Recent Studies in Engineering & Computing

Editor
Olkan Cuvalci

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The Academy of Transdisciplinary Learning & Advanced Studies

ATLAS Publishing, 2017

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ISBN: 0-9778129-8-7; doi: 10.22545/2021b/B5
Published in the United States of America
www.theatlas.org

Preface

This book focuses on recent studies in engineering and practical applications in the field of computer science. The volume's first chapter presents an advanced concept of information security in terms of comprehensive science. The three key values of information society (freedom, security and privacy) and their conflicts with each other are discussed.

The second chapter evaluates the development of a complex manufacturing network in comparison to principles of systems engineering to highlight areas that could have improved from the systems engineering methodology. Through computer simulation, a new funnel design for high temperature vacuum chamber and interactions between gas flow and the funnel structure are investigated in the third and fourth chapters. Chapter five also deals with computer simulation to predict the dynamic response of plywood when impacted by tornado missiles such as 2 x 4 wood timbers. Chapter six explores the application of Systems of System concept to the problem of homestead defense at the homestead level.

In chapter seven, author investigated the Software Defined Networking effort that has caused a major disruption in the networking world and how it addressed a big issue that has been lying dormant in this industry for more than two decades. Understanding of the *Internet of Things* has been discussed in Chapter eight. Philosophical discussion on the relationship between music and mathematics is covered in chapter nine. Chapter ten of this volume deals with protecting human capital through the intersection of architecture, engineering and worker safety. More specifically, Prevention through Design (PtD) is discussed to protect workers by eliminating hazards at work.

Chapter eleven constitutes the initial experiments with the WebQEM method applied to the Internet banking applications of three renowned Romanian banks, for the purpose of the comparative evaluation of their quality. Finally, chapter twelve deals with design topics and processes such as component-oriented axiomatic design, architectural considerations, and project planning in system design.

The editor is grateful to those who contributed chapters to this book and to the Academy of Transdisciplinary Learning and Advanced Studies (ATLAS) for providing support to all the book's publication.

Olkan Cuvalci

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CHAPTER 1

Advanced Concept of Information Security Comprehensive Science

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Information security and ethics as bases of our life are becoming increasingly important in the new information society which we have never experienced before. In this chapter, we present an advanced concept of information security in terms of comprehensive science. Freedom, Security and Privacy are the three key values of information society. These three values are liable to conflict with each other and among them, sometimes three contradictions arises. We use the concept of "Aufheben," (sublate), a technical term of philosophy, to cope with it. S. Tsujii introduced a new concept of information security as the comprehensive science in 1993. Moreover, we have endeavored to evaluate the effectiveness of the concept by establishing the "MELT UP Forum." The MELT UP Forum aims to foster, to identify and to extend a core or comprehensive science that deals with Management, Ethics, Law, and Technology across a wide spectrum of endeavors.

Keywords*:* Verification, privacy, software, legal documents, logic cryptosystem.

1.1 Introduction

Many of you have recognized feasibility that now is the time to start a new professional society to foster, to identify and to extend a core of science that deals with a comprehensive science across a broad spectrum of human, technological and economic endeavors. A spectrum that covers the traditional disciplines of communications, computer sciences, engineering, economics, management, manufacturing, mathematics, statistics and physical social sciences. A cross disciplinary science that can deal with rethinking, reshaping and reconstructing a rapidly ever-changing world order. A world which deals with creativity and innovation to enhance shared prosperity and social and cultural enrichment. In this chapter, we present an advanced concept of information security in terms of comprehensive science. Freedom, Security and Privacy are the three key values of information society. These three values are liable to conflict with each other and among them, sometimes three contradictions arises. We use a German word “Aufheben,” which has a meaning of “to lift up,” or “to sublate.” “Aufheben” unifies values contradicting each other progressively through a process of opposition and struggle and finally lift up these three values for a higher stage. In order to achieve the meaning of “Aufheben.” S. Tsujii introduced a new concept of information security in terms of comprehensive science in 1993 [5], [6], [7]. Moreover, we have been struggling to evaluate the effectiveness of his concept by establishing a new forum named “the MELT UP Forum.” The MELT UP Forum aims to fosters, to identify and to extend a core of comprehensive science that deals with Management, Ethics, Law, and Technology across a wide spectrum of endeavors.

To cope with the advent of new information society, information security and ethics as bases of our life are becoming increasingly important .We are now beginning to live in a new information society which is symbolized by the four keywords, namely Social, Mobile, Cloud and Smart. We have never experienced before and we are not yet accustomed in this new world. In this chapter, we present an advanced concept of information security in terms of comprehensive science. Freedom, Security and Privacy are key values of information society. These three key values are liable to conflict with each other and among them. We use a German word “Aufheben,” which has a meaning of “to lift up,” or “to sublate.” “Aufheben” unifies values contradicting each other progressively through a process of opposition and struggle and finally develop three values: Freedom, Security and Privacy for a higher stage. For achieving “Aufheben” function, we introduce a new concept of information security in terms of comprehensive science which was proposed by S. Tsujii in 1993. An idea of tightly coupled co-operation scheme named “the MELT UP Forum” is introduced.

1.1.1 Structure of the Chapter

This Chapter is structured as follows. First we propose the concept of the information security as the science to sublate the irrationality of the “contradicting requirements.” In sections 2 and 3, the technologies to overcome the contradiction, organization cryptosystems and logical cryptosystems, are described. And finally, the necessity of inter-disciplinary science and human resource development is discussed in section 4. The overall points are summarized in section 5.

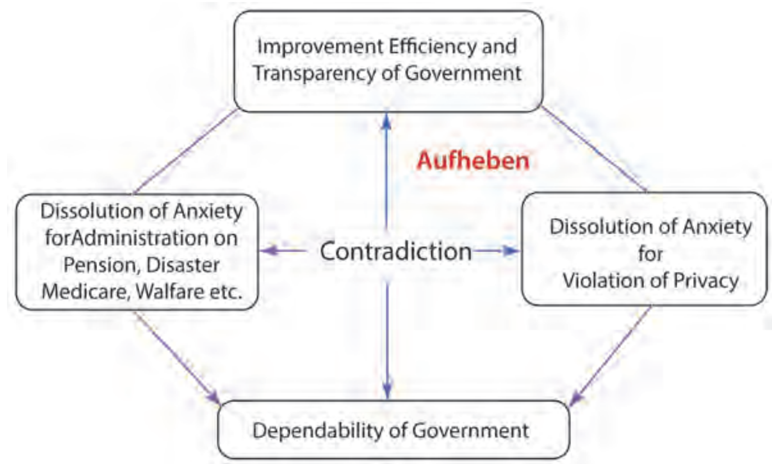

Figure 1.1: Contradiction in electronic government.

1.1.2 Philosophy and Concept of Information Security

Generally implementation of the information security requires not only the technical knowledge but also the business, law, politics or psychology. One of the ultimate basics would be the ethics and discussing what is right and what is wrong. It would require the discussion based on the humanities, philosophy and psychology. Therefore the information security is formed with a comprehensive science. Freedom, Security, Privacy– these three key words seems to summarize the ideal of the IT society. According to Hegel, a German philosopher, "History is the process of broadening freedom." It is certain that the law of history as defined by Hegel applies to the present day in spite of the historical and geographical distances. We can freely expanded from "Physical Space" to "Physical–Cyber Space". In the majority of the cases the compromise between the two has been sought for. However, Tsujii has claimed that the contradiction should be overcome by "sublation."

A new world that human beings have stepped into for the first time. In the new world, they have acquired greater freedom but, at the same time, been faced with unprecedented troubles in security, privacy protection. In the case of introduction of electronic government in Japan (Figure 1.1), protection of privacy is too much stressed ideologically and efficiency, fairness and correctness of various governmental services such as national pension is not seriously recognized, which seems to be unhappy to peoples. In this way, the development of the computer and the network expands freedom of the activity of people, but simultaneously causes a serious problem such as invasion of security and privacy. Because these are mutually contradicting confrontations, there is a value conflict situation difficult to resolve. If only the expansion of freedom is pursued, it is obvious that security level declines, and individual

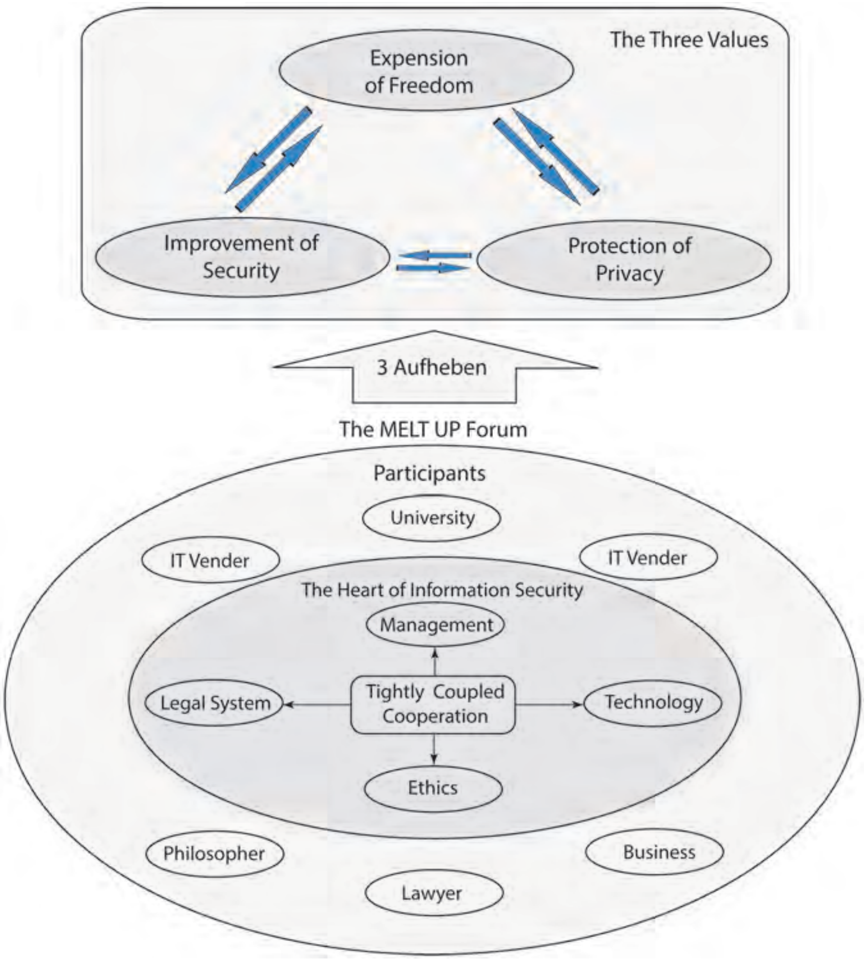

Figure 1.2: (sublation) of the three contradicting requirements.

information and privacy is seriously invaded.

We depict the three values (Expansion of Freedom, Protection of Privacy and Improvement of Security) in Figure 1.2.

If security is enhanced to the limit, not only freedom of activities is restricted but also privacy is infringed through intensified surveillance by cameras and E-mails.

On the contrary, if excessive attention is paid only to the protection of personal information and privacy, free distribution of information is obstructed, needless to say about a decline in convenience and efficiency, and security deterioration is induced by slow response in emergency and increasing crimes under anonymity. All these three parties are related one another with both thesis and anti-thesis, resolving the three contradicting confrontations in the state of three conflicting values of expansion of freedom, improvement of security and protection of individual information and privacy as shown in Figure 1.1.

Information Security of the organization requires to limit the freedom of the members, and look into their privacy. On the other hand, in many cases it often occurs that excessive protection of the privacy reduces the freedom or benefit of individuals.

We depict the relationship between the three key values (Expansion of Freedom, Protection of Privacy and Improvement of Security) in Figure 1.2, in which the the three key values are contradict mutually. We use a German word "Aufheben," which has a meaning of "to lift up," or "to sublate." "Aufheben" unifies values contradicting each other progressively through a process of opposition and struggle and finally develop three values: Freedom, Security and Privacy for a higher stage. For achieving a meaning of "Aufheben" function, an idea of tightly coupled co-operation organization named "The MELT UP Forum" is introduced in this chapter.

As shown in Figure 1.2, a major factors for constructing an information security is defined as The Ethics, The Law System, The Management and The Technology in which these four major factors are coupled tightly and deals with a comprehensive science across a broad spectrum of human, technological and economic endeavors. A spectrum that covers the traditional disciplines of communications, computer sciences, engineering, economics, management, manufacturing, mathematics, statistics and physical social sciences. Therefore, the information security will formalize some comprehensive science.

The MELT UP Forum is participated across a wide range of society, such as philosopher, lawyer, psychologist, physician, business manager, technologist. They argue, struggle and seek how to overcome the contradictions, irreconcilable difference among the three key values.

Tsujii has implemented the concept of promoting the information security and cryptosystem with the cooperation among Management(M), Ethics(E), Law(L), and Technology(T). So he launched the 'MELT-up' forum, meaning the improvement of the society achieved by the integrating the four fields. This forum holds seminars about the periodically. Here is an example of the MELT-up seminar:

(1) Theme: The issue of processing Japanese language in the days of Big Data Machine translation of Japanese is an important issue, since we will host the Olympic game in 2020. Besides, when a US subsidiary of a Japanese company was involved in a lawsuit, most of the cost of the pretrial was spent on translation of the internal document written in Japanese.

The current situation of Japanese language would be similar to the one of English in the late 17th century. In those days the Royal Academy took leadership in revolutionizing the language, identifying the fatal flaw that it had only emotional or sentimental expressions. English was not fitted for expressing the precise logic. They thought that England would not be able to compete with the developed countries in the Continent. That is why the English language that we know is entirely different from the Shakespeare English.

Japanese itself also has experienced the change several times, including the one during the time when the society has transformed from the aristocracy to the samurai government. Besides, Japanese was also changed in the era of Meiji, when a number of European documents were translated into Japanese. Currently Dr. Nagao, the director of the National Diet Library has been leading the advanced research and development of machine translation. The situation is changing, with the advance of the processors, so that the result of the development may be realized in the society.

This MELT-up forum was held with Dr. Takuya Katayama, the former dean of JAIST as the coordinator. We had some lectures by leading scientists in the machine translation or linguistics, and panel discussions among people in various fields.

(2) Theme: Rise, fall, and rebirth of the Japanese Information Industry Lectures about the case study of the sales activity in Latin America to promote the Television system in Japanese standard, or the analysis of the structural change in the semiconductor industry. There were also the panel discussion on the problems of Japanese society in promoting the information industry.

The relation between various contradiction and comprehensive science for information security is shown in Figure 1.3.

Generally implementation of the information security requires not only the technical knowledge but also the business, law, or politics. The ultimate basics would be the ethics, discussing what is right and what is wrong. It would require the discussion based on the humanities, philosophy, etc. Therefore the information security is a comprehensive science.

Our Definition of Information Security: Dynamic process for establishing an integrated system of social infrastructure designed to construct without infringing freedom broadened by ICT and with closer linkage and coordination among technologies, administration and management, legal and social systems, and information ethics in order to make compatible improved usability, efficiency and enhanced security, protected privacy and minimized surveil-lance over people, as shown in Figure 1.4.

The important thing is to train people to have the comprehensive ability. As shown in Figure 1.4, training in various disciplines should be given. None of them would have direct impact on the ability of managing information security. However, interaction of these disciplines would gradually raise the overall competence of the person.

1.1.3 Advanced Communication

Considering the above requirements in the ICT, the communication among organizations would require a new characteristic of the information security.

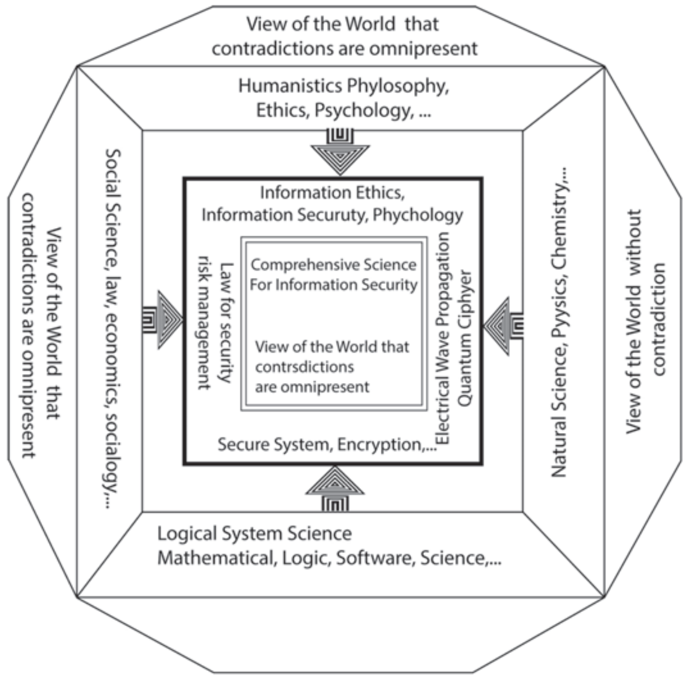

Figure 1.3: Information security as the inter-disciplinary comprehensive science.

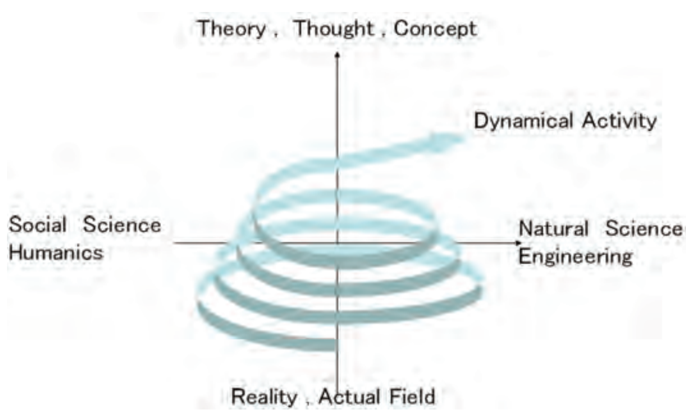

Figure 1.4: Educating the personnel with comprehensive ability.

Traditionally the requirement of the information security is described as maintaining "Confidentiality, Integrity, and Availability." The "integrity" is identified as "the information asset does not suffer unauthorized change." In concrete, integrity breach is regarded as unauthorized change by the intruders or malicious program, etc. We would supplement "logical consistency" to the meaning of the Integrity. It should be confirmed whether the rule or logic included in the document contradicts to the overriding rule.

1.2 Organizational Cryptosystem

Cryptosystem is usually used as a countermeasure against eavesdropping. Although it is sometimes used in managing access permission, in this case it is usually linked to the user identity. Traditionally access control has been the major part of the information security and therefore most of the security efforts have been on the authentication and network security. However, as the progress of the cloud computing, protection of the information asset against the "malicious system administrators," or storing data encrypted.

If all documents are important and delicate, they should be protected also from irrelevant members in the organization. Surest way is protecting the document with cryptosystem. But usually if each document is initially encrypted, it should be decrypted in changing the assignment of the key, or access permission. It is the organization cryptosystem which enables to do it without decryption.

1.2.1 Inter-organizational Communication between two Companies Working on the Same Project

Figure 1.5 shows an example of the communication between two organizations. The sender has 3 kinds of documents, the report to the manager, a draft agreement, and a proposal of the promotion plan. The three are integrated into one document package and sent to the receiver organization.

Each of the components and the package itself has a label (metadata) describing what the document is about. They are about an important project PJ13A21, but the organizational structure or the assignment of the roles in the project is not only transparent to outside, even to the partner of the project. In such a case, whole package is sent to the director of the receiver. Then the director judges who should be responsible for the activity related to the document. If the label says that the document is about the report to the manager, it should be forwarded to the project manager. If the document is about the agreement, legal person should be in charge. If it is about the proposal of the promotion, it should be sent to the sales representative.

We cannot discuss its security/reliability in the same way as the primitive electronic communications such as telephone. There is the feature of logicality/compliance, which varies according to the kind of the communication. The kinds of communication/broadcasting would be classified in a 2x2 matrix depicted in the Figure 1.6 [7].

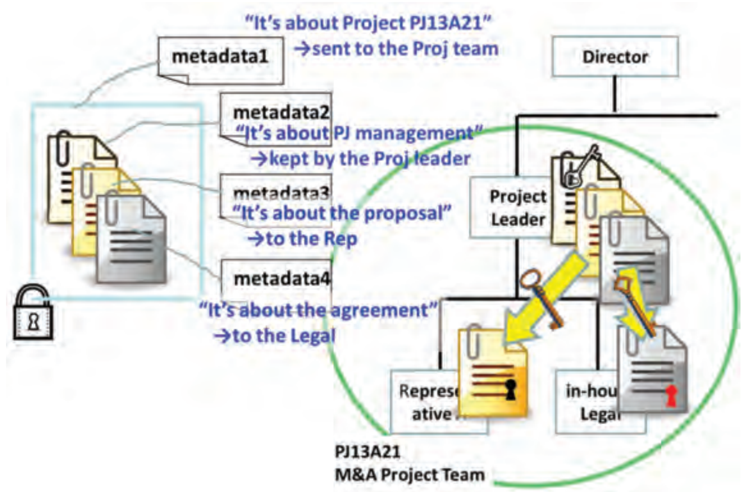

Figure 1.5: An example of inter-organizational communication and distribution of the document within the organization.

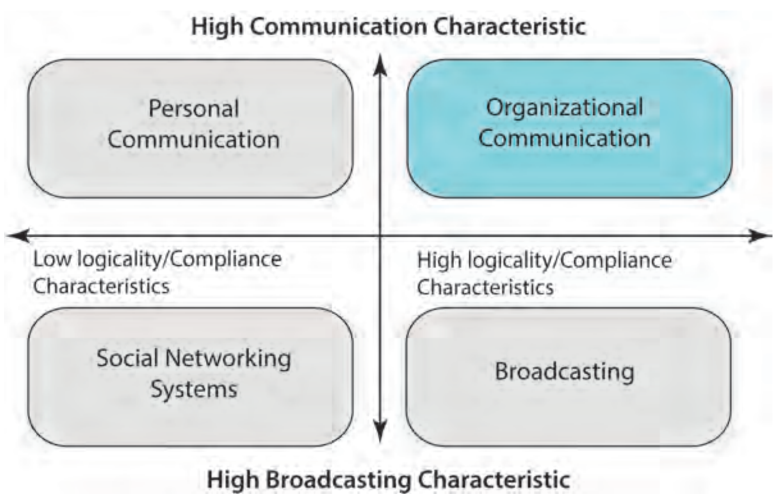

Figure 1.6: Four categories of broadcasting and communication.

There used to be only two categories until the late 20th century, the personal communication and broadcasting. However, since the beginning of the 21st century, Social Network Services (SNS) have come out. Not only do these services supply informal communication and information sharing among friends, they support exchanging niche knowledge such as the know-hows to cope with the difficulty of disability among the victims of drug-induced sufferings like the ones of thalidomide, as reported by the Firefly Research & Evaluation Limited (http://www.fiftyyearfight.org/images/Health_Grant _Evaluation_Year_3_Final_Report_July_2013_. pdf). Generally, these informal communications would require quick response or first-hand knowledge, rather than high reliability or logical consistency, which is required on broadcasting.

Then, we would notice the third kind of communication–organizational communication, which was pointed out by Tsujii [7]. The organizational communication is the ones between organizations such as companies, administrative organizations, or medical services, etc.

For that kind of system, we propose two security systems: One is the organization cryptosystem, which defines the access permission to the message which was sent from other organizations. This corresponds to the "Secure Inter-organizational Communication."

Cryptosystem is usually used as a countermeasure against eavesdropping. Although it is sometimes used in managing access permission, in this case it is usually linked to the user identity. Traditionally access control has been the major part of the information security and therefore most of the security efforts have been on the authentication and network security. However, as the progress of the cloud computing, protection of the information asset against the "malicious system administrators," or storing data encrypted.

If all documents are important and delicate, they should be protected also from irrelevant members in the organization. Surest way is protecting the document with cryptosystem. But usually if each document is initially encrypted, it should be decrypted in changing the assignment of the key, or access permission. It is the organization cryptosystem which enables to do it without decryption.

Figures 1.7 and 1.8 illustrate how the access permission is applied to each person. It is done by making the ciphertext decryptable with the member's secret key. It can be achieved with elliptic curve cryptosystem.

1.3 Logic Cryptosystem

We introduce a private verification scheme with logic cryptosystem that it preserves user's privacy without revealing any privacy related information not only against the logic verification scheme, but also against possible malicious administrators in the World Wide Web. Basic idea of logic cryptosystem is depicted in Figure 1.9. The input to logic cryptosystem to be verified by logical verification algorithm is called problems such as computer program, logical document, and Mathematics. These problems are consisted of two parts, i.e. logic part and part on privacy related values. Part on privacy related values contain some sensitive information. Basic idea of our proposal is based on separate a privacy preserving algorithm and a logical verification algorithm. In Figure 1.9, privacy related values are qualified to some symbols

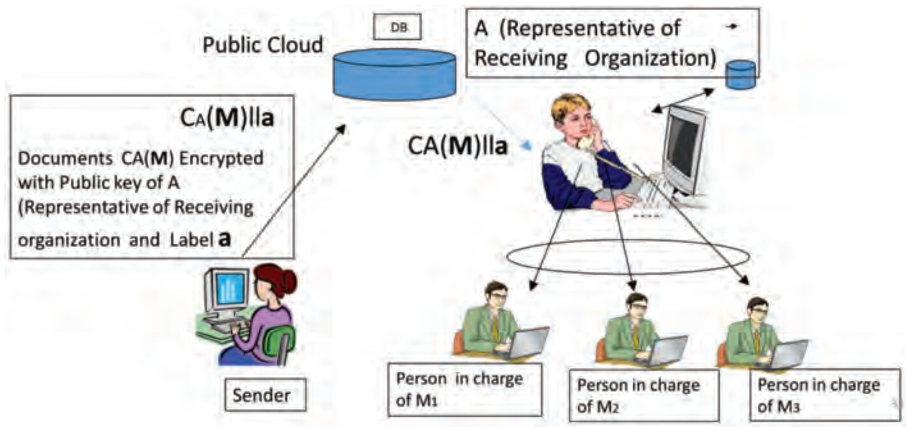

Figure 1.7: Assigning the access permission with Cryptosystem.

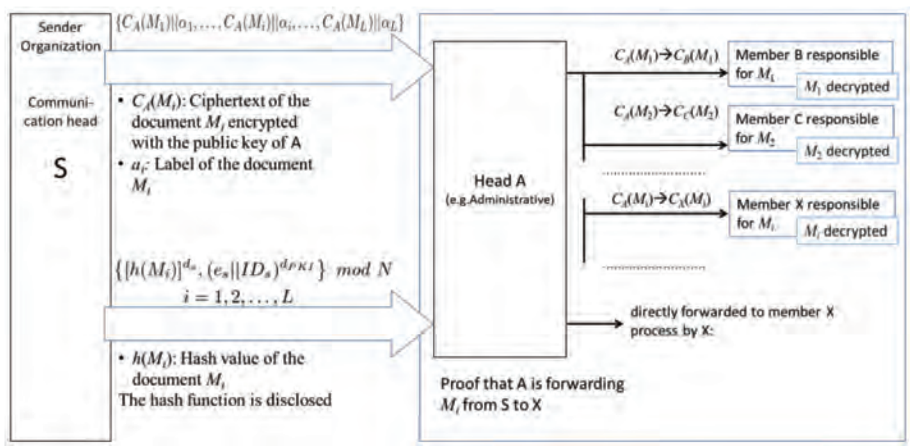

Figure 1.8: Practice of organizational cryptosystem.

or randomized data which we call "Encryption algorithm". Cipher text is consisted of formalized part and qualified values. Formalization is processed by user himself or logic cryptosystem. Logical verification algorithm verifies the cipher text sent from encryption algorithm and generates a result, while logical verification algorithm can obtain any information on privacy related values, due to the fact that its values are qualified in encryption step. In decryption algorithm, privacy related values reserved in qualification step are used to reconstruct privacy related values. We call this step as "Decryption".

