,4,5	4	0
G	3	0	2,3,4	5,6,7	2	2,3,4,5	0	0

The surveys data regarding current and past transfers and receives degrees of this system were summarized in Tables 49a and 49b simultaneously. Comparing the current and the past degree values, no changes occurred in both transfers and receives degree values for all facilities except for facilities B and E values and an addition of two facilities which are E and G.

Table 49a- SoS6 Past Transfers and Receives Degree Values

Facility	Past Transfer Degree Data	Past Receive Degree Data	Past Transfer Degree Ratio	Past Receive Degree Ratio
A	3	4	0.6	0.8
B	2	1	0.4	0.2
C	4	2	0.8	0.4
D	4	4	0.8	0.8
F	2	3	0.4	0.6

Table 49b- SoS6 Current Transfers and Receives Degree Values

Facility	Current Transfer Degree Data	Current Receive Degree Data	Current Transfer Degree Ratio	Current Receive Degree Ratio
A	3	4	0.6	0.8
B	3	1	0.6	0.2
C	4	2	0.8	0.4
D	4	4	0.8	0.8
E	4	4	0.8	0.8
F	2	3	0.4	0.6
G	4	1	0.8	0.2

The current and the past rate values were calculated and summarized in Tables 50a and 50b consecutively. Comparing the current and the past rate values, it was indicated that there was a change in values for facilities B, D, and F with addition of two facilities which are E and G.

Table 50a- SoS6 Past Transfers and Receives Rate Values

Facility	Past Transfer Rate Data	Past Receive Rate Data	Past Transfer Rate	Past Receive Rate
A	2	6	0.28	0.85
B	1	0	0.14	0
C	3	1	0.42	0.14
D	2	1	0.28	0.14
F	5	3	0.71	0.42

Table 50b- SoS6 Current Transfers and Receives Rate Values

Facility	Current Transfer Rate Data	Current Receive Rate Data	Current Transfer Rate	Current Receive Rate
A	2	6	0.28	0.85
B	3	0	0.42	0
C	3	1	0.42	0.14
D	2	2	0.28	0.28
E	2	0	0.28	0
F	6	5	0.85	0.71
G	3	0	0.42	0

Current and past performance values for SoS6 were summarized in Tables 51a and 51b. During the past 5 years, SoS6 had added two facilities which are E and G. Comparing the past and current performance values, all the individual performances have been enhanced during this time period.

Table 51a- SoS6 Calculated Individual Performance Scores Before Change

Facility	Performance Scores
A	0.87
B	0.88
C	0.43
D	0.89
F	0.85

Table 51b- SoS6 Calculated Individual Performance Scores After Change

Facility	Sum _Yearly Actual Rate Calculation	Total Treated Patients	Performance Scores
A	12593	12882	0.97
B	891	921	0.96
C	3115	3180	0.97
D	13655	13891	0.98
E	5391	5615	0.96
F	21325	21893	0.97
G	1101	1163	0.94

Current and past relative weights for SoS6 were calculated and summarized in Tables 52a and 52b. Comparing the past and current relative weights, a decrease in the number of treated patients has been noticed among all SoS6 facilities except for facility F.

Table 52a- SoS6 Relative Weights Before Change

Facilities	Relative Weights
A	0.24
B	0.07
C	0.16
D	0.26
F	0.27

Table 52b- SoS6 Relative Weights After Change

Facilities	Relative Weights
A	0.22
B	0.02
C	0.05
D	0.23
E	0.09
F	0.37
G	0.02

Comparing the resulting past and current overall performances; SoS performance scores increased from 0.82 to 0.97 as result of adding two new facilities, and change in interoperability parameters, performances, and relative weights. Therefore, all these changes have resulted in an 18 percent increase during this time period.

Following the verification procedure, the overall performance values calculated using Excel as shown in Tables 53a and 53b matched the overall performance values using the SAPM program.

Table 53a- SoS6 Performance Model Verification Before Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive-Transfer)	(1+(Receive-Transfer))*w	M	U
A	0.31	0.31	0.31	0.31	0.31	0.31
B	0.05	0.05	0.05	0.05	0.05	0.05
C	0.05	0.05	0.05	0.05	0.05	0.05
D	0.20	0.20	0.20	0.20	0.20	0.20
F	0.22	0.22	0.22	0.22	0.22	0.21
SoS6 Performance Score Before Change						**0.82**

Table 53b- SoS6 Performance Model Verification After Change

Facility	Transfer_ rate*degree	Receive_ rate*degree	1+(Receive-Transfer)	(1+(Receive-Transfer))*w	M	U
A	0.17	0.69	1.51	0.33	1.38	0.29
B	0.26	0.00	0.74	0.01	0.68	0.01
C	0.34	0.06	0.71	0.04	0.65	0.03
D	0.23	0.23	1.00	0.23	0.91	0.21
E	0.23	0.00	0.77	0.07	0.70	0.06
F	0.34	0.43	1.09	0.40	0.99	0.35
G	0.34	0.00	0.66	0.01	0.60	0.01
SoS6 Performance Score After Change						**0.97**

The statistical properties such as the mean, standard deviation, skewness, and kurtosis for SoS6 were calculated as shown in Table 54 and an average overall performance histogram was plotted as shown in Figure 18. The plot and the outputted skewness value of -0.3 indicated that the average overall performance distribution is close to normal with some skeweness to the left. Figure 18 represents the simulated average SoS performance where the red graph is the normal distribution and the blue graph is the simulated average SoS performance histogram constructed using 4000 repetitions. This histogram shows that average performances are either overestimated or underestimated with regard to the mean.

Table 54- SoS6 Statistical Properties

Healthcare System	Mean	Standard Deviation	Skewness	Kurtosis
SoS6	0.92	0.01	-0.3	2.56

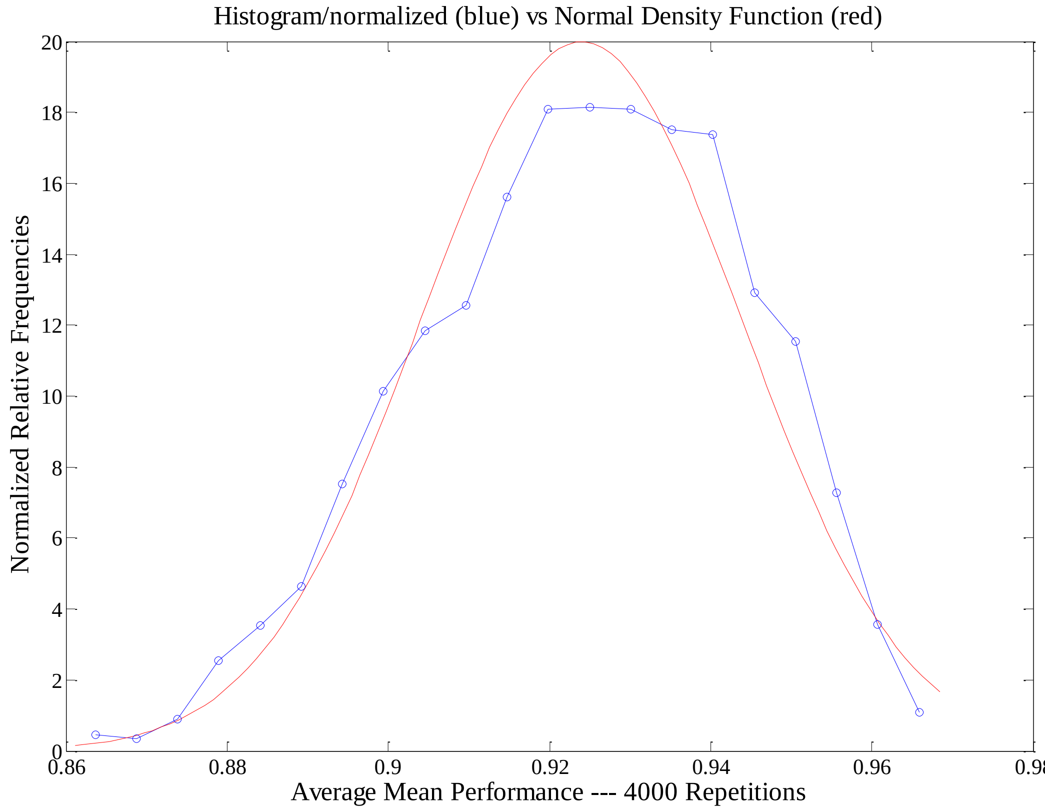

Figure 18- SoS6 Average Performance Histogram

Based on the survey answers on the shared resources section, 100 % of the facilities in SoS2 share information technologies among them, 71 % of the facilities share accounting, 100% of the facilities share purchasing, 71 % of its facilities have some type of sharing between their pharmacies, 14 % of the facilities share transportation, and 57 % share workforce among them.

4.8 Validation

To validate the model, a question within the SoS surveys asked the experts how their SoS performance progressed during the past five years. The question was based on a Likert scale that asked if the current quality of care is worse, same, or better than 5 years ago. The data survey was compared to the SPAM results by determining if there was an increase or not between the past and current states. Each of the participating healthcare systems' answers matched the SPAM results. Therefore, it was concluded that the SPAM model is valid.

4.9 Summary

Based on the results from the SPAM model using the data surveys and the Joint Commission quality reports, a conclusion was made that a change in one or more of these parameters, interoperability parameters, composition, individual performances, and relative weights, have an effect on the SoS performance. Each of the small and medium participating healthcare systems had a change in one or more of the parameters which resulted in an increase in the SoS performance.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

This chapter provides a general overview of the research which includes a restatement of the problem, purpose, objectives, and methodology and summarizes conclusions made at earlier chapters and brings closure to the current study. Also, it continues with a discussion of applications and suggestions with recommendations for future research.

