SYSTEMS ENGINEERING AND MANAGEMENT

Chase C. Lassiter

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Approved by

Advisory committee

Dr. –ing. Uwe Apel Dr. –ing Jurgen Westhof

L. Vince Howe Chair

Accepted By

Dean, Graduate School
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ABSTRACT

The idea of Systems Engineering has been around since the beginning of engineering and complex systems. Today it has evolved into a respected field of engineering taking many of its methods and best practices from earlier forms of engineering. The actual Systems Engineering process involves both technical engineering and management elements. This brings up the question, “should a successful manager oversee the process?” Managers already possess many of the skills required to properly implement the Systems Engineering process and they have the ability to create partnerships with all of the technical engineers and other members of the multi functional teams typically involved in the process. Currently, many system projects are failing because of neglect of the management elements involved with the approach.

Is there a current need for Systems Engineering? If so, should a successful manager oversee the process? Can Systems Engineering benefit the commercial construction field by being a useful tool for construction managers? Through secondary research and a practical application of Systems Engineering tools, these goals will be tested.

The results showed that it would be beneficial for successful managers to oversee the systems engineering approach. The results also showed that the systems engineering approach and its tools can be beneficial if properly applied to the construction industry including Thomas Simpson Construction.
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HISTORY OF SYSTEMS ENGINEERING

a. History of the Field of Engineering

The field of engineering has been unofficially supplementing inventions and projects since the beginning of time. In recent times, engineering has evolved into a diverse field with many different sub fields including Systems Engineering. The history of engineering is important because Systems Engineering takes some of its tools and best practices from the roots of engineering, as well as, the other sub fields of engineering.

The root of the word engineer is derived from the Latin word “ingeniare,” meaning to think in the sense of construct or craftsmanship (Luppicini 104). From this early translation of the modern word, one can already derive that engineers are mainly focused on the question of how. Energy and raw materials are the tools engineers have to work with, by utilizing these tools, engineers have to figure out how to effectively and efficiently “ingeniare” everything in the world (Smith 1-2). Another definition is that an engineer is anyone concerned with the process of developing a system component or process to meet required needs, while utilizing the sciences to convert resources effectively and efficiently into desired outputs (Frey Slide 28). From this definition of engineering, one can already derive the importance of the development of the field of Systems Engineering. From the fields inception engineers became known as the backbone of the whole industrial system (Dallaire 64).

Before there was officially a field of engineering, early humans had to develop a way to measure, including units of measurement. Unlike the detailed metric and customary units the world has today, these early forms of measurement were very primitive but served the
The Greeks were the first to discover and utilize a comprehensive measuring system which was based on units like the square plethron (Rossi 3). A square plethron represented the amount of land a yoke of oxen could plow up in one day (Rossi 3). This early measurement system coupled with new inventions of measurement tools, built the stage for the first emergence of engineers. One of the first and most influential instruments used for measurement in the engineering field was the abacus (Rossi 41). The next influential invention was the first level, called the chorobate. The chorobate successfully utilized the scientific technology of the inclination of water to determine if a structure was level (Rossi 17). Engineers equipped with these primitive tools of measurement and the level, were able to begin constructing structures like the early aqueducts of Rome. Most of these new applications of engineering were non professional and were driven mainly by basic human instincts. They included such inventions for the Greeks as irrigation, for the Romans aqueducts, roads, and public building; and for the Chinese gunpowder, and wheelbarrows (History of Engineering 1).

From the invention of stone tools in 1,000,000 BC, the invention of irrigation in 7,000 BC, and the invention of measuring devices, all led up to the inception of the first documented engineer, Imaotep. He was most famous for the construction of the Step Pyramid (Frey 29). All of this ancient history shaped the modern development of the engineering field and built a vast database of information and tools for system engineers to continue to utilize today.

The modern day field of engineering was built upon the building blocks of ancient engineering. There were educational materials referencing the tools and processes of engineering dating back to the Vitruvius de Architectura from Rome in 1 AD (Smith 2). Once educational materials about the field are documented, the field then made it possible to learn
from the mistakes of previous generations and begin to develop best practices. Some of these early best practices are still being utilized by system engineers today all around the world. The first professional engineers appeared in the 16th century and they were military engineers whose job was to build and design instruments of war, including catapults, battering rams, and fortifications (CSCE 1). During the 16th century engineers continued to build military structures and weapons but also started during times of peace, designing and constructing large buildings and cathedrals (History of Engineering 1). This trend of a divergence in the engineering field continued through the 17th century all the way to the industrial revolution. During the industrial revolution, many fields of engineering evolved from such influential inventions as the Watt Steam engine and railways (History of Engineering 1). The result was the divergence of the field of engineering into two different fields of engineering; civil and military (Boyer 1). Both of these fields deal with construction and take their roots and best practices from the early roots of engineering. Both fields are still influencing modern engineering techniques. The first engineering schools for military engineers date back to 18th century France (Luppicini 1). Although the essential practice of civil engineering dates back to structures such as the town of Machu Picchu in Peru, the first professional civil engineer was born in Great Britain. His name was John Smeaton and he built the Eddystone Lighthouse (CSCE 1). Civil engineering has ancient roots and is still today the predominant field of engineering. Other fields of engineering sprang up throughout time including mechanical and electrical engineering. Mechanical engineering dates back to Scotland and was conceived when inventions such as the Watt Steam engine appeared (Smith 2-3). Also the field of electrical engineering was started because of the invention of the electric cell in the 1800’s by Alessandro Volt. This discovery created the need
for electrical engineering (Smith 2-3). All of the reasons for the inception of different fields of engineering can be attributed to pull strategies because all of them derived from a void in engineering technology created by numerous new inventions. The American evolution of the field of professional engineering only dates back to the year 1794. In 1817, the Erie Canal was developed by early civil engineers and demonstrated the complex a project engineers could help complete efficiently and effectively (Boyer 1). In this same era, civil engineers in the US began mass production techniques for automobiles with Henry Ford’s first production of the Model T. The history of engineering and the invention of complex systems created a pull for Systems Engineering.

b. The Evolution of Complex Systems

The history of complex systems is dependent on the scientific definitions of systems and complex systems as well as their evolution throughout history. Hereafter is a list and analysis of many different influential definitions on the history of systems. The first definition is that a system is an integrated unit of people, products, and processes which perform a certain capability to satisfy a stated objective (Department of Defense 6). This first definition already exemplifies the fact that systems require the management of many different elements. Another definition of systems is that the different elements involved provide an output that is better than the results from the performance of the same elements used solo (Badiru 2). This definition shows that all of the different elements have to interact with each other to achieve the objective. The first systems in history date back to early civilizations and include; the wind motor from Afghanistan, and the braking system for carts developed in Rome (Rossi 161). Many of these first systems were not complex enough to require extensive system engineering.
On the other hand, complex systems which systems engineers are mainly concerned with, require planning, coordination, and management (Frey slide 29). The complex system is defined the same as a regular system except that the subsystems are significant enough to require their own attention (Jewell 35). A complex system is similar to a tree; the system is the main trunk, and the roots are the subsystems. Modern examples of complex systems include; the national aviation system, the national highway system, and the national defense system (Eisner 2). These complex systems require Systems Engineering techniques because they are usually large in size and are comprised of many different sub systems or components. They also involve the input of multi functional team members and involve scheduling and cost management elements.

c. The Evolution of Systems Engineering

Many of the early systems utilized elements of Systems Engineering, just not in a very formal way. When the great pyramids were constructed, the workers did not just simply, start collecting materials and stacking them in a perfect pyramid shape creating a structure which has withstood the sands of time. The systems approach way of thinking dates back to the early works of the great philosopher Aristotle, who wrote about the hierarchical structure of systems (Jewell 11). Many early complex systems like the construction of the great pyramid which involved over 10,000 people, and had a 30 year life cycle required many of the same elements included in the current best practices of Systems Engineering (Frey slide 34). Although complex systems like the great pyramids and the city of Macchu Piccu in Peru required elements of Systems Engineering the field was not yet developed as a professional field until the management of such projects such as Atlas and Sage (Frey slide 39). Just the fact that they
were complex systems does not mean Systems Engineering was present. The facts and evidence do not prove that these early complex systems were not riddled with safety, budget, and schedule problems. Also, the interactions with external environments would have been limited in scope, if not nonexistent.

The 1940’s was the official era when modern professional Systems Engineering began its evolution. The first time the actual phrase “Systems Engineering” was used was in 1940 at the prominent Bell laboratory, who owes its name to the inventor of the telephone, Mr. Alexander Graham Bell (Ji Hyon 1). The need for Systems Engineering at Bell laboratories was based on the invention of the vast new telecommunication network in the USA (Barry Kort 1). The 1940’s also saw the development of such projects such as the Atlas project, which was an intercontinental missile program. It was the military’s most complex system ever initiated and involved numerous subsystems, and new technology, not to mention 70,000 plus team members (Hallam 2). This system was an engineering feat and with Systems Engineering it was developed without many costly setbacks. During and after the second World War Systems Engineering was apparent in numerous complex military systems and in the growing telecommunication networks. During World War Two Systems Engineering helped to choose the design and implement a system to recover black boxes from airplanes brought down by enemy fire (Ji Hyon 1). After the war, the major applications of Systems Engineering steadily increased, prompted by the systems themselves becoming more complex, as well as, the external environments surrounding them. The Sage semi automatic ground environment for national defense was developed using the Systems Engineering approach and Systems Engineering management (Bode 4). From these large military projects, the systems engineers
also started utilizing a new source, computers (Eisner 1). Many other government projects
utilized and further developed the field of Systems Engineering and the application of
computers including; manned space flight, nuclear powered subs, communication satellites,
launch vehicles, modern aircraft, and deep space probes (Jamsheide 191).