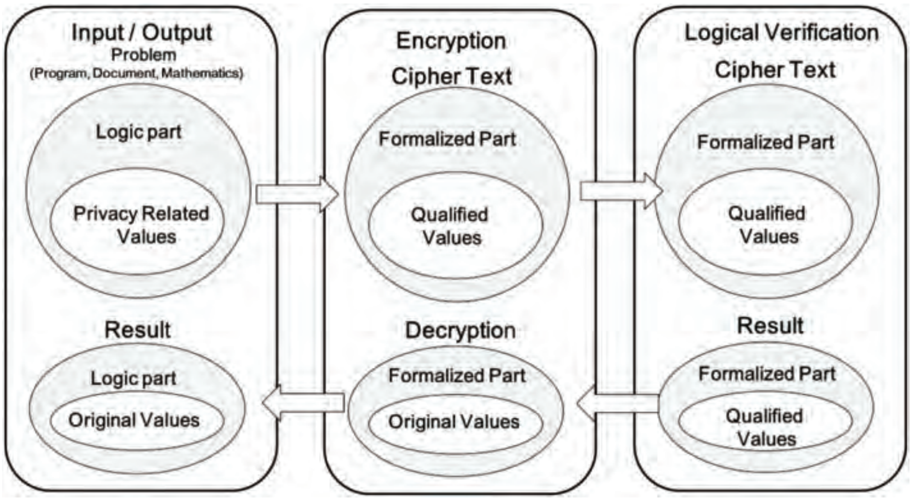

Figure 1.9: Basic Idea of logic cryptosystem.

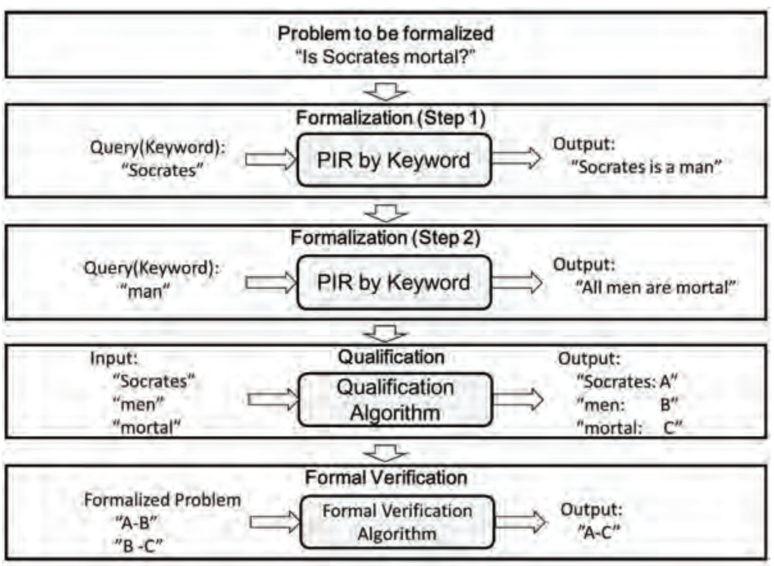

Figure 1.10: Formalization, qualification scheme.

1.3.1 Formalization and Qualification Scheme

We depict formalization and qualification scheme in Figure 10. A formalization procedure depicted in Figure 1.10 relies on an syllogism. A private informa-

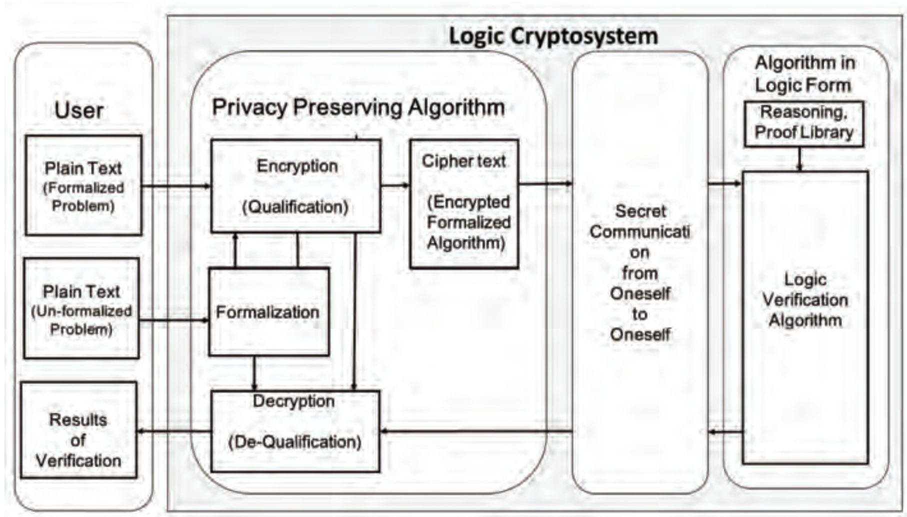

Figure 1.11: Work flow of logic cryptosystem.

tion retrieval (PIR) protocol allows a user to retrieve an item from a server in possession of a database without revealing which item is retrieved. In this example, user selects the keyword "Socrates" from a problem "Is Socrates mortal?" makes query to PIR scheme and obtains proposition sentence "Socrates is a man" as a reply. And then he selects "man" as predicate in this sentence, and obtains reply "All men are mortal". In these steps, he retrieve replies without revealing which keyword are retrieved. Therefore privacy on two keywords are guarded. In next step, he asks qualification algorithm and obtains the symbolized data. The logical verification algorithm check its logical formulation, but obtains any information on problem expressed in natural language.

1.3.2 Work Flow of Logic Cryptosystem

In this section, we describe the work flow of the logic cryptosystem. Three algorithms are applied to our approaches; the encryption algorithm, Logic operation, and decryption algorithm. Work flow is depicted in the Figure 1.11.

1.4 Advanced Communication

Three components of information security (Confidentiality, Integrity, and Availability) were defined since 1970s depicted in the Table 11.. However, due to the vast amount of communication data, and complexity of contents commu-

Table 1.1: Three components of Information Security.

Confidentiality	Only specific people with permission to access particular information can access it.
Integrity	Information and its associated processing methods are authentic and complete.
Availability	The ability of authorized users to access information and related assets reliably whenever necessary is preserved.

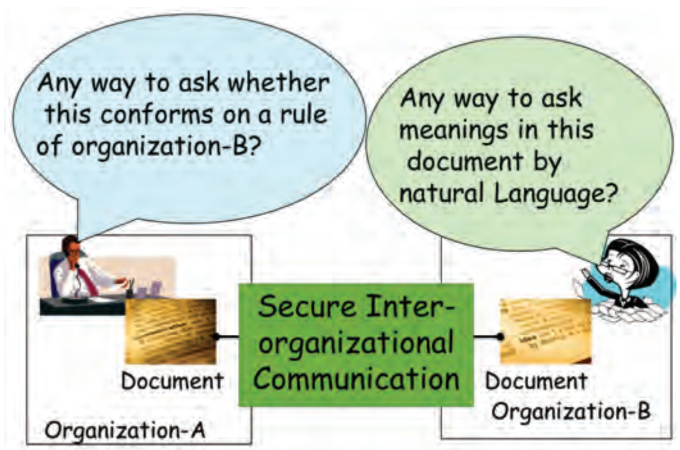

Figure 1.12: Problem in sending documents between organizations.

nicated have been arising a new demand for enhancing the quality of communication data. For example, the evaluation function of logical consistency may be helpful and effective for sender who can evaluate his sending data prior to sending to destination. We propose a new concept of advanced communication, in which logical evaluation service is able for enhancing the quality of data. We propose to apply the logic cryptosystem explained in this chapter and communicate between organizations by the organizational cryptosystem.

As shown in Figure 1.12, suppose some person in organization-A would like to be checked his document whether it conforms a rule of organization-B. In this case, logic checking service provider who is using the logical cryptosystem makes the communication more effective compared to current communication.

New Advanced Communication Scheme in which, users are able to en-

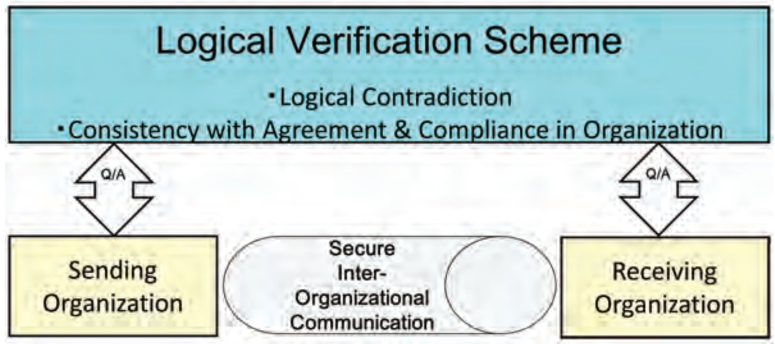

Figure 1.13: Security system maintaining the logical consistency.

hance the integrity of the content to be communicate. The logic cryptosystem can evaluates the logicality, contradiction and consistency of the sentences, in which various legal contents such as regulation rule in the organization are included.

Therefore, we would propose a system to maintain the logical consistency of the document/content as shown in Figure 1.13. The sender asks the Logical Verification Scheme whether the documents are going to send conforms to the internal rule or other regulation. If the check is OK, the message is sent through the secure path to the receiver. The receiver can also check whether the document contradicts any rule.

1.5 Summary

In this chapter, we present an advanced concept of information security in terms of comprehensive science. Freedom, Security and Privacy are the three key values of information society. These three values are liable to conflict with each other and among them, sometimes three contradictions arises. S. Tsujii introduced a new concept of information security in terms of comprehensive science in 1993. Moreover, we have been struggling to evaluate the effectiveness of his concept by establishing a new forum named “the MELT UP Forum.” The MELT UP Forum aims to fosters, to identify and to extend a core or comprehensive science that deals with Management, Ethics, Law, and Technology across a wide spectrum of endeavors. We introduced some example of activity by the MELT UP Forum which are practically resolving the contradiction conflicting current information society. Moreover, we introduced the abstract on the organizational cryptosystem and concept of logic cryptosystem which will become the infrastructure for constructing the information security system. Finally, we also introduced the idea of an advanced communication which will aid to overcome the contradiction near future.

Acknowledgment

This study is supported by the Project entitled "Development of Public-key Cryptosystem for confidential communication among Organizations (17201)" of the National Institute of Information and Communications Technology (NICT), an independent administrative corporation of Japanese Government.

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CHAPTER 2

System of Systems Analyses of RTI International Metals' Boeing 787 Seat Rail Supply Chain

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Systems engineering provides tools to effectively develop intricate systems as well as systems composed of systems. The use of systems engineering is becoming increasingly prevalent due to the methods ability to handle the increasing complexity of systems in modern society. Among these systems are today's global manufacturing networks, driven by recent trends in globalization. This work evaluates the development of a complex manufacturing network in comparison to principles of systems engineering to highlight areas that could have improved from the systems engineering methodology.

Keywords*:* System of systems, manufacturing network, complexity, risk management, systems engineering methodology.

2.1 Introduction

Within the aerospace manufacturing industry, there are multiple suppliers of finished machined metal components. A vertically integrated manufacturing company with a specialization in titanium is the source of this chapter. The intent is to take system engineering methods for evaluating a system of systems (SoS) and apply this to the evaluation of this manufacturing system. This tool was defined by the U.S. Department of Defense and is commonly used in integrated defense systems [1].

This analysis focuses on a manufacturing supply chain, which is a functioning SoS within RTI International Metals, Inc, Headquartered in Coraopolis, PA. The supply chain defines the manufacture of the seat rail, or sub floor framing, for the Boeing 787. This is a somewhat recent SoS development within the manufacturing company and provides insight into current systems engineering practices to be compared with published approaches. The functional model for the supply chain are depicted in Figure 2.1 that outline the production steps for the seat rail components.

Illustrated in the diagram of the SoS, the aerospace manufacturing company is depicted. The analyzed seat rail supply chain SoS is depicted with red flow lines. The chronology of systems in the supply chain are: extrusion, rough machining, welding, and finish machining. A level of complexity results because the rough machining and welding are not part of the aerospace manufacturing SoS.

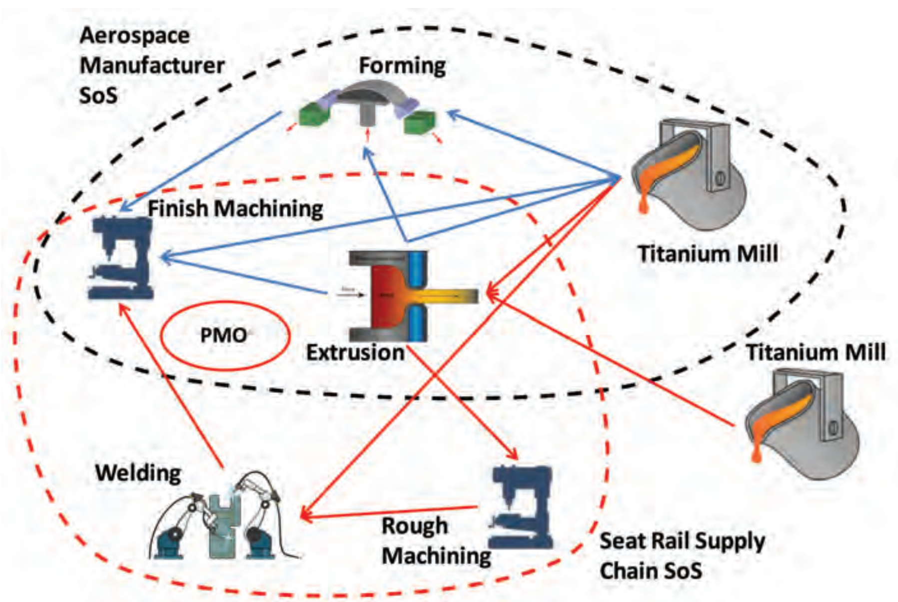

Figure 2.1: OV-1 illustrating top level system interaction of the SoS involved in the seat rail supply chain SoS. Red indicates Seat Rail flows and SoS boundaries. Blue and Black represent the manufacturing company's flows and boundaries.

In the discussion, the activity toward the establishment of the seat rail supply chain SoS will be examined in detail. This is partially contained within the aerospace manufacturing company SoS. These partially overlapping SoS create a complex dynamic in the operation of the SoS. Within the supply chain SoS exists the project management office. This is the SoS management of the supply chain and is mostly aligned with the finished machining individual system as they are considered the supply chain owner.

The SoS level key requirements present for the supply chain SoS are: deliver complete sets on time in full, minimize working capital, and maintain profit margins to within corporate goals [2].

2.2 Background

Systems engineering is the planning, organizing, integrating, and evaluating of individual systems into a SoS with a capability greater than the sum of the constituent systems capabilities [1].

In this evaluation, reference will be made to both systems and SoS, and the key differences should be known. A system is a related group of interacting elements that form an independent and unified whole entity. A SoS is composed of independent individual systems to form a larger system that delivers unique capabilities [1].

The governance of a SoS is more complex than for an individual system. Stakeholders exist for both the SoS as well as the constituent system of which it is composed. Sometimes there exist conflicting interests among these stakeholders depending on if they represent a constituent system or the SoS. The negative result of this conflict is the reluctance to assign priority to tasks outside of the constituent's system. It is common for the SoS to have objectives and resources; however, it is also common that individual systems possess their own management, funding, engineers, and development programs. This makes the governance of a SoS complex and difficult. In order for effective development and operation of a SoS, a collaborative approach must be taken by systems engineers to effectively govern the SoS [1].

There are four types of SoS: Virtual SoS, Collaborative SoS, Acknowledged SoS, and Directed SoS. These are listed in order of ascending dependency and centralized control. The seat rail supply chain SoS examined in this chapter currently represents a collaborative SoS. In this way, the systems are completely independent and interact with little central direction to meet agreed upon purposes. It is the objective of this study to identify avenues to improve SoS oversight to the point that an acknowledged SoS can be developed. In this way, the constituent systems would collaborate under a recognized SoS management while maintaining individual ownership and operation of their systems [1].

There exist seven core elements that define the activities of a SoS. These include: translating capability objectives; understanding systems and relationships; assessing performance to capability objectives; developing and evolving an SoS architecture; monitoring and assessing changes; addressing requirements and solution options; and orchestrating upgrades. The activities of a systems engineer operating on a singular system can be composed into 16 categories. These include: requirements development, logical analysis, design solutions, implementation, integration, verification, validation, transition, decision analysis, technical planning, technical assessment, requirements management, configuration management, data management, and interface management [1].

The application of these activities into the core elements for a SoS evaluation was generated for the manufacturing SoS as seen in Figure 2.2. In the depicted figure, the common systems engineering tasks that correlate the SoS activities are shown in gray. The horizontal axis represents common systems engineering activities for a system. The vertical axis represents the activities involved in SoS engineering. These applications are explored in detail within the chapter.

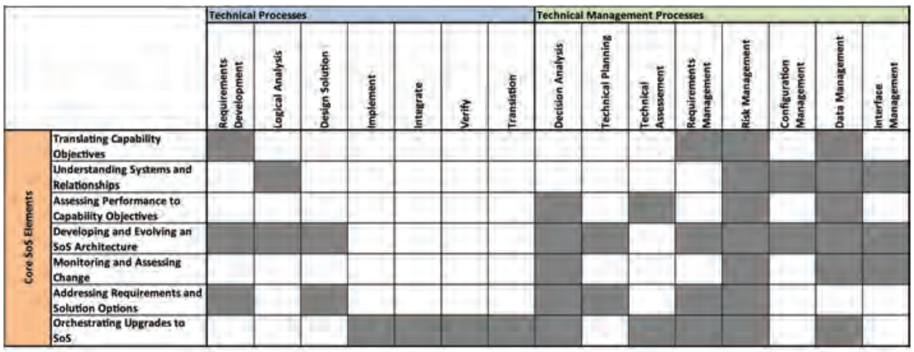

Figure 2.2: Activity mapping of systems engineering activities to SoS elements for the aerospace manufacturer SoS.

2.3 Translating Capability Objectives

The formation of a SoS relies on the identification of needed capabilities. The systems engineers are then responsible for articulating this in technical level functions and requirements. A portion of this task is the prioritization and weighting of requirements to ensure best SoS behavior. The generation of capability objectives will depend on stakeholder needs, external factors impacting the SoS, and feasibility based on the SoS architecture, limitations, and functionality [guide].

When the manufacturing SoS is defining a supply chain, the primary objective is the production of a specific product. Along with this are the properties that the component or assembly must possess. This is translated into technical requirements to achieve the specific properties with the desired geometry. These requirements are typically generated by engineers familiar with the processing dynamics with the individual systems in the company.

2.3.1 Technical Processes

Requirements Development

The translation of capabilities into requirements provides the foundation for the development of a SoS. This is often a dynamic process that refines through the development process. In many cases, requirements are specific to a manufacturing approach, and multiple requirement options may need to be produced so as not to limit solution options. The input of stakeholders must be taken and balanced to provide capabilities technically, practically, and affordably.

The manufacturing SoS will often need to determine the end customer needs for a required product. The technical staff receiving this stakeholder input would then translate this into technical requirements necessary to produce the product. In some cases, multiple production paths can be identified. In some instances, the customer has a more active role in defining the approach to manufacture and outlining of requirements. It is still common that some requirements will need to be generated beyond what is outlined by the customer.

In the aerospace manufacturer SoS, the individual systems maintain operational independence and often define their own requirements. The supply chain SoS also maintains requirements primarily geared toward satisfying customer and corporate stakeholders [2]. The requirements for the customer focus on quality, cost, and production rates. The company objectives address working capital, stakeholder value, and profitability. These SoS level objectives are not routinely communicated to constituent systems or collaboratively involved in their formation [2].

There is also opportunity for improvement with the collaborative development of technical requirements for the individual systems. A significant lesson learned occurred when a vendor in the initial seat rail supply chain could not meet a flowed down requirement. Rather than the SoS collaboratively working to resolve or mitigate the inability to meet the requirement, exceptions were taken for the requirement. The result was down stream product fallout, the cost of which was absorbed by the supply chain. This had significant impact on profitability, deliveries, and working capital [3]. This represents a significant opportunity for the manufacturing SoS.

2.3.2 Technical Management Processes

Requirements Managements

The management of requirements is critical to meeting long term capabilities of a SoS. Requirements should be documented back to the end customer needs or industry specifications. The management of this requirement information is critical to the defining, assessment, and prioritization of customer needs for the SoS capabilities. This effort also highlights justification for critical requirements and allows robust decisions for requirements of the system as objectives change with time [1].

The seat rail supply chain SoS maintains requirements for individual systems labeled as key performance indicators (KPI). These requirements are managed by the SoS for the top level requirements. The management of constituent system requirements falls on the individual systems. A centralized management tool does not exist to compile all system and SoS level requirements or track them back to stakeholder or industry requirements [2]. This represents an opportunity to improve visibility and traceability of requirements throughout the supply chain.

Risk Management

When addressing capability objectives for a system of systems, the risks associated with achieving these capabilities must be addressed. The level of risk associated with a capability will have some level of impact on decisions of capability feasibility or system modification to mitigate risk [1].

Prior to the start of a supply chain, gaps and weaknesses are evaluated for the supply chain. This is performed by the customer and high level technical staff within the manufacturing company. A key development that occurred in the SoS of the seat rail supply chain was the formation of a project management office (PMO) to oversee the SoS [4]. This was a key success as it provided the framework for effective SoS management for the supply chain.

Data Management

The availability of system data plays a significant role in defining capability objectives. This data allows for informed evaluations in regards to systems capabilities and expectations. The robust collection, centralized storage, and practical accessibility of system data enables more informed evaluation and accurate requirements development based on desired objectives.

The manufacturing system has centralized data hardware; however, individual systems currently operate on separate networks. There is an effort to implement a centralized quality management system that stores important manufacturing data from all individual system on a central location [4]. This unified access will allow universal access to requirements and documentation associated with requirements. This would improve fidelity of the supply chain system of systems.

2.4 Understanding Systems and Relationships

A key component of development of a supply chain is the understanding of how systems interact and support they the SoS's functionality. This understanding also includes the identification of technical details pertinent to the operation of the SoS. A major key to developing an understanding of a SoS is the definition of the following: system boundaries and interfaces, resource relationships, requirement responsibilities, relationships in the development processes, identification of stakeholders and their impact, and constituent systems relationships [1].

There is considerable work toward developing the understanding of systems and relationships within the manufacturing company. The manufacturer operates based on supply chains that are established and put into operation. Upon initial setup, there are still some iterative improvements to be realized in the operation of the established supply chain. During establishment and operation, change authority often lies with the end customer. This presents challenges to implementing changes or improvements and most efforts to build development plans must be performed collaboratively with the customer.

2.4.1 Technical Processes

Logical Analysis

Logical analysis provides the foundation for understanding a SoS by highlighting how each system supports functionality of the SoS. This is a technical task involving specific input and output parameters associated with each system [1].

In the manufacturing system, as is the case with many manufacturers, the individual systems represent organizations across the world acquired at different times. The recent acquisition of new entities represents a constantly changing set of relationships. Resources are devoted toward integration of new acquisitions, however, clear technical capabilities are not systematically distributed amongst the manufacturing system to foster systemic interactions [4].

A success of the SoS is that there are already resources devoted toward developing solutions optimized to the manufacturing SoS. This system wide logical understanding is localized within a portion of the organization in the technology development office. This is effective at establishing technical flows for a defined system, but operational mapping is not systematically utilized. Improvements could be realized by producing detailed logical analysis of each system in the manufacturing system, in all aspects. This analysis could be extended by identifying additional possible new relationships within the manufacturing system and fostering them [4].

In the SoS of the seat rail supply chain, the lack of logical analysis to define the SoS overview resulted in the misappropriation of capacity. The understanding of constituent system contributions, lag times, and requirements was not factored into demand signals to the individual systems. This production signal became chaotic and resulted in unnecessary shifts in production and diminished capacity. This caused delays and bottlenecks throughout the supply chain [3].

2.4.2 Technical Management Processes

Risk Management

A key task when developing the systems understanding for a SoS is identification of risk involved. The consideration of anticipated behavior of the SoS should be made. The systems engineer should also identify core functional paths, required changes due conflicting constituent system needs, capacity constraints, technical constraints, and stakeholder behaviors in the SoS understanding.

In the manufacturing SoS, there are many aspects of operation which require risk mitigation. A major area of risk management is in system capacity. The use of production readiness assessements (PRA) provides the level of risk for each system and the supply chain in different elements of operation [2]. An opportunity for improvement could include the collaborative evaluation of the supply chain. This would ensure that all activity, beyond the activity associated with the supply chain, is accounted for. Historically, this has proven a painful lesson when the total capacity was overestimated by not accounting for activity outside the supply chain. This resulted in a delayed identification of the need for capacity expansion and delays [3].

Configuration Management

The configuration management of SoS is primarily focused on the interaction of the constituent systems. The individual systems typically maintain their own baseline processes and the systems engineer works with the individual systems to develop logical links between functionality of these systems. These logical links could also represent future links for SoS expansions.

The configuration management for the metal manufacturing system is a key task in understanding systems and relationships. The pressures of globalization, corporate acquisitions and mergers, as well as expanding new technologies in the titanium industry, are certain to influence changes to the structure of the manufacturing system [5, 6]. The ability to redraw the SoS relationships in detail as individual systems are added, subtracted, or modified, will be central to effective operation of the manufacturing system. A formalized system is not in place to aid the process of change. Currently, with system changes, the process is entirely manual and resource intensive [2]. The formalization of the understanding of system relationships and functionality could reduce resources required to develop or change supply chains in the future. This systemic best practice could also include lessons learned to prevent reliving of mistakes with new SoS.

Data Management

The systems relationships are pivotal for understanding of SoS behavior. In order to facilitate greater understanding of systems interactions, the documentation defining the SoS should be centrally stored and accessible by constituent systems. This information would consist of systems relationships, functionality, interfaces, data flow, development plans, and shared attributes.

The centralized management of data from all individual systems plays a key role in the understanding of the system behaviors. Many of the behaviors of systems need to be characterized with data analysis to clearly define system inputs and outputs. Currently, many individual systems operate separate data systems, but significant effort has been put forward for a unified data management system, in the quality module [4]. The global collection of data and documentation throughout the manufacturing life will greatly increase the knowledge and visibility of relationships and performance characteristics within the manufacturing system. This will also provide statistical quantification of inputs and outputs for use in defining systems relationships.

Interface Management

The understanding of systems relationships in a system of systems is a direct contributor in defining interfaces between constituents. The interdependencies and critical flow of information dictate what information is transferred between constituent systems and what format it is in. How the individual systems utilize the transferred information in its functionality should also be taken into account in the analysis of the system [1].

In the seat rail supply chain SoS, the amount of data transfer is small in comparison to some system of systems. There are two systems being developed to facilitate interfaces between constituent systems. The interactions in regard to production parameters are to be handled by a VSMIS system [2]. This is to streamline interaction and tracking throughout the chain. The management of technical production information will be handled by the quality module tool [4]. The identification of the key data transfer involved in the SoS interfaces should be the result of the mapping of the system relationships [1]. This is a key opportunity for system improvement.

2.5 Assessing Performance to Capability Objectives

The operation SoS, as well as constituent systems, rely on the effective evaluation of performance driven by implemented decisions. The development of measures to determine performance relative to performance objectives is an effective way to quantify the outcome of a system change or current state of operation. These metrics should be developed in collaboration with the technical individuals from constituent systems to ensure key parameters are chosen as metrics to capture performance. Metrics should also be chosen to be compatible with future SoS changes and expected improvements [1].

In the manufacturing SoS, there are considerable amounts of performance metrics evaluated. The majority of SoS metrics are related to production rates, customer feedback, and the interaction with systems within the supply chain and outside the manufacturing company. The drive to reduce operating inventory and support lean manufacturing drives continuous adjustments to production rates and priorities based on needs and inventory levels. The development of technical metrics at the individual system level including mechanical, metallurgical, and geometrical properties and are necessary to ensure that operations were performed within defined operating limits [2, 4].

2.5.1 Technical Processes

Validation

The assessment of performance is vital in the validation process following a SoS change. As the SoS is developed or evolved, considerable assessment is required to determine if performance matches expectations for the planned change. This establishes the degree of improvement and dictates whether more change is warranted [1].

In the establishment of a supply chain SoS, where iterative refinement is common, the continuous assessment of performance is crucial. The performance data provides the validation for all iterative changes and justification for future changes and directions [4].

In the seat rail supply chain SoS, routine validation is performed in respect to production characteristics. The evaluation of machine and manpower capacity is performed to validate production performance [2]. An opportunity for the supply chain is to extend this global awareness to technical aspects of performance, which is currently handled by constituent systems [4]. This would enable comprehensive understanding of performance and enable SoS level development.

2.5.2 Technical Management Processes

Decision Analysis

The use of decision analysis in regards to performance assessment aims to evaluate that relevant data is being collected and evaluated for trends. The systems engineers should be assessing if critical data is being collected at the proper times and in the correct ways. Considerable evaluation of performance should also address the emergence of secondary performance impacts from a change, determination of root causes, and generation of alternative approaches.

In a manufacturing system, considerable decision analysis is performed by the technical individuals within constituent systems. The iterative refinement process, when defining a manufacturing process, uses thorough assessment of performance to drive refinement through much iteration until production is optimized [4].

The supply chain SoS does not formally utilize decision analysis to define paths to assess performance. Performance is currently assessed through standardized industry tools providing many aspects in the quantification of performance. An area for improvement, that is currently being explored, is the augmenting of these tools to include collaboratively defined metrics for the individual systems in the supply chain [2]. This should provide a more comprehensive evaluation of supply chain as well as constituent performance.