5.1 General Overview

From a practical perspective, healthcare systems are highly complex systems that are very costly and inefficient. Because of their complexity, there are no detailed models that capture the overall performance of these systems from a systems engineering perspective. The ultimate goal of this study was to provide decision makers with an assessment tool that can help them assess changes in interoperability and composition which affect the SoS performance of healthcare systems. However, this study does not investigate the reasons behind the changes in the performance of individual systems.

The specific question in this research is "Can a framework be developed for assessing the SoS performance as its interoperability and/or its composition changes?" and which ultimately led to these two sub-questions:

- Does change in interoperability have an impact on SoS performance?

<u>Hypothesis 1</u>: The degree of interoperability directly impacts SoS performance.

- Does change due to addition/removal of a member system affect the SoS performance?

<u>Hypothesis 2</u>: A change in structural architecture impact the SoS performance.

The research design used a quantitative technique to conduct this investigation. It was based on facility and healthcare system electronic surveys that were sent to inpatient acute care facilities and their top management healthcare systems located in the state of Tennessee. The healthcare systems were grouped into four categories which are Small, Medium, Large, and Mega healthcare systems. The last two categories were omitted from the study either due to their refusal to participate or insufficient answers; 100 percent of the surveys were completed by the first two categories.

The SPAM model was created based on the Tri-Ex framework which was used to assess performance before and after change. This model was verified using Excel software and validated by comparing the answers from the surveys with the SPAM results on SoS performances.

5.2 Summary of Findings

Using the survey data and the quality reports, the research question and sub-questions were answered and the hypotheses confirmed. Namely, in the Small category, changes in the interoperability parameters (rate) of one member system, performances, relative weights has increased the overall performance of one of the healthcare systems. Therefore, this may confirm that change in interoperability can impact the SoS performance. In addition, within the same category, the addition of a new system with a change in performances and relative weights had led to SoS performance enhancement. Therefore, this outcome may confirm that a change in composition (addition) impacts the SoS performance. Also, it has been noticed that small healthcare systems have no top management that manage the healthcare systems and only facilities with the highest size in terms of number of specialties and number of beds play the "Lead" as the top management in this group. In addition, it has been concluded in this research that SoS performance improves as the "Lead" system performance enhances.

Two out of the three healthcare systems in the Medium category had changes in the composition (addition), interoperability parameters, performances, and relative weights which lead to an augmentation in the SoS performance. The other healthcare system within the same category had no change in interoperability or in composition but had a modification in performances and relative weights which led to an increase in the SoS performance.

Furthermore, it has been concluded that changes in interoperability and composition are not the only factor that affect the SoS performance but there may be other factors that need to be further investigated. Besides, in this research, it has been assumed that patients transfers and receives are based on specialties' availability. This conjecture has been proven to be holding for each of the participating healthcare systems. However, further investigations need to be done toward this statement. In addition, it has been found that Small healthcare systems do not share all of their resources such as information technology, accounting, purchasing, pharmacies, transportation, and workforce. However, the Medium healthcare systems share all the resources mentioned earlier. Also, in these two groups, the mostly shared resource among all facilities within healthcare systems was information technology.

5.3 Application

Healthcare falls into the service sector, but it is not the only industry in this sector that has large, complex systems. The service sector has different categories such as distribution, knowledge-based, in-person services [76]. The "Distribution services can be in wholesale, retail, transport or storage. Knowledge-based services can be in communications, finance or insurance. In-person services can be restaurants, education, health, recreational or government services [76]". Therefore, the SPAM model and the Tri-Ex framework can be used to analyze these service systems.

The SPAM model can also be a tool for decision makers to use to assess the current performance and make a decision based on the likely outcome. In the case of a decision required about making changes in terms of interactions between the systems, a decision maker can perform an assessment by selecting the type of changes into the SPAM menu and obtain an expected performance value for the SoS. This process also can be done until the user is satisfied with the overall performance score and the parameters that achieved that score. In the case of a change in the composition of the SoS, decision makers can add or remove system through the SPAM before making an actual change. This model will help reevaluate the overall performance and be close to actualization without taking a risk. In the case of removing a system, assessors can reenter information about the rest of the systems and reevaluate the overall performance. Though, in the case of adding a facility, decision makers should be knowledgeable about the system they wish to add. Management must have a clear understanding of the purpose of adding a system, the type of interaction this facility would have with the current ones, its size, and its individual performance. This way affected stakeholders can have an insight about the effect of adding that system on the overall performance of the SoS. This is a benefit of using the Tri-Ex Framework – the ability to investigate proposed changes by using a structured approach that can be repeated and is documented. Not only can Tri-Ex be applied to the Enterprise level but can also be applied at any system level to evaluate the direct impact a change elsewhere in the system might have directly or indirectly on the another system.

5.4 Future Research

Based on the analysis of the data, the literature review, and the survey experience, these recommendations were formed:

- There is a need of application to the Large and Mega healthcare system to prove its application to all different categories.
- Supplementary studies should include all types of facilities within multihospital healthcare systems and study the effect of change on the SoS performance.
- Advanced research could be conducted by studying the effect of shared resources on the SoS performance.
- Additional investigation need to be carried out to study the effect of other measures on the SoS performance.
- Great need of comprehensive performance assessment including all levels of the SoS.

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Appendices

Appendix A

PERMISSION LETTER

Date

Participant

Name of Company

Address

Dear Participant:

My name is Karima Tayeb. I am a doctoral student in the Department of Industrial and Information Engineering at The University of Tennessee Space Institute, Tullahoma (UTSI). I am writing to solicit your participation in a survey to collect data for my dissertation, which is a partial requirement for a PhD degree. This input is needed for research on the impact of interactions among the facilities in a healthcare system on system-wide performance. If you agree to participate in this study, you will complete an electronic survey and it would be upon your request when you want the survey to be completed. In the case you cannot complete the survey for any reason; a random number is assigned to you to re-login at any time to continue answering the survey. The link to the survey and your access number will be attached in the e-mail. Completion of this survey is estimated to take no more than twenty minutes.

Please note that all of the information obtained will be kept confidential. Your facility name will not be used, and no information about your facility or employee(s) will ever leave the university premises. The survey will be marked with a number for data recording and analysis purposes only. Only I will ever know the assigned number. There are no risks associated with participation in this study.

The information collected from this study will be published in my dissertation and presented at research conferences for my discipline. The survey results should help us learn more about the effect of interaction between facilities in a health system on its overall performance. The results will be shared with your facility and your health system, and we hope that such information would be useful to your facility and your health system. The dissertation will be available in the Hodges library on the UTK campus.

My advisor, Dr. Denise Jackson has approved the survey. Her contact information is either (865)946-3248 or djackson@utsi.edu. We at UTSI appreciate the participation of people like you who help in carrying out the mission of developing knowledge through research. If you have any questions about the research, you may call me at (865)300-3062. If your facility agrees to participate, please confirm via e-mail to ktayeb@utk.edu stating when the survey will be administered. I thank you for your time and assistance.

Sincerely,

Karima Tayeb

Appendix B

CONSENT FORM

The University of Tennessee

Department of Industrial and Information Engineering

Title of Dissertation: Impact of Interoperability on Performance of System of Systems

Principal Investigator: Karima Tayeb (865-946-3246, ktayeb@utk.edu)

Other Investigators: Denise Jackson, Ph.D. (865-946-3248, djackson@utsi.edu)

Gregory Sedrick, Ph.D. (931-393-7292, gsedrick@utsi.edu)

Xueping Li, PhD. (865-974-7648, Xueping.Li@utk.edu)

Bruce Tonn, PhD. (865-974-7041, @btonn@utk.edu)

You are invited to participate in a dissertation research study about interaction between facilities in a health system. The purpose of this study is to understand and manage the emergent behaviors that come forth as a result of the interactions among the system components. Data collected during the survey will be used to analyze the effect of changes in interactions and structure on the overall health system performance.

Procedures

The participant agrees to the following procedures in order to participate in this study. The electronic survey-questionnaire contains 2 main sections: (1) General Information about the facility (2) overall section that consists of various questions about the current and past budget allocation, satisfaction, and interactions with other facilities.

Risks

While filling out the survey, no pain, discomfort, injury, or risks in any way are anticipated in participation. If significant pain, injury, or discomfort is experienced during completion of this survey, I will stop immediately and notify the investigator of the situation. I may refuse to answer any questions and may discontinue this study at any time.

Benefits

There are no benefits to me other than the psychological benefits that come from knowing that I assisted in a study that could possibly help understand complex systems.

Alternative Procedures

There are no alternative procedures incorporated into this study.

Emergency Medical Treatment

The University of Tennessee Space Institute does not "automatically" reimburse subjects for medical claims or other compensation. If physical injury is suffered in the course of research, or for more information, please notify the investigator in charge, Karima Tayeb (865-946-3246)

Time Duration for Completion of Forms

The electronic survey will require approximately 20 minutes to complete.

Confidentiality Statement

Your participation in this study is confidential. The investigator will be the only person with access to the survey information. This study will be subject to the usual confidentiality standards applied to normal research studies. In the event of any publication resulting from this study, no identifiable information will be disclosed.

Right to Ask Questions

You have the opportunity to ask any questions that you may have regarding this study and I am confident that they will be answered to your satisfaction.

Compensation

There is no compensation, monetary or otherwise, for participating in this study. You also understand that in the event of any physical or emotional injury resulting from my participation in this study will result in neither financial compensation nor free medical treatment from the University of Tennessee Space Institute.

Participation

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at anytime without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be destroyed.

CONSENT

I have read the above information and agree to participate in this study. I have received a copy of this form.

Participant's name (print) ___________________________

Participant's signature ______________________________ Date ______________

Appendix C

FACILITY SURVEY

Instructions: * This survey will not take more than 20 minutes to complete. * Access number given can be used if there is a need to re-login to finish the survey. * Please, carefully read and answer every question.