In the 1950’s and 1960’s the researchers had already identified that the implementation
of Systems Engineering required extensive management tasks including budgeting and
planning. The first two academic books of this era about Systems Engineering were; “An
Introduction to the Design of Large Scale Systems” 1957 by Harry H. Goode and Robert E
Machol, and “A methodology for Systems Engineering” 1962 Arthur D Hall (Ji Hyon 1). The
field of operations research and its academic knowledge was also very influential on the
development of Systems Engineering and the management of the process (Bode 3). The
evolution of Systems Engineering and its tools is a combination of the history of engineering,
the inception of large systems, the academic research from Bell labs, as well as government
involvement, and operations research.

SYSTEMS ENGINEERING

a. Definition of Systems Engineering and the Identification of the Tools and Processes Involved

Systems Engineering is a process which attempts to maximize the customer’s value. The
systems involved are pull systems, which means they are initiated by customers with a list of
specific requirements which have to be met (Hallam 5). This shows the importance of the
involvement of customer requirements in every decision of the process. The process also
involves not only the recognition, but also the appreciation and integration of all aspects of an
organization (Badiru 2). Systems engineering also utilizes the knowledge of various disciplines in an attempt to build an efficient and effective system (Bode 11). To meet or exceed customer requirements throughout the whole systems life cycle, the various disciplines and aspects of organizations have to be utilized. The Systems Engineering process is also characterized as being top down which means that the process to transform customer needs and requirement into a set of system products and process descriptions must be initiated from top management (Department of Defense 10). The different levels of resources involved have to communicate effectively the information required for the next level to achieve its objectives while maintaining a top down approach.

To achieve the results required of Systems Engineering from the customer, the field is broken up into two different disciplines; the technical knowledge domain, and the Systems Engineering management domain (Department of Defense 7). Typically both domains have been implemented by systems engineers. Both of these disciplines combine to successfully build proper complex systems. During the short history of Systems Engineering, best practices and many tools for all parts of the Systems Engineering process have been developed (Hallam 1). The different elements which work together in the Systems Engineering process to achieve a cost effective and efficient system are; tools, people, best practices, and a specific ways of thinking (Badiru 2). The process involves a great deal of management because of the complexity of the systems involved as well as the various different parties involved. The tools of systems engineers include; people, materials, equipment, energy, process tools, information, and best practices (Badiru 8-1). One of the best practices in the field is to break down the Systems Engineering process into five distinct phases. Arthur D. Hall one of the fathers of
Systems Engineering stated that the five phases were: systems studies, exploratory planning, development planning, studies during development, and current engineering (Hall 162). Risks are apparent in all of these phases and must be dealt with to ensure the system is practical to build. The most apparent and significant risks are end product and enabling product risks (Department of Defense 134). These risks have to be minimized and properly identified in the planning process.

Many different process tools are involved with the Systems Engineering process to ensure that the process meets customer requirements and achieves its goal of the production of an effective and efficient system. One of the first tools used, as well as, one of the most important is the requirement analysis (Department of Defense 8). The requirement analysis allows all parts of the team to see and be aware of what is required of the total system; it is like having goals for a company. Another tool used in the process is an analysis and allocation of functional objectives (Department of Defense 8). This functional analysis and allocation, along with the risks analysis, allows the management of the Systems Engineering process to effectively determine if the system is feasible to be built. These tools are used in Hall’s first two phases. One of the tools involved in the next phase of development planning is the Systems Engineering planning technical plan. This plan describes; what must be accomplished, how the system will be built, how the effort will be scheduled, what resources are needed, and how the efforts will be monitored and controlled (Department of Defense 10). The plan allows for all members of the team to understand how and why they are developing and implementing the complex system. Design syntheses are not only developed for the technical aspects of the system, they are also developed for the designs of the physical elements and the design of the
whole system (Department of Defense 8). The development of improvement strategies in the planning phases is a tool that can help the team deal with many problems including; changing customer needs, requirements changes, lack of technology availability, required reliability, maintenance upgrades, and various safety issues (Department of Defense 7). The most essential tools to assist with the whole process are flow diagrams, either in the form of a flow chart or mathematical model (Bode 2). These tools can be used in many of the phases and they also allow the team members to see all of the elements and their different interactions. Flow tools allow the team to develop a constantly updated list of objectives for all parties involved. The many tools of Systems Engineering and the systems approach, if used properly, can in general, produce many benefits including; fewer cost overruns, and fewer projects that run over schedule (Parker 10). The tools and definitions of the field are still evolving to produce even more desired results.

b. Current Literature in The Systems Engineering Field

Throughout the history of the Systems Engineering field customer requirements were considered important. The current research states that ultimately the field’s goal and main purpose is to trace and manage customer requirements through all phases of system development (Hallam 2). This shows the increased importance placed on this aspect of the Systems Engineering process. Another crucial element of the Systems Engineering process that the new research has identified as a high priority to the process is operational feasibility (Blanchard 49). This element has increased in importance because as systems grow in size and scope the failure to identify early non feasibility becomes even more costly for the government or commercial firm. Historically, the topic of Systems Engineering has not been a very popular
subject for researchers (Blanchard 49). The field is slowly increasing its database of research with research journals in many different countries, and many new topics of interest.

The new research has identified that complex systems should have an open architecture (Jamsheide 21). Open architecture can be implemented and have benefits in the development and implementation phases of the system. The research identifies the benefits of implementing open architecture as; emerging behavior and evolving structure because of quick exchange of external changes, better access to many sources of needed supply, easier integration, faster development of effective technology management, efficient development, and efficient sustainment (Jamsheide 23). The open architecture also helps the system and its developers deal effectively with changes in technology, growing resource constraints, and constantly changing requirements. The steps identified in the new research for the implementation of open architecture on a system are as follows: Phase 1- establish an environment conducive to open system architecture; Phase 2- define the capabilities and requirements of all subsystems; Phase 3- allocate capabilities to the appropriate constituent systems; Phase 4- develop an open executable architecture for all subsystems; Phase 5- simulate the evolution of subsystems and of possible emerging behaviors; Phase 6- constantly monitor and reassemble the subsystems as needed (Jamsheide 24). These phases if implemented correctly can produce a more efficient and effective system that meets or exceeds customer demands. The research about open architecture has pushed researchers in the Systems Engineering field to recognize a new sub field systems of Systems Engineering (Jamsheide 169).
The inception of the new subfield was a combination of a push from open architecture research and a pull from complex systems with increasingly complex subsystems. New systems projects which attempt to integrate new systems and components with legacy systems also pulled the inception of the new subfield systems of Systems Engineering (Keating 2). The definition of systems of systems is large scale integrated systems which are classified as heterogeneous and independently operable on their own, but are none the less networked together for a common goal (Jamshiede 2). From the definition one can already see that this new sub field requires increased total system management. This new approach enhances the old Systems Engineering techniques by emphasizing changing requirements and resulting designs, and it also exemplifies the interaction and interdependencies between systems, processes, best practices, and stakeholders (Jamsheide 21). Most of the new research in the field of systems of Systems Engineering is still trying to properly define the field and separate it from the Systems Engineering field. Some specific skills of systems of Systems Engineering identified include; epistemological, methodological, and ontological skills (Keating 15-16). An example of the application of systems of Systems Engineering is the future transportation fuel system of systems (Jamshiede 409). This complex system requires the integration of new systems to distribute clean diesel fuel and renewable fuels, and also a system to reduce the mpg rating for vehicles in the US (Jamshiede 409). Not only is this system important to the US and world economy, it requires management of very large and complex subsystems with no clear boundaries. Systems of Systems Engineering is a very new field but it is needed and can lend research to more common, less complex systems. The research in the Systems
Engineering field is increasing, but a major gap still exists for research related to the application of Systems Engineering to other fields besides the government and large commercial systems.