Technical Assessment

The assessment of performance is also used to evaluate the degree of technical progress a SoS is making. As changes are made to the SoS, the degree of effectiveness can be collected and used to determine if the desired effect is realized and that behavior is conducive with anticipated operating principles [1].

In manufacturing system SoS, this is most seen in the implementation of new technologies within constituent systems. The upgrade or addition of new equipment has thorough technical assessment and validation prior to full operation in the aerospace industry. Many technical parameters of production equipment have to be compared with theoretical datum or analog equipment to determine that performance matches technical plans [4].

The manufacturing system SoS does not have a formalized assessment method specifically aimed at technology. The main assessment tools currently examine entire systems within the SoS [2]. The grading of technology against production requirements represents a major opportunity to provide a basis to drive technological innovation to be most effective with development resources.

Risk Management

The assessment of performance is a key component of evaluating the level of risk in a SoS and to determine the effectiveness of mitigation steps. There is also a level of risk associated with the assessment of performance that engineers must address based on possible impact and mitigate this if possible [1].

In manufacturing systems, the receiving of false control and performance data can have significant impact on SoS performance. The failure of information during critical heat treatments and metalworking can render produced components unusable and can accumulate rapidly if left unnoticed.

A major lesson learned in the seat rail supply chain SoS occurred because of the lack of risk management with performance assessment at the start of the seat rail supply chain. The lack of collaborative developed understanding of risks and roles resulted in false production signals and the failure to capture this error in the system. The result was extensive over production of some components of the delivered sets [3]. The use of collaborative risk management methodologies should help to identify pit falls and establish assessment tools to capture these conditions.

Data Management

One of the centralized processes of assessing performance is the centralized collection and access to data. This becomes an accumulated body of knowledge to be drawn from in many circumstances to guide decisions. The centralized storage allows behavior evaluation for the constituent systems as well as the cumulative SoS [1].

In the SoS of the aerospace manufacturing system, work is currently being done to collect data on a unified production tool [4]. Where there still exist opportunity is to compile this data into useful formats that represent key metrics and establish access to this information both at the supply chain level as well as the constituent system level.

2.6 Developing and Evolving a System of Systems Architecture

With the definition of system requirements, logic flow of the systems, and definition of performance metrics, the architecture of the SoS should be developed. This effort encompasses the functional contributions, technical needs, internal and external systems relationships, communication infrastructure, and risks of the SoS. In some application, up front sensitivity analysis helps to identify critical aspects of a SoS architecture based on system output variability. Much of the system architecture is constrained by the functionality of the individual systems [1].

In the manufacturing system, this operation is often shared with the end customers who own the entire supply chain. The individual systems are also well established prior to their incorporation into the supply chain [5, 6]. The architecture will capture and manage the operation of the entire SoS, both inside and outside the company. This will be the vehicle that drives the effective operation of the supply chain SoS. This effort is also not heavily supported by the end customer as the identification of functional steps. The change of the functionality within the constituent systems in a supply chain SoS is limited in most cases. The interaction of each individual system in multiple supply chains restricts the ability to change functionality to address an individual supply chain SoS unless all supply chains accept the change concurrently.

2.6.1 Technical Processes

Requirements Development

The interpretation of stakeholder inputs into requirements is the driver for SoS evolution. The architecture must adapt to address the requirements. Changing requirements forces changes in the SoS. It is common to include requirements in a SoS for the enabling of future functionality needs. This defines an architecture that may not fit existing SoS structure, but will enable less cumbersome upgrades as functionality is incorporated.

In the supply chain SoS, the customer must be involved in all work that has an impact on finished product properties. Historically, the customer has driven most major supply chain architecture decisions and will likely maintain significant presence in these decisions [4]. However, recent changes in the industry indicate a shift of primary ownership toward the tier one suppliers.

These primary suppliers have significant authority in supply chain requirements development [5, 6]. The ability to define supply chain requirements presents an opportunity to compete for tier one status on more supply chains in the future.

Logical Analysis

The logical flow of SoS architecture is critical for changing the system. The identification of SoS operational environment, functional mapping, information and material flows, trigger conditions, expected behaviors, and span of operation will be the basis for understanding of the impact of evolving the system.

There was a significant lesson learned with the failure to adequately map product flows and trigger conditions in the seat rail supply chain SoS. The lack of trigger conditions necessary to synchronize production between individual systems in the supply chain resulted in the individual systems optimizing their own operation. This resulted in a push model across the supply chain. The result of this was a severe swelling of operating inventory and congestion at bottlenecks of the supply chain [3]. The establishment of logical mapping of the entire SoS, as well as anticipated upgrades, is a significant opportunity to improve operational coordination.

Design Solutions

The generation of alternative design solutions based on requirements and logical analysis is a central role of a systems engineer. The engineer must outline how the systems will work together by defining functional components, behavioral principles, and relationships. The generation of solutions that will be useful over time is critical. This is done by understanding where change is needed and likely. A design solution for the SoS will be generated by the systems engineer. The design engineers for the constituent systems will be responsible for designing sub-systems to meet their requirements. This operation will be iterative until the SoS and constituent systems designs are compatible.

In the SoS of the aerospace manufacturer, the customer will have significant influence on all design solutions created to manufacture components [4]. This will prove an additional challenge as all designs must be iteratively developed with them as well. The ability to design solutions for manufacture is a new responsibility being realized by top level suppliers in the aerospace industry [5, 6]. This presents an opportunity to expand the role and ownership of supply chains across the industry and leverage vertical integration across the supply chain.

2.6.2 Technical Management Processes

Design Analysis

The use of decision analysis is the basis for selecting the best design solution from the multiple design options generated. This evaluation of the design options relative to performance metrics should also examine flexibility, change timeline, funding requirements to enact and upgrade, and adaptability to change [1].

In the seat rail supply chain SoS, limited work has been done on solution analysis [2]. This represents an additional opportunity to strengthen skills necessary to be a tier one supplier in the evolving aerospace industry [5, 6].

The development of a technical plan to evolve a proposed design option toward its final envisioned architecture should be included with assumed strategies and mitigation strategies to support the plan. This should be developed in coordination with the technical plans of the constituent systems [1].

The planning of technology evolution of supply chain is a critical ability for a SoS. The manufacturing system SoS maintains a research and development budget and personnel within the manufacturing SoS [4]. Where there is opportunity for improvement is in supply chain technical planning for supply chains. This would provide a tool to effectively implement development resources to support major production lines.

Requirements Management

With all SoS that evolve over time, a system for the management of requirements is critical. The centralized tracking and documentation allows for changing requirements to be verified against their original justification regardless of the date of change [1].

In manufacturing systems, the need for requirements documentation is critical. The loss of traceability to requirement justification requires costly redevelopment of requirements and opens the SoS for errors from replication after the fact [4]. This is very difficult because usually some portions of decisions are internal to the end customer only and regeneration is very difficult [2]. Currently, top level requirements are managed by the system engineers for the seat rail supply chain and flowed down within the production orders. A formal requirement management tool to ensure continuity of requirements is not currently being utilized in the supply chain [2]. This represents an opportunity for improvement and could be incorporated into the developing quality module tool.

Risk Management

Risk management helps to systematically mitigate costly failures associated with the changing of SoS architecture. At this stage, risk management should focus on key functional risks, constituent system synchronization risks, issues with inflexibility of constituents, technical risks, and resistance to change [1].

In a created supply chain SoS, there is a considerable amount of risk to evolving the architecture. Essentially, the system has to be re-qualified technically and from a capacity standpoint [4]. The failure to address risks upfront proves costly from redesign and late delivery standpoints.

In the supply chain SoS, quarterly risk analysis is performed on the supply chain architecture to analyze potential scenarios and risk mitigation techniques for production rates [2]. The expansion of risk management to incorporate technical risks associated with the supply chain architecture represents an opportunity to improve the robustness of risk mitigation.

Configuration Management

As the SoS evolves, considerable amount of attention has to be given to configuration management. Through the changes to the SoS, the critical information flow and data acquisitions should continue to ensure seamless system operational integrity. This becomes more difficult with significant modifications to system architecture and should be addressed by the systems engineers [1].

Plans exist in the seat rail SoS to develop a configuration management tool to assist the development of other SoS. This would include anticipated customer expectations, lessons learned, and identified best practices to aid the development of this and other supply chain SoS [2]. This represents a major opportunity to improve supply chain development effectiveness.

Data Management

The validation of changes to a SoS architecture requires the availability of critical data prior to and after changes are made. This information is required for SoS evaluation as much so as internal to the individual systems. This critical data includes architecture drivers and tradeoffs, architecture representations, control logics, operating principles, risks, key metrics, and technical plans [1].

In the aerospace supply chain SoS, the centralized management of data is also key to operation. The high level of interdependency and qualification rigors merit high levels of data collection. The development of a data management tool to operate within the SoS architecture is a critical task. The development of the quality module's role as a data management tool for supply chains represents a major success within the manufacturing system SoS [4].

Interface Management

The interface between constituent systems relies on common communication mechanisms. The addition or replacement of systems within a SoS requires this to be revisited to ensure communications of key information is preserved and functionality is not lost in the SoS [1].

In the manufacturing system SoS, the amount of data flow is much lower during operation. The style of data is also less important as much of this can be converted to other formats, such as drawings and collected data [4]. The purposeful planning of interfaces when the supply chain is created ensures that data is transferred completely and conveniently to reduce lost time and effort [1]. The development of clear communication protocols between constituent systems represents an opportunity for improvement by allowing minimal wasted time and effort for inter-system transactions.

2.7 Monitoring and Assessing Changes

A key activity with all SoS is addressing changes outside the SoS, which could have an impact on functionality and performance. This could be an environmental change as well as a change to individual subsystems. It is up to the system owners to address these in the system through intervention to alleviate the effects or attempt to mitigate their negative impacts. Additionally, the constituent systems often evolve independent of the SoS, and the impact of this must be continuously revisited and evaluated. The uses of technical meetings, between shareholders from individual systems, are common to identifying anticipated future developments and collaboratively evaluate their impact on the SoS [1].

In the titanium manufacturing supply chain, this is a collaborative effort since much of the change authority is owned by the end customer. These potential influences must be carefully evaluated and communicated to the tier one supplier so effective changes and mitigations can be coordinated. There has been considerable impact on this industry in the recent past with raw material shortages causing delays in deliveries [5].

2.7.1 Technical Management Processes

Decision Analysis

As the SoS environment evolves, there will be a need to implement changes. Decision analysis will provide the basis for evaluating options to implement for the SoS. These changes can encompass new and enabling technologies, changing SoS objectives, or customer demand shifts. Analysis should be performed with criteria with the objective of optimizing the SoS and the constituent systems [1].

In the aerospace manufacturing SoS, the reaction to changes is driven by the end customers. Though input is common, the end customer is involved with large changes in any supply chain [4]. Top level individuals are involved with decisions regarding significant changes in the seat rail supply chain. The immediate upstream and downstream systems are often included in discussions to identify impacts [2]. An opportunity for improvement lies in the development of a collaborative forum to evaluate impact from external factors on all constituents in the supply chain as well as the SoS as a whole.

Risk Management

The evaluation of risk associated with external environmental change is a critical metric for determining if action is required. The reduction or risk through mitigation techniques is also important information in monitoring change.

The supply chain SoS utilizes operating environment changes in the quarterly risk analysis. The analysis of anticipated impact and likelihood for possible scenarios in the external environment assist the determination of potential risk to the supply chain. This result motivates a course of action [2].

Data Management

The collection of data associated with constituent system changes and external environment changes aids the tracking and evaluation of the SoS situation. The impact of actions taken in the past is also useful in guiding future decisions [1].

A success of the aerospace manufacturing SoS is that quantitative data is tracked for customer demand [2]. There exists opportunity for improvement in how this data is managed and extracted for use in the systems of the SoS. A lesson learned in the seat rail supply chain occurred when the production requirements for other supported supply chains for an individual system were not evaluated. The cumulative increase warranted capital investment to expand capacity. The evaluation of each supply chain individually did not indicate this. This resulted in a delayed ordering and temporary lack of adequate capacity [3].

Interface Management

The assessment of change in a SoS addresses the changes in interface between individual systems. This must be managed to ensure communications are not lost between systems.

Development of an interface management tool, VSMIS, has the aim of streamlining interaction between systems. The amount of data transfer between constituent systems in the seat rail supply chain is small compared to some SoS. One example of an emerging interface management change, is a growing demand for 3D digital scanning of components to demonstrate conformance. This aids in decision making for machining systems, however, this requires costly equipment and time for the metalworking constituent systems [4]. The periodic evaluation of customer interfaces is an area for improvement to ensure seamless interaction with the supply chains.

2.8 Addressing Requirements and Solution Options

When considering the operation of a SoS, there are needs and requirements of the system that must be prioritized and addressed. A number of solution options would need to be generated to attempt to meet the system's needs and requirements. A key aspect of this activity is understanding the individual systems from a technical, organizational, and constraint perspective and applying this when evaluating solution options. The requirements managers from the individual subsystems should be engaged in the derivation and division of subsystems requirements in order to balance needs within the SoS [1].

The outcome of this effort is the formation of a technical plan to address the requirements with a SoS. This may also indicate the need to develop upgrades to the SoS architecture if the existing SoS is incapable of delivering to the requirements [1].

In the aerospace manufacturing SoS, the customer has played a primary role in designing of supply chains. [4] Current trends in the aerospace industry are indicating shifts toward tier one supplier owned supply chains. [5] The ability to address various supply chain options in relation to requirements has not been formalized due to the lack of need to thus far dictated by the end customer [4].

2.8.1 Technical Processes

Requirements Development

The generation of technical requirements based on requirements from stakeholders is a primary focus when addressing requirements. These technical requirements are interpreted and conveyed to individual sub-systems. This can be complicated by the presence of multiple options within the SoS. The development of requirements should also account for constituent system resources, human capital, equipment, and funding necessary to meet requirements. This can result in an iterative process to develop requirements.

In the manufacturing SoS, there are often multiple alternatives when developing a supply chain SoS. The requirements for competing systems can also have very different technical requirements.

Limited requirement development is done at the SoS level for the supply chain SoS [2]. Much of the detailed requirements are created by the constituent systems [4]. A significant opportunity for improvement exists by developing a method for collaborative development of requirements for the systems as well as the SoS. This will allow requirements to be optimized to a specific solution design.

Design Solution

The development of design options based off of generated technical requirements is a key function for the systems engineer. Ideally, a number of alternative design options are created, of which the most ideal solution is chosen. It is also noteworthy that the most ideal solution can dictate the extension beyond the SoS [1].

In the manufacturing SoS, the generation of design solutions involves many of the stakeholders. The end customers typically oversee developmental efforts and designs of supply chains. In more rare cases, suppliers will undertake developmental efforts in the anticipation of future work. This involves significant risk and assumptions of acceptance. The qualification processes in the aerospace industry are very intensive. It is common that design options are generated between established and proven processing technologies [4].

In the seat rail supply chain SoS ,the initial top level solution was determined by the customer [4]. The customer maintains a significant presence in development of design solutions, however increased collaboration between systems has increased involvement with the customer in proposing solution options [2].

2.8.2 Technical Management Processes

Decision Analysis

The activity of decision analysis drives the evaluation and selecting of alternatives amongst design options. This analysis is based off the answer to two key questions:

1. Which requirements can be practically implemented in the next iteration?
2. What are the options for their implementation?

The development of answers to these questions can be very complex endeavors requiring extensive knowledge and rigor. It is also important to consider the available opportunities that involve a variety of different systems [1].

When evaluating options for a possible supply chain in a SoS, it is important to know costs and difficulties associated with various processing operations. Typically, operations will be based on a combination of mature existing processing technologies, as high levels of uncertainty surround the qualification of new processing technologies. The project manager will also have to look beyond the realm of the SoS. It is common to have a supply chain that is not completely encompassed within one manufacturing SoS [2].

The current state of much of the decision analysis lies with the end customer or lead integrator. The supply chain provides input into the decisions, but decision analysis lies within the end customer [4]. This stifles the SoS evaluation as one stakeholder is driving the supply chain architecture. The incorporation of all stakeholders in decision analysis provides opportunity to balance all stakeholder objectives in an ideal solution [1]. The expansion of collaboration with constituent systems and stakeholders is an opportunity for improvement of design outcomes and stakeholder relationships.

Technical Planning

Upon the selection of a preferred design option, a systems engineer develops a detailed technical plan to outline the scope of the SoS. This plan should account for resources, schedules, milestones, and costs. This should also incorporate input from iterative negotiations with engineers from constituent systems [1].

The aspect of technical planning faces the same complexity that decision analysis experiences to address solution options. The customer will be involved in major supply chain alterations [4]. In smaller scoped improvements, the level of customer involvement will be less. Currently, there are plans intended to develop a collaborative forum to evaluate systems and develop technical plans for improvement [2]. This is a major opportunity for improvement of constituent systems with a global perspective of SoS requirements.

Requirements Management

The management of requirements during the assessment and selection of design options is typically a multi-level task. As design options are iterated, the requirements for the supply chain and individual systems may change, and these changes must by tracked back to industry specifications. The individual systems typically track their own requirement changes, and the systems engineer will track the changes for the supply chain. The use of a tracking tool aids the synchronization of requirement changes into a unified system [1].

Currently, the manufacturing SoS does not have formalized tools for management of requirements across a SoS, though plans are in place for the development [2]. The central management of all constituent requirements represents a major opportunity for improvement. This establishes system requirements traceability back to design information and analysis performed at the time of solution option evaluation.

Risk Management

The evaluation of risk for all design options is an important factor in a design decision. The amount of risk that a design option presents directly impacts the likely hood of failure. Options can present risk based on uncertainty of root causes of behavior, requirements to change existing systems, and implementation of design options [1].

In the supply chain SoS, there are existing risk management methods for the existing SoS [2]. A major opportunity is to extend this into a formal method to be utilized at the time of supply chain option evaluation. This would identify risk factors that may lead to one solution option over another.

Configuration Management

Configuration management involves using sound practice to ensure the consistency of a product's attributes. These practices are identified as functional baselines and incorporated into standard operating procedures [1].

In the manufacturing system, the use of quality management tools are implemented into operating procedures. Planning would be done to adapt and expand existing quality checks to encompass the critical parameters of the proposed supply chain SoS [4]. An opportunity for improvement lies in the task of identification of key quality and business attributes for all proposed solution options. This would allow more understanding of the involved aspects of each solution and a framework for configuration management at the time of developing the system architecture.

2.9 Orchestrating Upgrades

In the realm of SoS, the orchestration of upgrades involves addressing system requirements through a change. This activity involves the facilitation, monitoring, and coordination of changes being implemented. This effort typically will require iterative planning with independent systems to arrive at a phasing plan that is acceptable to all individual systems in the SoS. In addition to planning, this will involve the alignment of resources to support the critical path of project implementation. Typically a SoS upgrade occurs when the involved systems agree on a technical plan to address SoS requirements [1].

Several external factors must be continuously accounted for in the execution of upgrades that may affect the outcome. These include technical issues, design changes, budget cuts, program changes, regulatory changes, or a reprioritization of development efforts. These types of changes require the continuous revision of the technical plans to incrementally address requirements [1].

In the manufacturing SoS, the enacting of a supply chain within the SoS can be considered an orchestrated upgrade. A subset of systems within the SoS, and some outside of the SoS, are aligning themselves to address the unmet requirement of producing a specified product for a customer. Each individual system will have their requirements involving their contribution to the finished product. The supply chain, which becomes a SoS within the manufacturing SoS, will also have requirements to ensure a comprehensive production and quality throughout the supply chain.

2.9.1 Technical Processes

Implementation

Typically implementation is primarily performed by individual systems under the guidance and support of the systems engineers. During this effort, the timing, steps, methods, and backwards compatibility should be addressed for the involved systems [1].

In the supply chain SoS, the compatibility is critical to individual systems in the sense that existing production lines must be supported as well as the new supply chain activities. Major infrastructural changes to systems would have an impact on other product families but may be necessary to support the new supply chain. With all changes, a series of requirements for all production will surface involving process qualification, operational methods, and quality assurance. The implementation of the seat rail SoS was overseen by a project management office formed at the announcement of the supply chain formation [4]. There lacked formalized procedures for implementation of the changes, and activities were manually implemented by qualified technical individuals. A major success is the initiation of the development of a procedure outlining this activity to aid future supply chain formation [2].

Integration

The integration of the individual systems into a single unified SoS is a key function in producing beginning to end functionality of the SoS. This is done by the systems engineer collaboratively with all systems. Since the individual systems will likely have competing requirements, it is key that the integration activity be coordinated by the systems engineer independent from any individual system [2].

The manufacturing supply chain integration will involve the development of communication systems between systems to facilitate communication, technical developments, production requirements, and delivery of physical products. This is a collaborative effort to ensure that an agreed upon flow of critical information and product results [1]. The involvement of all constituent systems in discussion to form the supply chain is a method to improve results in the future. The failure to involve all constituent systems during the modification of finished component requirements resulted in a partial SoS adjustment when changes were not adequately pushed down the supply chain [3]. Moving forward integration efforts would aid in promoting improved SoS behavior and improvements.

Verification

The verification process is a continuous effort to ensure that the upgrades are enacted according to plan. The establishment of key parameters of each system should be identified and tested. This step involves a continuous evaluation and possible modification to plans to ensure that system requirements are met. This also includes the communication of results to other systems so modifications to other systems' plans can be made as necessary to ensure requirements of the SoS is met [1].

This is a critical operation of the manufacturing supply chain. As with many manufacturing systems, there is likely to be some level of iterative refinement of the processes of production. In some instances, a great deal of development occurs beyond the initial plans set out for the supply chain because of the complexity of many of the processing operations, making finite design infeasible. This step is a critical step and can take extended periods of time in some cases. This effort is primarily contained within individual systems as of present [4]. A success lies in the existence of extensive verification procedures with changes to systems. This is also performed by qualified technical individuals with multi level sign offs. [4] An avenue for improvement lies in the distribution of results from the verification effort to constituent systems in a SoS may allow other systems to adjust to optimize the SoS.

Validation

The validation step involves proving that the SoS operates as desired. This is often a limited effort until the end of the upgrade as end to end simulation or verification is limited until development is more concrete. Often this functional testing is focused on areas with the greatest risk [1].

In the manufacturing SoS, this entails limited production through the supply chain. This often brings to light issues around integration on top of issues with individual systems. This task is typically not performed with simulation, as simulation tools effectively accounting for all aspects of production have not proven practical [4]. An area for improvement lies in the development of more formalized documentation of initial production and procedures for doing so. This should also be shared among the entire supply chain to allow collaborative decision making.

Transition

The transition activities in systems of systems focus primarily on support and sustainment of the SoS. In the supply chain SoS, this operation would entail operations surrounding the production ramp up. This is also critical, as many issues will not surface until significant production rates are achieved. In the roll out of the 787 production, it was soon discovered that titanium raw material suppliers were not keeping up with demand, and supply chain shortages arose [5]. An area for improvement lies in the global evaluation of supply chain resources [3]. The accounting for all aspects, including competition for resources and capacity across the industry, will aid the effective support of operation of future developed supply chains.

2.9.2 Technical Management Processes

Decision Analysis

Many decisions must be made during the orchestrating of an upgrade that affects the implementation of the technical plan. The key operation in the decisions analysis is the balancing of needs and requirements of constituent systems. This is particularly important when upgrades do not go as planned and modification of other systems is required to achieve SoS requirements. These changes will draw heavily on knowledge of system interdependencies to define new requirement windows [1].

In the supply chain SoS, there is an inherent interdependency as the production output of one system is the input for another system. Variation or error in one system has the potential to affect all downstream operations of the supply chain SoS. A key aspect of decision analysis is requirements optimization for the SoS. This ensures that individual systems, in an effort to simplify their operation, do not impose impractical requirements on other systems that cause unnecessary production rejections or deviations. The failure to optimize the whole SoS will result in the entire SoS failing to perform [1].

Currently, decision analysis involving a supply chain is conducted by the project management office or office of technology commercialization. This is performed by technical individuals familiar with the constituent systems [4]. An area for improvement would directly involve the constituent systems in the decision analysis to optimize the system during an upgrade.

Technical Assessment

The technical assessment for a SoS is the examination of the change implementation of the constituent systems. The evaluation of system inputs and outputs relative to critical criteria should be performed routinely by the systems engineers. This step also includes the addressing of changes when progress is not being made [1].

In the manufacturing SoS, this operation is dependent on the level of innovation of the supply chain. In the majority of product supply chains, industry specifications govern high level operating parameters that ensure production outputs are in the desired form [4]. With more complex production supply chains, industry specifications may be insufficient and must be expanded and evaluated to ensure desired material properties. In these cases technical assessments are performed by the qualified technical personnel within the manufacturing SoS [4]. An area for improvement could lie in the development of formalized methods to reduce time required to perform an assessment.

Requirements Management

The management of requirements through the orchestration of an upgrade provides effective documentation for the production of components and traceability to ensure quality. As changes are made during the implementation, changes to requirements may be required and should be documented back to their original sources. The updating of the information systems housing the requirements will ensure that the supply chain operates on the same set of requirements after the upgrade [1].

The aerospace supply chain SoS requires documentation of met requirements throughout the entire production chain. The finished component's properties are the accumulation of all processing steps throughout the SoS, and all critical requirements are necessary at the final stages for quality assurance upon delivery. The iterative development of the production process in some processing systems makes requirements management difficult and critical to ensure that requirements are being met by the system [4]. An area for improvement lies in the development of a centralized requirements management tool to maintain greater visibility of any requirement changes during upgrades.

Risk Management

The identification of risks associated with a SoS is an effective mitigation method for preventing undesired outcomes in implementation. The evaluation of risk level and contingencies for risks threatening the performance of a SoS or the constituent systems reduces late stage failures [1].

In the manufacturing supply chain, risk management is a complex undertaking. The manufacturing systems themselves have numerous factors affecting their operations [4]. An area for improvement learned during the implementation of the seat rail supply chain implementation was the need for collaborative identification of risk. The risk associated with a welding vendor was not identified in other systems. The result was higher levels of product fallout and lost capital [3].

Data Management

The data management associated with orchestrating upgrades focuses on documentation of changes throughout the process. The availability of the detailed information about changes provides insight into decision analysis and future changes [1].

The manufacturing system will rely on the project managers and engineers to document changes and upgrades to the current state of the SoS. The storing of these changes on a centralized network with access by all constituent systems and involved parties will allow improved decision making criteria for similar changes in the future. There does not currently exist centralized data networks and universal access across the supply chain SoS [2]. The incorporation of this data into the developing centralized data network, quality module, would be an avenue for improvement.

2.10 Conclusion

The analysis of the seat rail supply chain SoS has revealed several areas where SoS methods are in the process of being formed independent of the results of this analysis. These developments are the result of a number of lessons learned through the development process of this SoS.

There were also a number of areas for improvement to improve the ability to form and manage the supply chain SoS. Given that shifts are beginning to occur within the industry, supply chain development and collaborative design are to be expected behaviors of top level suppliers [5, 6]. An improved system engineering ability in relation to SoS will position the manufacturing SoS as a collaborative partner with end customers. It will also allow influence in supply chain architectures and an ability to leverage vertical integration and extensive industry expertise to maintain competitive advantages in the industry.

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CHAPTER 3

Design of Quartz Chemical Delivery Parts for High Temperature Vacuum Chambers Based on Simulation Results

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Many of today's technologies and research techniques depend on process and methods in high and ultra-high vacuum. High temperature vacuum chambers require creative design and use of exotic materials in design to achieve quality performance. In order to obtain good performance, the temperature and gas delivery on the vacuum chamber surface must be uniformly distributed. In this work, a new funnel for high temperature vacuum chamber was successfully designed and tested using computer-based simulation techniques. The funnel was made of quartz crystal due to ability to absorb temperature, properties of low gas permeability and low temperature coefficient. In order to mitigate O-rings from high temperature failure and to reduce non-uniformity effect during temperature delivery, a new quartz funnel was developed. The simulation and experimental results show that uniformity distributions in temperature of vacuum chamber surface were obtained with new funnel design.

Keywords*:* High temperature Vacuum Chambers, computer simulation, quartz crystal to absorb temperature.