Please, indicate your job title. (Select one answer)

Chief Executive Officer

Quality Assurance Officer

Chief Operating Officer

Chief Administrative Officer

Director of Quality Improvement

Other:

1. Please, check your facility.

   Name of Facility 1

   Name of Facility 2

   Name of Facility 3

Transfer To

2. How many other inpatient facilities in your health system do you **currently** transfer patients to? (0 - 255)

3. How many Inpatient facilities in your health system did you transfer patients to **5 years ago**? (0 - 255)

4. For the inpatient facilities that you **currently transfer patients to**, how many of these transfers were not done **5 years ago**? (0 - 255)

5. For the Inpatient facilities **you transferred patients to 5 years ago**, how many of those are you **No longer** transferring your patients to? (0 - 255)

6. How often do you **currently transfer patients to** other Inpatient facilities in your health system on the average?

	Never	Seldom	Sometimes	Often	Always
Transfer Patients To					

7. How often did you **transfer your patients to** other Inpatient facilities in your health system **5 years ago**?

	Never	Seldom	Sometimes	Often	Always
Transferred Patients To					

Receive From

8. How many other inpatient facilities in your health system do you **currently** receive patients from? (0 - 255)

9. How many Inpatient facilities in your health system did you receive patients from **5 years ago**? (0 - 255)

10. For the inpatient facilities that you **currently receive patients from**, how many of these receipts were not done **5 years ago**? (0 - 255)

11. For the Inpatient facilities **you received patients from 5 years ago**, how many of those are you no longer receiving patients from? (0 - 255)

12. How often do you **currently receive patients from** other Inpatient facilities in your health system on the average?

	Never	Seldom	Sometimes	Often	Always
Receive Patients From					

13. How often did you **receive patients from** other Inpatient facilities in your health system **5 years ago**?

	Never	Seldom	Sometimes	Often	Always
Received Patients From					

Performance

14. For the measures that your facility use to measure quality of care, how did you progress in the **past 5 years**?

	Worse Than 5 Years	Same as 5 Years Ago	Better Than 5 Years
Quality of Care			

Functions Shared Across System

15. Please, indicate which of each function among these are shared under your facility.

Functions	**Shared**
Information Technologies	
Accounting	
Purchasing	
Pharmacies	
Transportation	
Workforce	
Other 1	
Other 2	
Other 3	

Appendix D

SYSTEM OF SYSTEMS SURVEY

Instructions: *This survey will not take more than 20 minutes to complete. *The access number given can be used in case you need to re-login to finish the survey. *Please, carefully read and answer every question.

Please, select your job title. (Select one answer)

President

Vice President

Assistant Vice President

Chief Executive Officer

Chief Operating Officer

Quality Assurance Officer

Director, Quality Improvement

Other:

1. Please, check all inpatient facilities that were **Initially** part of the health system, inpatient facilities that are **Currently** part of your health system, inpatient facilities that were **Added in the last 5 years,** inpatient facilities that were **Removed in the last 5 years**. (Select ALL that apply)

Facilities	**Initially**	**Currently**	**Added Last 5**	**Removed Last**	**NA**
Facility 1					
Facility 2					
Facility 3					

2. Please, check all the **current transfers** made by each facility to other facilities in your health system. (Select ALL that apply)

Transfer	**To**		
	Facility 1	Facility 2	Facility 3
Facility 1			
Facility 2			
Facility 3			

CHANGES IN THE SYSTEM

Change in Relationships

3. Please, check all the **transfers** made by each facility to other facilities in your health system in the **past 5 years**. (Select ALL that apply)

Transfer	**To**		
	Facility 1	Facility 2	Facility 3
Facility 1			
Facility 2			
Facility 3			

Removals

4. Approximately, what percent of beds in the system were lost? (0 - 100)

5. For each possible reason for an inpatient facility to leave a system, please indicate, where appropriate, the effect of such removals had on the effectiveness of your health system?

	Very Low	Low	No	High	Very High	NA
Financial Reason						
Low Employee						
Low Patient						
Other:						

6. Please, indicate changes in relationships among inpatient facilities due to recent (last 5 years) removals.

	Number of Transfers/Receives (0 - 255)		
	# Increased	# Decreased	NA
Transfers			
Receives			

7. Please, indicate changes in number of inpatient facilities transferring/receiving patients due to recent (last 5 years) removals.

	Number of Facilities (0 - 255)		
	# Increased	# Decreased	NA
Transfer			
Receive			

Additions

8. Approximately, what is the total number of beds of the added inpatient facility? (0 - 255)

9. For each possible reason for an inpatient facility to enter a system, please indicate, where appropriate, the effect of such addition had on the effectiveness of your health system?

Reasons to Enter	**Very Low**	**Low effect**	**No effect**	**High**	**Very High**	**NA**
Financial Reason						
Increase Employee						
Increase Patient						
Other:						

10. Please, indicate changes in relationships among inpatient facilities due to recent (last 5 years) additions.

	Number of Transfers/receives (0 - 255)		
	# Increased	# Decreased	NA
Transferring of Patients			
Receiving of Patients			

11. Please, indicate changes in number of inpatient facilities transferring/receiving patients due to recent (last 5 years) additions.

	Number of Facilities (0 - 255)	
	# Increased	# Decreased
Transfer		
Receive		

Performance

12. For the measures that your healthcare system use to measure quality of care, how did you progress in the **past 5 years**?

	Worse Than 5 Years Ago	Same as 5 Years Ago	Better Than 5 Years Ago
Quality of Care			

Shared Resources

12. Please, indicate which of each function among these are shared across all inpatient facilities under your health system.

	Shared	
Functions	**Yes**	**No**
Information Technologies		
Accounting		
Purchasing		
Pharmacies		
Transportation		
Workforce		
Other (Specify):		

Appendix E

SPAM OUTPUTS

SoS1 SPAM Output

Enter Number of Systems 3
Enter Transfers R-F for S1 0
Enter Transfers Degree for S1 .2
Enter Receives R-F for S1 0.666666667
Enter Receives Degree for S1 .8
Enter Transfers R-F for S2 0.333333333
Enter Transfers Degree for S2 .8
Enter Receives R-F for S2 0
Enter Receives Degree for S2 .2
Enter Transfers R-F for S3 0.333333333
Enter Transfers Degree for S3 .8
Enter Receives R-F for S3 0.333333333
Enter Receives Degree for S3 .4
Enter Weight for S 1 0.63057041
Enter Weight for S2 0.117647059
Enter Weight for S3 0.251782531
Enter Performance for S1 0.853710219
Enter Performance for S2 0.863636392
Enter Performance for S3 0.880530893
Contributed Performance for S1 0.760504
Contributed Performance for S2 0.067860
Contributed Performance for S3 0.171636
SoS1 Performance Before Change 0.858987

Reevaluation of Performance After Change
Enter -1 for System Number to break
Enter System 3
Enter Transfers Fraction 0.333333333
Enter Receives Fraction 0
Enter Weight for S1 0.806375042
Enter Weight for S2 0.124448966
Enter Weight for S3 0.069175992
Enter Performance for S1 0.967199
Enter Performance for S2 0.855586
Enter Performance for System 3 0.901961
Contributed Performance for S1 0.896991
Contributed Performance for S2 0.066207

Contributed Performance for S3 0.036802
SoS1 Performance After Change   0.957408

SoS2 SPAM Output

Enter Number of Systems   3
Enter Transfers R-F for S 1   0.333333333
Enter Transfers Degree for S1   .4
Enter Receives R-F for S1   0.666666667
Enter Receives Degree for S1   .6
Enter Transfers R-F for S2   0.666666667
Enter Transfers Degree for S2   .8
Enter Receives R-F for S2   0.666666667
Enter Receives Degree for S2   .8
Enter Transfers R-F for S3   0.333333333
Enter Transfers Degree for S3   .4
Enter Receives R-F for S3   0.666666667
Enter Receives Degree for S3   .8
Enter Weight for S1   0.258039385
Enter Weight for S2   0.224280459
Enter Weight for S3   0.517680156
Enter Performance for S1   0.790171037
Enter Performance for S2   0.793130038
Enter Performance for S3   0.801855995
Contributed Performance for S1   0.256176
Contributed Performance for S2   0.175785
Contributed Performance for S3   0.568040
SoS2 Performance Before Change   0.797329

Reevaluation of Performance After Change

Enter 1 to Add a System   1
Enter Transfers R-F for S1   .25
Enter Transfers Degree for S1   .4
Enter Receives R-F for S1   .75
Enter Receives Degree for S1   .6
Enter Transfers R-F for S2   .5
Enter Transfers Degree for S2   .8
Enter Receives R-F for S2   .5
Enter Receives Degree for S2   .8
Enter Transfers R-F for S 3   .25
Enter Transfers Degree for S3   .4
Enter Receives R-F for S3   .5
Enter Receives Degree for S3   .8
Enter Transfers R-F for S4   .75

Enter Transfers Degree for S4 .4
Enter Receives R-F for S4 0
Enter Receives Degree for S4 .2
Enter Weight for S1 0.275075773
Enter Weight for S2 0.2868878
Enter Weight for S3 0.423023539
Enter Weight for S4 0.015012888
Enter Performance for S1 0.954279
Enter Performance for S2 0.953989
Enter Performance for S3 0.964243
Enter Performance for S4 0.958473785
Enter 1 to Add a System (-1 to break) -1
Contributed Performance for S1 0.304717
Contributed Performance for S2 0.235409
Contributed Performance for S3 0.451251
Contributed Performance for S4 0.008623
SoS2 Performance After Change 0.958743