5c. Current Need for Systems Engineering and Better Management of The Systems Engineering Process

The increasingly changing external environment and subsequent increase in the laws and regulations surrounding systems, coupled with the increasing complexity of systems, has increased the need for Systems Engineering. This current complex globalized work environment requires someone to look at systems and their architecture from all possible angles and be able to integrate efficiently and effectively all resources. The Systems Engineering process can reduce surprises and the effects of surprises which can be costly if not detrimental for a firm in today’s economic environment (Department of Defense 10). The United States economy produced fifteen trillion dollars worth of goods and services in 2008, which was the largest in the world (Leonhardt 1). Large systems projects make up a large part of this fifteen trillion dollars. Although it was the biggest economy in the world, ever since 2007, the US economy has been in a recession and is facing the current challenge of getting out of the slump, while at the same time adding new jobs (Leonhardt 1). Systems Engineering has to be applied properly to all of the major systems projects in the US, so the projects stay within budget and ahead of schedule allowing the companies and governmental agencies to save money and add new jobs. To keep the systems on budget and ahead of schedule in these economic crisis times, the system engineer has to pay attention to the technical aspects, and also pay increased attention to the effects of the economy during all stages of the system cycle (Leonhardt 1).
Technology is another factor that is increasing the need for proper systems engineering due to constant and dramatic changes. From 1995-1999 the technology growth rate rose 1.9% to a staggering 5% (Gorman 1). Since 1999 the growth rate has been constantly increasing with no end in sight. This calls for systems engineers to build systems with the capability to be reconfigured rapidly and efficiently, in response to changing technology (Jamsheide 22). For example, if a system is being built utilizing a certain technology and the same technology is developed in the east cheaper the system has to be able to accommodate the changes so that system costs can be lowered.

Another example of external environment changes which affect the need for proper Systems Engineering is the new trend in the US of governmental bailouts and ownership. A current example is the US government’s large stake in General Motors. Many governmentally owned businesses like General Motors have failed including the Russian Car company who produced the Lada car (Faiola 1). In a small number of the cases like Airbus and the Chinese cell phone company, the governmental ownership actually helps the company and its interacting partners succeed (Faiola 1). On one hand, governmental ownership can help shield a company from the harsh economic environment, but on the other hand it cancels out the well tested principles of the free market. Other large corporations in the US utilizing large systems projects are urged to utilize Systems Engineering because it looks at the whole picture including the interactions with the external environment, which might in some cases be the government. If the systems engineer identifies a governmentally owned corporation as an interacting partner in their systems development, they have to prepare for either success and lower costs or a
replacement partner and time loss. The preparation for either case will benefit the system
development and ultimately increase jobs.

The current increase in large systems projects and failures of the recent ones, combines
with the rapidly changing environmental factors to drive companies and the government to
increase the use and quality of their Systems Engineering efforts. For example, in the years
2009 through 2014, the US military has a proposed budget of 900 billion dollars allotted for
large systems projects (Taubman 1). All of these projects require proper Systems Engineering
and management of the Systems Engineering process. Military projects, like the ones planned
for 2009 have historically been over budget and behind schedule. For example, in 2007, 95
large military systems projects ran over budget by 295 billion dollars (Taubman 1). This shows
the immediate need for proper Systems Engineering. The reason for this major overrun in the
budget is that the US Air Force ignored very basic Systems Engineering processes such as:
looking at alternatives in the design process, and whether or not the technology is even
attainable efficiently (Taubman 1). If the Systems Engineering process was implemented
properly, this would not have happened and could be prevented in the upcoming projects. An
example of a specific project was a military satellite system development project whose
purpose was to detect foreign missile launches (Taubman 2). The design phase planning did not
even recognize that two of the sensors on the satellite could not even work in proximity of each
other, without immediate failure (Taubman 2). Even after the major cost overruns and
numerous examples like the satellite, large military projects are still over budget and not
meeting customer requirements (Beizer 1-2). This project shows not only the need for proper
Systems Engineering but also the need for competent system project management skills. This
also brings to light a problem with the second domain of Systems Engineering management of the Systems Engineering process. Another project exemplifying the need for proper Systems Engineering is the WLAN project system upgrade for all of the Air Force bases in the United States of America. After the completion of only 11 bases, the project was already 16.8 billion dollars over initial projections. There were no acquisition plans ever created and a realistic schedule was never initiated (Beizer 1-2). A proper implementation of the Systems Engineering approach, including management of the whole system project could have saved the nation billions of dollars. For commercial contractors and other large commercial businesses such an overrun in today’s economy could call for Chapter 11 bankruptcy. Another problem arising from this example is the lack of Systems Engineering knowledge and cooperation from upper management. In this case, top management being the Inspector General of the Department of Defense, only reviewed the system in the implementation phase (Beizer 1-2). This shows that top management must be educated and included in the proper Systems Engineering process. Another example exemplifying the need for proper Systems Engineering was a modern satellite system for all 4 parts of the United States military. The development stage was initiated before even a simple performance requirement analysis was performed (Taubman 2). That is similar to building a roof without planning the rest of the house. The CA/T project failure includes elements like 1/3 of the budget spent on remediation, planning maps missing, and predictions based on anecdotal evidence, not hard evidence from an engineer (Frey slide 44). The CA/T project includes at least 3 costly errors that could have been avoided with proper system engineering and proper management of the Systems Engineering process. Other large systems projects have failed because the elements surrounding the whole system were not identified
including; French efforts to build Panama Canal, Tacoma Narrows bridge, and Three Mile island Nuclear plant (Badiru 1-1). Recently a few top educational institutions including, Purdue and Georgia Tech have come to their senses and expanded their degrees to include a Systems Engineering degree (Taubman 2). The rapidly changing external environment and the failures of Systems Engineering projects shows that there should be an increase in the use of Systems Engineering, as well as, better management of the processes.

5d. Typical Traits Required of a Systems Engineer and The Traits Needed to Manage The Systems Engineering Process.

The systems engineer is like the conductor of an orchestra. He or she does not play every instrument, but they make sure every instrument or subsystem interacts properly with the whole system, and the environment to produce a flawless performance. Systems engineers need to have knowledge of all fields’ not just extensive knowledge of one specific field (Hallam 4). Systems engineers have many responsibilities including: 1. Development of total system design solutions that balance costs, schedule, performance and risk; 2. Development and tracking of technical information needed for decision making; 3. Verification that technical solutions satisfy customer requirements; 4. Development of a system that can be produced economically and supported throughout the whole life cycle; 5. Development and monitoring of internal and external interface compatibility of the system and subsystems using open systems approach; 6. Establishment of baselines and configuration control (Department of Defense 3). These requirements translate into skills that allow the systems engineer to properly design and execute large systems and sub systems. Typical daily tasks of a systems engineer include: 1. Definition of needs, goals, and objectives; 2. Requirement analysis, 3. Requirements allocation;
4. Functional analysis; 5. Functional allocation; 6. Specification development; 7. System and sub system design; 8. System and sub system analysis; 9. Trade off and alternative evaluation; 10. Software development and analysis; 11. Interface definition; 12. Schedule development; 13. Life cycle costing; 14. Technical performance measurement; 15. Program and decision analysis; 16. Risk analysis; 17. Integrated logistics support; 18. Pre-planned product improvement strategies; 19. Reliability, maintainability, and availability studies; 20. Integration of sub systems; 21. Test and evaluations; 22. Configuration management; 23. Quality assurance; 24. Training; and 25. Installation of the system (Eisner 3). These tasks have to be performed with every unique sub system and the whole system project. While carrying out all of these daily activities, the systems engineer has to, like other engineers, figure out how, but unlike other engineers they must also figure out why (Bode 1). The systems engineer has to have the general skills to be able to analyze, control, make estimates, produce designs, perform modeling, controllability, observability, stability, filtering, and simulation (Jawshide 3). These general skills help the systems engineer in applying the Systems Engineering process to any type of application from department of defense projects to communication networks. Many of the daily tasks of a systems engineer listed earlier require mathematical skills to be able to manipulate results and feedback information from the system and the systems design (Bode 5). Mathmatical skills and technological skills are where most engineers excel and these traits are crucial in all phases of the Systems Engineering process.

Not only does the system engineering process require technical and mathematical skills, it also requires the systems engineer to be capable of managing a large systems project. When SMEs look for system engineers, they look not only at their qualifications as an engineer, but
also at their competencies as a manager, as well as a leader (Taylor 1). Also at many schools like the Polytechnic University in China the Systems Engineering master students are required to attend classes focused on management and leadership (Taylor 1). Even when a company or the government is looking for a systems engineer, not even a leader for the whole process; they are already evaluating the candidate on management and leadership skills. This shows the importance of Management and leadership skills when implementing a proper Systems Engineering process. Systems Engineering projects just like regular business projects have to be on schedule and have to be planned out so the project can successfully utilize the available resources (Jewell 321). “The leader of the total Systems Engineering process’s aims are the, effective management of people, coordinating techniques in the business organization, and adapting technological innovation toward achieving increased performance” (Badiru 8-1). This helps to prove that the Systems Engineering process has a technical orientation and a management orientation. To implement a proper Systems Engineering effort the leader of the Systems Engineering process has to be creative and stimulate awareness in all subordinates about the surrounding legal, environmental, and socioeconomic factors (Badiru 8-1). The leader of the total systems project also has to analyze the customer requirements and effectively delegate the work of design and implementation to systems engineers and other multifunctional team members (Hallam 1). This shows that many multifunctional team members, are involved which requires the systems engineer to coordinate and effectively manage not only the technical details but also team dynamics. The leadership of the total system project has to ensure that requirements are carefully analyzed, and that they flow down to the individual team members to become detailed sufficient designs (Department of Defense
200). From this information it was concluded that systems engineers and the leaders of the systems process not only have to possess the technological knowledge of engineering but also be able to control multidisciplinary teams and constantly juggle customer needs and changing external environments while at the same time achieving desired results.