3.1 Introduction

Computer-based simulations program are extensively used across all fields of science to model real systems and their responses. As computing power becomes cheaper and commercially available software becomes more powerful, application of simulation models became widespread in science and engineering fields. Simulation and analysis programs are helpful to determine the optimum design parameters in the early stage of problem solving. The funnel is one of the most important parts of high vacuum chamber due to gas inflow region. In the literature, many funnel design studies have used computational modelling to optimize temperature delivery. Vacuum chamber designers should have the knowledge of the funnel thermal performance which will enable him to find efficient means to eliminate some of the problems and also to avoid the costly post construction additions and changes. High quality vacuum chambers are very important to the equipment's performance under different vacuum condition during the process. Traditionally, vacuum chambers and their parts are made of variety of metals [1] but, high temperature vacuum chambers require use of exotic materials in design to achieve quality performance. Hence, the funnel was made of quartz crystal due to properties of ability to absorb temperature and low temperature coefficient.

This chapter describes a simple new high vacuum chamber funnel design using computational modeling of temperatures on and around the funnel. The aim of this chapter was to achieve quality performance and obtain uniformly temperature distribution of vacuum chamber with design of a new quartz funnel including its temperature properties in the heater temperature range from 300 °C to 650 °C through simulation analysis.

3.2 Material Selection

Quartz crystal is an interesting and a remarkable material for design in diverse fields. The mechanical, physical and chemical properties of quartz crystal make it suitable for many uses. It is one of the common allotropes of silicon dioxide (SiO_2) and the most abundant mineral in Earth's crust. Compared to other materials, it exhibits several unusual properties; including pressure, induced amorphization, low thermal expansion, ability to absorb temperature, high pressure and temperature phase transitions, frequency stability, anomalous elastic properties, soft mode behavior [2, 3]. Quartz in its various crystalline and amorphous forms finds several industrial applications including being a raw material. SiO_2 occurs naturally as sand or rock, and when melted, the resulting product is called fused quartz. Fused quartz is very pure, has a high chemical resistance, good thermal shock resistance and is very strong in compression.

Quartz crystal has a very low thermal expansion coefficient and can easily withstand quick changes in temperature. Also, it is very stable in varying temperatures, especially at atmospheric temperatures and pressures. The temperature coefficient is specified in units of parts per million over the operating temperature change. In this chapter, in order to mitigate O-rings failure from high temperature and to reduce non-uniformity effect during temperature delivery, the funnel was made of fused quartz crystal (Type 214) due to ability to absorb temperature, properties of low gas permeability and low temperature coefficient. Material properties for the fused quartz (SiO2) are given in Table 3.1 [4].

Table 3.1: Material properties of the fused quartz (SiO_2).

Quality Grade (Type 214)	2
Apparent porosity (%)	0
Density (g cm^3)	2.2
Melting point (°C)	1715
Thermal Conductivity (W m^{-1} K^{-1})	1.46 @ 20°C
Coefficient of thermal expansion ($\times 10^{-6}$ K^{-1})	0.54 @ 20-1000°C
Coefficient of absorption (±max at 2800 nm), cm^{-1}	0.045

3.3 Design Rules for Vacuum Chamber

Vacuum chambers are commonly used in analytical applications and manufacturing process. The design of a vacuum chamber is critical to its ability to achieve and maintain contamination-free vacuum at high vacuum levels. The criteria are generally taken into consideration for the vacuum chamber and the design is realized within this framework. In order to achieve a significant leap in vacuum performance, the design requirements of a vacuum chamber must be clearly defined. Huntington designed an ultra-high vacuum, low-cost universal vacuum chamber suitable for a variety of research experiments including surface science. The chamber was made from stainless steel with a 14 inch nominal diameter [5]. Hauviller [6] designed an ultra-high vacuum and offered the methodology, methods and hints for designing vacuum chambers with his work. Owing to the high temperature vacuum chamber design requirements, its components should be designed according to the several boundary conditions [7-9]. Materials of vacuum parts, operating pressure and temperature, environmental conditions and minimum virtual leaks criteria are important in high vacuum design. To determine the ambient pressure and temperature are clearly the first step. The sub-sections are not necessarily exhaustive, but the list of physical phenomena influencing the design of vacuum chambers is probably complete. Parts that will be inside the chamber should be made of low out gassing materials, and should be cleanable and bakeable to very high temperatures. Dimensional stability of the chamber is of fundamental importance for establishing base pressures and obtaining temperature integrity. Dimensional stability usually equates to chamber rigidity and there is a hierarchy of basic chamber shapes in terms of this rigidity. In the physical design of interior high vacuum chamber systems, high temperature gradient occurrence must be avoided or at least it must be minimized. High temperatures are sources of low temperature coefficient that are physically trapped within the vacuum chamber. Hence, the funnel was made of quartz crystal because of its low gas permeability [10-12].

The chamber must be designed to obtain good performance with uniformly distributed temperature and gas delivery on the vacuum chamber surface. Uniformity of temperature on funnel surfaces is important for efficient O-

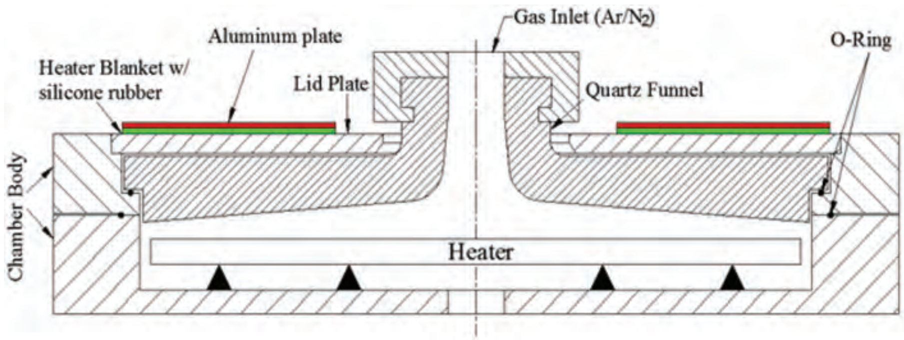

Figure 3.1: Schematic representation of new high vacuum system.

ring characteristics. Therefore, in vacuum chamber design, minimization of chamber parts and chamber surface with uniform temperature distribution are essential.

3.4 Design and Simulation Results of Vacuum Chamber

3.4.1 Design of New Vacuum Chamber

A description of a new vacuum chamber design for controlled studies of funnel is presented. The aim of new design is to mitigate O-rings from high temperature failure and overall improvement of the funnel design and its serviceability. The funnel was made of fussed quartz crystal due to properties of low gas permeability and absorption coefficient. Quartz funnel mounted on closed lid plate and heater blanket is used in order to control temperature distribution. Kalrez 7075 O-rings are also used between chamber bodies due to properties of improved thermal resistance that extends maximum service temperature to 327 °C (see Figure 3.1). For efficient heating a 2 kW heater was used. We simulated the temperature distribution on and around the quartz funnel when the heater is controlled at temperature range from 300 °C to 650 °C at 1 atm external pressure and room temperature. Axi-symmetric model is considered and 2D axi-symmetric thermal simulations are carried out. Gas flow effects are ignore due to low heat capacity of gas and low pressure limit effects of gas flow on temperature distribution.

3.4.2 Simulations Results of New Quartz Funnel Design

An example of vacuum chamber finite elemet (FE) modeling with new funnel design is investigated to show the accuracy of results from ANSYS. This section focuses on analysis of temperature distributions through the funnel when

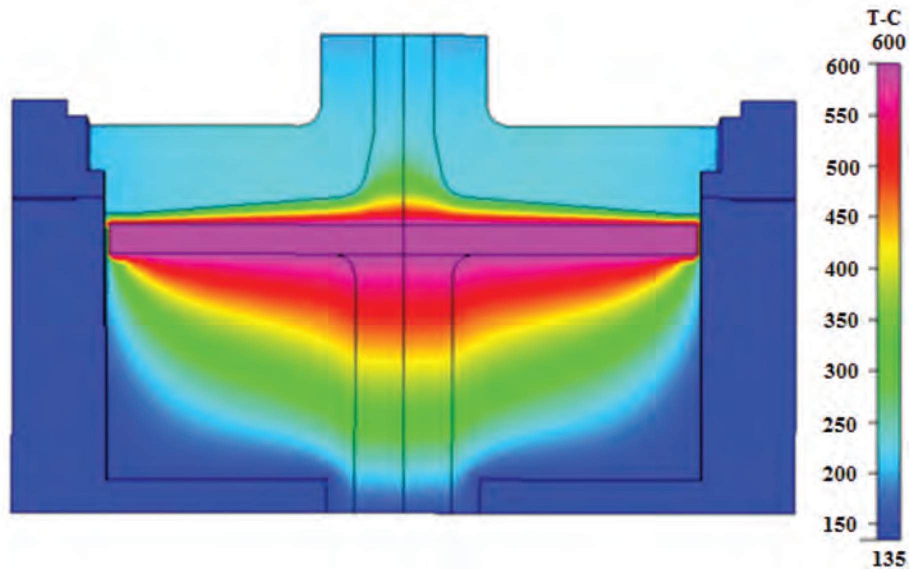

Figure 3.2: Thermal simulations of calibration model.

the heater is controlled at temperature range from 300 °C to 650 °C. The absent of O-ring has a direct impact on the uniformity of temperature into the vacuum chamber. An increase in the diameter of funnel causes a decrease in the temperature and hence enhances the uniformity of temperature generated into the vacuum chamber. The results obtained from the cross-section measurements showed that the shape of the funnel has maximal impact on the temperature uniformity.

As shown in Figure 3.2, the heater temperature was calibrated at 600 °C with the chamber body temperature of 1350 °C. Calibration was made at room temperature. Simulation condition for quartz funnel, thermal conductivity and coefficient of absorption are chosen as K=0.2 W/mK and 0.9, respectively.

To predict the temperature distribution by the simulation, the locations of 14 points on and around the funnel are shown in Figure 3.3. Also, a thermocouple number 8 which is not shown in the figure is placed on chamber body to estimate temperature of inner surface of wall of chamber body.

Through thermocouples measurements, Figure 3.4 shows the temperature distributions on and around the funnel in the range of 195-231°C. In the case of modified funnel, the combining of the parts to one part significantly increases the temperature drop and makes the temperature uniformity higher than the previous case. The temperature values are very close to the value read from the Figure 3.4 in all points where the temperature drop equals approximately 35°C with respect to TC points.

After obtaining calibration results, temperatures of heater and chamber

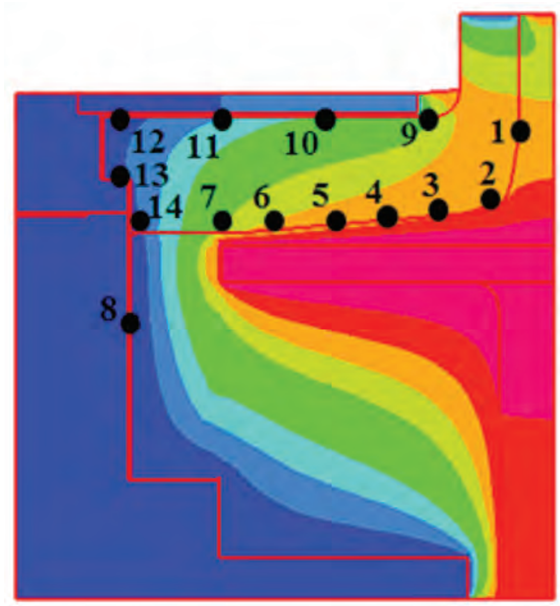

Figure 3.3: Thermocouple position (TC) on and around the funnel.

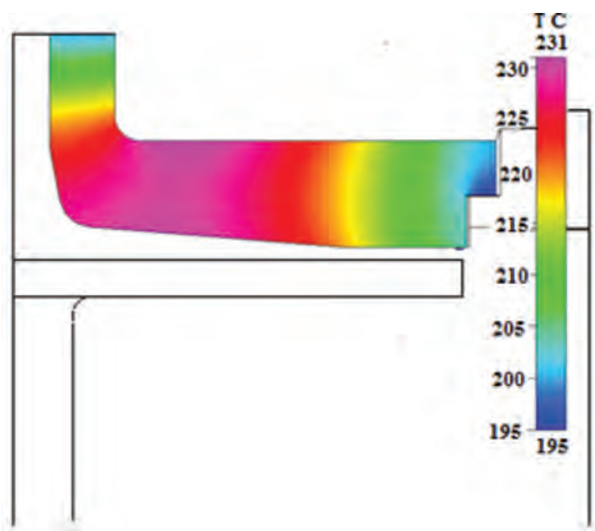

Figure 3.4: Results of temperature distribution for calibration model.

body are increased step by step to obtain temperature distribution by simulations and experiment for the new design. Experimental results are compared

Figure 3.5: Simulation and experimental results of temperature distributions.

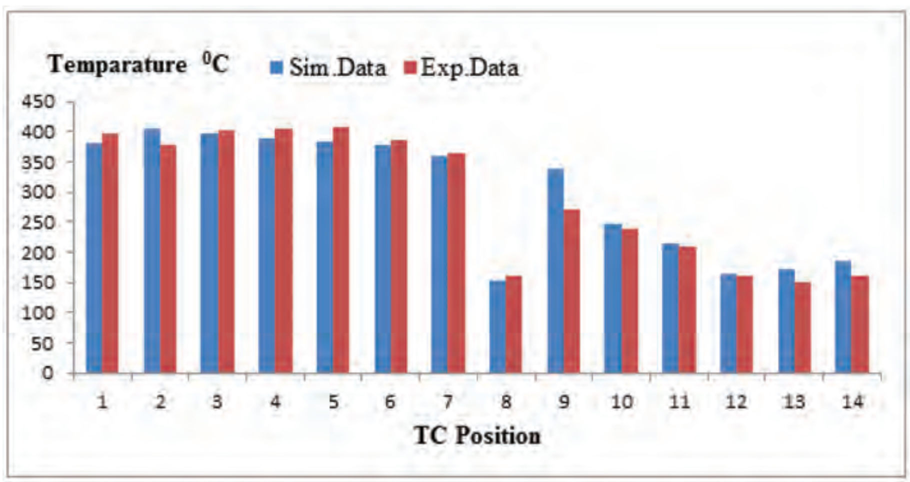

Figure 3.6: Simulation and experimental results of temperature distributions.

with FEM results at different vacuum condition (see Figure 3.5 and Figure 3.6).

As shown in both figures, results show good agreement between the experimental data and simulated temperatures. At higher temperatures, there is a difference between experimental and simulated temperatures. This is may be due to the change of radiation properties of the materials. For the first case, the temperature of chamber body was controlled by 135 °C with the heater temperature of 300 °C. The temperature distributions on and around the funnel were measured at the range of 140-230°C from TC of chamber through simulation. The temperature of inner wall surface of chamber body also was measured at 139 °C. The simulation and experimental results show that the temperature distribution near the heater is uniform within the manufacturing process region – at TC points 1-7.

For the second case, the temperature of chamber body was controlled by 150 °C with the heater temperature of 500 °C. The temperature distributions on and around the funnel were measured at the range of 163-405 °C from simulation results (see Figure 3.6). The temperature of inner surface of chamber body was also measured at 153 °C. The results generated with the FEM simulations show very good agreement with the experimental data, which can be used for the refinement of models and modelling parameters. Temperature results obtained from 14 points are changed accordingly based on the distance along the cross-section of funnel. Figure 3.5 and Figure 3.6 show the comparison of temperature uniformity among different TC points from both horizontal and vertical measurements. All the temperature intensity results align well on a single trend, which indicates that there is no distinguishable difference with the heater temperatures used. The temperature inside the chamber can be considered to have reached a fully developed temperature gradient beyond the simulation of TC points 1-7. On the other hand, a comparison of the vertical temperature fields does not change as the heater temperature decreases.

Temperatures of heater and chamber body are increased step by step to estimate temperature distribution on and around the funnel at higher temperature by FE simulations. When the temperature of chamber body was controlled at 180 °C with the heater temperature of 600 °C, temperature distributions inside of the chamber body were measured at the range of 182-498 °C from TC points of chamber. The simulation results show that temperature distributions closed to the heater are observed about 90 °C differences between TC points 1-7 (see Figure 3.7).

In a subsequent study, the temperature of heater was controlled by 650 °C with the chamber body temperatures of 150 and 210 °C as seen from Figures 8 and 9, respectively. As seen from figure 8, when the temperature of chamber body was controlled at 150 °C, the temperature distributions thorough the funnel was measured between 181-538 °C. The temperature of inner surface of chamber body was also measured as 157 °C. On the other hand, as shown in Figure 3.9, temperature of chamber body increased to 216 °C and temperature delivery thorough the funnel was measured at the range of 239-546 °C at heater temperature of 650 °C. Temperature results obtained from 14 TC points are changed accordingly based on the distance along the cross-section of funnel. From the figures, it can be seen that the temperature measurements decreases with the distance from center of funnel. All the temperature intensity results align well on a single trend, which indicates that there is no distinguishable difference with the heater temperatures used.

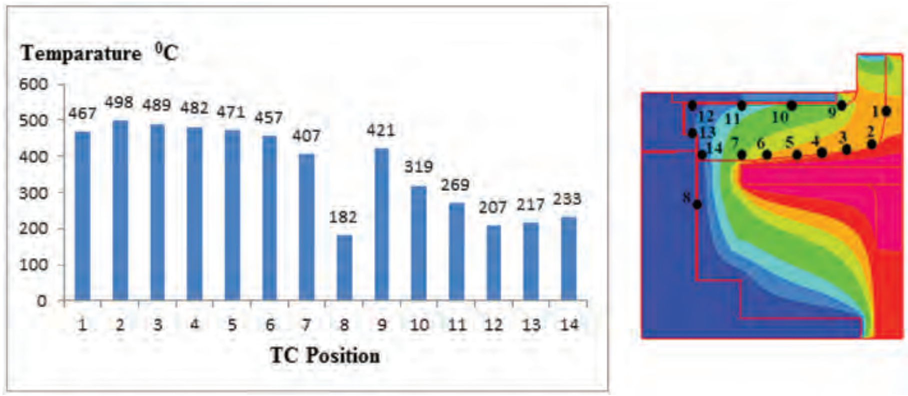

Figure 3.7: Simulation results of temperature distributions (Heater 600 °C, Body 180 °C).

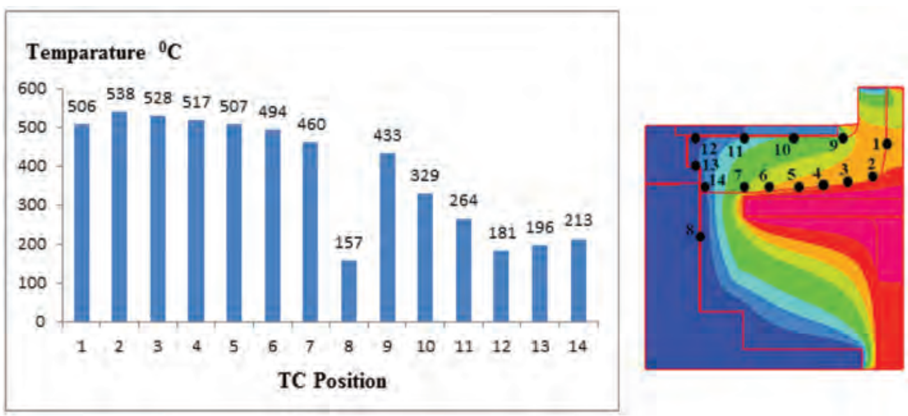

Figure 3.8: Simulation results of temperature distributions (Heater 650 °C, Body 150 °C).

3.5 Conclusion

In this work, a new funnel, made of quartz crystal, for high temperature vacuum chamber was successfully designed and tested using computer-based simulation techniques. The results of this work show that the joint application of modern simulation methods such as process simulation is a powerful tool for the design and optimization of an innovative concept. Generally, these tools enable the simulation and analysis of numerous complex processes in the chemical engineering practice in an early stage of the project. The results of the analysis of temperature distributions as well as the results generated with

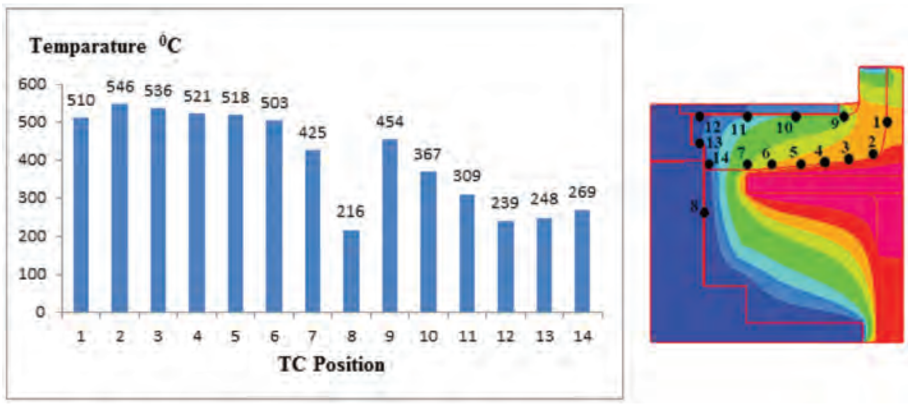

Figure 3.9: Simulation results of temperature distributions (Heater 650 °C, Body 210 °C).

the simulations mostly show uniformity distributions in temperature, which can be used for the refinement of models and modeling parameters. The work reported in this chapter is a complete numerical investigation of parametric study of temperature distribution through the funnel of a chamber. On the base of obtained results, the new behavioral quartz model has been developed which appears to be more efficient than old design – with the new funnel design within the process region, uniform temperature distribution can be obtained on the vacuum chamber surface.

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CHAPTER 4

Design and Optimization of Chemical Mixing System for Vacuum Chambers: Simulation Results

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Computational fluid dynamics (CFD) is widely used in device design to determine gas flow patterns and turbulence levels. CFD is also used to simulate particles and droplets, which are subjected to various forces, turbulence and wall interactions. These studies can now be performed routinely because of the availability of commercial software containing high quality turbulence and particle models. In order to understand how the gas is brought down to wafer, it is necessary to have a knowledge of the gas flow behavior very early in the design spiral of the Tantalum nitride-Atomic layer deposition(TaN-ALD) chamber by undertaking parametric investigation of the interaction effect between gas flow and the funnel structure. This chapter presents such a parametric investigation on a generic TaN-ALD chamber using CFD. The results presented have been analyzed for a total of 11 different cases by varying neck and nozzle angles for a process gas. The gas flow was mainly investigated for the nozzle angles of 4.5°, 9°, 12° and 20° and the film thickness results were compared with numerical flow patterns. CFD simulations using the turbulence model in ANSYS Fluent v.13 are undertaken. The parametric study has demonstrated that CFD is a powerful tool to study the problem of gas flow-structure interaction on funnel and is capable of providing a means of visualizing the path of the gas under different operating conditions.

Keywords*:* Chemical Mixing System, Vacuum Chambers, flow-structure interaction, funnel design.

4.1 Introduction

Computer-based simulation is now widely used across all branches of science and engineering and is finding ever more applications as computing power becomes cheaper and commercially available software becomes more powerful. Here we review some of the many studies of the design of TaN-ALD Chamber funnel that have used computational modeling of gas flow and particle dynamics to optimize gas delivery. It is worth noting that computational tools are used widely in the manufacture of the actual device, where Finite Element Analysis (FEA) is used to ensure that the device has sufficient strength without being over-engineered and wasting valuable material.

The prediction of flow path of gas through the chamber funnel is extremely complicated since the phenomenon is affected by a large number of parameters like gas velocity and direction, level of turbulence, geometry of the structures on the funnel, efflux velocity of gas etc. [1-3]. To complicate the matters, the entire turbulent flow field is subject to abrupt changes as the nozzle angle alters. It is not always possible to cover the entire range of all parameters to simulate every possible working condition in the funnel [4,5]. CFD has emerged as a serious alternative to funnel studies and is capable of providing solutions very early in the design. This chapter presents the results of parametric investigation of the interaction effect between the gas flow and the nozzle angle of the funnel (Figure 1) using CFD by varying the parameters of lid shape [6-9]. Four variants of the nozzle angles (Figure 2) were investigated at four funnel types each and further, each of these combinations were investigated at two different onset flow conditions. The results are from the numerical studies of typical cases (Case 1, 9, 10, and 11) undertaken with an aim of gaining an understanding of the typical flow field around the topside of wafer and the interaction between the shape (combination of nozzle and neck angles of the funnel, making a total of 11 cases) and the funnel's gas flow.

Realizing of non-uniform film thickness of wafer is therefore an important aspect of funnel design that falls under the category of TaN-ALD Chamber. However, very often, this application of TaN-ALD Chamber is not recognized a priori in the design of funnel. In order to take the film thickness problem into account, the vacuum chamber designer needs to be able to have a means of visualizing the path of the funnel under different conditions during the design phase, which will enable detection of shortfalls very early in the design spiral. This requires the vacuum chamber designer to have knowledge of gas flow behavior through the TaN-ALD Chamber, which shall enable him to find efficient means to eliminate the problem and also to avoid the costly post construction additions and alterations. Traditionally, the funnel performance has been investigated using ANSYS fluent in a vacuum chamber at a relatively advanced stage of design, when many aspects of the design are frozen.

4.2 Simulations Conditions

CFD simulations were conducted to determine the flow of the gas through the funnel lid and the subsequent film thickness on wafer. In general, flow fields were simulated using commercial CFD codes, with the majority of researchers utilizing ANSYS CFX or ANSYS Fluent. CFD simulations also identify the uniformity of the film thickness of the wafer when the flow pattern of the process gas was changed. However increasing the rotating of flow for any given process gas could provide this uniformity well. Furthermore, by altering design parameters, such as nozzle angle and neck

Table 4.1: Summary of CFD solvers turbulence model used.

CFD code/software	Turbulence model	Reference number
ANSYS CFX	k-ε	[12]
	SST	[13–21]
	k-ω	[22]
ANSYS Fluent	k-ω	[12,22–25]
	k-ε	[12]
	Laminar flow	[26–28]
	Not specified but used	[29,30]
CFD-ACE+	Laminar flow	[31,32]

diameter will allow the simulation of gas at a size range suitable for funnel delivery, ensuring mixture within the funnel airways.

In general, flow fields were simulated using commercial CFD codes of ANSYS CFX or ANSYS Fluent.The $k-\varepsilon$ model or the Shear Stress Transport (SST) model was usually used for turbulence modelling. It is substantial that most researchers have used the $k-\omega$ or SST models which have the capability to be applied throughout the turbulent boundary layer. Launder and Spalding (1974) [10] and Menter (1994) [11] provide more details on these turbulence models. The specific CFD code and turbulence modelling utilised by each researcher is outlined in Table 4.1.

4.3 Results and Discussions

In order to identify the underlying effects of funnel shape on the turbulence intensities generated in the vacuum chamber, it is necessary to analyze the flow field results obtained from CFD measurements . Since nozzle angle is found to have important effect on the turbulence intensity inside the vacuum chamber, the flow field results of the different shapes of nozzle are used for more detailed analysis. Figure 4.1 shows the flow field results obtained from front cross-section measurements of nozzle. The color contours in the figures illustrate the magnitude of the turbulence intensity from low (blue)to high (red) levels. The direction and size of the vectors represent the direction and magnitude of the gas flow at each particular node.

CFD was utilized to simulate the mixture of the gas spray in order to determine the best operating conditions. Specifically, we investigated the influence of velocity vectors and gas paths, as well as the role of the nozzle angle on the mixture of gas flow. Table 4.2 shows the presence of 11 typical cases, respectively that involves the flow pattern, center non-uniformity and overall uniformity. It was found that changing the nozzle angle through the funnel altered the level of uniformity, optimal performance was achieved at rotating flow pattern, but the improvement is limited with wafer when the funnel type was changed further. In Figure 3, the rotating flow pattern of the gas was found to run in with the precursor consumption flux distributions agreeing with measured film thickness map, and increasing neck angle was found to decrease the uniformity of center but the overall non-uniformity of the

Table 4.2: Optimization of dimensions.