SoS3 SPAM Output

Enter Number of Systems 3
Enter Transfers R-F for S1 .5
Enter Transfers Degree for S1 .8
Enter Receives R-F for S1 .25
Enter Receives Degree for S1 .6
Enter Transfers R-F for S2 0
Enter Transfers Degree for S2 .4
Enter Receives R-F for S2 .25
Enter Receives Degree for S2 .6
Enter Transfers R-F for S3 .25
Enter Transfers Degree for S3 .6
Enter Receives R-F for S3 .5
Enter Receives Degree for S3 1
Enter Weight for S1 0.285191348
Enter Weight for S2 0.611980033
Enter Weight for S3 0.102828619
Enter Performance for S1 0.912485466
Enter Performance for S2 0.237629034
Enter Performance for S3 0.452151275
Contributed Performance for S1 0.20245
Contributed Performance for S2 0.66614
Contributed Performance for S3 0.13139
SoS3 Performance Before Change 0.402446

Reevaluation of Performance After Change

Enter 1 to Add a System 1
Enter Transfers R-F for S1 .5
Enter Transfers Degree for S1 .8
Enter Receives R-F for S1 .25
Enter Receives Degree for S1 .6
Enter Transfers R-F for S2 .5
Enter Transfers Degree for S2 .6
Enter Receives R-F for S2 .5
Enter Receives Degree for S2 .6
Enter Transfers R-F for S3 .25
Enter Transfers Degree for S3 .6
Enter Receives R-F for S3 .5
Enter Receives Degree for S3 1
Enter Transfers R-F for S4 .25
Enter Transfers Degree for S4 .8
Enter Receives R-F for S4 .5
Enter Receives Degree for S4 .6
Enter Relative Weight for S1 0.1867350
Enter Weight for S2 0.6458744
Enter Weight for S3 0.0931701
Enter Weight for S4 0.0742202
Enter Performance for S1 0.9319213
Enter Performance for S2 0.8966992
Enter Performance for S3 0.6386590
Enter Performance for S4 0.9319213
Enter 1 to Add a System (-1 to break) -1
Contributed Performance for S1 0.1409
Contributed Performance for S2 0.6502
Contributed Performance for S3 0.1266
Contributed Performance for S4 0.0821
SoS3 Performance After Change 0.871886

SoS4 SPAM Output

Enter Number of Systems 6
Enter Transfers R-F for S1 0.166666667
Enter Transfers Degree for S1 .8
Enter Receives R-F for S1 0.166666667
Enter Receives Degree for S1 .6
Enter Transfers R-F for S2 0.833333333
Enter Transfers Degree for S2 .8
Enter Receives R-F for S2 0.166666667

Enter Receives Degree for S2 .4
Enter Transfers R-F for S3 0.333333333
Enter Transfers Degree for S3 .8
Enter Receives R-F for S3 0.166666667
Enter Receives Degree for S3 .4
Enter Transfers R-F for S4 0.166666667
Enter Transfers Degree for S4 .8
Enter Receives R-F for S4 0.166666667
Enter Receives Degree for S4 .4
Enter Transfers R-F for S5 0
Enter Transfers Degree for S5 .4
Enter Receives R-F for S5 0.833333333
Enter Receives Degree for S5 .8
Enter Transfers R-F for S6 0.833333333
Enter Transfers Degree for S6 .8
Enter Receives R-F for S6 0.666666667
Enter Receives Degree for S6 .8
Enter Weight for S1 0.02578191
Enter Weight for S2 0.011496196
Enter Weight for S3 0.020371936
Enter Weight for S4 0.044632291
Enter Weight for S5 0.871344041
Enter Weight for S6 0.026373626
Enter Performance for S1 0.809835987
Enter Performance for S2 0.727941066
Enter Performance for S3 0.809128718
Enter Performance for S4 0.784090869
Enter Performance for S5 0.723418576
Enter Performance for S6 0.887820554
Contributed Performance for S1 0.015950
Contributed Performance for S2 0.002943
Contributed Performance for S3 0.010430
Contributed Performance for S4 0.026659
Contributed Performance for S5 0.929390
Contributed Performance for S6 0.014628
SoS4 Performance Before Change 0.729726

<u>Reevaluation of Performance After Change</u>
Enter Weight for S1 0.005200709
Enter Weight for S2 0.003852377
Enter Weight for S3 0.005894137
Enter Weight for S4 0.00735804
Enter Weight for S5 0.970336698
Enter Weight for S6 0.00735804
Enter Performance for S1 0.607407

Enter Performance for S2 0.84
Enter Performance for S3 0.764706
Enter Performance for S4 0.8272251
Enter Performance for S5 0.887804
Enter Performance for S6 0.95288
Contributed Performance for S1 0.003062
Contributed Performance for S2 0.000939
Contributed Performance for S3 0.002872
Contributed Performance for S4 0.004183
Contributed Performance for S5 0.985060
Contributed Performance for S6 0.003884
SoS4 Performance After Change 0.886546

SoS5 SPAM Output

Enter Number of Systems 5
Enter Transfers R-F for S1 0
Enter Transfers Degree for S1 .2
Enter Receives R-F for S1 0
Enter Receives Degree for S1 .2
Enter Transfers R-F for S2 0
Enter Transfers Degree for S2 .2
Enter Receives R-F for S2 0
Enter Receives Degree for S2 .6
Enter Transfers R-F for S3 0.142857143
Enter Transfers Degree for S3 .6
Enter Receives R-F for S3 0
Enter Receives Degree for S3 .4
Enter Transfers R-F for S4 0.142857143
Enter Transfers Degree for S4 .8
Enter Receives R-F for S4 0
Enter Receives Degree for S4 .2
Enter Transfers R-F for S5 0.428571429
Enter Transfers Degree for S5 .6
Enter Receives R-F for S5 0
Enter Receives Degree for S5 .6
Enter Relative Weight for S1 0.302742261
Enter Relative Weight for S2 0.107671602
Enter Relative Weight for S3 0.134084791
Enter Relative Weight for S4 0.167900404
Enter Relative Weight for S5 0.082940781
Enter Individual Performance for S1 0.878299652
Enter Individual Performance for S2 0.891620874
Enter Individual Performance for S3 0.880175669
Enter Individual Performance for S4 0.925851782

Enter Individual Performance for S5	0.889452353
Contributed Performance for S1	0.407278
Contributed Performance for S2	0.144850
Contributed Performance for S3	0.164922
Contributed Performance for S4	0.200061
Contributed Performance for S5	0.082888
SoS5 Performance Before Change	**0.890976**

Reevaluation of Performance After Change

Enter 1 to Add a System (-1 to break)	1
Enter Transfers R-F for S1	.33333
Enter Transfers Degree for S1	.8
Enter Receives R-F for S1	.5
Enter Receives Degree for S1	.4
Enter Transfers R-F for S2	.5
Enter Transfers Degree for S2	.4
Enter Receives R-F for S2	.5
Enter Receives Degree for S2	.8
Enter Transfers R-F for S3	1
Enter Transfers Degree for S3	.6
Enter Receives R-F for S3	1
Enter Receives Degree for S3	.6
Enter Transfers R-F for S4	.66666
Enter Transfers Degree for S4	.6
Enter Receives R-F for S4	.16666
Enter Receives Degree for S4	.4
Enter Transfers R-F for S5	.5
Enter Transfers Degree for S5	1
Enter Receives R-F for S5	0
Enter Receives Degree for S5	.2
Enter Transfers R-F for S6	.33333
Enter Transfers Degree for S6	.6
Enter Receives R-F for S6	0
Enter Receives Degree for S6	.4
Enter Relative Weight for S1	0.414352608
Enter Relative Weight for S2	0.113143853
Enter Relative Weight for S3	0.120984428
Enter Relative Weight for S4	0.104432103
Enter Relative Weight for S5	0.196341065
Enter Relative Weight for S6	0.050745944
Enter Individual Performance for S1	0.964058
Enter Individual Performance for S2	0.964058
Enter Individual Performance for S3	0.964058
Enter Individual Performance for S4	0.940563

Enter Individual Performance for S5	0.978924
Enter Individual Performance for S6	0.940187783
Enter 1 to Add a System (-1 to break)	1
Enter Transfers R-F for S1	0.285714286
Enter Transfers Degree for S1	.8
Enter Receives R-F for S1	0.428571429
Enter Receives Degree for S1	.4
Enter Transfers R-F for S2	0.428571429
Enter Transfers Degree for S2	.4
Enter Receives R-F for S2	0.428571429
Enter Receives Degree for S2	.8
Enter Transfers R-F for S3	0.857142857
Enter Transfers Degree for S3	.6
Enter Receives R-F for S3	0.857142857
Enter Receives Degree for S3	.6
Enter Transfers R-F for S4	0.571428571
Enter Transfers Degree for S4	.6
Enter Receives R-F for S4	0.142857143
Enter Receives Degree for S4	.4
Enter Transfers R-F for S5	0.285714286
Enter Transfers Degree for S5	.8
Enter Receives R-F for S5	0
Enter Receives Degree for S5	.4
Enter Transfers R-F for S6	0.428571429
Enter Transfers Degree for S6	1
Enter Receives R-F for S6	0
Enter Receives Degree for S6	.2
Enter Transfers R-F for S7	0.285714286
Enter Transfers Degree for S7	.6
Enter Receives R-F for S7	0
Enter Receives Degree for S7	.4
Enter Relative Weight for S1	0.35801656
Enter Relative Weight for S2	0.097760632
Enter Relative Weight for S3	0.10453519
Enter Relative Weight for S4	0.090233346
Enter Relative Weight for S5	0.135961611
Enter Relative Weight for S6	0.169646218
Enter Relative Weight for S7	0.043846443
Enter Individual Performance for S1	0.964058
Enter Individual Performance for S2	0.964058
Enter Individual Performance for S3	0.964058
Enter Individual Performance for S4	0.940563
Enter Individual Performance for S5	0.59654
Enter Individual Performance for S6	0.978924
Enter Individual Performance for S7	0.940187783