MANAGEMENT OF THE SYSTEMS ENGINEERING PROCESS

a. Typical Traits of a Male Manager

First, before determining if managers should oversee or lead the Systems Engineering process, this paper will attempt to break through stereotypical barriers and identify a successful manager, regardless of gender. Successful managers are typically seen as having characteristics common to successful male managers (Adebayo 244). In the same academic study, it was found that likable managers are also typically seen as possessing typical male manager characteristics (Adebayo 244). Typical Male manager traits have been linked to agentic qualities including; assertism and control, aggressive, ambitious, dominant, self confident, forceful, self reliant, and individualistic (Eagley 66). As well as agentic qualities and traits male managers are also seen as cold competitive and authoritarian (Kawakami 1). This collectively shows the typical traits of a male manager for the analysis of stereotypical issues. The male manager also posses the traits needed to lead the Systems Engineering process such as scheduling, managing cross functional teams and budgeting. The male manager does not start out his career as the underdog, like the female manager. Recent tests have proven that even two managers in the same position one female and one male, the male is still seen as more likable (Adebayo 242).
b. Typical Traits of a Female Manager

Female Managers are seen as having communal tendencies which results in them having the traits; compassionate, kind, sentimental, helpful, and generous (Bono 816). Another study showed that women managers are also typically; affectionate, friendly, sympathetic, sensitive, gentle, and soft spoken (Eagley 65). Together this list of traits, shows the stereotypical traits typically associated with female managers. The female manager has typically been overlooked for promotions because of gender stereotypes. The think manager think male phenomenon is real and it does affect the perception of the abilities of a female manager (Adebayo 240). Another academic experimental and correlation study showed that men are promoted faster and receive higher evaluations in typical male management roles (Eagly 65). If women take on these typical male management roles they are commonly seen as threatening or ineffective (Kawakami 1). A direct example of this discrimination is when a male manager is assertive they are considered control freaks and when a female manager is also being assertive they are seen by subordinates as being passionate (Eagley 66). Without modesty, successful female managers are seen as deceitful, pushy, selfish, and abrasive (Eagley 65). This example shows that even if female managers try to possess and express the required traits of the typical male management position, they are not seen as fulfilling the position as well as a man. In 2005 female employees earned 19 cents per dollar less than male employees in equivalent positions (Eagley 65). The DAC survey from 1983-2000 concluded that other factors like; women working less hours per year, marriage and parenthood, and the resulting lowered job experience all combine to account for most of the 19 cent disparage (Eagley 65). Still after analyzing the situation, taking out all of these exceptions there was still a disparage that was unaccounted
for. This shows that discrimination did and still exists in the workplace. The discrimination does not stop with the money. For example, when subjects in a survey study were asked to rate their bosses as successful or not, the correspondents who had an experience with a female manager were less likely to rate females as successful (Bono 834-835). Statistics also show that 40% of middle management is made up of women in the US, but only 2% of the CEO positions are held by women (Eagley 63). Women have only recently held 40% of management roles, so most of the older more experienced managers who occupy CEO positions are male. Again like earlier with the money discrepancy, this accounts for a part, but not all, of the difference. In the European Union the facts are not comparably better. In the top 50 companies of each nation in the EU only 4% of all CEO positions are held by women (Eagley 64). In both of these cases the few female CEO’s and presidents of nations proves the theory of glass ceiling wrong, but brings about a new concept of a Labyrinth. The article states that women do not face a glass ceiling but along their whole career they have to weave their way through a Labyrinth to obtain ultimate success (Eagley 64). To combat this labyrinth, most female managers have tried to take on male traits and express them in the workplace. A new academic study found that actually for females to become successful managers they should demonstrate the traits of warmth and mindfulness not take on the traits of a male manager (Kawakami 1).

Over the past 30 years the perceptions of women as managers has slowly begun to improve. The perception that only male managers can be agentic and task oriented has faded and women are using their own traits, not just trying to take on another’s genders role, to become successful managers (Bono 816). This new perception owes itself partly to the Civil Rights Act of 1964, and the resulting company initiatives to end discrimination in the workplace
(Bono 830). The Civil Rights Act and the resulting company initiatives allow for the typical
gender role associated with most management roles to be lowered allowing for women to use
their own traits to prove themselves. The findings of a recent survey showed that both women
and men possess the typical traits of a successful manager (Bono 830). Other new research also
states that currently women managers are seen as likable by subordinates if they use their own
traits to manage the department (Adebayo 240). All of this new research begins to disprove
theories like the Role Congruity Theory, Expectation States Theory, and the Heilman Studies of
1989 (Adebayo 240). Mindfulness is a trait that can help both female and male managers alike.
Women can use it to combat discrimination and gender specific roles, and both female and
male managers can use it to become successful managers and possibly the leader of the
Systems Engineering process.

c. The Traits of a Successful Manager

Successful managers are those who can produce results and gain the trust of their
employees. The typical attributes of a successful manager that allow him or her to produce
results and increase likability among employees consist of: leadership ability, competence,
knowledge, consistency, self confidence, trustworthiness, self control, informed, intelligent,
fair, sense of purpose, and extensive business skills (Bono appendix). All of these traits can be
possessed by both genders and can be crucial skills when overseeing the Systems Engineering
process. The traits of a successful manager are agentic, communal, task oriented, relationship
oriented, and transformational (Bono 833). The same study also identified that the two most
important traits for a successful manager were agentic and communal (Bono 833). The success
of bosses like Michael Dell, who with these identified traits, turned a garage company into the massive company it is today, are a testament of the great potential of managers.

A study by Corsini identified the 9 traits of great managers as; curiosity, irreverence, imagination, sense of humor, vision, organized personality, well integrated political schizoid, political relativity, and pragmatism (corsini 16-17). All of these nine traits denote a successful manager but also can be helpful tools for a manager overseeing the Systems Engineering process. The first trait, curiosity, will benefit the Systems Engineering process because the engineering methods will constantly be scrutinized by the curious manager allowing him or her to identify reforms and potential setbacks. Irreverence helps the manager in the Systems Engineering process because they will always question every decision of feasibility, catching parts of a system or total systems that should not be built. The next trait identified, imagination, allows the manager to more effectively think of all possible risks and scenarios during the planning process. This will directly affect the cost and time constraints placed on the project. A sense of humor helps because large scale systems projects require many long hour days and stressful situations for everyone involved, and the sense of humor can lighten the mood and keep everyone involved motivated. The manager’s vision of an end goal and all of the means to achieve it, including cost and scheduling management, can help lower the number of current Systems Engineering project failures. The sixth trait of successful managers identified in the study, an organized personality, helps the Systems Engineering process because in complex systems projects there are many different sub systems and concurrent tasks. Without organization the projects would not run smoothly. A well integrated political schizoid helps the manager oversee the Systems Engineering process because it allows the
successful manager to integrate all of the cross functional team members. Another identified trait, political relativity, gives the manager the power to take what worked in another situation in their career and apply it effectively to the current management related dilemma. The last trait identified was pragmatism. This helps the manager oversee the planning stage of the Systems Engineering process because it allows a selfless view of the system, allowing him or her to see if the end result justifies all of the work involved. As shown in this analysis, successful managers possess many good traits which can be applied to overseeing the Systems Engineering process.

Male or female managers can both be successful as well as likable and possess the traits needed to manage the Systems Engineering process effectively. The Schein Descriptive Index is an instrument used in research studies which assesses attitudes towards male and female managers (Adebayo 243). For the purpose of this study the results of the schein index were used to prove there are not male or female managers but successful manager’s who can be beneficial in the management of the Systems Engineering process. The study used comparability and the Schein Descriptive Index to find that successful male and female managers are both seen as likable by their employees (Adebayo 240). The study also identified that although the two different genders achieve likability among employees differently, they are both able to achieve extreme likability and gain the trust and cooperation of their employees (Adebayo 240). This will help successful managers in the Systems Engineering process because some large complex projects like the Atlas Project which had over 70,000 employees. In the current research some findings have even suggested that successful managers utilize more historically female traits as a transformational leader (Bono 816).
example is Mike Krzyzewski, head coach of the Duke College basketball team in North Carolina. He utilizes successful managerial traits, as well as, interpersonal skills and mentoring to successfully manage the basketball program at Duke University (Eagley 67). According to James MacGregor, transformational leaders like Mike Krzyzewski make themselves known as role models by gaining a followers trust and confidence. This helps them to instill goals and develop the players (Eagley 67). Transformational leadership skills can also help managers lead the Systems Engineering process. Transactional leadership skills, like give and take relationships, combined with the typical traits and transformational leadership skills, can create a successful and effective manager (Eagley 68). Another trait possessed by a successful manager is the ability to build lasting social communication networks with all parties involved (Eagley 70). Systems Engineering requires constant two way communication. Someone must act as the switchboard operator. Many parts of the Systems Engineering process, including the planning process, are already involved in a typical successful managers everyday activities. This analysis shows that the traits possessed by successful managers regardless of gender can be applied to a leadership role in the Systems Engineering process.

d. Should a Successful Manager oversee the Whole Systems Engineering Process?