Case	Nozzle Angle, α [deg]	Neck angle [deg]	Φ [inch]	Lid fillet R [inch]	H1 [inch]	Flow pattern	Center non-uniformity	Overall non-uniformity
1	12	4.5	0.55	0.0	2.0	Rotating	3.7	9.9
2	8	4.5	0.55	0.6	2.0	Impinging	5.5	17.5
3	8	4.5	0.55	0.25	2.0	Impinging	6	18
4	8	4.5	0.65	0.25	2.0	Rotating	5.4	12.7
5	14	4.5	0.55	0.6	2.0	Rotating	3.2	10.2
6	20	4.5	0.55	0.6	2.0	Rotating	3.6	9.7
7	30	4.5	0.55	0.6	2.0	Rotating	4.4	10.1
8	4.5	4.5	0.57	0.6	1.5	Rotating	3.6	9.8
9	12	9	0.55	0.7	2.0	Rotating	1.4	8.0
10	20	12	0.55	1.2	2.0	Rotating	2.5	7.4
11	12	20	0.55	0.7	2.0	Rotating	2.6	7.9

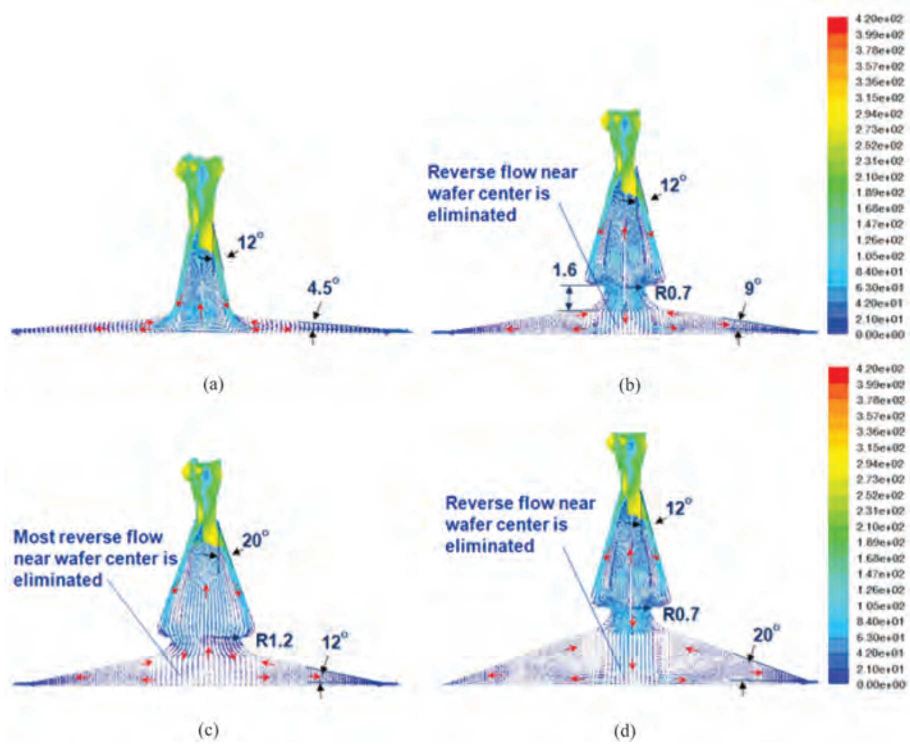

Figure 4.1: Gas Velocity Vectors [m/s] (a) Case 1, Current Hardware, (b) Case 9, R0.7" Neck, 9°, (c) Case 10, R1.2" Neck, 12°, (d) Case 11, R0.7" Neck, 20°.

film thickness remained unchanged.

The shape of funnel causes funnel gases to disperse downward toward the center more rapidly than side. This has many adverse consequences like the non-uniformity of film thickness. The existing fillet of lid played no significant effect on the performance or the flow field generated and widening the fillet of lid (R) made little difference to the uniformity performance, but reduced the angle of the nozzle leading to changed flow pattern. Flow patterns with a wide nozzle angle were found to be more easily rotating; however the effect of lid fillet size was less significant than the nozzle angle size, especially at high flow velocities [33, 34]. Interestingly, nozzle angle of 12° with neck angle of 20° was found to be important to film uniformity. On the other hand, uniformity efficiency was found to be directly proportional to the ratio of the flow pattern [8, 34].

Table 4.3: Breakdown of depth non-uniformity.

Non-uniformity break down	Non-uniformity [%]	Improvement method
Center low	3.7	Eliminate reverse flow
Radial gradient	6.6	Introduce precursor to edge
Circumferential gradient	3.3	Enhance mixing

4.3.1 Effect of Funnel Lid Dimensions on Gas Velocity Vectors [m/s]

Figure 4.1 shows the variation of gas velocities with the nozzle angle of the funnel. The present simulation is carried out with four nozzle angles. The lid has been shaped with the angles of 4.5°,9°, 12° and 20°, respectively. It can be seen from the Figure 4.1 that the reverse flow initially decreases after the angle of 9° and then is mostly eliminated with the angle of 12°, suggesting the existence of an optimum lid angle. The center line velocity drop is significant when the nozzle angle is 12°, so there is less non-uniform film thickness near the center of wafer for this case [18]. But after the nozzle angle of 12° the center line velocity vector becomes significant and the gas velocity near the wafer center rises. Even though some reverse flow is observed, the absence of large variation velocity fields gives rise to only small turbulence intensity. Both the increases in gas velocity and decreases in reverse flow are stronger on the wafer with good uniformity because of the decreased reverse flow streams from the turbulence [16].

Similar change in flow patterns is also observed using other nozzle angles as shown in Table 4.2. A comparison of the flow fields among Fig 4.2(a)–(b) also confirms that an increase in angle from 4.5° to 12° amplifies the formation of turbulence intensities. The distinctive difference between the rotating and impinging flow patterns thus give rise to a high turbulence intensity shows that as the process gas travels from the inlet, the expansion motion of gas becomes more irregular [16,18,35]. Reverse gas flow can also be observed near wafer center. Particularly, path lines near the center of the wafer are mixed with the vortex. The vortex generated is also spreading from initially the central region to the entire wafer. Additional vortices are generated from the converging flow pattern and hence the turbulence intensity is further improved. As a result, the turbulence intensity increases because of the changed shape parameters of funnel lid.

4.3.2 Effect of Funnel Lid Dimensions on Consumption Flux [kg/(m^2 s)] of Process Gas

The simulation is carried out for four nozzle angles located at the funnel lid as shown in Figure 4.2. The analysis is also carried out for four cases as has been shown in Figure 4.3 which demonstrates the effect of nozzle angles on consumption flux of the process gas. The nozzle angles considered for the CFD analysis were 4.5°, 9°, 12°, and 20°. In the 1st case the consumption flux on the wafer is kept 9.9% from max to min, in 2nd case the flux of the center is 8.0% to the circumferential and in 3rd case

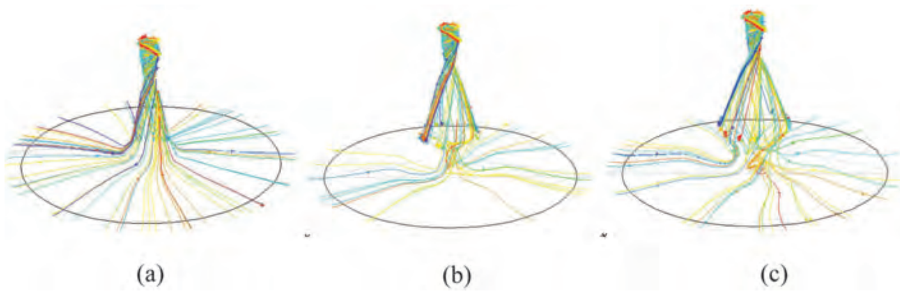

Figure 4.2: Effect of funnel lid dimensions on Gas Path Lines, (a) Case 1, Current Hardwareb) Case 9, R0.7" Neck, 9°, (c) Case 10, R1.2" Neck, 12°.

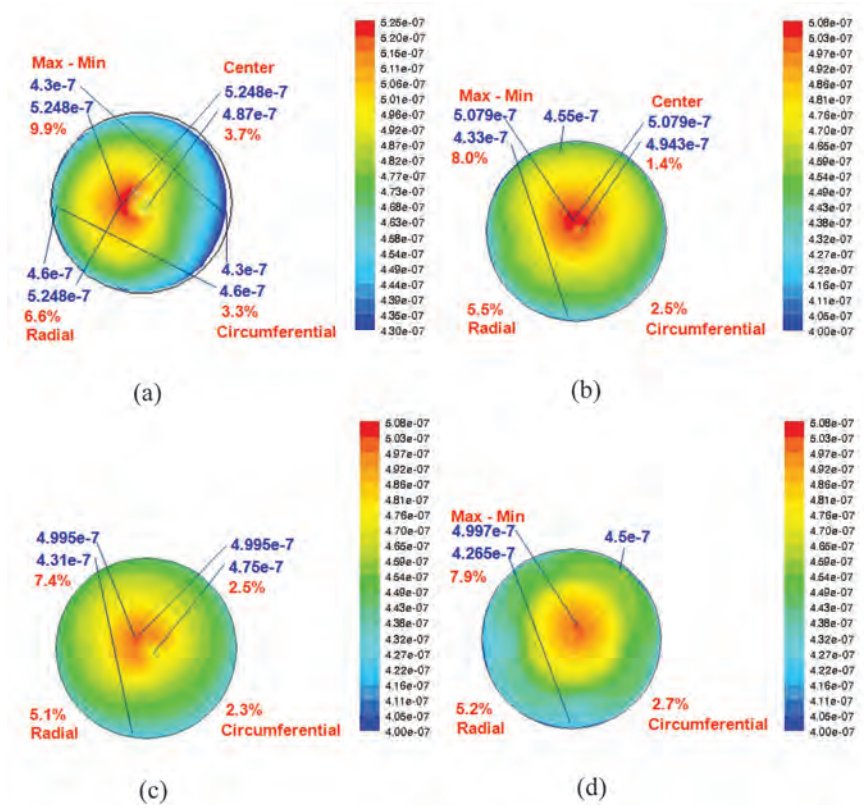

Figure 4.3: Consumption Flux [kg/(m^2 s)] of Process Gas, (a) Case 1, Current Hardware, (b)Case 9, R0.7" Neck, 9°, (c) Case 10, R1.2" Neck, 12°, (d) Case 11, R0.7" Neck, 20°.

the consumption flux on the wafer is kept 7.4% from max to min. When the nozzle angle is 9° the center flux becomes the best uniformity but the overall uniformity on the wafer is still lower compared to the case of a nozzle angle of 12° because the consumption flux along the centerline of the wafer is too quick for the case of nozzle angle of 9°. Since the funnel becomes narrow, the viscous effect becomes prominent and the pressure rises quickly along the axis of the funnel causing less gas ingress into the funnel. So, there is the existence of a highest turbulence for optimum consumption flux into the funnel. Optimal performance was achieved at a working shape of Case 10 which generated center non-uniformity with a mean percentage of 3.7 at an overall non-uniformity of 9.9 percentage. This can be explained from the fact that the reverse flow velocity near the center of wafer is not increased significantly as rotating flow velocity through the funnel is increased. However, neck angle on the funnel is found to have negligible effect on the turbulence intensity generated [6]. It is also concluded from Figure 4.3 that the variation of neck angle does not contribute significantly to the change of radial uniformity.

The variation of flow pattern due to the inclination of the nozzle angle is shown in Table 4.3 and rotating flow pattern is preferred as impinging flow shown in Figure 4.4 cause non-uniformity. As a matter of fact, a comparison of the velocity vector in the side cross-sections shown in Figure 4.4 indicates that the co-presence of high velocity streams and low velocity of reverse flow diminishes the effect of non-uniformity of film thickness as the turbulence intensity is a measure of the difference in the velocity fields. At narrow nozzle angle condition, a certain portion of turbulence intensity is contributed by the change in gas velocity due to the substantial change in flow area. However, at wide nozzle angle conditions in Figure 4.4, the reduction in flow velocity becomes less significant that the turbulence intensity is essentially governed by the reverse flow streams. An interpretation of both vertical and horizontal cross-sectional views together suggests a spiral flow generated inside the vacuum chamber. This is because a large velocity gradient is generated due to the sudden expansion in the flow area as the gas flows pass the nozzle. As a result, turbulence is generated and intensifies along the axial location before reaching a fully developed flow [6], [18].

4.3.3 Effect of Funnel Lid Dimensions on Mole Fraction of Process Gas on Wafer Variation with Time

Figure 4.5 shows the comparison of the mole fractions of two cases. It can be seen that the purge duration increases to 245 m/s from 98 m/s. It is evident from Fig. 6 that the purging is influenced with the inclination of the nozzle angle. It can be seen from the plot the mole fraction of the process gas decreases into the funnel as the nozzle angle increases. High nozzle angle creates a low pressure field around the funnel [35]. Due to this low pressure field, the difference in pressure across the funnel (inside and outside the funnel) decreases causing less suction of gas from the funnel. Therefore, it can be concluded the entrainment of mole fraction of the process gas in the funnel decreases with increase in angle on nozzle of the funnel.

4.4 Conclusion

The results of this work show that the prominent application of modern simulation methods such as process simulation and CFD is an effective tool for the optimization

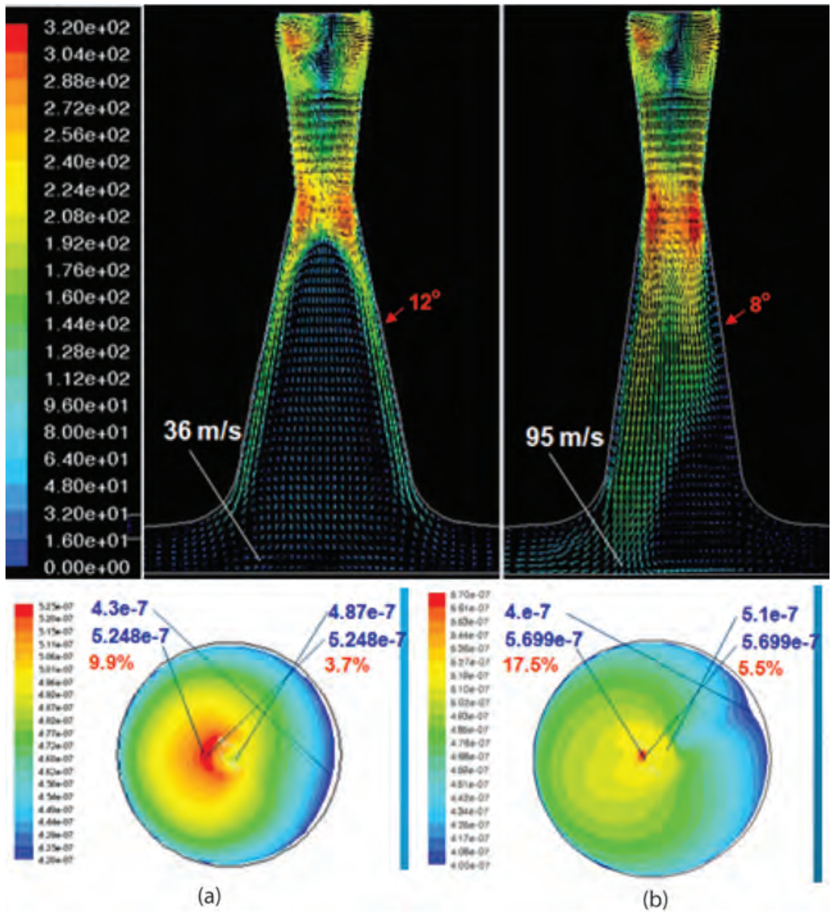

Figure 4.4: Comparison between Simulated Precursors: Velocity Vector [m/s] and Consumption Flux of Process Gas a)Case 1, Rotating Flow (Current Hardware) b)Case 2, Impinging Flow.

and design of an innovative concept for the gas flow of funnels. Generally, these tools enable the simulation and analysis of numerous complex processes in the chemical engineering practice in an early stage of the project. The application of powerful calculation tools with a sound physical basis combined with the reduction of experimental efforts result in lower development costs and a shorter time-to-market of new processes and apparatuses. The results of the flow calculations as well as the results generated with the CFD simulations mostly show very good agreement with film uniformity of the wafer, which can be used for the refinement of models and modeling the funnel parameters of a ALD chamber.

The work reported in this chapter is a complete numerical investigation of parametric study of gas flow through the funnel of a ALD chamber. Throughout the

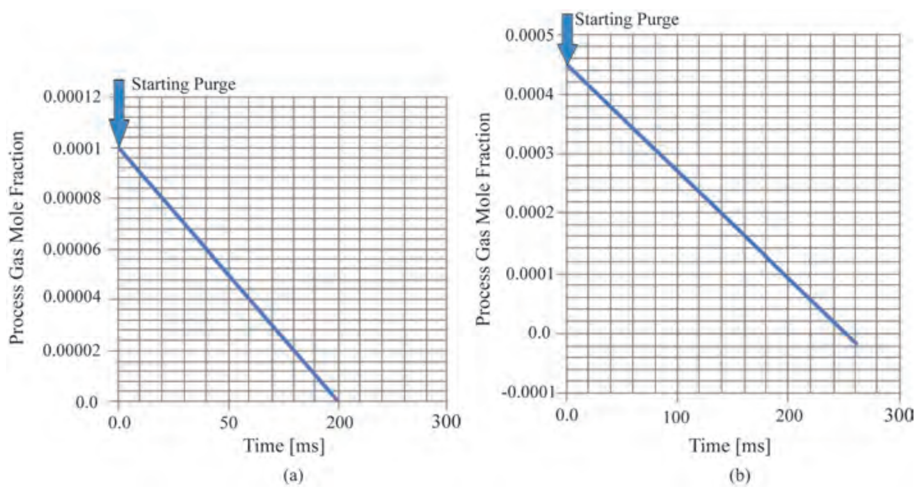

Figure 4.5: (a) Case 1, Current Hardware (Case 1: 98 ms to reduce the process gas concentration by 5 orders) (b) Case 10, R1.2" Neck, 12° (Case 10: 245 ms to reduce the concentration by 5 orders at wafer edge (center)).

entire CFD analysis vacuum conditions has been considered to be constant in the chamber. The following conclusions are drawn from the results of the present study:

- The performance of the funnel flow in the chamber is found to recover at the nozzle angles between 9° and 12° and therefore, these may be termed as "favorable range of nozzle angles" as far as uniform film at the wafer is concerned. It is strongly recommended that the funnel designer should specially study the flow conditions with relative flow patterns over the favorable range of nozzle angles.
- The reverse flow initially decreases after the angle of 9° and then is mostly eliminated with the angle of 12°, suggesting the existence of an optimum funnel nozzle angle. This can be explained from the fact that the reverse flow velocity near the center of wafer is not increased significantly as rotating flow velocity through the funnel is increased.
- Rotating flow pattern is preferred as impinging flow cause non-uniformity. The rotating flow increases with increase in nozzle angle. Center thin map is caused by imperfect mixing and flow pattern with funnel.
- The uniformity rate is independent of amount of fillet radius but strongly depends on nozzle angle of funnel. The study clearly indicates that gas flow is not influenced with the fillet radius of the funnel but depends a bit on the neck angle of the funnel. Therefore the cooperation of the gas flow pattern with the neck angle is not negligible and the neck angle should always be considered in such calculations.
- The purging time of the process gas increases into the funnel as the nozzle angle rises. From the CFD analysis it has become clear that increasing the nozzle angle of the funnel, the purging time is increased. But increase in

purging time of the chamber is limited due to design of funnel as well as from economical point of view. Film uniformity may be improved by optimizing the dimensions, but the improvement is limited with the purging time cost. But it is suggested that the maximum possible funnel nozzle angle of 12° should be used.

- Simulated precursor consumption flux distributions agree with measured film thickness map.
- Strong correlation between simulated gas flow patterns (re-circulating flow, vortex) and on-wafer deposition pattern. Re-circulating of the flow has improved the wafer deposition efficiency. It seems that this is mainly due to the vortex of gas flow, due to increasing the re-circulating flow in which the vortex takes place.
- With concise mathematical models at hand, process simulation and CFD provide efficient and cost-saving assistance for chemical engineers and vacuum chamber constructors. CFD methods allow complex flow patterns around the chamber to be identified and problems about gas flow can now be addressed during the early stages of chamber design. CFD also provides capabilities for problem troubleshooting and solving of the gas flow problem on the already constructed and operational vacuum chambers.
- This study has demonstrated that CFD is a powerful tool capable of predicting the features of the gas flow-structure interaction. As a flow simulation tool, CFD can predict gas flow –structure interaction throughout the funnel, which is particularly advantageous for the investigation of ALD Chambers with complex structures. Further, the results of the study show that level of detail and the realistic physical foundations of the CFD simulation of the flow pattern and dispersal of gas flow over the wafer gives unique opportunities to chamber designers that were not available before.

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CHAPTER 5

Safe Room Wall Design for Tornado Survival

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A safe room is a reinforced structure specially designed to meet the Federal Emergency Management Agency (FEMA) criteria and provide protection in extreme weather events, including tornadoes and hurricanes. The materials used for safe room walls are expected to resist loads imposed and tornado debris impact. Tornadoes rated as high as EF-5 can create maximum wind speeds of more than 300 mph, which is enough to demolish any structures in their path. These maximum wind speeds produce forces that are about twice as large as those produced by the strongest hurricanes. One of the common safe room wall designs is made of plywood/steel-plate composite. The main objective of this chapter is to use a finite element simulation code, LS-DYNA, to predict the dynamic response of plywood when impacted by tornado missiles such as 2 x 4 wood timbers.

Keywords*:* Tornado, debris, Impact, simulation.

5.1 Introduction

The safe room project is part of a continuing FEMA initiative named Project Impact: Building Disaster Resistant Communities designed to urge people and communities to take measures to protect themselves and their property before disasters occur.

Throughout history tornadoes have signified a force of nature that is both admired and feared. Tornadoes tend to strike with little warning, without regard to season, and just as quickly they are gone. The result is often devastating in terms of property damage and the human toll. Until recently, the fundamental knowledge of tornado behavior escaped explanation. As our understanding of tornadoes advances, it is more evident than ever that tornadoes are not magical entities. They are natural phenomena that follow the laws of physics, and as such are excellent subjects of deep research. Most of the research regarding the tornado belongs to the atmospheric sciences, but this status is experiencing a change. With the introduction of engineering into the sphere of tornado research, a new paradigm is changing the way that the world looks at these natural wonders.

Figure 5.1: Automobiles are no match for 200+ mph winds [4].

While tornadoes occur in different parts of the world, the highest concentration of tornadoes occur in the United States [1]. Approximately 1,200 tornadoes per year strike the United States; more than any other nation in the world. According to the National Climate Data Center from 1953 through 2005, there were 48,632 reported tornadoes in the United States, resulting in 4,388 deaths [2]. The most devastating tornado in recorded history took place in 1925. The path of this tornado (or possibly a family of tornadoes) extended through Missouri, Illinois, and Indiana. During the 219-mile track (at times 1200 yards wide with a forward speed of up to 72 miles per hour), 695 people were killed, 13,000 injured, and caused $17 million in property damage [3]. This tornado stayed on ground for 3 hours. Though tornadoes do not represent the greatest threat against life in the United States, they embody a particularly disturbing hazard.

Debris is a hidden danger in tornado. People can be easily injured by flying debris. One of the strongest tornadoes, rated an EF-4 ripped though the Union University campus in Jackson Tennessee in 2008. The damage at Union University was severe. Automobiles became debris and some of the dormitories suffered catastrophic damage (see Figures 5.1 and 5.2) [4].

The materials used for safe room walls are expected to resist loads imposed and tornado debris impact. Tornadoes rated as high as EF-5 can create maximum wind speeds of more than 300 mph, which is enough to demolish any structures in their path. These maximum wind speeds produce forces that are about twice as large as those produced by the strongest hurricanes. The main objective of this chapter is to investigate the performance of safe room wall assemblies when subjected to the impact and penetration of windborne debris.

Figure 5.2: The original location of these automobiles are unknown [4].

5.2 Penetration mechanics

Widespread research exists on penetration problems by many researchers to develop fundamental relationships applied to areas such as hypervelocity impact, shaped-charge penetration, long-rod penetration, small arms, ballistic protection, and armor design. The basic understanding of penetration mechanics is as follows. Given a projectile, a target, and details of the initial geometry, kinematics, and materials properties; investigate whether or not target perforation occurs. If perforated, investigate what the residual characteristics of projectile and target will be, and if not, investigate the depth of penetration.

Penetration mechanics is one of the most involved problems in the research field of mechanics, and researchers have been working on the solutions many years. Solution approaches exist on three different levels as follows [5]:

- Data correlation
- Engineering models
- Numerical simulation

Many research works have occurred, resulting in satisfactorily accurate simulations of penetration problems [6, 7, 8, 9, and 10]. Zukas and Anderson reviewed the state of the art of numerical simulations which describes the impact and penetration mechanics including a comprehensive review [11]. They examined the general capabilities and limitations of numerical simulations. They stated that as the size and speed of computers have increased so has the complexity of codes used for these purposes; but certain characteristic difficulties persist [12].

5.3 Modeling

Composite materials have been used widely in many applications such as in the oil industry, space structures, pressure vessels, and automobile industries. Many researchers have investigated a solution to the impact on composite laminates using finite element method [13, 14, 15, 16].

Plywood is a layered, cross-ply, unidirectional, fiber-reinforced composite. Plywood strength and progressive failure resistance are important for the survivability of house frames when earthquakes, tornados, and/or hurricanes occur. Plywood is made of thin sheets of timber called plies. The plies are cut by rotating the trunks then stacking them together with the fiber direction of each ply perpendicular to the fiber direction of its adjacent ones. The plies are bonded using strong adhesive under heat and pressure. In general, plywood has an odd number of plies [17].

One of the common safe room wall designs is made of plywood/steel-plate composite. In this research, numerical simulation LS-DYNA analysis code predicts the dynamic response of plywood when impacted by tornado derbis such as 2 x 4 wood timbers will be used. Due to the differences in speed between the types and classes of wind events, specific criteria were developed to simulate the results of such an impact event.

In this chapter, the LS-DYNA analysis code is used to identify the damage of the composite plywood impacted by a rigid projectile. Because of the symmetry of the problem, only one quarter of the geometry is modeled. In this case, the plywood is assumed to be five layers of composite material. In order to reduce the computational time while keeping the inertia of projectile same as 15 lb 12 ft 2x4 wood timber, a 1.5 inch projectile was used. The projectile was assumed to be rigid and the target (3/4 plywood) assumed to be elastic-plastic material. In modeling, solid elements were used because of the ease of use and better stability of contact problems (Chatiri, Gull and Matzenmiller n.d.). Each layer of the target is 8” x 8” x 0.15” and the projectile dimensions are 1.75” x 0.75” x 1.5”. The density of the projectile arranged such that the projectile part has a weight of 15 lbs.

The projectile and the target are discredited by 8-node hexahedron solid elements, using only one integration point. The target has simulated 5 layers through the thickness. The impact region has a fine mesh with element size of 2.12mm x 2.12mm x 3.81mm for each layer. The transition region has an element size of 2.12mm x 4.23mm x 3.81mm, and the transition region’s coarse mesh size is 4.23mm x 4.23mm x 3.81mm. The element size for the projectile is finer than that of the impact zone of the target which is 1.27 mm x 1.27mm x 3.81mm. Each layer of the target has 3933 brick elements therefore target has total 19665 brick elements. Projectile has 1818 brick elements.

As shown in Figure 5.3, two different kinds of boundary conditions are used because of the symmetry of the problem–fixed-boundary condition and symmetry-boundary condition. The symmetry boundary condition is applied on the bottom and right face of both the target and the projectile. The fixed boundary condition is applied on the model on the upper and left face of the target. The bonding between the plies is modeled with “contact tie break surfaces,” which has the fracture-mechanics-based delimitation capability. The contact was defined between each ply, allowing them to delaminate from each other. Moreover, eroding contact surfaces are modeled to control the impact force between the projectile and the target. The most important factor of the contact surfaces is that it helps to redefine itself after

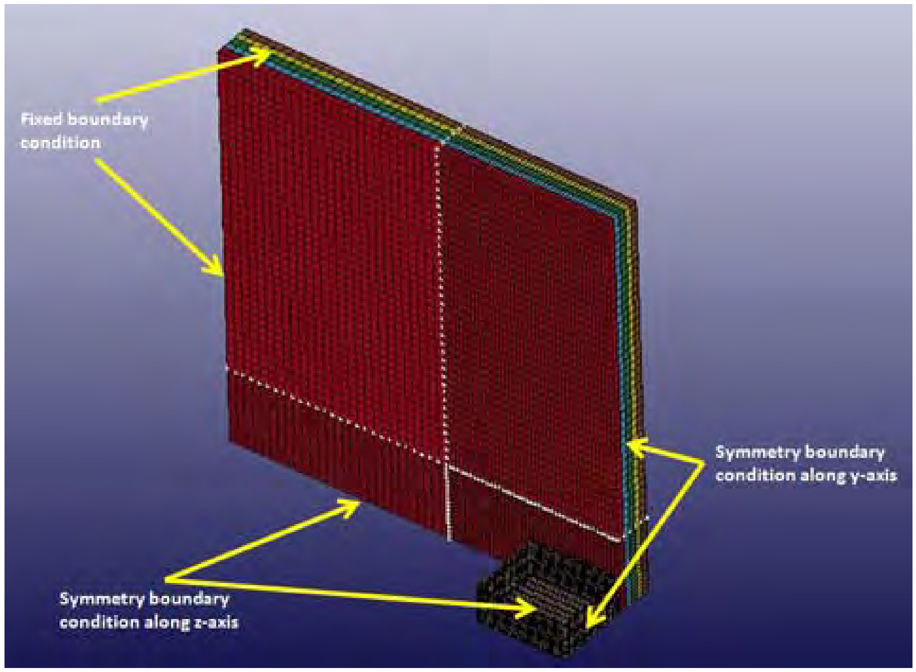

Figure 5.3: Boundary Conditions.

an element fails and is removed from the model.