Enter 1 to Add a System (-1 to break)	-1
Contributed Performance for S1	0.392866
Contributed Performance for S2	0.133283
Contributed Performance for S3	0.121663
Contributed Performance for S4	0.075013
Contributed Performance for S5	0.122070
Contributed Performance for S6	0.112824
Contributed Performance for S7	0.042282
SoS5 Performance After Change	**0.918101**

SoS6 SPAM Output

Enter Number of Systems	5
Enter Transfers R-F for S1	.29
Enter Transfers Degree for S1	.6
Enter Receives R-F for S1	.86
Enter Receives Degree for S1	.8
Enter Transfers R-F for S2	.14
Enter Transfers Degree for S2	.4
Enter Receives R-F for S2	0
Enter Receives Degree for S2	.2
Enter Transfers R-F for S3	.43
Enter Transfers Degree for S3	.8
Enter Receives R-F for S3	.14
Enter Receives Degree for S3	.4
Enter Transfers R-F for S4	.29
Enter Transfers Degree for S4	.8
Enter Receives R-F for S4	.14
Enter Receives Degree for S4	.8
Enter Transfers R-F for S5	.71
Enter Transfers Degree for S5	.4
Enter Receives R-F for S5	.43
Enter Receives Degree for S5	.6
Enter Relative Weight for S1	.24
Enter Relative Weight for S2	.07
Enter Relative Weight for S3	.16
Enter Relative Weight for S4	.26
Enter Relative Weight for S5	.27
Enter Individual Performance for S1	.87
Enter Individual Performance for S2	.88
Enter Individual Performance for S3	.43
Enter Individual Performance for S4	.89
Enter Individual Performance for S5	.85

Contributed Performance for S1	0.351025
Contributed Performance for S2	0.063837
Contributed Performance for S3	0.110053
Contributed Performance for S4	0.221033
Contributed Performance for S5	0.254053
SoS Performance Before Change	**0.821555**

Reevaluation of Performance After Change

Enter 1 to Add a System (-1 to break)	1
Enter Transfers R-F for S1	.29
Enter Transfers Degree for S1	.6
Enter Receives R-F for S1	.86
Enter Receives Degree for S1	.8
Enter Transfers R-F for S2	.43
Enter Transfers Degree for S2	.6
Enter Receives R-F for S2	0
Enter Receives Degree for S2	.2
Enter Transfers R-F for S3	.43
Enter Transfers Degree for S3	.8
Enter Receives R-F for S3	.14
Enter Receives Degree for S3	.4
Enter Transfers R-F for S4	.29
Enter Transfers Degree for S4	.8
Enter Receives R-F for S4	.29
Enter Receives Degree for S4	.8
Enter Transfers R-F for S5	.86
Enter Transfers Degree for S5	.4
Enter Receives R-F for S5	.71
Enter Receives Degree for S5	.6
Enter Transfers R-F for S6	.29
Enter Transfers Degree for S6	.8
Enter Receives R-F for S6	0
Enter Receives Degree for S6	.8
Enter Relative Weight for S1	.22
Enter Relative Weight for S2	.02
Enter Relative Weight for S3	.05
Enter Relative Weight for S4	.23
Enter Relative Weight for S5	.37
Enter Relative Weight for S6	.09
Enter Individual Performance for S1	.97
Enter Individual Performance for S2	.96
Enter Individual Performance for S3	.97
Enter Individual Performance for S4	.98
Enter Individual Performance for S5	.97

Enter Individual Performance for S6	.96
Enter 1 to Add a System (-1 to break)	1
Enter Transfers R-F for S1	.29
Enter Transfers Degree for S1	.6
Enter Receives R-F for S1	.86
Enter Receives Degree for S1	.8
Enter Transfers R-F for S2	.43
Enter Transfers Degree for S2	.6
Enter Receives R-F for S2	0
Enter Receives Degree for S2	.2
Enter Transfers R-F for S3	.43
Enter Transfers Degree for S3	.8
Enter Receives R-F for S3	.14
Enter Receives Degree for S3	.4
Enter Transfers R-F for S4	.29
Enter Transfers Degree for S4	.8
Enter Receives R-F for S4	.29
Enter Receives Degree for S4	.8
Enter Transfers R-F for S5	.86
Enter Transfers Degree for S5	.4
Enter Receives R-F for S5	.71
Enter Receives Degree for S5	.6
Enter Transfers R-F for S6	.29
Enter Transfers Degree for S6	.8
Enter Receives R-F for S6	0
Enter Receives Degree for S6	.8
Enter Transfers R-F for S7	.43
Enter Transfers Degree for S7	.8
Enter Receives R-F for S7	0
Enter Receives Degree for S7	.2
Enter Relative Weight for S1	.22
Enter Relative Weight for S2	.02
Enter Relative Weight for S3	.05
Enter Relative Weight for S4	.23
Enter Relative Weight for S5	.37
Enter Relative Weight for S6	.09
Enter Relative Weight for S7	.02
Enter Individual Performance for S1	.97
Enter Individual Performance for S2	.96
Enter Individual Performance for S3	.97
Enter Individual Performance for S4	.98
Enter Individual Performance for S5	.97
Enter Individual Performance for S6	.96
Enter Individual Performance for S7	.94
Enter 1 to Add a System (-1 to break)	-1

Contributed Performance for S1	0.303877
Contributed Performance for S2	0.013539
Contributed Performance for S3	0.032479
Contributed Performance for S4	0.209835
Contributed Performance for S5	0.365240
Contributed Performance for S6	0.063060
Contributed Performance for S7	0.011970
SoS6 Performance After Change	**0.970973**

Appendix F

SIMULATION INPUTS

This file was used in the simulation model for SoS1

#Number_of_Systems 3

#Maximum_Transitions 10

2 10 1 .4 .001

#Weights 0.63057041 0.117647059 0.251782531

#Weights 0.806375042 0.124448966 0.069175992

#System_1_Rate 2

10 0.666666667 0.666666667 1 .4 .001

#System_1_Degree 2

10 .8 .8 1 .4 .001

#System_1_Performance 2

10 0.853710219 0.967199 1 .4 .001

#System_2_Rate 2

10 -0.333333333 -0.333333333 1 .4 .001

#System_2_Degree 2

10 .8 .8 1 .4 .001

#System_2_Performance 2

10 0.863636392 0.855586 1 .4 .001

#System_3_Rate 2

10 -0.222222222 -0.333333333 1 .4 .001

#System_3_Degree 2

10 .6 .8 1 .4 .001

#System_3_Performance 2

10 0.880530893 0.901961 1 .4 .001

This file was used in the simulation model for SoS 2

#Number_of_Systems 4

#Maximum_Transitions 10

2 10 1 .4 .001

#Weights 0.258039385 0.224280459 0.517680156 0

#Weights 0.275075773 0.2868878 0.423023539 0.015012888

#System_1_Rate 2

10 0.5 0.636363636 1 .4 .001

#System_1_Degree 2

10 0.533333333 0.55 1 .4 .001

#System_1_Performance 2

10 0.790171037 0.954279 1 .4 .001

#System_2_Rate 2

10 0 0 1 .4 .001

#System_2_Degree 2

10 0.8 0.8 1 .4 .001

#System_2_Performance 2

10 0.793130038 0.953989 1 .4 .001

#System_3_Rate 2

10 0.6 0.45 1 .4 .001

#System_3_Degree 2

10 0.666666667 0.666666667 1 .4 .001

#System_3_Performance 2

10 0.801855995 0.964243 1 .4 .001

#System_4_Rate 2

10 0 -0.75 1 .4 .001

#System_4_Degree 2

10 0 0.4 1 .4 .001

#System_4_Performance 2

10 0.79 0.957793956 1 .4 .001

This file was used in the simulation model for SoS3

#Number_of_Systems 4

#Maximum_Transitions 10

2 10 1 .4 .001

#Weights 0.285191348 0.611980033 0.102828619 0

#Weights 0.186735097 0.645874457 0.093170154 0.074220292

#System_1_Rate 2

10 -0.340909091 -0.340909091 1 .4 .001

#System_1_Degree 2

10 0.733333333 0.733333333 1 .4 .001

#System_1_Performance 2

10 0.912485466 0.931921325 1 .4 .001

#System_3_Rate 2

10 .25 0 1 .4 .001

#System_3_Degree 2

10 0.6 0.6 1 .4 .001

#System_3_Performance 2

10 0.237629034 0.896699221 1 .4 .001

#System_4_Rate 2

10 0.403846154 0.403846154 1 .4 .001

#System_4_Degree 2

10 0.866666667 0.866666667 1 .4 .001

#System_4_Performance 2

10 0.452151275 0.638659088 1 .4 .001

#System_2_Rate 2

10 0 0.15 1 .4 .001

#System_2_Degree 2

10 0 0.666666667 1 .4 .001

#System_2_Performance 2

10 0.53 0.931921325 1 .4 .001

This file was used in the simulation model for SoS4

#Number_of_Systems 6

#Maximum_Transitions 10

2 10 1 .4 .001

#Weights 0.02578191 0.011496196 0.020371936 0.044632291 0.871344041 0.026373626

#Weights 0.005200709 0.003852377 0.005894137 0.00735804 0.970336698 0.00735804

#System_1_Rate 2

10 -0.047619048 -0.047619048 1 .4 .001

#System_1_Degree 2

10 .7 .7 1 .4 .001

#System_1_Performance 2

10 0.809835987 0.607407 1 .4 .001

#System_2_Rate 2

10 -0.818181818 -0.818181818 1 .4 .001

#System_2_Degree 2

10 0.733333333 0.733333333 1 .4 .001

#System_2_Performance 2

10 0.727941066 0.84 1 .4 .001

#System_3_Rate 2

10 -0.3 -0.3 1 .4 .001

#System_3_Degree 2

10 0.666666667 0.666666667 1 .4 .001

#System_3_Performance 2

10 0.809128718 0.764706 1 .4 .001

#System_4_Rate 2

10 -0.111111111 -0.111111111 1 .4 .001

#System_4_Degree 2

10 0.6 .6 1 .4 .001

#System_4_Performance 2

10 0.784090869 0.8272251 1 .4 .001

#System_5_Rate 2

10 0.833333333 0.833333333 1 .4 .001

#System_5_Degree 2

10 .8 .8 1 .4 .001

#System_5_Performance 2

10 0.723418576 0.887804 1 .4 .001

#System_6_Rate 2

10 -0.166666667 -0.166666667 1 .4 .001

#System_6_Degree 2

10 .8 .8 1 .4 .001

#System_6_Performance 2

10 0.887820554 0.95288 1 .4 .001

This file was used in the simulation model for SoS5

#Number_of_Systems 7

#Maximum_Transitions 10

2 10 1 .4 .001

#Weights 0.293364852 0.135311379 0.129931529 0.162699707 0.080371699 0.077111184 0.121209651