According to the research, the duties attached to leader of the whole Systems Engineering process including coordination of all subsystems, has historically and currently been performed by head engineers or aloof upper management. If the systems projects are not managed properly, not only will the project suffer, but also the customer and ultimately the whole business will be impacted by insufficient management (Parker 1). In the past, 70% of engineers were promoted to head engineer or management of engineering projects within 15
years (Boyer 1). This shows that historically and currently, most leaders of engineering processes, including Systems Engineering processes are promoted engineers. These engineers tend to overly explain answers when communicating with subordinates, which can be time consuming and reduce trust (Department of Defense 203). This is true especially on the typical and productive multidisciplinary teams that are present in most Systems Engineering projects (Department of Defense 203). This is a great trait to have as an engineer because the technical designs have to be flawless, but for management of the total system project it can and has caused major time delays and communication problems. Many of the failed projects in the current need section showed that time delays were a major factor of failure. Another reason these promoted engineers are not as qualified as managers to lead the whole Systems Engineering process, is the fact that true engineers have an ethical obligation to provide honest engineering (Department of Defense 203). This helps the engineer perform the many technical aspects of Systems Engineering honestly, but if they also have to manage the whole process it becomes difficult to focus on providing honest results driven engineering. Some parts of the Systems Engineering process already require upper management participation. Four different review progress points require upper management to review the work of the engineers and all members of the multidisciplinary team (Eisner 2 48). The four review gates are; system requirements review SRR, the system design review SDR, the preliminary design review PDR, and the critical design review CDR (Eisner 2 48). These reviews by upper management like in the Navy’s wireless lan project example have proven insufficient and are not being given the proper attention that a successful manager overseeing the process would give them. When
there are complex engineering tasks, a trained engineer should be involved but for the total planning and monitoring of the system project, a successful manager should be utilized.

Many projects in the Aerospace industry are going over budget and are missing launch dates even with the use of Systems Engineering (Parker 1). The technical aspects of the Systems Engineering process were not found as the reason for failure. Most of the failures were due to scheduling and planning problems. If a successful manager had been overseeing the process the projects could have stayed on schedule and potentially saved the industry billions of dollars. In many of the failed projects lead by head engineers, or aloof upper management, the Systems Engineering process was initiated at the same time as other disciplines representing a lack of knowledge of the management aspects of the Systems Engineering process (Parker 1). As stated earlier in the research the Systems Engineering planning process should commence well before the whole systems project, so that analysis and requirement development can take place. If a successful manager trained in the management aspects of Systems Engineering was running the whole process while utilizing open communication with crucial systems engineers, the planning process would have begun on time and the cost overruns could have been avoided.

The definition of management alone helps show why managers should oversee the whole Systems Engineering process. The Project Management Institute defines management as an act of directing and controlling a group of people for the purpose of coordinating and harmonizing the group towards accomplishing a goal beyond the scope of individual effort (PMI 264). This definition illustrates that successful managers possess the traits needed to properly
manage the whole Systems Engineering process and all of the parties involved. The planning process of the Systems Engineering process is similar to the planning process successful managers perform in all industries (Department of Defense 10). One of the gurus of the Systems Engineering field Hall hinted that management should be involved when he said that even difficult systems problems can be solved by looking at them in a generalized light (Hall 162). Another argument for managers to manage the whole Systems Engineering process is that sometimes engineers will overlook feasibility and the economics of projects, just to introduce new technologies (Blanchard 54). A manager overseeing the process allows the engineers to focus on the question of how, and not the question of why. The engineers can develop the crucial technical designs of subsystems, and the manager can deal with functional designs and the management of all of the team members (Eisner 2 43). The aerospace industry is reliant on Systems Engineering and the management of these large scale systems projects is a top priority of the industry (Parker 1). A successful manager educated in Systems Engineering leading the systems projects in the Aerospace industry could create a conducive environment for the engineers and keep the projects running efficiently and effectively. Not only has the aerospace industry benefited from Systems Engineering tools and processes, many other industries including; the academic field, industry, government, and SMEs have also benefited (Department of Defense 157). All of the fields utilizing Systems Engineering could benefit from better management of the process and other fields like commercial construction could benefit from the initial implementation of the Systems Engineering process as well. In all of the applications, the successful manager leading the Systems Engineering process, and the system engineers should be partners. They both bring forth unique traits and specialize in their own
respective areas. Many reasons combine to prove that a successful manager leading the Systems Engineering process of large system projects would be beneficial. The first reason is that there are numerous examples of failed systems projects because of the neglect or mismanagement of management related problems. The second is that even though the process requires many management related traits it also requires the same amount of technical expertise, meaning the successful managers have to create a conducive environment for teamwork and an open communication link with all of the team members. This will allow the technical engineers to focus on their job. The third reason is that a manager can relate the thinking of Systems Engineering for large systems projects to many other diverse industries, and also relate their knowledge from other industries to the system project.

A SYSTEMS ENGINEERING TOOL FOR MANAGERS

a. Systems Engineering Management Plan

The Systems Engineering management plan is a supplemental tool that managers as overseers of the whole Systems Engineering process have to be made aware of. The Systems Engineering management plan is a formal report for management that outlines the elements of the system and how it will be engineered throughout its life cycle. The plan includes elements such as design, development, production, and maintenance (Rigby 1). The characteristics of the plan are that it is a living document, there is no required length, it is regularly updated, and that it references organizational procedures and policies (Brook 80). The plan is different for every system application and helps organize the complex system projects. The leaders of the Systems Engineering process have to look at all elements such as schedule, cost, interfaces with other
systems, use of commercial off the counter components, and non developed components, to develop an appropriate management plan for the systems project (Eisner 255). The successful likable manager should develop this plan utilizing the open communication partnership with the technical team members. There are different standards for the production of the SEMPs one for commercial application, that will be explained hereafter, and the mil-std 498 which is used for military system development projects (Eisner 255). These two standards can be seen as lengthy and unnecessary, but the leader has to decide which sections to focus more effort on, so that the plan is useful in reducing costs and increasing organization within.

The commercial standard is broken up into six different sections. The first section is the scope of the whole systems project (Rigby 1). This part describes the total system and all its subsystems as well as the introduction to the rest of the plan. Section 2 is the section where all applicable documents are referenced (Rigby 1). This includes all contractual documents and important non contractual documents which allows the team members easy access to important guidelines. Section 3 of the SEMP states who is in charge during all parts of the system life cycle process (Rigby 1). This part of the plan is where the progress gates are laid out and when major milestones will be monitored. Section 4 explains the process to be utilized and how it satisfies the requirements of the system (Rigby 1). This section is dependent on the customer demands analysis which leads to the development of the requirements for the system. Section 5 explains the specialty engineers needed to complete the complex system project (Rigby 1). A successful manager has the previous knowledge of managing and finding the appropriate outsourced talent for this section. The last section is optional but includes important notes about the organization of the whole project (Rigby 1). This last section allows
the leadership to give all of the team members a section to reference when they are completing their individual share of the workload. This plan helps the successful manager organize total work effort and keep all team members on the same page.

PRACTICAL APPLICATION OF THE SYSTEMS ENGINEERING APPROACH IN CONSTRUCTION MANAGEMENT

a. Introduction

Systems Engineering has evolved into an approach that can be used by managers in many different industries. This practical application will attempt to backup the argument that the Systems Engineering approach can be lead by a successful manager, and prove that the Systems Engineering approach can be beneficial for commercial construction companies. The commercial construction industry in the US generates over 450 billion dollars a year, and is comprised of over 8,000 firms including Thomas Simpson Construction (Gottlieb 3). Thomas Simpson Construction is the focus of this practical application of Systems Engineering. Thomas Simpson Construction company is a family owned and operated construction business located in Moorehead city North Carolina. It has served the area with commercial and residential construction for over 30 years. They have evolved into a very diverse construction company tackling a diverse portfolio of projects while at the same time specializing in underground utilities and highway grading. With, an unclassified unlimited license and 25 employees the company maintains over ten million in sales annually. General contractors like Thomas Simpson Construction do not perform the bulk of the labor sub contractors do. The many different sub contractors specializing in sub systems of ground up work or finish out work have
to be managed and scheduled appropriately. While the company does not perform the bulk of
the work, they have to manage and constantly monitor the whole system including; architects,
engineers, consultants, suppliers, insurance providers, unions, attorneys and the client (Gottlieb
2). This shows that commercial contractors deal with not only the construction part of the
project but also the surrounding system as well. Superintendents are the managers of the
specific projects of a construction company and they must look at the whole system not just the
task at hand. When the industry was first analyzed many other apparent issues justify the
implementation of the Systems Engineering approach. These issues include; consolidation of
construction projects, safety and liability, high amount of work related injuries 6.8 per 100 full
time workers, and high insurance costs (Gottlieb 1). The commercial construction industry is a
good candidate for the application of Systems Engineering because it has to deal with
complicated systems and external factors daily (Gottlieb 2). This application attempts to apply
the Systems Engineering technique to commercial construction projects like the crystal coast
veteran cemetery expansion project to lower costs and keep the business profitable in a time of
economic turmoil.