Material modeling – Material Model 20 "MAT-RIGID" is applied for modeling the projectile while Material Model 143 "MAT_WOOD_PINE" is applied for modeling the target layers. For this study, material model 143 is used for 10% moisture content. Table 5.1 shows the material properties of the projectile material and Tables 5.2, 5.3, 5.4, and 5.5 (see Appendix) show the material properties of the target with 1%, 10%, 20%, and 30% moisture contents.

5.4 Results and Discussions

In order to find the impact velocity that penetrates the composite plywood, velocities of 4m/s, 6m/s, 8m/s, 10m/s, 12m/s, 13m/s, 13.5m/s, 13.8m/s ,13.9m/s, 14m/s, 15m/s, 16m/s, 17m/s, 18m/s, 20m/s, 22m/s, 30m/s, 40m/s, and 45m/s with 10% moisture content plywood are simulated. Furthermore, 1% moisture content, 20% moisture content and, 30% moisture content plywood are also simulated with velocities of 13.5 m/s, 13.6 m/s, 13.8m/s, 13.9 m/s, and 14 m/s in order to record the difference resulting from various moisture contents.

To clarify the characteristics, side and back views of the simulation at 2.3 and 10 seconds are shown for only velocities of 4 m/s and 13.9 m/s at this time (see Figures 5.4 and 5.5). As seen in Figure 5.4, portraits (a) and (b) are the side views and

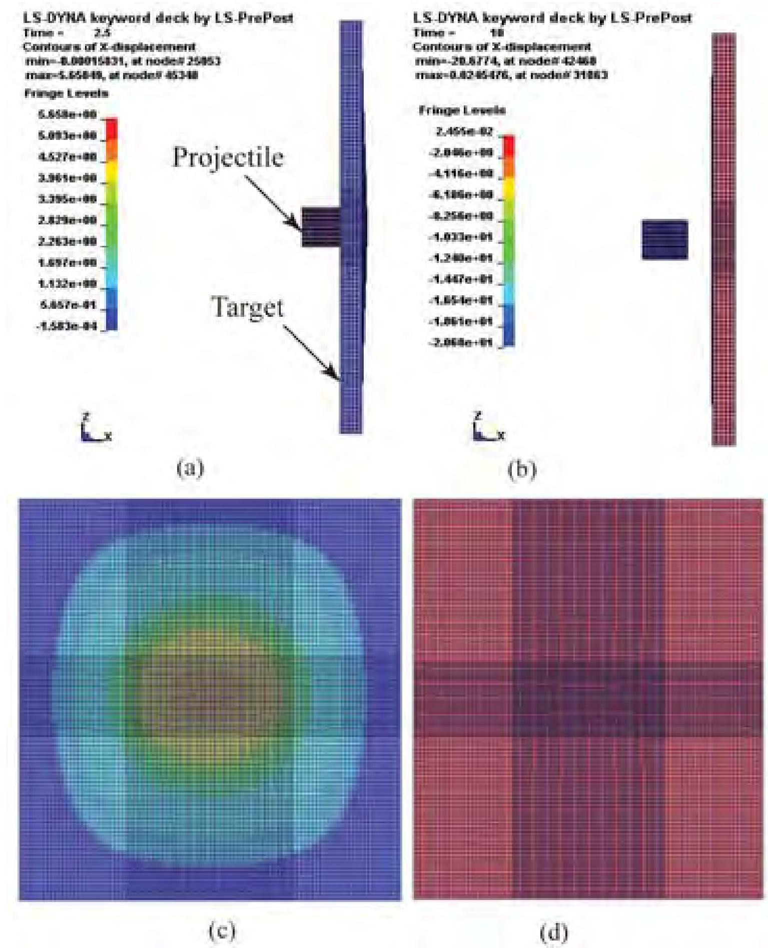

Figure 5.4: Composite plywood impacted by 4 m/s projectile.

portraits (c) and (d) are the back views of the simulation. Portraits (a) and (c) show the x-displacement at 2.5 seconds after the initial impact. Portraits (b) and (d) show the x-displacement at 10 seconds after the initial impact (the final configuration of the deformation). In some cases there was no deformation found after the impact and the projectile returns to the direction from which it came.

Identical simulation results are obtained until we reach the velocity of 13.9 m/s, meaning, deformation was elastic and no penetration was observed. However, as seen in Figure 5.5, penetration has occurred at velocity 13.9 m/s. It is clear from this figure that the penetrating projectile has extricated a solid block in the positive x-direction.

Penetration phenomenon is also evident from Figure 5.6(b). As shown in this figure, the projectile travels 13.9 m/sec in the positive x-direction and penetrated the target. Because there is no deflection in the x-direction, the rebound velocity

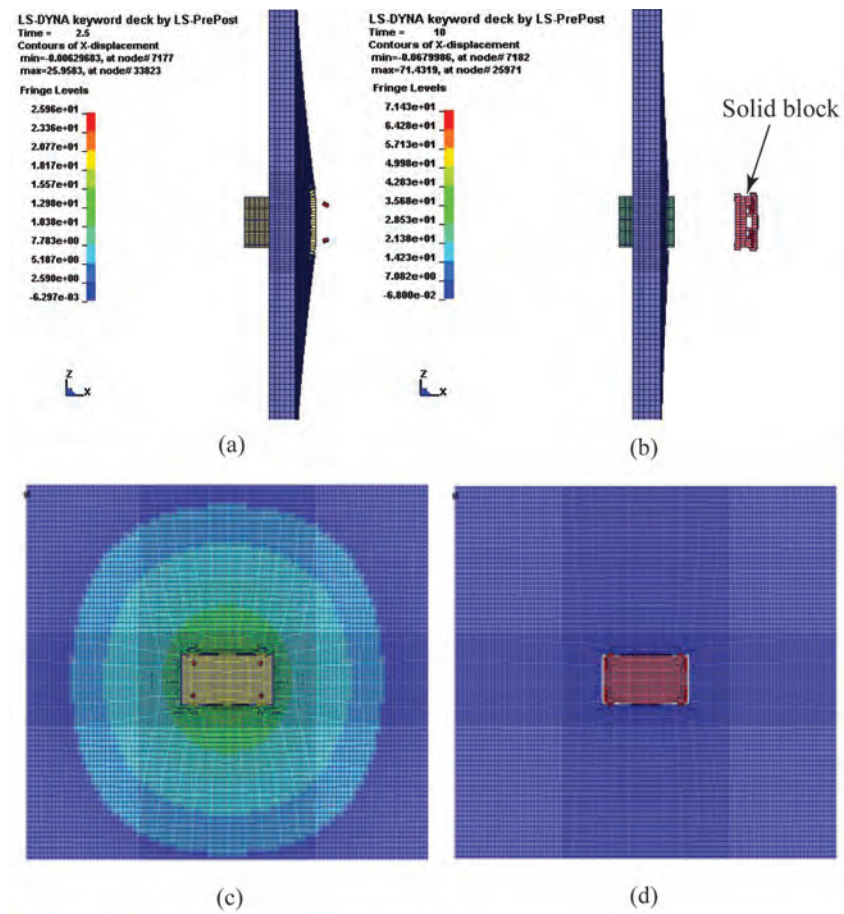

Figure 5.5: Composite plywood impacted by 13.9 m/s projectile.

no longer exists. Instead, a projectile has residual velocity. The projectile residual velocity is 1.22 m/s (9% of impact velocity). This shows that the target absorbed most of the kinetic energy. As shown in this figure, the velocity remained in the positive region. As shown in Figure 5.6(a), the projectile travels at 4 m/sec in the positive x-direction and made contact with the target at which point the projectile and the target exchange energy – the projectile is deflected and travels in the negative x-direction with the rebound velocity of 3.75 m/sec. This makes the rebound velocity 94% of the initial impact velocity. This illustrates that the target absorbed very little of the kinetic energy from the impact. As shown in this figure, the transition of the velocity from positive to negative is exposed.

Figures 5.7 and 5.8 show the impact velocity profiles for all the velocities mentioned earlier. Figure 5.7 illustrates the first set of example. All the projectile impact velocities in this set fails to penetrate. As shown in this figure, rebound velocity oc-

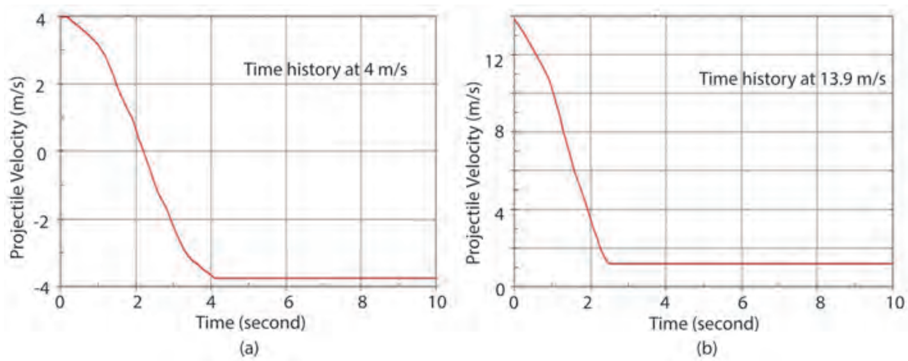

Figure 5.6: Projectile velocity vs. time history for 4 m/s and 13.9 m/s.

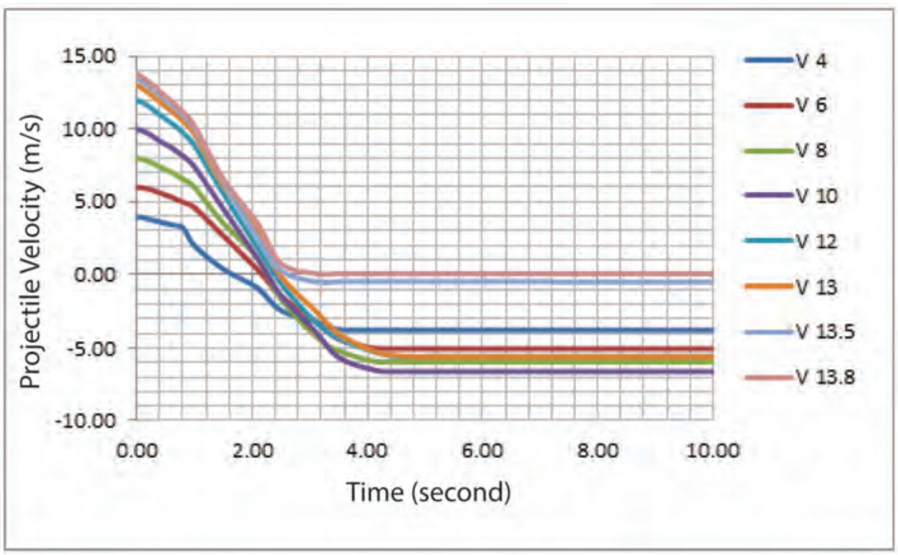

Figure 5.7: Projectile velocity vs. time history before the penetration.

curs between 4 m/s and 13.8 m/s with the projectile deflecting in the x-direction (below zero) because of the energy exchange between the projectile and the target. However, as shown in Figure 5.8, all the projectile impact velocities penetrate the target – residual velocity occurs between 13.9 m/s and 45 m/s with the projectile penetrating the target. Simulation at an impact velocity of 13.9 m/s is important as it predicts the limiting velocity for penetration. Texas Tech University test results indicate that the range of limiting impact velocity for penetration is between 13.2 and 14 m/s (29 and 31 mph). Note that since the simulation result at this impact velocity indicates that the remaining (residual) velocity is 2.75 m /s, the limiting ve-

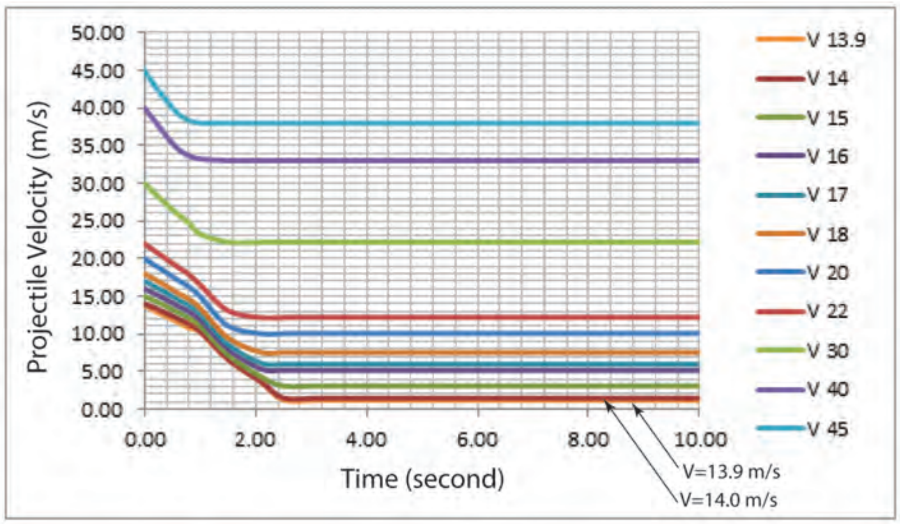

Figure 5.8: Projectile velocity vs. time history after the penetration.

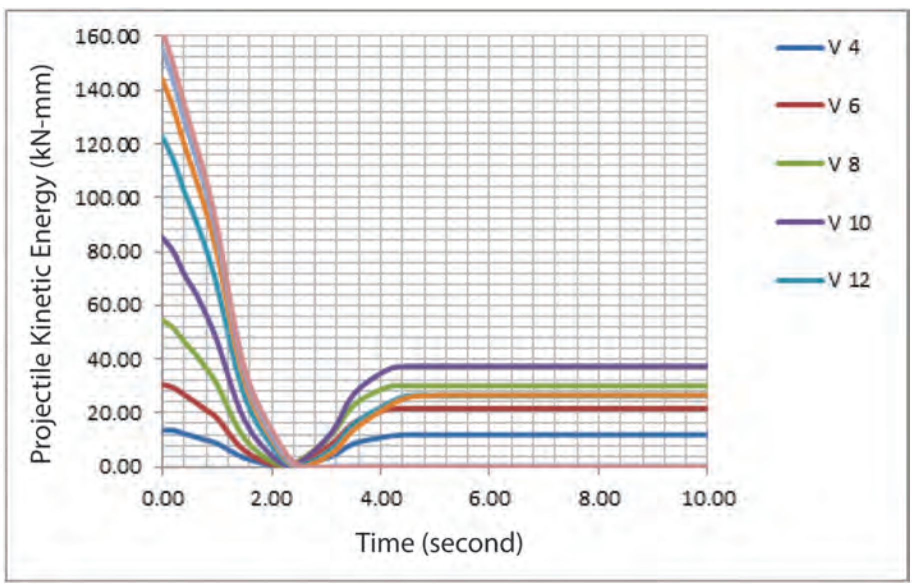

Figure 5.9: Projectile kinetic energy vs. time before the penetration.

locity for penetration is somewhere below 14 m/s (31.3 mph). This is in reasonable agreement with the TTU experimental results.

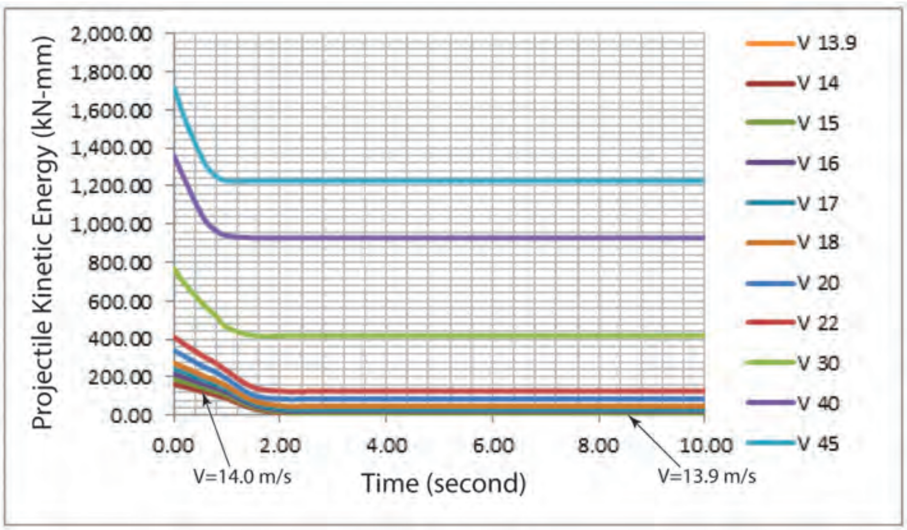

Figure 5.10: Projectile kinetic energy vs. time after the penetration.

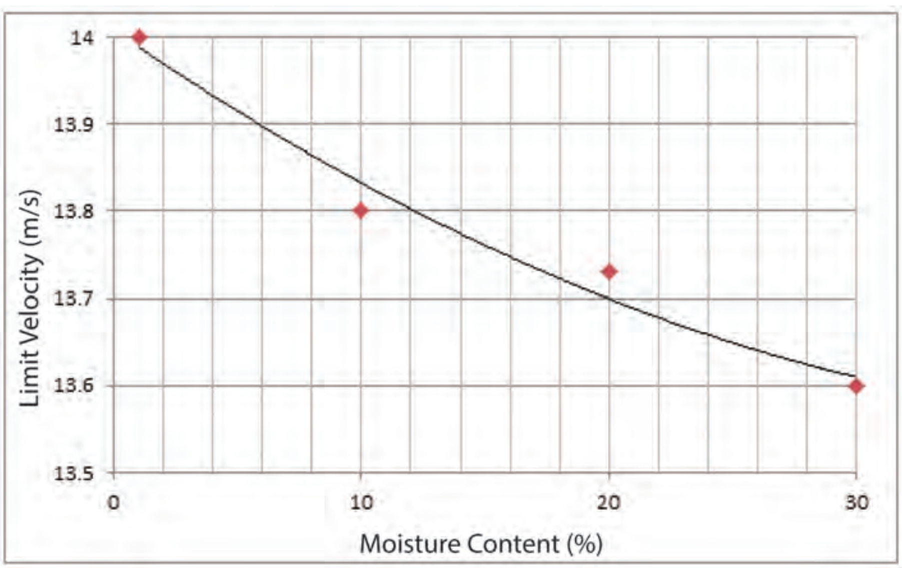

Figure 5.11: Limit velocity vs. moisture contents.

Figures 5.9 and 5.10 illustrate the kinetic energy changes between projectile and the target (plywood). As shown in Figure 5.9, for example, when the projectile impact velocity is 4 m/s, the kinetic energy of the projectile decreased rapidly after

Table 5.1: Penetration velocity comparison.

Projectile Speed (m/s)	TTU Test Results	LS-DYNA Simulation Results
< 13	Projectile repercussed the target	Projectile repercussed the target
13-14	Projectile damaged the target	Projectile damaged and penetrated the target
>14	Projectile penetrated the target	The penetration of the projectile become effortless

the impact. Since the projectile did not penetrate but changed direction, the velocity went to zero as the direction changed and then kinetic energy increased rapidly. However as shown in Figure 5.10, the kinetic energy of the projectile traveling at 13.9 m/sec decreased rapidly after the impact of the system. Since there is penetration, the target absorbed most of the energy – after the penetration projectile has almost zero velocity

Penetration limit velocity, V_L as mentioned earlier, is the minimum velocity level for penetrationof the projectile to embed in the target. In other words, when the projectile passes through the thickness of the target, remaining velocity becomes zero. For impacting velocities smaller than the penetration limit velocity, the projectile rebounds from the target. In this study, V_L-13.9 m/s is the limit velocity to penetrate one plywood. This value can also be verified by using following equation [1]:

$$V_L = \sqrt{\frac{R_t}{\gamma}(e^{2\alpha\gamma w} - 1)} \tag{5.1}$$

Where R_t is the strength of the plywood (taget), w is the thickness of the target, and

$$\alpha = \frac{A}{m}; \qquad \gamma = \frac{1}{2}\rho_t \tag{5.2}$$

Where m is the mass of the penetrator (projectile), A is the penetrator average cross-sectional area, and ρ_t is the density of the target. Using the data given in this chapter, Eqn (5.1) provides limit velocity of approximately 14.3 m/s.

Figure 5.11 shows penetration limit velocity with respect to moisture content of the plywood. As seen from the figure, fully saturated wood is weaker than the less saturated wood. The penetration velocity is 13.6 m/sec for 30%, 13.73m/sec for 20%, 13.8 m/sec for 10%, and 14 m/sec for 1%. Thus, as the moisture content decreases, the material becomes stronger.

5.5 Conclusion

A 15 lb. 2”×4” rigid projectile impact on plywood composite panels has been studied by LS-DYNA for modeling the progressive failure behavior of a one single plywood composite layers. The Texas Tech University Wind Science and Engineering Research Center’s study on the wind-generated missile impact on a composite wall was a major motivation on this study. Existing TTU experimental test data of 1 layer of 3/4 in plywood impacted by a 15lb 2”×4” board is used to guide and judge the finite element model development. Table 5.1 shows the data reported by the TTU Wind Science and Engineering Research Center. As seen from this table there is a reasonable agreement between the results of the TTU experiments and the numerical simulation. This study showed that the simulation using LS-DYNA can be used to design a safe room wall assembly.

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Table 5.2: Southern Pine Wood Material Properties with Moisture Content 1%

Material Parameters based on Moisture Content of Southern Pine Wood		
Moisture Content 1%		
Density 6.731E-07		
Units (kg, mm, ms, kN, Gpa)		
Stiffness:		
EL	Parallel Normal Modulus	16.72
ET	Perpendicular Normal Modulus	0.9597
GLT	Parallel Shear Modulus	0.8119
GLR	Perpendicular Shear Modulus	0.3493
PR	Parallel Major Poisson's Ratio	0.3033
Strength:		
Xt	Parallel Tensile Strength	0.042590
Xc	Parallel Compressive Strength	0.054760
Yt	Perpendicular Tensile Strength	0.001477
Yc	Perpendicular Compressive Strengt	0.010310
Sxy	Parallel Shear Strength	0.009351
Syz	Perpendicular Shear Strength	0.013090
Damage:		
Gf1	Parallel Fracture Energy in Tension	0.011670
Gf2	Parallel Fracture Energy in Shear	0.028480
Bfit	Parallel Softening Parameter	30
Dmax	Parallel Maximum Damage	0.9999
Gf1	Perpendicular Fracture Energy in Tension	0.000233
Gf2	Perpendicular Fracture Energy in Shear	0.000570
Dfit	Perpendicular Softening Parameter	30
Dmax	Perpendicular Maximum Damage	0.99
Hardening:		
Npar	Parallel Hardening Initiation	0.5
Cpar	Parallel Hardening Rate	1008
Nper	Perpendicular Hardening Initiation	0.4
Cper	Perpendicular Hardening Rate	252

Table 5.3: Southern Pine Wood Material Properties with Moisture Content 10%

Material Parameters based on Moisture Content of Southern Pine Wood Moisture Content 10% Density 6.731E-07 Units (kg, mm, ms, kN, Gpa)		
Stiffness:		
EL	Parallel Normal Modulus	15.49
ET	Perpendicular Normal Modulus	0.9101
GLT	Parallel Shear Modulus	0.7898
GLR	Perpendicular Shear Modulus	0.3323
PR	Parallel Major Poisson's Ratio	0.2586
Strength:		
Xt	Parallel Tensile Strength	0.066190
Xc	Parallel Compressive Strength	0.037
Yt	Perpendicular Tensile Strength	0.002139
Yc	Perpendicular Compressive Strengt	0.007145
Sxy	Parallel Shear Strength	0.008526
Syz	Perpendicular Shear Strength	0.011940
Damage:		
Gf1	Parallel Fracture Energy in Tension	0.013840
Gf2	Parallel Fracture Energy in Shear	0.050160
Bfit	Parallel Softening Parameter	30
Dmax	Parallel Maximum Damage	0.9999
Gf1	Perpendicular Fracture Energy in Tension	0.000277
Gf2	Perpendicular Fracture Energy in Shear	0.001003
Dfit	Perpendicular Softening Parameter	30
Dmax	Perpendicular Maximum Damage	0.99
Hardening:		
Npar	Parallel Hardening Initiation	0.5
Cpar	Parallel Hardening Rate	1008
Nper	Perpendicular Hardening Initiation	0.4
Cper	Perpendicular Hardening Rate	252

Table 5.4: Southern Pine Wood Material Properties with Moisture Content 20 %

Material Parameters based on Moisture Content of Southern Pine Wood Moisture Content 20% Density 6.731E-07 Units (kg, mm, ms, kN, Gpa)	
Stiffness:	
EL Parallel Normal Modulus	12.56
ET Perpendicular Normal Modulus	0.4619
GLT Parallel Shear Modulus	0.7369
GLR Perpendicular Shear Modulus	0.1655
PR Parallel Major Poisson's Ratio	0.1842
Strength:	
Xt Parallel Tensile Strength	0.052380
Xc Parallel Compressive Strength	0.018580
Yt Perpendicular Tensile Strength	0.001458
Yc Perpendicular Compressive Strengt	0.003627
Sxy Parallel Shear Strength	0.005577
Syz Perpendicular Shear Strength	0.007808
Damage:	
Gf1 Parallel Fracture Energy in Tension	0.015660
Gf2 Parallel Fracture Energy in Shear	0.046150
Bfit Parallel Softening Parameter	30
Dmax Parallel Maximum Damage	0.9999
Gf1 Perpendicular Fracture Energy in Tension	0.00313
Gf2 Perpendicular Fracture Energy in Shear	0.000923
Dfit Perpendicular Softening Parameter	30
Dmax Perpendicular Maximum Damage	0.99
Hardening:	
Npar Parallel Hardening Initiation	0.5
Cpar Parallel Hardening Rate	1008
Nper Perpendicular Hardening Initiation	0.4
Cper Perpendicular Hardening Rate	252

Table 5.5: Southern Pine Wood Material Properties with Moisture Content 30 %

Material Parameters based on Moisture Content of Southern Pine Wood Moisture Content 30% Density 6.731E-07 Units (kg, mm, ms, kN, Gpa)		
Stiffness:		
EL	Parallel Normal Modulus	11.35000
ET	Perpendicular Normal Modulus	0.24680
GLT	Parallel Shear Modulus	0.71520
GLR	Perpendicular Shear Modulus	0.08751
PR	Parallel Major Poisson's Ratio	0.15680
Strength:		
Xt	Parallel Tensile Strength	0.04003
Xc	Parallel Compressive Strength	0.01332
Yt	Perpendicular Tensile Strength	0.00096
Yc	Perpendicular Compressive Strengt	0.00257
Sxy	Parallel Shear Strength	0.00428
Syz	Perpendicular Shear Strength	0.00599
Damage:		
Gf1	Parallel Fracture Energy in Tension	0.02005
Gf2	Parallel Fracture Energy in Shear	0.04148
Bfit	Parallel Softening Parameter	30
Dmax	Parallel Maximum Damage	0.9999
Gf1	Perpendicular Fracture Energy in Tension	0.00040
Gf2	Perpendicular Fracture Energy in Shear	0.00830
Dfit	Perpendicular Softening Parameter	30
Dmax	Perpendicular Maximum Damage	0.99
Hardening:		
Npar	Parallel Hardening Initiation	0.5
Cpar	Parallel Hardening Rate	1008
Nper	Perpendicular Hardening Initiation	0.4
Cper	Perpendicular Hardening Ra	252

CHAPTER 6

Homeland Security" at Home

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Homeland Security began at the national level in the United States after the terrorist attacks on 11 September 2001. The concept can be extended to the very basic level of protecting literal homesteads. This chapter explores the application of Systems of System concepts developed by the United States' Department of Defense (DoD) to the problem of homestead defense at the homestead level. It outlines the problem, the applications of the DoD concept, the selected solution, and the results and recommendations.

Keywords*:* Homeland security, system engineering, surveillance.

6.1 Introduction

In 2008, the Systems and Software Engineering (SSE) Directorate of the Office of the Deputy Under Secretary of Defense for Acquisition and Technology (ODUSD(A&T)) in the United States (U. S. or just US) Department of Defense (DoD) published a guide for systems engineering (SE) of systems of systems (SoS), recognizing that systems engineering is a key enabler of successful systems acquisition, operation, and sustainment in an environment where there are growing numbers of dependent and interdependent systems used to provide war fighter capability. The result was version 1 of the Systems Engineering Guide for Systems of Systems [1] ("Guide").