#Weights 0.35801656 0.10453519 0.090233346 0.169646218 0.043846443 0.097760632 0.135961611

#System_1_Rate 2

10 0 -0.102040816 1 .4 .001

#System_1_Degree 2

10 0 0.56 1 .4 .001

#System_1_Performance 2

10 0.878299652 0.964058 1 .4 .001

#System_3_Rate 2

10 0 0 1 .4 .001

#System_3_Degree 2

10 0 0.6 1 .4 .001

#System_3_Performance 2

10 0.840309268 0.964058 1 .4 .001

#System_4_Rate 2

10 -0.142857143 -0.510204082 1 .4 .001

#System_4_Degree 2

10 0.6 0.56 1 .4 .001

#System_4_Performance 2

10 0.880175669 0.940563 1 .4 .001

#System_6_Rate 2

10 -0.142857143 -0.428571429 1 .4 .001

#System_6_Degree 2

10 0.8 1 1 .4 .001

#System_6_Performance 2

10 0.925851782 0.978924 1 .4 .001

#System_7_Rate 2

10 -0.428571429 -0.285714286 1 .4 .001

#System_7_Degree 2

10 0.6 0.6 1 .4 .001

#System_7_Performance 2

10 0.889452353 0.940187783 1 .4 .001

#System_2_Rate 2

10 0 0.285714286 1 .4 .001

#System_2_Degree 2

10 0 0.6 1 .4 .001

#System_2_Performance 2

10 0.778012747 0.964058 1 .4 .001

#System_5_Rate 2

10 -0.285714286 -0.285714286 1 .4 .001

#System_5_Degree 2

10 0.8 0.8 1 .4 .001

#System_5_Performance 2

10 0.597848027 0.59654 1 .4 .001

This file was used in the simulation model for SoS6

#Number_of_Systems 7

#Maximum_Transitions 10

2 10 1 .4 .001

#Weights 0.24 0.07 0.16 0.26 0.27

#Weights 0.22 0.02 0.05 0.23 0.37 0.09 0.02

#System_1_Rate 2

10 0.69 0.69 1 .4 .001

#System_1_Degree 2

10 0.75 0.75 1 .4 .001

#System_1_Performance 2

10 0.8782 0.977 1 .4 .001

#System_2_Rate 2

10 -0.14 -0.43 1 .4 .001

#System_2_Degree 2

10 0.4 0.6 1 .4 .001

#System_2_Performance 2

10 0.88 0.967 1 .4 .001

#System_3_Rate 2

10 -0.41 -0.41 1 .4 .001

#System_3_Degree 2

10 0.7 0.7 1 .4 .001

#System_3_Performance 2

10 0.44 0.979 1 .4 .001

#System_4_Rate 2

10 -0.14 0 1 .4 .001

#System_4_Degree 2

10 0.8 0.8 1 .4 .001

#System_4_Performance 2

10 0.89 0.98 1 .4 .001

#System_6_Rate 2

10 0 0.17 1 .4 .001

#System_6_Degree 2

10 0 0.49 1 .4 .001

#System_6_Performance 2

10 0.85 0.974 1 .4 .001

#System_5_Rate 2

10 -0.29 -0.29 1 .4 .001

#System_5_Degree 2

10 0 0.8 0.8 1 .4 .001

#System_5_Performance 2

10 0.96 0.96 1 .4 .001

#System_7_Rate 2

10 -0.43 -0.43 1 .4 .001

#System_7_Degree 2

10 0.8 0.8 1 .4 .001

#System_7_Performance 2

10 0.946 0.946 1 .4 .001

Appendix G

MATLAB CODE

Histogram and statistical properties

```
clear;

Sim_file_name=input('Simulation File Name\n', 's');

Tm=input('Maximum Time\n');

n_rep=input('Enter Number of Repetitions\n');

% Neg_avg= input('Enter Negative Treshold\n');


TExt=0:Tm/400:Tm;

for k=1:n_rep

    [Tsort,OSpf, O, Pt, Rt, Dt,
OSpfExt,OExt,PtExt,RtExt,DtExt]=OverallTransition_All(Sim_file_name, TExt);

    szT=size(TExt);

sz1=szT(2);

z1=trapz(TExt,OSpfExt)/TExt(sz1);

avgExt(k)=z1;

%fprintf('\navg 1 = %.5f\n',z1);

end

%[avg, avg_p, t, SR_F, SD_F, SP_F, Tsort_F, OSpf_F, Pt_F,avgExt,
avg_pExt]=Avg_Performance_MonteCarlo1_0912(Sim_file_name,Tm,n_rep,TExt);

mu_avg=mean(avgExt);

std_avg=std(avgExt);

fprintf('\n avg mean performance %.6f over time 0 to %.6f for %d runs, standard
deviation %.6f\n', mu_avg, Tm, n_rep, std_avg);
```

```
fprintf('\n skewness %.6f, kurtosis %.6f \n',  skewness(avgExt),  kurtosis(avgExt));

% A=find(avg <= Neg_avg);

% sz=size(A);

% fprintf('\n number of negative averages %d  proportion %.3f \n', sz(2), sz(2)/n_rep);

[mh mn]=hist(avgExt, 21);

mh=mh/sum(mh)/(mn(2)-mn(1));

dx=(mn(2)-mn(1))/2;

nx=mn(1)-dx:(mn(21)-mn(1)+2*dx)/100:mn(21)+dx;

nd=1/(sqrt(2*pi)*std_avg)*exp(-(nx-ones(1,101)*mu_avg).^2/(2*std_avg^2));

figure(1)

plot(mn,mh,'-b',nx,nd,'-r',mn,mh,'ob')

title('Histogram/normalized (blue) vs Normal Density Function (red)');

xlabel(sprintf('average mean performance --- %d repetitions', n_rep));

ylabel('normalized relative frequencies');

%sz_1=size(avg_pExt);

% m=sz_1(1);

% for v=1:m

% mu_avg_p=mean(avg_pExt(v,:));

% std_avg_p=std(avg_pExt(v,:));

% fprintf('\n avg mean performance %.6f of system %d over time 0 to %.6f for %d runs,
standard deviation %.6f\n', mu_avg_p, v, Tm, n_rep, std_avg_p);

% % clear A;

% % Neg_avg= input(sprintf('Enter Negative Treshold for system %d \n', v));

% % A=find(avg_p(v,:) <= Neg_avg);

% % sz=size(A);
```

```
% % fprintf('\n number of negative averages %d  proportion %.3f \n', sz(2), sz(2)/n_rep);

% end
```