One of Thomas Simpson’s current construction projects, the Crystal Coast Veteran
Cemetery Expansion, is the example used and studied in this practical application. Thomas
Simpson Construction Company bid on the fixed price contract job and was the lowest bidder.
Fixed price contract jobs can benefit the most from an application of Systems Engineering
because any savings the construction manager can identify can be directly handled as profit.
Thomas Simpson Construction Company only deals with fixed price contract jobs. The 1.38
million dollar project is a nine acre expansion of the crystal coast veteran cemetery in
Jacksonville NC. Tasks involved with the whole system include; construction of a new maintenance facility, clearing and grading of six plus acres for installation of new gravesites, construction of four independent columbarium’s, installation of 600 feet of integrated sidewalk, all related underground utilities including water sewer and electrical, as well as landscaping and irrigation of the total project area. The leader of the total system in this case Noah Simpson Superintendant for Thomas Simpson Construction has been assigned the task of overseeing the design and implementation of the whole system project. He has to make sure all of the work gets done in an efficient and effective manner. The Systems Engineering approach will hopefully help make his task a little less arduous.

b. Identification of Systems Engineering Tools and Methods Which Can Be Beneficial to Commercial Construction Companies

The estimation and bidding process is crucial to a commercial construction company and is one of the major factors identified where Systems Engineering techniques can be applied. With Systems Engineering the estimations can be more accurate and reflect future savings. This will allow the company to consistently be the lowest bidder. Analytical estimating is an estimation process in which the construction manager establishes all the rates for each individual part of the system including; per hour labor rate, cost per unit of material, project overhead costs, contingencies, inflation, and identified risks costs (Brook 200). By establishing rates for the whole system including commonly forgotten company overhead and profit as well as costs of all risks the estimation can be improved. This view taking into account the whole system during the estimation of the project can benefit the company by allowing them to see the end result before they begin the process (Simpson). General company overhead has to be
carefully calculated utilizing all parties involved in the whole system as well as unforeseen overhead costs like insurance claims (Brook 200). Without the total system view by the manager these overhead costs might be too low causing the company to lose money on the job. Another Systems Engineering tool a estimation technique is called the cost planning technique. This technique divides the total construction project into subsystems so that the exact costs of different subsystems can be used to make new cost estimates (Potts 52). The breakdown of the project into unique subsystems also allows for a more detailed risk analysis. These more detailed risk analyses allow for the risk allowances included in the estimation to better reflect the foreseen risks (Potts 58). Noah said during our work together that in today’s current economy risks have to be monitored closely and their occurrence has to be minimized because overestimated risk allowances cannot be added while still consistently winning jobs.

The systems way of thinking identified that sub contractors and suppliers prices directly affect the cost estimate and can be altered over the course of time. Construction managers can consider renegotiating prices with sub contractors and suppliers after contract has been won to account for not being able to add a risk allowance or profit in today’s economy (Brook 200). For example in the Crystal Coast Veteran Cemetery project the framer, during the bidding process, was unable to commit to the schedule the project required, and a new framer bid 4,000 dollars less for the same work. This shows that prices can be altered after the estimation and bidding processes are completed. Just like in large systems projects all parties involved in the total system have to cooperate and be lead by a capable manager. The design process should include all parties and take into account function ability, build quality, and impact on the environment, as well as the satisfaction level of the customer (Potts 25). In the Millennium
Bridge construction project in London a design failure caused major impacts on the cost and time constraints (Potts 118). This is a good example of why the design of the total system, which affects how the company bids the job, should include all parties involved. If the designer and contractor would have worked together before the actual implementation of the project they would have caught the design flaw earlier and saved money and time. Due to the fact that the systems process should begin well before implementation; contractors need to take advantage of the 18,750 shovel ready projects President Obama plans to fund in the near future (Cenciros 2). If the contractors begin to identify all players involved in the system and break it down into subsystems for proper estimations they can lower their costs and effectively lower their bids helping them win jobs.

After the US department of energy implemented the Systems Engineering approach on building structures they found ways to incorporate energy savings for the customer at little or no extra costs (USA 1). This is crucial because the customer is the most important element according to the systems approach; and this is a way to satisfy their needs while at the same time profiting as a commercial construction business. Following the systems approach the department of energy looked at the relationship between all of the involved subsystems; building site, building envelope, all mechanical systems, and other factors (USA 1-6). It allowed them to identify ways to save time and see places where energy savings could be realized. Along with looking at the total system and the interactions of the subsystems the department of energy also encouraged the coordination of the whole multi discipline team that was involved in the typical construction process (USA 1-6). Combined this Systems Engineering tool for construction is termed total system construction (USA 1-6). Using total system construction
the study identified many problem areas and new ways to save energy while not causing unnecessary work or costs on the construction companies like Thomas Simpson Construction.
One thing they identified was to use 2x6 studs while framing instead of the normal 2x4’s spaced 24 inches on center resulting in saved time and material costs for the contractor which can be passed on directly to the customer (USA 1-6). Another problem area identified was the windows; they were letting in too much sunlight and letting out to much cold air. The study found that low emission windows trimmed in vinyl saved on electricity costs for the customer and were not a cost burden on the construction company (USA 1-6). R 30 insulation also allowed the house to be heated and cooled more efficiently (USA 1-6). Along with the low emission windows proper shading and orientation of the actual house also helped reduce energy consumption and total strain on the hvac system (USA 1-6). The systems approach also identified that the orientation of the hvac unit impacted its efficiency (USA 1-6). When the hvac unit was located in a central location it was able to heat and cool a much larger space (USA 1-6).
Total system construction also has many other benefits that can be beneficial for Thomas Simpson Construction including; reduced call backs, lower costs, less waste, and the benefits of community learning curves (USA 6). Thomas Simpson owner of Thomas Simpson Construction and an expert in the field said that energy saving techniques like the ones identified by the study should have been practiced for years and can be very beneficial for construction companies and their customers (Simpson). The customer who is the focus of the Systems Engineering effort is benefited by energy saving construction techniques because of the increase in quality and the decrease of the impact on the environment. This tool of Systems
Engineering adapted to construction by the department of energy has many benefits and will be a useful tool for construction managers in the future.

Many other Systems Engineering tools and methods identified by analyzing construction jobs using the systems approach exist. Concurrent engineering is a tool that allows the most efficient coordination of materials and crews (Badiru 31-7). When a construction manager understands the whole system and the interactions with the different subsystems he or she can implement concurrent engineering. Which is a just in time approach to construction. The reason this tool is so important for construction companies is because it can reduce labor costs, which are a major part of the costs of construction companies. During the implementation of the Crystal Coast Cemetery expansion project a concrete pumping crew came to fill the concrete columns holding up the roof of the new maintenance facility. The concrete truck arrived early and the concrete pump crew took over an hour to set up. After this time the concrete in the truck was no longer usable. Then while another truck was coming to the job site the concrete pumping crew had to be paid to wait. If the construction manager would have used concurrent engineering the concrete truck would have arrived just after the concrete pump crew was ready to begin their work. Concurrent engineering in this case could have saved the cost of a whole load of concrete, and the labor costs associated with the concrete pumping crew. Another tool for the construction companies to use is total quality controls. Total quality controls allow; improved customer satisfaction, reduced cycle times, documented cost savings, and more satisfied and productive work forces (Badiru 31-5). One total quality control mechanism is total quality management which guides the construction manager through monitoring and improving quality throughout the whole systems and the whole
systems life cycle. Many awards exist for total quality management including one just for the construction industry the national housing quality award (Badiru 31-5).