While the intent of the Guide is to support DoD programs and warfighters, SoS are increasingly a part of contemporary enterprise architecture and engineering. For example, Honour, in his 2008 short course "Systems of Systems" [2] identifies airports as systems of systems. In their 2011 paper on complexity [3], Geraldi, Maylor, and Williams list the enterprises (not necessarily defense related) where systems are comprised of systems, yielding complexity. In their 2009 paper on health care, Hata, Kobashi, and Nakajima [4] show how health care delivery is via a system of systems. In their 2004 paper on public policy decisions, DeLaurentis and Callaway use an example of the next generation national transportation system as a context for their systems of systems discussion [5]. These are collected in Table 6.1. There are *many* others. In particular, Luzeaux and Ruault [6] in their book Systems of Systems include "zone control and surveillance" as another example of a system of systems. That particular type of system of systems is the subject of this research and report.

Table 6.1: Enterprises Where Systems are Comprised of Systems

Enterprises Where Systems are Comprised Of Systems	Reference
Airport	[2]
Construction	[3]
Enterprise Resource Planning (ERP) Implementation	[3]
Health Care	[4]
Information Systems	[3]
Plant Engineering	[3]
Product Development	[3]
Transportation System	[5]
Zone Control and Surveillance	[6]

6.2 Zone Control and Surveillance – The Ultimate Homeland Security

Luzeaux and Ruault [6] describe "zone control and surveillance" in a strictly military context. But since September 2001, especially in the US, this concept has extended to include homeland and perimeter security. In the ultimate sense, perimeter security includes security of the home i.e., domicile, and surroundings.

In particular, the end user has a concern with neighbor unfriendly dog breaking through a chain link fence protecting an underlying wooden privacy fence, potentially belligerent vandals, and maintaining a secure environment for yard care and the end user's pets. The end user expressed a need for high-resolution video surveillance that would provide objective evidence if legal action was necessary. An incumbent contractor provides monitored security for magnetic door and window alarms on the perimeter of the home. The first approach was to engage the incumbent contractor to orchestrate an upgrade to the existing SoS. That approach proved unworkable, so the end user engaged a second contractor to satisfy the material requirements and a third contractor to install the material solution as detailed below.

6.3 Application to Problem Under Consideration

Table 6.2 shows how the principles listed in the Guide [1] apply to this problem of zone control and surveillance. These are discussed in the sections below, considering a row of the table at a time.

Section 4.1.1 of [1], Translating Capability Objectives, is intimately related to Requirements Development. In this example, the objective of monitoring the premises is translated into specific requirements for cameras, field of view/regard, and light sensitivity. Likewise, this requirement needs to be considered in the context of requirements, risk, configuration, data, and interface management in the zone control and surveillance. Interface management has been added to the baseline from the Guide [1] and is shown in italics. Interface management is considered in the context of translating capability objectives because of the variety of physical and electrical interfaces to be considered (e.g., coax vs Ethernet).

In 4.1.2 of [1], Understanding Systems and Concepts, logical analysis is a method of associating concepts with systems that satisfy those concepts. In this example, the concept of providing home surveillance is realized by surveillance systems, such as

Table 6.2: Relationships between SoS Core Elements and SE Processes ([1]).

4.2 SE Process Support for System of Systems Engineering / 4.1 Core Elements of SoS SE	Technical Processes								Technical Management Processes							
	4.2.1 Requirements Development	4.2.2 Logical Analysis	4.2.3 Design Solution	4.2.4 Implement	4.2.5 Integrate	4.2.6 Verify	4.2.7 Validate	4.2.8 Transition	4.2.9 Decision Analysis	4.2.10 Tech Planning	4.2.11 Tech Assessment	4.2.12 Requirements Management	4.2.13 Risk Management	4.2.14 Configuration Management	4.2.15 Data Management	4.2.16 Interface Management
4.1.1 Translating Capability Objectives	X											X	X	X	X	X
4.1.2 Understanding Systems & Relationships		X											X	X	X	X
4.1.3 Assessing Performance to Capability Objectives							X		X	X	X		X		X	
4.1.4 Developing and Evolving a SoS Architecture	X	X	X						X	X		X	X	X	X	X
4.1.5 Monitoring and Assessing Changes									X				X	X	X	X
4.1.6 Addressing Requirements and Solution Options	X		X						X	X		X	X	X	X	X
4.1.7 Orchestrating Upgrades				X	X	X	X	X	X	X	X	X	X		X	X

cameras and movement detection algorithms that might activate alarms. As noted above, Translating Capability Objectives is concerned with requirements management, so that need would be redundant in Understanding Systems and Concepts. But because surveillance systems that realize concepts span related but different areas in the solution space, Understanding Systems and Concepts also needs to consider risk, configuration, data, and interface management.

Considering 4.1.3 of [1], Assessing Performance to Capability Objectives, the military learned long ago that satisfying the wrong set of requirements perfectly yields a perfectly wrong solution [[7],[8] and many other examples]. Among the many responses to this engineering process flaw is Performance Based Specifications that attempt to focus more on outcome than on details. For example, The Guide for Performance Specifications, SD-15, dated 24 August 2009 [9], states:

> "It is the policy of the Department of Defense (DoD), as required in DoD Directive 5000.01, The Defense Acquisition System, to state requirements in performance terms whenever possible. Part II of the Federal Acquisition Regulation also requires federal agencies to give preference to performance-oriented documents over detailed design documents when describing agency needs. To implement DoD and federal preferential policies on stating requirements in performance terms, DoD 4120.24-M, Defense Standardization Program (DSP) Policies and Procedures, gives preference to developing and using performance specifications over detail specifications."

An unexpected consequence unfortunately is that the outcomes do not favor adoption of the approach. In Edouard Kujawski's insightful Unintended Consequences of Performance Specifications for the Reliability of Military Weapon Systems [10], he notes

> "Reliability data from 1996 to 2000 might be an indicator of negative unintended consequences of the cancellation of military specifications. The acquisition of successful military systems requires a mix of performance and prescriptive reliability requirements that depend on the application, technology maturity, and complexity."

So the first relationship of Assessing Performance to Capability Objectives is that of validation – making sure the requirement actually satisfies an end user need. Likewise, there is a relationship with Decision Analysis because there is a need for traceability – why was the decision made to map a particular performance objective to a particular capability objective[1]. Requirements traceability is a critical aspect in maintenance, for example [[8], [11], and many others]. Next, Tech Planning and Tech Assessment are important to Assessing Performance to Capability Objectives. Tech Assessment has been added to the baseline from the Guide [1] and is shown in *italics*. The author contends it is difficult to address Tech Planning without Tech Assessment. For example, if Tech Planning is proposing to achieve a lower noise figure by a change to Boltzman's constant, perhaps Tech Assessment is needed to assess requirements development by Tech Planning[2]. Tech Planning and Tech Assessment naturally relate to Risk Management: a planned and even assessed technology might still not be ready for use. The Army's Future Combat Systems (FCS) program,

[1]Perhaps Decision Analysis should, in general, be more broadly associated and applied
[2]Author's note: Boltzman's constant is indeed a constant

for example, spent billions of dollars before it was cancelled because the technology planned for and assessed was still immature [12].

For 4.1.4 of [1], Developing and Evolving a SoS Architecture, this project, though new, relies on current COTS technologies: cameras, network video recorders, change detection algorithms, and others. But this does not mean that evolution should not be considered in design. For example, a large tree on the property and other obscurants indicate the potential need for additional cameras. The video processing system selected comes with eight cameras, was procured with twelve, and is capable of integrating four more cameras (+33% margin for a total of sixteen) to accommodate this possibility. The Guide [1] states

> "Ideally the architecture of an SoS will persist over multiple increments of SoS development, allowing for change in some areas while providing stability in others. This ability to persist and provide a useful framework in light of changes is a core characteristic of a good architecture. Over time, the SoS will face changes from a number of sources (e.g., capability objectives, actual user experience, changing CONOPS and technology, and unanticipated changes in systems) [that] may all affect the viability of the architecture and may call for changes. Consequently the SoS systems engineer needs to regularly assess the architecture to ensure that it supports the SoS evolution."

The system selection process for this SoS considered these concepts. As noted above, the potential evolution to sixteen cameras was considered in the evaluation of potential solution systems. Contemporary as well as evolving video protocols were considered. Environmental changes such as growth of trees was considered. Software upgrade and patch application methodology was considered in this context. And in exact alignment to the guide, these changes are considered to be over multiple increments when the end user can afford to or must update and upgrade when needed.

Requirements development, logical analysis, and design solution are all relevant to Developing and Evolving a SoS Solution. Requirements satisfaction is relevant to solution selection.

Solutions and requirements are analyzed with logic, and the design solution is selected based on a logical process. Decision Analysis is relevant because choices are made as a SoS Solution is developed and evolved. Tech Planning is related because, as noted below, technology evolves and solutions will migrate to evolved technology. Requirements Management, Risk Management, Configuration Management, Data Management, and Interface Management are all relevant to developing, evolving, and sustaining a SoS Solution.

For 4.1.5 of [1], Monitoring and Assessing Changes, technology (including software) is not static. But with each push forward, change introduces risk. For example, upgrading the video monitoring software may make it incompatible with connected monitoring equipment in general and computers in particular. Maintaining awareness of the suppliers' plans is helpful, but often suppliers' plans are not adequately revealed until the moment of upgrade (or after). Microsoft, for example, announced a schedule for upgrades but not does not reveal content or compatibility concerns. In this context, consumer awareness of supplier compatibilities both present and future are a concern. The end user in this case uses Apple products, from iMac, to Macbook Pro, to iPad, to iPhone. If the current equipment provider elected in the future to be only Microsoft compatible, this would introduce a continuity of service issue. The guide [1] states

> "A core activity of SoS SE is to anticipate changes outside the control of the SoS that could affect the functionality or performance of an SoS capability. This includes changes to the technologies used to support the SoS or changes to the missions of the individual systems as well as external demands on the SoS. To be successful, the SoS systems engineer requires a broad awareness and understanding of trends in enabling technologies, technology insertion, and mission evolution."

In this problem, supplier changes are outside the control of the SoS end user, and this puts the end user's investment at risk. A reasonable assessment of this risk determined that the concern is "small" but the risk is real and is not zero. The end user or their representative are delegated this concern.

Decision Analysis applies Monitoring and Assessing Changes because decisions need to be made about changes. Risk Management, Configuration Management, Data Management, and Interface Management are all relevant to monitoring and assessing changes.

For 4.1.6 of [1], Addressing Requirements and Solution Options, eliciting end user needs and deriving associated requirements is essential if the procured and integrated SoS is to satisfy the end user's expectations. In this problem, the end user's expectation of fidelity even at the extremes of the field of view dictated a requirement for a high definition camera. The limited time the end user could devote to examining the recorded video surveillance dictated both media large enough to store a significant amount of collected video and software assisted change detection and screening so that motion caused by wind blowing the pecan tree is not flagged as suspicious but motion caused by a neighbor dropping a limb into the region under surveillance is flagged as suspicious. The target area required analysis as detailed in Results below to determine the number and pointing directions of surveillance cameras.

Requirements Analysis is naturally related to Addressing Requirements and Solution Options. Likewise, the Design Solution is naturally related to Addressing Requirements and Solution Options. Decision Analysis and Tech Planning are related because of the need to have solutions that meet customer expectations. Requirements Management, Risk Management, Configuration Management, Data Management, and Interface Management are all relevant to Addressing Requirements and Solution because satisfaction is not without risk. Configuration Management is part of Solution Options as these are satisfied and evolve. Likewise, Data Management and Interface Management are part of Solution Options as the selected solution must interface with existing user premises equipment.

In 4.1.7 of [1], Orchestrating Upgrades, upgrades are a fact of life in systems of systems. In this case, orchestration must consider a number of providers who (a) assure that upgrades across the system of systems do not degrade performance but (b) who do not necessarily coordinate their upgrades. This means the end user of the SoS, or a hired proxy, must assure that upgraded elements and systems in the system of systems will continue to work as expected after upgrades and recapitalization. In this case, for example, the vendor of the recorder console (Swann) states "The NVR is guaranteed to work with Swann branded network cameras only". This means there is a risk of using other vendor cameras even though Swann states of their cameras that "These NVR IP cameras will only work with NVR (Network Video Recorder) DVR systems that are ONVIF compliant. If using a different brand ONVIF[3] compliant camera with a different brand ONVIF compliant recorder they may not be 'Plug-n-Play' and some configuration may be needed at setup."

For the all Swann recorder and camera system of systems discussed here, the upgrade risk is minimal until that point where Swann equipment is no longer backward compatible, at which point a recapitalization decision by the end user will be required.

Thus, Implement is relevant as are Integrate, Verify, and Validate. This project is not really a transition of equipment but is a transition of the SoS end user who has no legacy equipment for this function. Thus, Decision Analysis and Tech Planning are relevant as the SoS evolves into the future to assure continued satisfaction of user needs. Tech Planning is not on the original Guide and so has been added in italics. Tech Assessment, Requirements Management, Risk Management, and Configuration, Data, and Interface Management are needed to assure the smooth transition across evolved SoS as a consequence of Orchestrating Upgrades.

6.4 Requirements

Figure 6.1 graphically shows the zone requiring surveillance for the problem. Figure 6.2 shows the plot of the zone to be protected. Figure 6.2 was required to consider sensor capability and placement and was developed by outlining the home and property boundaries on a scan of the survey acquired for the property at the time of purchase. Discussions with the end user determined that high definition persistent video surveillance over 100% of the threatened property to be the top-level system of systems (enterprise) requirement. Analysis was required to determine the characteristics (distance and pointing capability) of some of the sensors. Most fields of regard (FOR) were determined by inspection, but one required analysis as incorporated into Figure 6.4. Figure 6.3 shows the rendering of the plot shown in Figure 6.2 into a graphic. Measurements using conventional tools (e.g., tape measure) are included in Figure 6.3 and used in the analysis in Figure 6.4. Fields of regard (FOR) were developed based on logical camera locations as shown in Figure 6.4. FOR were determined by inspection except in one case that was determined by trigonometric analysis incorporated into Figure 6.4.

The requirements derived for this system of systems are shown in Table 6.3. Since at least one vendor claimed satisfaction of the requirements, achieving compliance is not an issue.

6.5 Results

The requirements in Table 6.3 are satisfied in the Operational Viewpoint shown in Figure 6.5. Figure 6.5 shows camera emplacements along the eaves of the protected home. In operation, wired Ethernet transfers the collected video surveillance to a central Network Video Recorder (NVR) in the protected home. Software in the NVR processes the collected video to isolate changes, and these are stored in the NVR for end user evaluation.

[3] Open Network Video Interface Forum (ONVIF), see http://www.onvif.org

Figure 6.1: Back view of house requiring Zone Control and Surveillance. Threatened dog shown. Threats absent.

There are several video surveillance systems of systems that could conceivably satisfy the requirements enumerated in Table 6.3 above. Trade studies are not the subject of this report (trades are frequently cited in [1]), but major factors involved in the selection of the vendor are, in addition to the cost of the system, the availability of qualified installers, ease of use, compatibility with user premises equipment, and vendor stability.

Camera selection was driven by the requirement for high definition and the need for numerous coverage areas, which in turn drove cost. There was a requirement for ordinary and low visible light sensitivity. The HD aspect of the cameras made wireless connections implausible due to the bandwidth requirements of each camera and the required number of independent channels, combined with a lack of encryption from the point of origin for privacy. Wired options offered were a single Ethernet cable that carries digital video and status from each camera in one direction and power (Power over Ethernet), command, and control in the other direction or multiple wires from each camera carrying video and status in one direction and other wires carrying power, command, and control in the other direction. The single wire option was assessed as less risky due to less potentially faulty connections. The end user decided that one wire for data, power, status, and control is preferred over more than one from an installation, reliability, and maintenance perspective. Ultimately, Swann cameras were selected. Swann says their cameras will work with any NVR as long as it is ONVIF compliant (see above), but, curiously, they guarantee success only with their cameras paired with their NVRs. Faced with limited time to consider alternatives, the end user decided on a Swann NVR. The purchased NVR and cameras it is packaged with are shown in Figure 6.6. The NVR comes with a wired mouse but no monitor. A monitor is needed to set up the system and to view the recorded video. The NVR has a High-Definition Multimedia Interface (HDMI) output, and the cameras are HD, so a HDMI compatible monitor was selected and added to the ensemble.

The NVR was purchased as a package that included eight fixed mount cameras

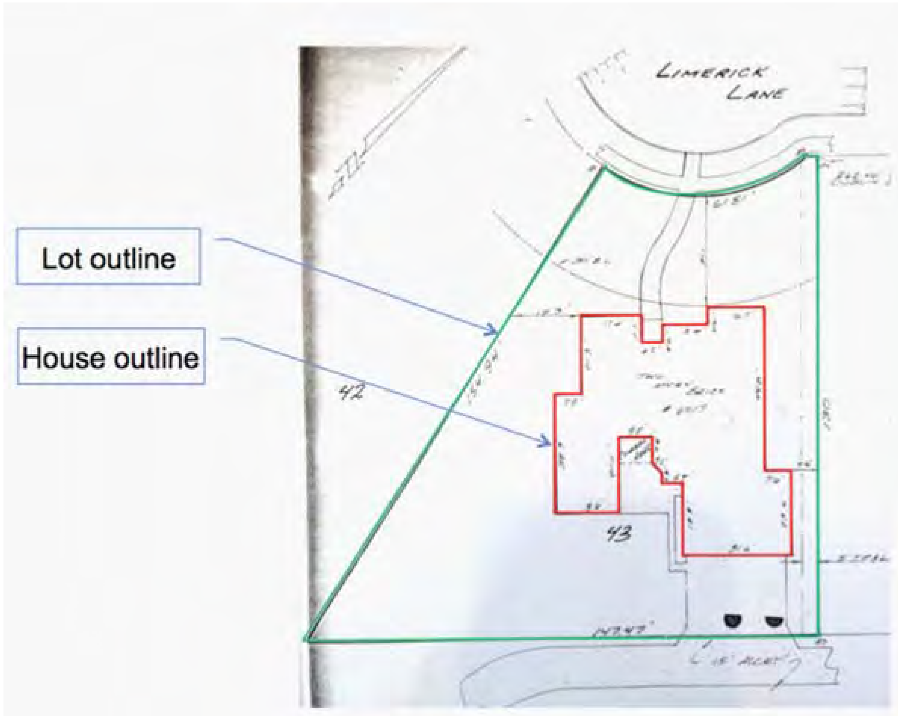

Figure 6.2: Top view of zone to be protected includes front and back of the home.

with no pan or tilt. Six of the cameras are fixed field focus and two are variable focus as shown in Figure 6.7. Geometric analysis showed that four more individual cameras are needed to provide continuous surveillance across the operational area. The variable focus was assessed as not pertinent to the SoS requirements, so four more fixed focus cameras (at slightly lower cost) were selected.

6.6 Successes and Challenges

The requirements were successfully satisfied. The end user coordinated the set of requirements in Table 6.3 with a contractor that provided the material components of the SoS. The vendor recommended another contractor who installed the SoS and trained the end user in its operation.

But this effort was not without challenges. First, the incumbent perimeter monitoring contractor was found to be unequipped or unwilling to satisfy the new requirements. As a consequence, a new contractor was selected and performed the effort.

Cost and time were a second challenge. Satisfying the specified requirements proved to be costly and demanding of the end user's time.

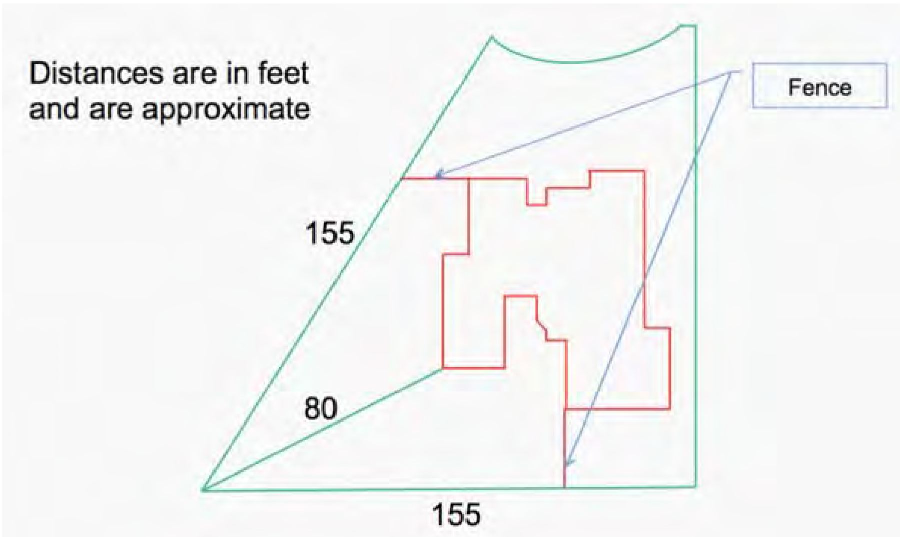

Figure 6.3: Measurements show the maximum required viewing distance from the camera mount point to be about 80 feet (Measurements, except for the trigonometric analysis, are from the survey).

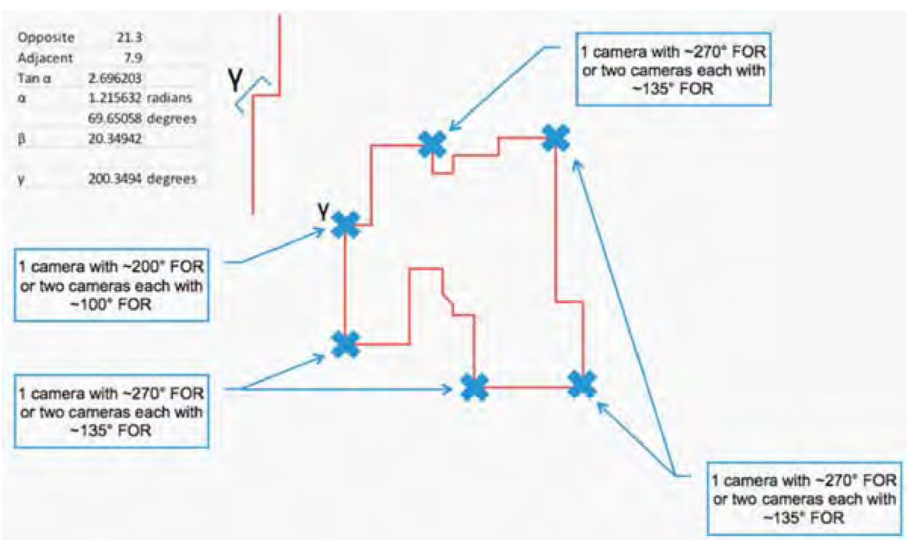

Figure 6.4: The Field of Regard (FOR) for most sensors was determined by inspection, but one required trigonometric analysis.

Table 6.3: Requirements for the System of Systems solution to the design problem.

Requirement	As Bought
12 cameras, each with Not Less Than (NLT) 135° Field of Regard (FOR, see Figure 4) • Each camera must be able to pan, tilt, and zoom independently • Two cameras autofocus • Frame rate adjust in proportion to activity	12 cameras, each with ±75° FOR, each on a fixed mount • 10 cameras with fixed focus • 2 cameras with variable focus Assessed compliant
Minimum imaging distance 80 feet (see Figure 3)	115 feet imaging distance
HD visible and low light video • Visible in daylight, low light capable in "dark"	1 lux@F1.2, 0 lux with Infrared (IR)
Wired power (or Power over Ethernet, PoE)	PoE
Recorder and monitor/computer interface inside	Compliant
Up to 16 cameras for growth	Compliant
Eight x 24 hour days recording • Lossless compression	"up to 45 days of continuous recording from all 16 channels or record for even longer with motion triggered recording" Assessed as compliant
Processing • Preserves date and time • Selected snapshots conversion to jpeg • Selected clips conversion to mpeg 4 (H.264 Part 10 aka QuickTime)	 Compliant Compliant Compliant
Playback at up to 16x real time	Assessed compliant: can jump ahead

"lux" is the metric unit of illumination; lower units represent lower illumination levels and hence better performance in darker environments
"F" numbers are is the ratio of the lens's focal length to the diameter of the entrance pupil; lower numbers generally represent a greater diameter lens (hence improved capability in lower light situations)

Figure 6.5: Operational Viewpoint (OV-1) for Zone Control and Surveillance. Threatened dog in back yard shown. Threat dog shown, approximately to scale.

Finally, there were operational challenges that required tuning the installed sys-

Figure 6.6: Recorder console requires only installation and connection of cameras and a HD monitor to become operational.

Figure 6.7: The selected HD cameras use "Power Over Ethernet" so that only one wire is needed to connect the camera to the recorder console.

tem for best results. For example, motion sensitive cameras proved to be too sensitive to motion of deciduous tree branches in seasons where the branches had leaves. The contract equipment provided a software capability to selectively edit the area in the field of view where the motion detection capability applied, but this required significant time to set properly. Convenient connection of the end user's computers to the new premises equipment was challenging, requiring installation of new Power over Ethernet (PoE) wiring in the end user's site, use of the end user's wireless access point, and complicated configuration of the end user's wireless devices.

6.7 Details of Lessons Learned

Ultimately, the end user was satisfied. An important lesson learned is that it is much easier and cheaper to install power, data, and control cabling at the time of construction, even if no monitoring equipment is installed at that time. If a potential end user ever builds a house, this is should be a consideration.

Another lesson learned is the numbers, types, and diversity of systems of systems that claim to satisfy the SoS requirements are so numerous that objective analysis of the possibilities proved to take too much time. The selected vendor was in Australia and simple responses to questions took at least a day. The final selection was based on objective and subjective measures that would never be acceptable in a government or business setting (for example, the selection of contractors for the US government's NETCENTS 2 IDIQ contract took at least three years [13]). The lesson learned is that "good enough" sometimes is preferred to "flawless" when considering all selection factors.

6.8 Conclusions

When persistent High Definition video premises monitoring is required, numerous qualified companies and equipment are available to satisfy the requirements. Some vendor offerings are superior to others. Vendor selection, while complicated, does not have to be perfect to be effective. A successful realization, even with challenges, is within reach of the end user by applying the disciplined System of Systems principles developed by the United States Department of Defense. Multiple providers, when reasonably coordinated, can perform an installation of a relatively complicated system of systems. This system is non-commercial in that every constituent system is not provided by the same vendor, with the resulting system of systems requiring integration by the installer and the end user. Collaboration between the provider and the user resulted in a more satisfying outcome, somewhat supporting the claim that performance specifications are superior to prescriptive specifications.

Other conclusions are more nuanced. For example, since the initial installation, one camera of the original twelve has failed. The failure appeared to be connection related, so the end user contacted the installer, who confirmed that the originally installed PoE cables are still connected, leading to the conclusion that the failure lies in purchased products from the equipment vendor. The installer confirmed this and the equipment vendor was contacted, but with thus far unsatisfactory results. The ultimate results are as of now unknown.

Also, the installers were not well trained in setting up the wireless monitoring feature of the vendor product. They were trained on the prior generation product, but that training had limited applicability to this installation. Better training is indicated, complicated by the profusion of available user wireless devices.

A premises video monitoring system is easily available subject to the cautions advanced in this chapter.

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CHAPTER 7

Software Defined "X"

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The power of computing has been realized in two main directions, 1) The growth of hardware devices and systems 2) The enhancements in software technologies. The growth of hardware has branched out into two areas, specialized hardware for vertical focus and generic hardware with applicability in multiple areas. While the growth in the software arena also started in the same path the morphs that software technologies have taken are much faster and much more wider in scope. Hence we do see a faster growing software economy. The Software Defined "X" trend that we have seen has been evolving in the last decade started getting recognition with the Software Defined Radios (SDRs). SDRs, which offered capabilities to make the hardware radio frequency layer or layer 1 in the OSI stack controllable via software and offering the same hardware to latch onto multiple radio frequency channels led the way to more software defined technologies to be researched and invented. In this chapter we would study the Software Defined Networking effort that has caused a major disruption in the networking world and how it addressed a big issue that has been lying dormant in this industry for more than two decades. The technological innovations applied to the Software Defined Networking segment helps build-out a wider industry application base, hence creating a level playing field for a larger yet targeted software application base helping the consumers get better choices to decide on their consumption needs.

Keywords: Software, networking platform, network policies, networking systems.

7.1 Introduction

Software Defined "X" is a means for disruptive forces to push innovation in areas that were rigid and structured via hardware as the fundamental basis for development. We have seen a tremendous growth in software and hardware in the last decade. The growth has been backed by the insatiable demand for computing in not only the normally existing areas where computing usage has been a key driver but also areas where computing could be used for various reasons ranging for feasibility, form-factor, practical closures of the applications, connectivity, lack of reasonable interfaces, etc. The growth also has seen multiplicative effect with the revolution of hardware and software innovations. We will focus in the Software Defined "X" with some details covering the Software Defined Networking area, but we will also expand into other areas of Software Defined technology innovations.