Overall Transition All

```
function
[Tsort,OSpf,O,Pt,Rt,Dt,OSpfExt,OExt,PtExt,RtExt,DtExt]=OverallTransition_All(Sim_file_name,TExt)


[A ] = textread(Sim_file_name,'%s',-1);

m=str2double(A(2));

x=str2double(A(4));

M=zeros((m+1)*9, x+1);


n = str2double(A(5));


t= str2double(A(6));

 Tr(m*3+1)=t;

    clear P;

    for u=1:n

        P(u)= u;

    end

     k=str2double(A(7));

     clear y;

    for u=1:floor(n*n-n)

        y(u)= str2double(A(7+u));
```

```
    end


    s=8+floor(n*n-n);
for v=1:m
   wx(1,v)=str2double(A(s+v));
end
s=s+m+1;
for v=1:m
   wx(2,v)=str2double(A(s+v));
end
clear q;
    u=1;
    for r=1:n
      for c=1:n
         if r~=c
            q(r,c)= y(u);
            u=u+1;
         end
      end
    end


clear Ts;
    clear St;
    clear Sp;
```

```
    [Ts,St,Sp, Sp_min,Sp_max]=SystemTransition0717(n,t,P,k,q);


    M(m*9+1, 1:t+1)=Ts;
    M(m*9+2, 1:t+1)=St;
    M(m*9+3, 1:t+1)=Sp;


s=s+m+2;
for v=1:m
    n = str2double(A(s));
    t= str2double(A(s+1));
    Tr((v-1)*3+1)=t;
    clear P;
    for u=1:n
        P(u)= str2double(A(s+1+u));
    end
    k=str2double(A(s+1+n+1));
    clear y;
    for u=1:floor(n*n-n)
        y(u)= str2double(A(s+n+2+u));
    end
    s=floor(s+n*n+4);
    clear q;
    u=1;
```

```
  for r=1:n
   for c=1:n
     if r~=c
       q(r,c)= y(u);
       u=u+1;
     end
   end
  end

  clear Ts;
  clear St;
  clear Sp;

  [Ts,St,Sp, Sp_min,Sp_max]=SystemTransition0717(n,t,P,k,q);
%    display('end');
  M((v-1)*9+1, 1:t+1)=Ts;
  M((v-1)*9+2, 1:t+1)=St;
  M((v-1)*9+3, 1:t+1)=Sp;

  n = str2double(A(s));
  t= str2double(A(s+1));
  Tr((v-1)*3+2)=t;
  clear P;
  for u=1:n
```

```
    P(u)= str2double(A(s+1+u));
end
k=str2double(A(s+1+n+1));
clear y;
for u=1:floor(n*n-n)
    y(u)= str2double(A(s+n+2+u));
end
s=floor(s+n*n+4);
clear q;
u=1;
for r=1:n
  for c=1:n
     if r~=c
        q(r,c)= y(u);
        u=u+1;
     end
  end
end

clear Ts;
clear St;
clear Sp;
[Ts,St,Sp, Sp_min,Sp_max]=SystemTransition0717(n,t,P,k,q);
M((v-1)*9+4, 1:t+1)=Ts;
```

```
M((v-1)*9+5, 1:t+1)=St;
M((v-1)*9+6, 1:t+1)=Sp;


n = str2double(A(s));
t= str2double(A(s+1));
Tr((v-1)*3+3)=t;
clear P;
for u=1:n
    P(u)= str2double(A(s+1+u));
end
k=str2double(A(s+1+n+1));
clear y;
for u=1:floor(n*n-n)
    y(u)= str2double(A(s+n+2+u));
end
s=floor(s+n*n+4);
clear q;
u=1;
for r=1:n
  for c=1:n
     if r~=c
        q(r,c)= y(u);
        u=u+1;
     end
```

```
      end
    end

    clear Ts;
    clear St;
    clear Sp;
    [Ts,St,Sp, Sp_min,Sp_max]=SystemTransition0717(n,t,P,k,q);
    M((v-1)*9+7, 1:t+1)=Ts;
    M((v-1)*9+8, 1:t+1)=St;
    M((v-1)*9+9, 1:t+1)=Sp;
end

j1=1;
j2=0;
for v=1:m
    j1=j2+1;
    j2=j2+Tr((v-1)*3+1)+1;
    Ta(1,j1:j2)=M((v-1)*9+1, 1:Tr((v-1)*3+1)+1);
    Ta(2,j1:j2)=M((v-1)*9+2, 1:Tr((v-1)*3+1)+1);
    Ta(3,j1:j2)=M((v-1)*9+3, 1:Tr((v-1)*3+1)+1);
    j1=j2+1;
    j2=j2+Tr((v-1)*3+2)+1;
    Ta(1,j1:j2)=M((v-1)*9+4, 1:Tr((v-1)*3+2)+1);
    Ta(2,j1:j2)=M((v-1)*9+5, 1:Tr((v-1)*3+2)+1);
```

```
    Ta(3,j1:j2)=M((v-1)*9+6, 1:Tr((v-1)*3+2)+1);
    j1=j2+1;
    j2=j2+Tr((v-1)*3+3)+1;
    Ta(1,j1:j2)=M((v-1)*9+7, 1:Tr((v-1)*3+3)+1);
    Ta(2,j1:j2)=M((v-1)*9+8, 1:Tr((v-1)*3+3)+1);
    Ta(3,j1:j2)=M((v-1)*9+9, 1:Tr((v-1)*3+3)+1);
end
 j1=j2+1;
    j2=j2+Tr(m*3+1)+1;
    Ta(1,j1:j2)=M(m*9+1, 1:Tr(m*3+1)+1);
    Ta(2,j1:j2)=M(m*9+2, 1:Tr(m*3+1)+1);
    Ta(3,j1:j2)=M(m*9+3, 1:Tr(m*3+1)+1);


Ttmp=sort(Ta(1,:));
Tsort=Ttmp(4*m:j2);
j3=j2-4*m+1;
for r=1:j3
    j1=1;
    j2=0;
for v=1:m
    j1=j2+1;
    j2=j2+Tr((v-1)*3+1)+1;
    clear Fnd;
```

```
    clear I;
     Fnd=find(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1) <= 0);

      [z I]=max(Fnd);
    d=I(1);
Rt(v,r)=Ta(3,j1+d-1);

    j1=j2+1;
    j2=j2+Tr((v-1)*3+2)+1;
    clear Fnd;
    clear I;
    Fnd=find(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1) <= 0);

      [z I]=max(Fnd);
    d=I(1);
    Dt(v,r)=Ta(3,j1+d-1);

j1=j2+1;
    j2=j2+Tr((v-1)*3+3)+1;
    clear Fnd;
    clear I;
    Fnd=find(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1) <= 0);

      [z I]=max(Fnd);
```

```
    d=I(1);

    Pt(v,r)=Ta(3,j1+d-1);

end


    j1=j2+1;

    j2=j2+Tr(m*3+1)+1;

    clear Fnd;

    clear I;

     Fnd=find(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1) <= 0);


      [z I]=max(Fnd);

    d=I(1);

Wt(r)=Ta(3,j1+d-1);

end


for v=1:m

O(v,:)=ones(1,j3)+Rt(v,:).*Dt(v,:);

% O(v,:)=Rt(v,:).*Dt(v,:);

end


for r=1:j3

   w(r,:)= wx(Wt(r),:);

end

for r=1:j3
```

```
%     OSpf(r)=dot(Pt(:,r).*w',O(:,r));
    OSpf(r)=dot(Pt(:,r).*w(r,:)',O(:,r))/dot(w(r,:)',O(:,r));
end
sz=size(TExt);
j3=sz(2);

for r=1:j3
    j1=1;
    j2=0;
for v=1:m
    j1=j2+1;
    j2=j2+Tr((v-1)*3+1)+1;
    clear Fnd;
    clear I;
%    Fnd=abs(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1));
     FndExt=find(Ta(1,j1:j2)-TExt(r)*ones(1,j2-j1+1) <= 0);
      [z I]=max(FndExt);
%     [z I]=min(Fnd);
    d=I(1);
%     d=z;
RtExt(v,r)=Ta(3,j1+d-1);

j1=j2+1;
    j2=j2+Tr((v-1)*3+2)+1;
```

```
    clear Fnd;
    clear I;
%    Fnd=abs(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1));
     FndExt=find(Ta(1,j1:j2)-TExt(r)*ones(1,j2-j1+1) <= 0);
      [z I]=max(FndExt);
%     [z I]=min(Fnd);
    d=I(1);
%     d=z;
DtExt(v,r)=Ta(3,j1+d-1);


j1=j2+1;
    j2=j2+Tr((v-1)*3+3)+1;
    clear Fnd;
    clear I;
%    Fnd=abs(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1));
     FndExt=find(Ta(1,j1:j2)-TExt(r)*ones(1,j2-j1+1) <= 0);
      [z I]=max(FndExt);
%     [z I]=min(Fnd);
    d=I(1);
%     d=z;
PtExt(v,r)=Ta(3,j1+d-1);
end
   j1=j2+1;
    j2=j2+Tr(m*3+1)+1;
```

```
    clear Fnd;

    clear I;

     Fnd=find(Ta(1,j1:j2)-TExt(r)*ones(1,j2-j1+1) <= 0);


      [z I]=max(Fnd);

    d=I(1);

WtExt(r)=Ta(3,j1+d-1);

end


for r=1:j3

   wExt(r,:)= wx(WtExt(r),:);

end

for v=1:m

OExt(v,:)=ones(1,j3)+RtExt(v,:).*DtExt(v,:);

% OExt(v,:)=RtExt(v,:).*DtExt(v,:);

end

for r=1:j3

%     OSpfExt(r)=dot(PtExt(:,r).*w',OExt(:,r));

      OSpfExt(r)=dot(PtExt(:,r).*wExt(r,:)',OExt(:,r))/dot(wExt(r,:)',OExt(:,r));

end
```

Average Performance Monte Carlo 1_ 0912

```
function [avg, avg_p, t, SR_F, SD_F, SP_F, Tsort_F, OSpf_F, Pt_F,avgExt,
avg_pExt,OSpfExt,PtExt]=Avg_Performance_MonteCarlo1_0912(Sim_file_name,Tm,n_rep,TE
xt)
```

```
t=Tm;

for r= 1:n_rep

    clear Tsort;

    clear OSpf;

    clear O;

    clear Pt;

    clear Tsort_Tm;

    clear OSpf_Tm;

    clear Pt_Tm;

[Tsort,OSpf,O,Pt,Rt,Dt,OSpfExt,OExt,PtExt,RtExt,DtExt,SR,SD,SP]=OverallTransition_All_St
1(Sim_file_name,TExt);

    A=find(Tsort > Tm);

    sz=size(A);

    if sz(2)> 0

        [X I]=min(A);

        u=X;

        Tsort_Tm =Tsort(1:u);

        OSpf_Tm =OSpf(1:u);

        Tsort_Tm(1,u)=Tm;

        Pt_Tm=Pt(:,1:u);

        SR_F=SR(:,u);

        SD_F=SD(:,u);

        SP_F=SP(:,u);

    else
```

```
        sz_2=size(Tsort);
        u=sz_2(2);
        Tsort_Tm=Tsort;
        OSpf_Tm=OSpf;
        Tsort_Tm(1,u)=Tm;
        Pt_Tm=Pt(:,1:u);
        SR_F=SR(:,u);
        SD_F=SD(:,u);
        SP_F=SP(:,u);
    end
    if Tsort(u) < t
       t=Tsort(u);
    end
    avg(r)=trapz(Tsort_Tm(1,:),OSpf_Tm(1,:))/Tsort_Tm(1,u);
    sz_4=size(TExt);
    avgExt(r)=trapz(TExt,OSpfExt)/TExt(sz_4(2));
    sz_3=size(Pt);
    m=sz_3(1);
    for v= 1:m
    avg_p(v,r)=trapz(Tsort_Tm(1,:),Pt_Tm(v,:))/Tsort_Tm(1,u);
    avg_pExt(v,r)=trapz(TExt,PtExt(v,:))/TExt(sz_4(2));
    end
end
Tsort_F= Tsort_Tm(1:u);
```

```
OSpf_F= OSpf(1:u);

Pt_F=Pt(:,1:u);
```