Value engineering is another tool that construction managers can use to better manage the whole construction system. Thomas Simpson Construction used value engineering techniques during the crystal coast veteran's cemetery expansion project. Value engineering is a tested method for identifying alternative approaches to satisfy customer requirements while simultaneously lowering overall costs (Badiru 31-6). Throughout the process the construction manager for Thomas Simpson Construction brainstormed more economical ways to perform the required tasks, then generated ideas from himself and the workers as well as other players in the multi functional systems team. One example was that the construction manager found that the concreted columns could be pumped instead of having to be poured by a large crane concrete truck. Proper value engineering is a seven step process involving the whole system and systems team as well as the construction manager. The steps are: 1 team selection, 2 information gathering, 3 brainstorming, 4. Evaluation of alternatives cost and ease of implementation, 5 recommendation of alternatives, 6 implementation, 7 optimization of projects with value engineering (Badiru 31-7). The US army corps of engineers saved over 90 million dollars in 2001 alone with the implementation of value engineering to their whole system construction projects (Badiru 31-6). A specific example of savings from value engineering was at the port of San Diego general services facility. When value engineering was applied in the design phase building costs and energy costs were both reduced by ten percent (Badiru 31-6). These are examples of how this Systems Engineering tool can be successfully applied to construction management. Many other Systems Engineering tools can be beneficial
to construction jobs including productivity analysis’s and post occupancy evaluations. The application of all of these Systems Engineering tools on construction jobs as well as viewing the process as a whole system can increase efficiency and effectiveness.

c. Design and Build

Another tool to increase efficiency of the construction system is the design and build approach which creates an integrated system that can benefit from shared knowledge of the process. The design and build approach allows at an early stage the consideration of site specific construction issues that a contracted designer might not be able to realize on their own (Potts 142). This approach also allows the construction company to better manage customer requirements because it gives the customer one entity to deal with. With the design and build approach all team members can input which avoids mistakes like the case of Cardiff millennium stadium where a design flaw resulted in a 31 million pound loss for the general contractor (Potts 142). Integrating the design and implementation phases of construction allows for an overlap of design and construction phases as well as more accurate cost estimations (Brook 17). This approach creates many opportunities for the construction company to save money, but it also creates the need for a manager to oversee the whole construction system. The design and build approach also creates a project team to deal with the whole construction system. The team consists of the designer, academic advisors, client advisor, Construction Company, and the manager overseeing the whole system (Lafford 20). As with the systems approach for large scale systems the application of the systems approach for large construction projects also relies heavily on communication between all involved parties. Thomas Simpson exemplified the fact that total cooperation and communication is the only way design and build is beneficial for all
involved parties (Simpson). The constructive communication must be initiated in the design phase between client designers, constructers, mechanical and electrical engineers, mechanical and electrical installers, regulatory bodies, and the community (Lafford 23). The research also stated that historically if the original team is kept intact throughout the whole life cycle of the project better results can be achieved (Lafford 23). Other ways to keep the team together and productive throughout the life cycle of the construction system are: document control, meaning new designs should be dispersed as soon as possible to all members, design change control the designer and manager of entire system should check off on all design changes, quality control implement defect free construction with all sub contractors, also as built records which allow the commercial construction company to learn from their mistakes (Lafford 29). If this process is implemented and managed properly companies like Thomas Simpson Construction can improve profitability and increase their customers level of satisfaction. The Design and build process design phase includes three different designs all with different purposes; concept design which is an overview design and feasibility test, definitive design which describes and lists the pricing strategy, procurement process, and needed equipment, the last design is the detailed design which gives the constructers and sub contractors a design to follow during implementation (Lafford 36-37). The designs have to be flawless and include input of all parties because the contractor takes on much more risks by designing and overseeing construction of the whole system. Like in Japan where business relationships revolve around trust the parties involved in the design and build process have to trust each other so they can create a impeccable result (Lafford 72). The design and build approach adds value to the construction projects but also carries many risks that have to be avoided by
proactive and constant management of the process and multifunctional team. The many elements that add value from the design and build process include: constructers and suppliers best solutions, the fact that designer and constructers share similar goals, the best practices all parties have developed through experience, communication is easier and less formal, simplified insurance, and improved build ability (Lafford 72). The risks involved for general contractors like Thomas Simpson Construction include; tender designs are not economically feasible, underestimation of job costs resulting in a loss, or a failure to meet customer requirements (Lafford 73). Most of these risks are apparent with any construction project and the design and build approach as well as other Systems Engineering tools, and proper construction management combine to help manage and minimize these risks.

d. Job Site Safety

Job site safety is a major part of the construction project system and is commonly overlooked as an area that can produce increased productivity and lower costs. From the Labor Statistics 2002 it was identified that the construction field accounted for 21 percent of all work related deaths and 11 percent of all disabling injuries and illnesses (Labor 1). Recently in 2008 the number of work related deaths from the construction industry has declined by 20 percent to a new total of 969 cases (Fatal Work 1). The total number of work related deaths in the US for all industries in 2008 was only 5,071 and the construction related deaths accounted for 1/5 of these (Fatal Work 1). Hopefully with a Systems Engineering view and approach of job site safety these numbers that continue to inhibit the construction industry, will be lowered. The construction industry should follow the proven successful example of the worldwide shipping industry which has been working on risk management of their systems for over 150 years
(Mainelli 48). The shipping industry has enjoyed the benefits of lowered safety related deaths and injuries, as well as the added benefit of lowered insurance costs due to the lowered number of insurance claims and Systems Engineering. During the study of the crystal coast veteran cemetery expansion job and from an expert in the field it was identified that the two main safety concerns on the job site are; extra materials not needed at that particular time in the schedule, and keeping the job site clean (Brown). An example is if the building has to be sided with vinyl siding on the next day and the materials are already on the job site then the other workers who need to work that day have to place ladders in odd positions around the supplies to do their job. This often results in unnecessary accidents on the job site. Regular cleanup of the jobsite and an understanding of which part of the system needs what supplies at what time, as well as other Systems Engineering tools can help reduce these unnecessary accidents. Bunni identified 6 factors to assure safety of the whole construction system: communication and organization of all team members, inspection of construction by structural engineer, general quality of the design, structural connection design details, selection of architects, and timely dissemination of technical data (Bunni 91). Another tool to reduce safety related injuries is the adaption of system safety guidelines to construction jobs. System safety is a discipline of Systems Engineering which applies engineering and management techniques to make systems safer throughout their whole life cycle (Badiru 9-2,10). The systems safety guideline mil std 88 part 2b says to reduce safety related deaths and injuries the construction manager should; design the system for minimal risk, incorporate safety devices, provide warning devices, develop procedures and training, and accept the remaining risks if their hazard level is acceptable according to previously set standards (Badiru 9-2,10). This provides a
nice guideline for construction managers to follow. Another tool construction managers can use to improve system safety and reduce insurance claims is to produce a failure mode effects analysis from the hazard analysis (Badiru 9-2,10) The fmea looks at the likelihood of occurrence and severity of all identified risks. This is an example of a safety risk analysis for the Crystal Coast Veteran Cemetery Expansion job at Thomas Simpson Construction.

<table>
<thead>
<tr>
<th>Potential Mainellis</th>
<th>Severity 1-10</th>
<th>Frequency 1-10</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>dehydration</td>
<td>6</td>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>falling off scaffold</td>
<td>7</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>10,000 pound concrete slab falling</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>blowout of 18&quot; sono tubes</td>
<td>6</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>falling off ladders</td>
<td>5</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>different crews working at same time</td>
<td>3</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>injuries from saw work</td>
<td>9</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td>injuries from heavy equipment use</td>
<td>7</td>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>high roof work</td>
<td>5</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>civilians using the area</td>
<td>8</td>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>injuries resulting from uneven ground</td>
<td>3</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>heavy traffic from dump trucks</td>
<td>8</td>
<td>2</td>
<td>16</td>
</tr>
</tbody>
</table>

Any safety concern scoring over 20 is unacceptable.
From the hazard analysis and the FMEA for the system a systems safety plan can be produced and distributed to all parties involved in the effort. This systems safety plan highlights the most important safety concerns and what to do upon their occurrence. This is an example of a system safety plan for the Crystal Coast Veteran Cemetery expansion job at Thomas Simpson Construction.

Table 1a System Safety Plan

<table>
<thead>
<tr>
<th>Concern</th>
<th>How to Prevent</th>
</tr>
</thead>
<tbody>
<tr>
<td>dehydration</td>
<td>Thomas Simpson Construction will provide water for all workers on the jobsite.</td>
</tr>
<tr>
<td>falling off ladders</td>
<td>Remind all crews about ladder safety and keep concrete dry.</td>
</tr>
<tr>
<td>different crews working at same time</td>
<td>Require a supervisor for every crew to be present at all times.</td>
</tr>
<tr>
<td>injuries from saw work</td>
<td>Use caution and restricted areas around saws.</td>
</tr>
<tr>
<td>injuries from heavy equipment use</td>
<td>Screen all drivers of heavy equipment and allow only certain workers to operate the equipment.</td>
</tr>
<tr>
<td>civilians using the area</td>
<td>Keep civilians and state workers out of restricted area who are not covered by insurance.</td>
</tr>
</tbody>
</table>
Many problems during implementation of the system safety plan can occur according to a study of the Kuwait construction industry. Problems when implementing the plan include; disorganized labor, a poor accident and reporting system, extensive use of foreign labor, extensive use of untested subcontractors, lack of safety regulations and legislation, low priority given to safety, small size of construction firms, competitive bidding system, and severe weather conditions (Kartam 1-8). These problems should be understood and addressed when implementing the system safety plan. Poor job site design is a major factor of job site related injuries and should be avoided, just looking at the design as a whole interacting system coupled with a design created by all members of the construction system can reduce the occurrence of poor job site designs. The ergonomics of the tools used including; weight, size, vibration, and operating temperature can affect the laborers in different ways. The scheduling and number of workers on a particular sub system has to reflect this (Badiru 31-3,6). One example of this from work with D. Brown construction is the fatigue caused by the shoe mold and crown having to be sawed outside. After knowing this the workers found that a portable crown and shoe mold saw would save time and stress on the laborers. To continually monitor safety concerns throughout the life cycle of the system and to build best practices the company should record and publish safety problems and barely avoided safety problems, as well as prevention activities (Mainelli 48). An expert in the field said that recording these safety problems and concerns lowers the rates of their occurrence in the future (Simpson). Safety is one of the major factors in construction costs and can benefit from the Systems Engineering approach.
When analyzing the construction system and trying to balance cost schedules and performance it was noticed that insurance costs are a major part of total costs for a construction company and could be lowered using the systems approach and Systems Engineering. At Thomas Simpson construction insurance accounts deductible costs are at 100,000 dollars a year, and are a major part of their costs. In the US construction sector an estimated one billion pounds is lost every year because of high insurance costs (Mainelli 47). This figure shows that the field of insurance is a major part of the construction project system and if it can be improved by Systems Engineering it will have a direct impact on net profit (Bunni 1). An example of early construction insurance is the Hammurabi code from 1760 bc.