Overall Transition All St1

```
function
[Tsort,OSpf,O,Pt,Rt,Dt,OSpfExt,OExt,PtExt,RtExt,DtExt,SR,SD,SP]=OverallTransition_All_St
1(Sim_file_name,TExt)

[A ] = textread(Sim_file_name,'%s',-1);

m=str2double(A(2));

x=str2double(A(4));

M=zeros(m*9, x+1);

for v=1:m

  w(v)=str2double(A(5+v));

end


s=7+m;

for v=1:m

    n = str2double(A(s));

    t= str2double(A(s+1));

    Tr((v-1)*3+1)=t;

    clear P;

    for u=1:n

        P(u)= str2double(A(s+1+u));

    end

    k=str2double(A(s+1+n+1));
```

```
    clear y;
    for u=1:floor(n*n-n)
        y(u)= str2double(A(s+n+2+u));
    end
    s=floor(s+n*n+4);
    clear q;
    u=1;
    for r=1:n
      for c=1:n
         if r~=c
            q(r,c)= y(u);
            u=u+1;
         end
      end
    end
    clear Ts;
    clear St;
    clear Sp;
%     display (q);
%     display(t);
    [Ts,St,Sp, Sp_min,Sp_max]=SystemTransition0717(n,t,P,k,q);
%     display('end');
    M((v-1)*9+1, 1:t+1)=Ts;
    M((v-1)*9+2, 1:t+1)=St;
```

```
M((v-1)*9+3, 1:t+1)=Sp;


n = str2double(A(s));
t= str2double(A(s+1));
Tr((v-1)*3+2)=t;
clear P;
for u=1:n
    P(u)= str2double(A(s+1+u));
end
k=str2double(A(s+1+n+1));
clear y;
for u=1:floor(n*n-n)
    y(u)= str2double(A(s+n+2+u));
end
s=floor(s+n*n+4);
clear q;
u=1;
for r=1:n
  for c=1:n
     if r~=c
        q(r,c)= y(u);
        u=u+1;
     end
  end
```

```
end


clear Ts;
clear St;
clear Sp;
[Ts,St,Sp, Sp_min,Sp_max]=SystemTransition0717(n,t,P,k,q);
M((v-1)*9+4, 1:t+1)=Ts;
M((v-1)*9+5, 1:t+1)=St;
M((v-1)*9+6, 1:t+1)=Sp;


n = str2double(A(s));
t= str2double(A(s+1));
Tr((v-1)*3+3)=t;
clear P;
for u=1:n
   P(u)= str2double(A(s+1+u));
end
k=str2double(A(s+1+n+1));
clear y;
for u=1:floor(n*n-n)
   y(u)= str2double(A(s+n+2+u));
end
s=floor(s+n*n+4);
clear q;
```

```
    u=1;
    for r=1:n
      for c=1:n
         if r~=c
            q(r,c)= y(u);
            u=u+1;
         end
      end
    end

    clear Ts;
    clear St;
    clear Sp;
    [Ts,St,Sp, Sp_min,Sp_max]=SystemTransition0717(n,t,P,k,q);
    M((v-1)*9+7, 1:t+1)=Ts;
    M((v-1)*9+8, 1:t+1)=St;
    M((v-1)*9+9, 1:t+1)=Sp;
end

j1=1;
j2=0;
for v=1:m
    j1=j2+1;
    j2=j2+Tr((v-1)*3+1)+1;
```

```
    Ta(1,j1:j2)=M((v-1)*9+1, 1:Tr((v-1)*3+1)+1);
%     if v==1
%     display( Ta(1,j1:j2));
%     end
    Ta(2,j1:j2)=M((v-1)*9+2, 1:Tr((v-1)*3+1)+1);
    Ta(3,j1:j2)=M((v-1)*9+3, 1:Tr((v-1)*3+1)+1);
    j1=j2+1;
    j2=j2+Tr((v-1)*3+2)+1;
    Ta(1,j1:j2)=M((v-1)*9+4, 1:Tr((v-1)*3+2)+1);
    Ta(2,j1:j2)=M((v-1)*9+5, 1:Tr((v-1)*3+2)+1);
    Ta(3,j1:j2)=M((v-1)*9+6, 1:Tr((v-1)*3+2)+1);
    j1=j2+1;
    j2=j2+Tr((v-1)*3+3)+1;
    Ta(1,j1:j2)=M((v-1)*9+7, 1:Tr((v-1)*3+3)+1);
    Ta(2,j1:j2)=M((v-1)*9+8, 1:Tr((v-1)*3+3)+1);
    Ta(3,j1:j2)=M((v-1)*9+9, 1:Tr((v-1)*3+3)+1);
end


Ttmp=sort(Ta(1,:));
Tsort=Ttmp(3*m:j2);
% display(Tsort);
j3=j2-3*m+1;
for r=1:j3
    j1=1;
```

```
    j2=0;
for v=1:m
    j1=j2+1;
    j2=j2+Tr((v-1)*3+1)+1;
    clear Fnd;
    clear I;
%     Fnd=abs(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1));
     Fnd=find(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1) <= 0);


      [z I]=max(Fnd);
%     [z I]=min(Fnd);
    d=I(1);
%     d=z;
Rt(v,r)=Ta(3,j1+d-1);
SR(v,r)=Ta(2,j1+d-1);
% if r<=5 && v==1
%     display (Fnd);
%      display(Ta(1,j1:j2));
%      display(Ta(3,j1:j2));
%      display(Rt(v,r));
%      display(d);
%      end
% if d==1
%     Rt(v,r)=Ta(3,j1+d-1);
```

```
%
% elseif d==j2-j1+1;
%     Rt(v,r)=Ta(3,j2);
% else
%     if z< Ta(1,d)
%     Rt(v,r)=Ta(3,j1+d-1);
%     else
%     Rt(v,r)=Ta(3,j1+d-2);
%     end
% end
    j1=j2+1;
    j2=j2+Tr((v-1)*3+2)+1;
    clear Fnd;
    clear I;
%     Fnd=abs(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1));
    Fnd=find(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1) <= 0);


      [z I]=max(Fnd);
%     [z I]=min(Fnd);
    d=I(1);
    Dt(v,r)=Ta(3,j1+d-1);
    SD(v,r)=Ta(2,j1+d-1);
% if d==1
%     Dt(v,r)=Ta(3,j1+d-1);
```

```
% elseif d==j2-j1+1;
%     Dt(v,r)=Ta(3,j2);
% else
%     if z< Ta(1,d)
%     Dt(v,r)=Ta(3,j1+d-1);
%     else
%     Dt(v,r)=Ta(3,j1+d-2);
%     end
% end
j1=j2+1;
    j2=j2+Tr((v-1)*3+3)+1;
    clear Fnd;
    clear I;
%     Fnd=abs(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1));
    Fnd=find(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1) <= 0);


      [z I]=max(Fnd);
%     [z I]=min(Fnd);
    d=I(1);
    Pt(v,r)=Ta(3,j1+d-1);
    SP(v,r)=Ta(2,j1+d-1);
% if d==1
%     Pt(v,r)=Ta(3,j1+d-1);
% elseif d==j2-j1+1;
```

```
%     Pt(v,r)=Ta(3,j2);
% else
%     if z< Ta(1,d)
%     Pt(v,r)=Ta(3,j1+d-1);
%     else
%     Pt(v,r)=Ta(3,j1+d-2);
%     end
% end
end
end

for v=1:m
O(v,:)=ones(1,j3)+Rt(v,:).*Dt(v,:);
end

for r=1:j3
    OSpf(r)=dot(Pt(:,r).*w',O(:,r));
end

sz=size(TExt);
j3=sz(2);

for r=1:j3
    j1=1;
```

```
    j2=0;
for v=1:m
    j1=j2+1;
    j2=j2+Tr((v-1)*3+1)+1;
    clear Fnd;
    clear I;
%    Fnd=abs(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1));
     FndExt=find(Ta(1,j1:j2)-TExt(r)*ones(1,j2-j1+1) <= 0);
      [z I]=max(FndExt);
%     [z I]=min(Fnd);
    d=I(1);
%     d=z;
RtExt(v,r)=Ta(3,j1+d-1);


j1=j2+1;
    j2=j2+Tr((v-1)*3+2)+1;
    clear Fnd;
    clear I;
%    Fnd=abs(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1));
     FndExt=find(Ta(1,j1:j2)-TExt(r)*ones(1,j2-j1+1) <= 0);
      [z I]=max(FndExt);
%     [z I]=min(Fnd);
    d=I(1);
%     d=z;
```

```
DtExt(v,r)=Ta(3,j1+d-1);
j1=j2+1;
    j2=j2+Tr((v-1)*3+3)+1;
    clear Fnd;
    clear I;
%    Fnd=abs(Ta(1,j1:j2)-Tsort(r)*ones(1,j2-j1+1));
     FndExt=find(Ta(1,j1:j2)-TExt(r)*ones(1,j2-j1+1) <= 0);
      [z I]=max(FndExt);
%     [z I]=min(Fnd);
    d=I(1);
%     d=z;
PtExt(v,r)=Ta(3,j1+d-1);
end
end

for v=1:m
OExt(v,:)=ones(1,j3)+RtExt(v,:).*DtExt(v,:);
end
for r=1:j3
    OSpfExt(r)=dot(PtExt(:,r).*w',OExt(:,r))/dot(w',OExt(:,r));
end
```

VITA

Karima Tayeb is a native of Casablanca, Morocco. Her academic achievements include a Bachelor of Science Degree in Industrial Engineering (2005) and a Master of Science Degree in Industrial Engineering, both from The University of Tennessee, Knoxville. She is currently fulfilling the requirements for a Doctor of Philosophy Degree in Industrial Engineering at the University of Tennessee in Knoxville, Tennessee and is expected to complete the Ph.D. degree in Summer 2011.