The Hammurabi code states that: if builder builds a house and it is not firm and collapses which causes death of the owner said contractor shall be put to death, if death of the son of owner occurs son of construction company owner shall be put to death, if it causes death of a slave of the house the contractor has to provide a slave for the owners of the house, if the house is destroyed and was not built firm the construction company must rebuild at their own costs, and if the wall built falls in and was not built to requirements it must be strengthened at the construction companies expense (Bunni 1-2). Although these early insurance laws were a little harsh and not to mention inhumane they have not changed in one aspect over time and that is that in most cases the construction company is held reliable. Today, a company like Thomas Simpson Construction might not lose the owners son for a mistake but could lose all of its assets in court. Modern insurance is based on the law of contracts which requires the contractor to; do work with care and skill in a workman like manner, to use materials of sound
quality, and make sure that both the work and material will be reasonable fit for the purposes for which they were required (Bunni 120).

The same risk assessment system engineering tool used for system safety management is also beneficial to lowering insurance costs. The risk assessment process steps for the whole construction system include: identification of potential Mainells, failures, and unplanned events, estimate probability of occurrence, estimate likely severity of occurrence, categorize risks in a matrix of probability of occurrence and likely severity of consequences, identify which risk category is unacceptable, review design eliminate or reduce risk to acceptable levels, lastly make contingency allowances for residual risks (Lafford 55). The common form of risk assessment tools the fmea should be created to proactively manage risks which directly affect the number of insurance claims and ultimately the cost of the companies insurance. Also any claim should be settled as quickly as possible because the longer they are put off the more significant the resulting delays will be on the total process (Potts 240). The insurance the general contractor firm needs is the insurance needed to cover the responsibilities allocated and the liabilities the company wishes to cover (Bunni 293). Like in the case of Thomas Simpson Construction the general contractor does not have to carry insurance for all subcontractors, simply by requiring all sub contractors to have their own proof of insurance. The four main types of insurance policies for general contractors are; contractors all risks insurance, public liability insurance, employers liability insurance, and professional indemnity insurance (Bunni 282). There are many other special forms of insurance general contractor construction companies have to carry for their different systems like; Difference in condition method, automobile insurance, or marine insurance but the main four are the most important
and where Systems Engineering can help lower the costs (Bunni 282,152). The first and most important is contractors all risk insurance which covers the current construction project system against any physical or tangible risks (Bunni 282). With the systems approach and proper risk management the construction managers should calculate insurance costs for each individual system and their subsystems (Mainelli 47). This bottom up approach would increase the accuracy of the total amount of coverage needed. Corporate risks should also be calculated on a individual job system basis making the risk plan more accurate and in the long term saving the company money and time. An expert in the construction field identified other ways Systems Engineering lowers insurance costs. He said that any part of the systems safety management identified earlier helps to reduce the costs of employers liability insurance more specifically workman’s comp insurance (Brown). The proper scheduling of the supplies needed helps lower contractors all risk because there is not extra unneeded material on the job site that can be damaged or stolen resulting in unnecessary insurance claims (Brown). The feasibility analysis would also help lower general liability costs, because if the house or structure sits after it is finished for any length of time mold can form causing the contractor to file a claim with the insurance company which will raise the deductible and overall insurance costs (Brown).

Captive or internally based insurance is another way which construction companies can save money on insurance costs. For captive insurance to work the general contractor has to properly identify and manage all risks possible within the whole system as well as manage all external factors properly. Captive insurance could help Thomas Simpson Construction share the insurance risks while at the same time lower the cost of insurances and overall costs for jobs, ultimately gaining the ability to outbid other competitors (IN131-Case Study 1). In the
case study the studied general construction company had insurance premiums for their required insurance of 650,000 pounds a year. After the company implemented captive insurance their costs dropped by 175,000 pounds a year and the company was still covered for losses of up to the same amount as the previous year (IN131-Case Study 2). Thomas Simpson Construction Company with its yearly insurance premiums of 100,000 dollars and a clean insurance claims record can benefit from captive insurance. The only limitation is that the company must have a satisfactory claims record and have a risk management plan in place (IN131-Case Study 2). The risk management plan should be affected by all prior insurance claim causing risks as well as near misses to assure that all possible risks are dealt with (Mainelli 48). Captive or internally based insurance saves money by utilizing Systems Engineering and the lowered involvement with, or reliance on expensive insurance companies. These owner controlled or captive insurance programs have recently increased in popularity. Obama’s proposed American Recovery and Reinvestment Act is 787 billion dollars of the Federal government’s budget and 196.75 billion of it is allocated for infrastructure projects (Cenceros 1). This will result in a increase of insurance for all general contractors who will work on these projects. If the companies use Systems Engineering they can take on some of the insurance risk and increase their profit more from these infrastructure projects. If companies like Thomas Simpson cannot implement captive insurance they should at least work with insurers to better understand their policy and try daily to implement captive insurance.

The research on the application of Systems Engineering in the construction industry and the practical work experience with Thomas Simpson Construction as well as the interviews with
professionals all combine to prove that the Systems Engineering approach would be beneficial as a tool for construction managers to implement.

FURTHER RESEARCH

a. Recommendation for Further Research

To further test my statements I wish there was more exploratory research besides my practical application and secondary research to prove that a successful manager overseeing the whole systems project is beneficial. An extensive study of successful managers actually overseeing large systems projects should be conducted. This study should involve several different projects with private corporations and the government to provide accurate results. Another study could be conducted to see why more business schools are not teaching managers the essentials of engineering so that the trained managers can properly lead engineers and lead the systems engineering process. To help prove that Systems Engineering is beneficial in the commercial construction industry a follow up study of the implemented recommendations at Thomas Simpson Construction should be conducted. Also if the managers are promoted to leader of the Systems Engineering process what else can reward engineers when they would have previously been promoted to head engineer. Due to time and resource constraints this research will have to be explored in a more in-depth dissertation of the subject possibly during my PHD.

CONCLUSION

The Purpose of this thesis was to let today’s global managers and international companies as well as management institutions know that Systems Engineering is beneficial for all managers
and is applicable to a variety of applications. The current rapid increase in surrounding elements and the failures of large system projects overseen by engineers or managers without knowledge of Systems Engineering, and full cooperation with the engineers, shows that typical successful managers need to be trained in Systems Engineering and oversee the development of proper systems. The research proved this because the Systems Engineering Process requires not only technical engineering aspects but also management competencies. Leadership of the process also requires the leader to manage a multi functional team and to create partnerships with the engineers. The day to day elements of the systems engineering process should be performed by engineers but the feasibility studies and management of the whole process should be left to successful managers. This thesis also showed that the Systems Engineering process can be beneficial as a tool for construction managers of commercial construction companies. It can help the company win tender contracts, lower accident rates, lower insurance costs, and show an overall increase in net profit. Overall the systems engineering process and way of thinking, is a useful tool that should be utilized more often; and when it is used the process should be lead by a successful competent manager.


APPENDIX 1

Interview Thomas Simpson

Email Interview

1. What is your view on energy saving building techniques as a general contractor?

Energy should have been practiced for years. It is the way of the future. Everyone should be energy conscious and look at new building techniques. It will improve the quality of contraction. There will be less of an impact on environment. Green is the new trend.

2. Do you think it is beneficial to use the systems approach ie. Looking at design of the whole job including all subsystems taking into account function ability, build quality, impact on environment, as well as satisfaction of customer needs.

As a general contractor that is what we do. We must see the end before we can start the beginning.

3. What is your professional opinion of the design and build approach?

Works best when it is a business that is specialized and the owners can express what they want. Team build is what we would use to describe when all three entities work together as a team. It does not work as well and is not efficient for the contractor if the customer does not completely understand what they want and constantly change plans in the middle of construction.

4. In your opinion would it be beneficial for superintendents to record and publish not only actual safety problems but also near misses and ways that safety on the job site was improved?

Yes. When responsible peoples see things going wrong constantly and don’t do anything about it then problems can happen. If near misses are recorded then there should be no reason in the future for that same near miss or that same problem to happen again.

5. What is your opinion on captive insurance? ie when the company insures its own risks lowering insurance premiums?

We are in the general contracting business and not the insurance business.