Networking itself is a wide area to cover and we will talk about the Wide Area Networking, which has seen a lot of research and applications already actively deployed. We will address aspects of Security, Wireless Networking and Storage as well. The basic definition of software driving functionalities within hardware on which is operates is not a new area. We find that the last decade or so we have seen more software penetration of software in controlling hardware. Hardware has always existed as a purpose built entity, architected, designed and developed for a specific job. Due to the way hardware gets designed and developed it is difficult to bring in changes into the functionality of hardware easily and in less time. The arduous process involved in designing a good hardware system makes it difficult to make changes on the fly. Software, on the other hand, has different characteristics. Software reuse is a very important characteristic of a good software design. Given that modularity and reuse are important items that software industry as followed making changes and getting newer and different implementations to be added are expected modes of software driven operations.

7.2 System Elements

Software defining [3, 5] functionalities have been experimented in many areas. It starts with things like languages [3] and frameworks [7] that are used to develop these software systems. Languages used to build new software defined modules are domain centric hence of the language constructs [3, 8] will be more application centric. Domain-aware programming languages were developed to make it easy to program applications with constructs that are directly applicable to the applications with the specific domain. In [3] the authors present a domain specific language used to develop software defined networking applications. Software Defined Networking platform is being designed to house new applications along with the existing ones with certain structural programming model changes that will help evolve and expose things within networking framework which were considered hard-wired. Although the characteristics of the networking framework don't change the ways the functionality is exposed and managed change significantly.

Pyretics [16] policy language has a number of features that are designed to make it easy to construct and combine policies in a modular way. Most networks perform multiple tasks, such as routing, monitoring, and access control. Ideally, programmers would be able to implement these tasks independently, using separate modules. But the programming interfaces available today make this difficult, since packet-handling rules installed by one module often interfere with overlapping rules installed by another module. It allows the networking switch to do the following; 'query the current network state', 'express new network policies' such that the networking data plane reacts according to the fed in policies and 'reconfigure the network' such that different behavior can be implemented. All of these can be done on an ad-hoc basis and fed into the switches in real time. There is no downtime expressed in reprogramming the network. With the help of the language the authors have created a new environment for the applications to be created by many programmers who are not original owners of the network switch. The abstractions offered helps reduce the barrier to creativity.

Table 7.1: Sample programming.

Syntax	Summary
identity	returns original packet
drop	return empty set
match ($f = v$)	identity if field matches v, drop otherwise
modify ($f = v$)	returns packet with field f set to v
fwd(a)	modify (port = a)
flood ()	returns one packet for each local port on the network spanning tree

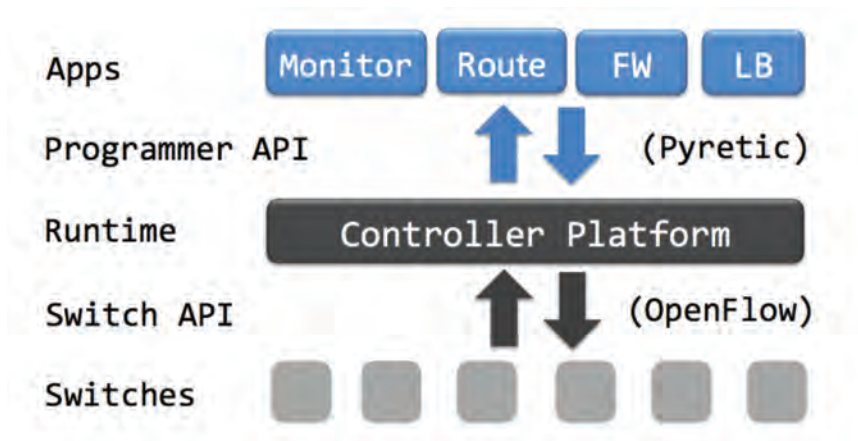

Figure 7.1: Software defined networks.

In Figure 7.1 above, using Pyretics applications like Monitor (monitors traffic flowing through the network switch), Route (feeds in specialized routes that are manually injected for traffic to follow instead of routes being discovered from within the network), etc. An application developer can easily use the Pyretics language to develop simple applications that can be developed externally and injected into a switch that is complaint with the framework. A two-tiered software framework is shown with the architecture.

A domain specific syntax supported by the Pyretic language is shown Table 7.1. A subset of syntax is listed on the left hand side of the diagram. As the syntax suggest they are very specific operations that can be closely tied to the network switch domain. For e.g. the syntax '**flood**' is generally used to broadcast the same packet across all the networking ports within the switch. The syntax '**drop**' is used to drop a packet once it is received on a port. There could be qualifiers that can be passed to make sure that the action of dropping a packet is performed after certain filters are matched. The syntax '**modify**' would allow for a modification of packet content by replacing one or more field values with another. The syntax '**fwd**' would instruct the system to forward a specific type of a packet to be forwarded to a specific port. The forwarding of the packet to a port can be time driven or with certain matching fields values.

Languages play a strong part in building software-defining actions within the network segment and several others segments has had languages with syntax that are applicable for their domains. Such domain specific languages do form framework and/or platform via which such value-added applications can be developed. The frameworks generally come with the language syntaxes and interpreter or compiler arranged to create intermediate binary.

Software defined systems required modes in which new software base logic can be injected within an existing, live environment. This fundamental need exist no matter which domain it has been applied to. The model of building software needs modularity in such environment where software components are decomposed into smaller modules. These smaller modules can be replaced; enhancement or new control flows can be inserted or added into the system. Those derivations help upgrade, make it more relevant per target applications, or morph the device for business relevant needs.

7.3 Application Domains

Various application domains have already seen early stage impacts of software defined networking architectures being implemented. Some of the areas where Software defined solutions are being actively researched and implemented and discussed in this chapter are Wide Area Networking[9, 11] (WAN), Optical Networking Transport [5], Soft-Radio implementation[1], Orthogonal Frequency based wireless encoding [2, 15], Storage Networking [12, 14].

Wide Area Networking systems are a critical piece of the entire Internet connectivity to be maintained. A good operating WAN needs to have a uniform utilization across all the links in a WAN. High utilization requires frequent updates to the network's data plane. The data plane is the path where data traffic flows in real time. The data plane is established during a flow when the path is discovered via the route discovery process. Changes in traffic demand based on flow needs as well as changes in the network topology based on route outages or reroutes based on policy changes are common in WAN. A key challenge is to implement these updates without causing transient congestion that can hurt latency-sensitive traffic. The underlying problem is that the updates are not atomic, as they require changes to multiple switches in the network. Even if the before and after states are not congested, congestion can occur during updates if traffic that a link is supposed to carry after the update arrives before the traffic that is supposed to leave has left. The extent and duration of such congestion is worse when the network is busier and has larger RTTs (which lead to greater temporal disparity in the application of updates). Both these conditions hold for our setting, and we find that uncoordinated updates lead to severe congestion and heavy packet loss. Some of the issues that need to dealt with are fully using network capacity requires many forwarding rules at switches, to exploit many alternative paths through the network, but commodity switches support a limited number of forwarding rules.

Analysis of a production inter-data center WAN shows that the number of rules required to fully use its capacity exceeds the limits of even next generation SDN switches. We address this challenge by dynamically changing, based on traffic demand, the set of paths available in the network. On the same WAN, our technique

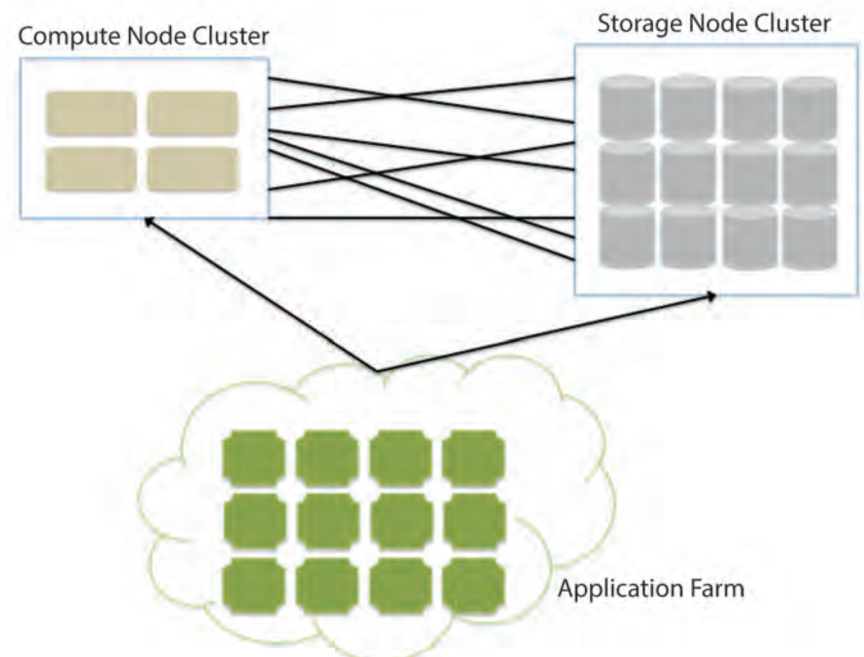

Figure 7.2: Software networking in virtual machine clusters.

can fully use network capacity with an order of magnitude fewer rules. Due to the distributed approach of rules designed it is possible to have them farmed properly to the right links. The distribution of the rules relevant for specific segment can be fed into the system. WAN optimization is quite a challenging problem as the state of a link within a WAN segment changes constantly. Due to the change it is hard to predict what type of rules will have what impact for any route flows. Any applied rule will have to deal with re-prioritization of traffic flow of some type(s) and rerouting the flows can create turbulence within the entire WAN.

Storage Networking and IO's within a storage area network has some very interesting applications that software defined networking can bring to the table. Storage area networks deal with IO traffic from the application to the storage systems. These storage entities are network attached at various levels within the network stack. Each class of storage device has its own performance criteria called ratings. The ratings are utilized in architecting a storage networking sub-system. Software defined systems within a storage networking area helps in building frameworks which can be used in developing dynamic data and IO flows. Virtual Machines are a big factor in data centers and enterprise networks. Storage systems are decoupled from compute systems and in the world of virtualizations compute nodes, IO nodes and application processing can all be virtualized. This virtualization provides some very exciting ways for applications to be consuming storage and networking resources. Figure 7.2, shows an example of application farm or cluster virtualized from the compute nodes that they will be using as well as the IO nodes that will be used during the functioning of the application. As is shown in the figure, the application(s) are not tied to one specific compute entity or a one specific storage block. Due to abstractions being introduced within the layers it is possible to decouple them and perform dynamic mappings based on the needs of the applications and the time the application is running. A policy engine is needed to facilitate policies that can be injected into the system. Some policy implementation is dynamic and some are static. Static policy engine need the system to be bootstrapped with the policies already fed into it. The ones that support dynamic injection of policies add more dynamism within the entire storage-networking framework.

Implementations of policies act as key driver into the software defined networking systems. Although, policy based networking existed for a much longer time than Software Defined Networking, what allows the policy engine implementation to be adding more value is for the system behavior change that can be implemented with and SDN is far more granular and more impactful for applications to leverage the environment. The customizability from the run-time point of view is far more superior with SDNs. Application level queues as well as system level queues are introduces at the end-points where policies are implemented. While network devices have implemented queue management algorithms based on network traffic, i.e. packet header inspection, for storage networking these are not that easily implementable per existing architectures. Some of the limitations may be due to changes in packet envelope data identifiers, which impact the forwarding on a link-by-link basis. Hence uniform policies can be devised and pushed into the storage networks. One of the key expectations of the queues would be to make sure rate limiting behavior is expected on the type of the queue. Rate limiting is hard in traditional storage networks due to the unpredictable relationship between processing of the request and the rate at which IO is consumed. Factors that effect these could be data locality, ratings of the actual physical block on which data resides, the type of virtualization layer that will be encountered within the IO stack, etc. Given all these, various types of controls need to be added at various IO processing layers as well as at different systems, some closer to the hardware and some much higher and distributed within the entire system. The distributed nature also adds additional network traffic for proper compliance of the system. With SDN mode of development the modularity and the abstractions are built per the specific infrastructure and as the storage network topology changes, it can be reconfigured and reprogrammed with extreme ease.

In Figure 7.2 we see that the applications use compute resources as deemed required from the compute pool and the storage pool provides its applicability per the need from the applications. The virtualization layer that exists between these layers is completely transparent to the application. As software developers design their application there is cognizance of realistic limits of resources availability but no practical programming models offer ways to limit the implementation based on the restrictions made available. Furthermore, the restrictions change depending on the state of the environment. Virtualization leads to multi-use and multiplexing of resources and hence workload prediction becomes really hard. Multi-tenancy within these environments makes it even harder to manage resources and user experiences. The application server instance becomes the front-end for the abstracted storage volumes and the compute processing nodes. Storage is usually virtualized i.e. a VMs are often unaware of the details of the interconnect fabric and the storage configuration. Virtual machines are presented with virtual hard disks that will simplify

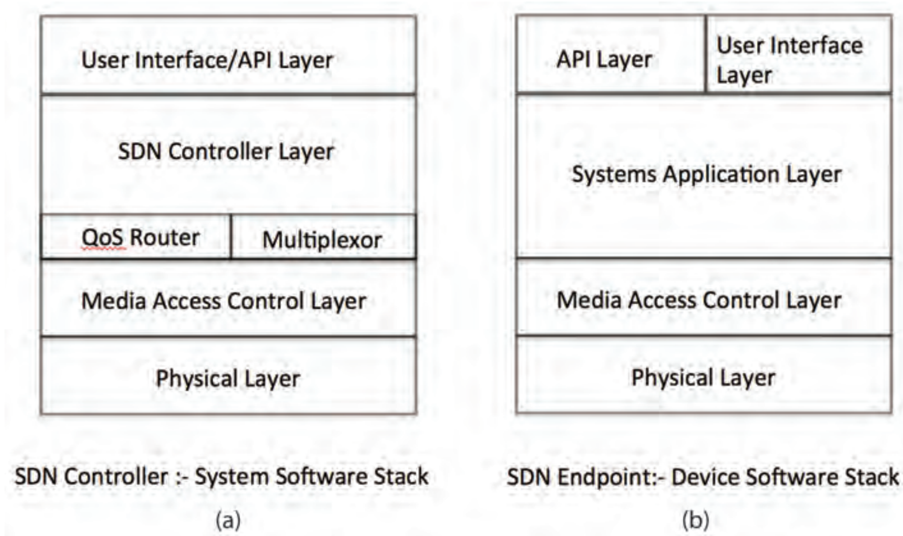

Figure 7.3: (a) SDN controller for a wireless networking environment, (b) SDN endpoint of a wireless networking environment.

large files on the storage servers. These types of storage virtualization will reduce the complexity of management like volume and block migration including the entire virtual machine migration.

Wireless networking [2, 15] has seen some research and investigations of software-defined environments to figure out the benefits for this domain. Wireless networking, in this discussion applies to all the ranges of RF protocols in the wireless domain that is in business play, like 2.4 GHz, 5.0 GHz. As other frequency bands get into the consumption range similar work may be applicable to them, albeit there may be some new protocol related optimizations that may be special to the new frequency bands that are difficult to generalize.

Figure 7.3(a) shows an SDN controller for a wireless controller. In this example we show a controller software stack with some of the major components and their layering. For this discussion we will ignore the physical layer and the media access control layer as well as their software/firmware modules including the encoding/decoding methods. The SDN controller is the main software block, which coordinates with the end-points in its range. The controller has a important task of coordinating with the end-points, reading their current status, making sure any network policies are passed on to the end-points and they are implementable. Like an air-traffic controller it handles reroutes, end-to-end discoveries and destination knowledge.

Figure 7.3(b) shows the SND endpoint devices software stack. As in the case of Figure 7.3(a), this is also one specific design listing the major software modules or components. There can be many more low-level details that may or may not be listed here and other designs may have emphasis which is either not listed here or not relevant for our discussion.

The system applications layer is the main target module that houses the details of the endpoint system logic. One of the key functionality the endpoint performs is packet forwarding. The process of forwarding includes making changes in the metadata of the packet. Most of the endpoints do not function as a bridge and hence no bridging logic is added into it. The controller plays and important to make a decision as to which endpoint should get the packet.

The wireless networking infrastructure when deployed has the goals of making sure packets over the RF channels moves from the sender to the network backhaul or to the same RF channel to reach the destination. While doing this, it also has to make sure that the local information from the endpoints are collected and forwarded to the central controller, which can either use the data or forward it to the aggregated uplinks. This is also called topology discovery process. In the wireless networking world where the endpoints are not tethered to specific locations or switches we do expect them to move and the moves can be as complex as going from one controller administrative zone to another one or zone hopping. The process of communication between the endpoint and a controller requires each endpoint to know which exactly is its primary controller. Since the endpoints typically work with one and only one controller the primary controller is the only controller. Beacon packets are generated by the endpoints that are broadcasted. The beacon packets have values like the receive signal strength indicator, battery power, etc. Through the beacon packet broadcast all the other nodes deduce the hops to reach each other. The endpoints store the information about its neighbors in a local table that it shares with the controller from time to time. The central controller deduces the network topology at any point in time with the help of the information it collected form the local tables received from the endpoints.

With a programmable interface that allows systems software to be embedded within the network controllers, which in turn feeds them into the endpoints we can form a real-time and dynamically reacting wireless environment. The behavior shown via these systems can change its functionalities and the total system behavior at any point in time, which is not possible in the current systems. New ranges of protocol and implementation design are being researched as well as accepted within the wireless networking domain to create reactive systems with low latency impersonations being injected into the environment.

7.4 Technology Impact

The SDN framework, which is appearing in terms of software system that is domain independent as a base yet has many different vertical segment impacts are creeping in from research world into the consumer/business world. It has started making waves in environments where things were expected to be rigid and fixed in nature. It has brought into light the gains that can be shown and the richness that can be housed within systems that are not point and packaged products anymore but play-beds for real-time changes based on environment where it is exercised. These environments are rich and real. They are live and yet changeable. The amount of research in technology in various areas of computing has given rise to tremendous amount of cross-domain innovation.

Businesses deal with the innovation in terms of new products that are created and evolved into the market place. Research leads the way and business follows one research stabilizes and has end systems that can be build and deployed in the real world.

7.5 Conclusion

Software-Defined Network and Software defined frameworks to be more generic lead to things that can be created from within the existing systems. SDN does not proclaim change in the functionality. It only lays new ideas and new ways for make systems more agile and reactive to the environments that need them. These changes are valuable in end up creating new market segments. It allows existing markets to grow and help us provide better modes of learning new things and implementing new things can result in better and smarter utilization. The non-existence of these modes of operations was due to the fact that the level of maturity in protocols, hardware architecture, communicating interfaces were not taken into account at atomic levels. The transformations of the same components were due to the fact that the system was decomposable and the decompositions helped it to evolve into actionable elements that can be externally interfaced.

SDNs have already seen quite a bit of growth over the last few years. With the maturity in some areas and with the understanding of SDN in multiple domains the rate at it could grow is far more effective. It has demonstrated some of its values in domains that were well mature already. It has opened doors for innovation and refueled the market with new ideas that has started the process of rejuvenation of the technology. We see this effecting academia as well as the industry.

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CHAPTER 8

Communications from Inanimate Objects: Internet of Things

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Proliferation of networks with the connectivity that is managed in a distributed nature via the Internet has been growing in the last decade. This growth initially started with computers and large scale computing devices being the end-points for communication but now has reached out to devices that perform tasks in the electro-mechanical areas and more. The aspect of computing is attached to these existing and modified peripherals such that the interconnection of network and the reach is extended. While the "Internet of Things" has not been formally defined or a formal definition that is accepted by any standard means, it can be loosely understood as a network of things (i.e. inanimate objects) that communicates or shows and transfers its activities to the global Internet. Two main outcomes that positively impacts any vertical segment that gets applied to this principles are 1) Extended reach 2) Better real-time knowledge. One of the outcomes of these two actions would be more visible control over the components and the devices distributed geographically. The "Internet"-ing of these devices called the "things" helps increase our quest of knowledge with data coming from various systems and devices that impact people's lives.

Keywords*:* Software, networking platform, network policies, networking systems.

8.1 Introduction

Internet of things has become a common phrase in networking community and this vernacular is spreading within the world of business. The spread within the wide business community has given rise to intense amount of research to help identify what more can utilize this amorphous system and how they can benefit from the utility. Given the fact that Internet of Things (IoT) is a gradually growing segment with more applications being derived in areas that could normally not participate in the networking world provides a fertile ground for researchers to address more creativity in this arena.

"Internet-working" of computing systems was invented about 40 years ago. For computing devices to talk to each other communication protocols were invented such that sender and receiver can identify themselves and speak a language that can be interpreted between the parties communicating without having share any dictionaries. As more development happened we started having more and more richness added to the communication layer. This ended creating more applications and services that can be built for communicating parties to leverage across the board, globally. The bounds of networking were limited to physical connectivity and the medium through which communications could be channelized. The expansion [4] of the medium and the establishments of various type [3] of medium has led to massive potentials for varied adoption.

8.2 Definition

Due to lack of an accepted standard definition of Internet of Things we would take an attempt in the chapter to define what is Internet of Things (IoT). IoT are smaller entities that can be deployed anywhere with the goals of extending the reach of information source. Traditional computing devices cannot reach these areas or cannot be installed in these zones. Some of the reasons why the existing networking devices cannot be used for them are form-factor, power consumption, electro-magnetic characteristics, existing input and output interfaces, etc. Some of them are presented with physical limitations and some operational limitations. IoT challenges these assumptions and breaks the barriers to reach into zones of information gathering by innovations in all of the areas mentioned above. IoT forms a connected internet-work facilitating information flow and information gathering devices so more intelligence can be build for all types of components and operating environments ranging from health, transportation, system tracking, Oil-n-Gas, pipelines systems, long-haul carrier network, connected home appliances, energy monitoring and energy conservation, etc. The reason we see that "Things" has been emphasized in the "Internet of Things" is due to the fact that it focuses on getting inanimate objects lite up so that they send and receive data of value. They participate in building a semantic network of domain specific information flow that would help in bettering service offerings, being smart about the environment, learning more about to optimize and finding out more information.

8.3 Growth Factors

We start researching the key drivers that impact the positive demand from research and usage point of view for solution involving Internet of Things. Some of the important characteristics that are shown in some of the upcoming IoT devices are as follows. They are smaller in form-factor. The components smaller and they keep inventing even smaller components and complete devices, which helps the usage of these IoT components in smaller areas and places where it is impractical to have larger footprint hardware. With the miniaturization of the hardware and lesser software needs devices, which can fit inside a wristwatch, smaller controller chips inside Credit Cards, frames of eyewear, in key chains, little OBD2 dongles inside a car, active artificial heart valves used to regulate heart beats, etc. Along with miniaturization cost reduction has been another big add-on to the strong drive to create deeper penetration of IoT.

Technology Component	2010 Cost*	2015 Cost**
Radio, Wi-Fi	1.50	0.80
Radio, Bluetooth	1.00	0.50
Processor (basic 8-bit microcontroller chip with embedded flash memory)	1.00	0.85
Sensor (temperature)	1.00	0.75
Sensor (vibration/accelerometer)	1.50	1.00
Camera (1.8 megapixel CMOS image sensor)	1.80	1.20
Microphone	1.20	1.00
GPS	1.25	0.70
Energy Source (inductive loop wireless power, incremental cost per unit)	2.50	2.00

*Lowest costs for simplest realistic implementation; **2015 cost assumes the same functionality as the corresponding 2010 figure
CMOS = complementary metal-oxide semiconductor

Source: Gartner (November 2011)

Figure 8.1: Cost reductions of the technology components used in smaller devices and Internet of Things devices [7].

In Figure 8.1 shows the cost reduction from 2010 to the year 2015. The figure shows the predictions by Gartner [7] based on what has been seen in the last few years. The cost reductions are anywhere from 30% to 50% from the prices in 2010. The indicators of current pricing show that we have already achieved the cost structures in many of the areas. The impact of the cost reduction is a big encouragement and motivation for newer solutions to be invented in markets where low cost solutions are more practical.

The second very impactful drivers for IoT are the increase in the network bandwidth. Figure 2, shows the increase in the download link speed from the year 2004 till 2013. With more networking devices increasing the load of data flow within the internet-work adds more stress within the network backbone. The growth in the network bandwidth, both uplink and downlink will help in a significant way in reducing the network stress. It will reduce network congestions, which will reduce the need for network retransmission, network content buffering.

Third factor of importance for IoT is the reduction of network latency. Figure 3 documents the network latencies with the network coding systems introduced. We see that as we moved from GPRS systems to LTE the latencies in milliseconds within the network from 670ms to almost 20ms. Reduced network latencies gives rise to the options of creation smaller data packets that can be send between the sender and the receiver within the network. IoT's generally are used in applications where smaller chunks of data are transacted between multiple parties. Although these are smaller chunks of data the frequency at which these exchanges happen are quite high. Smaller network data chunks do create quite a bit of sparse traffic within the network.

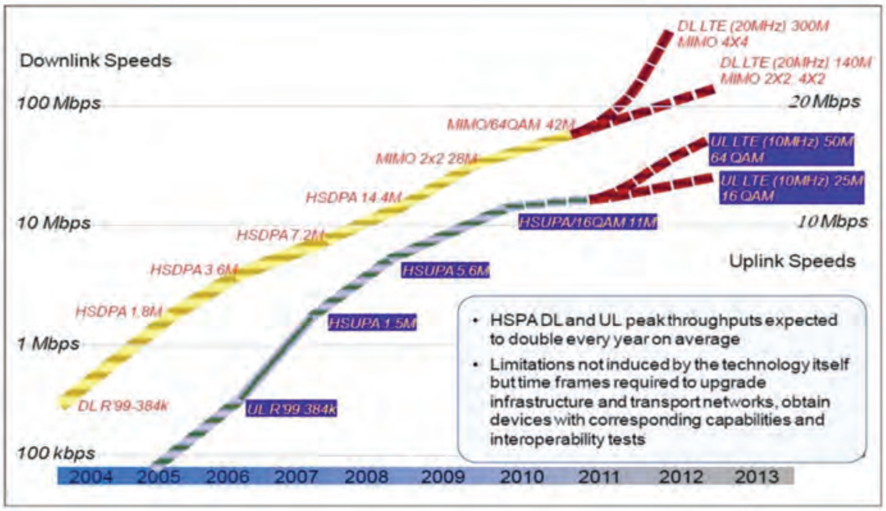

Figure 8.2: Download link speed increase [7].

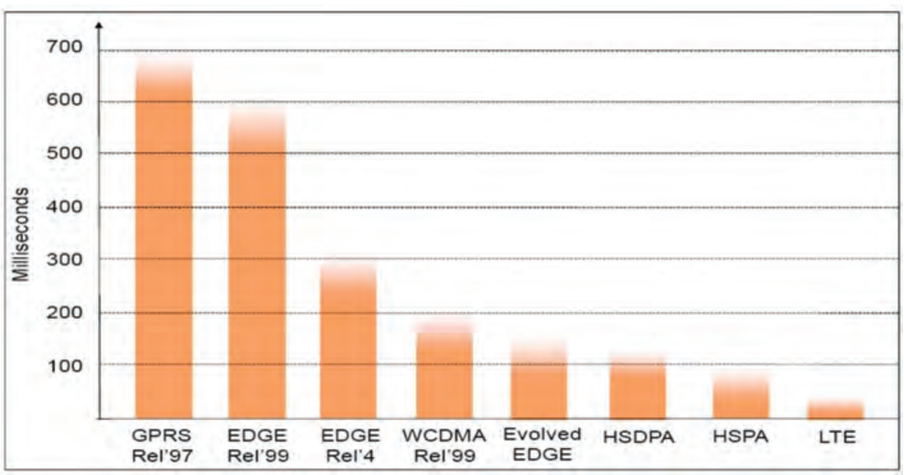

Figure 8.3: Download link speed increase [7].

There are various other drivers for the growth of IoT and many of them stem out of the elements that hold the infrastructural support.

8.4 Business Innovation & Impact

The business model design has become the central topic of business innovation since the rise of internet-based e-businesses. The primary challenge is the difference in interpretation between business research and engineering research. There are many different business modeling methodologies based on different classification criteria, such as the degree of innovation, degree of integration, profit making activity, relative position on the price-value continuum, degree of economic control, degree of value integration, strategy of objectives, source of value, critical success factors, core competencies, and resources /sales /profit /capital models, etc. Stakeholder Analysis is another approach for business innovation, in which the stakeholders' influences, interests, and a scoring matrix quantizes satisfactions. In a value chain of IoT service, a large number of stakeholders are involved ranging from individual consumers, to enterprises and public authorities. From different stakeholder's viewpoint, the main concerns and expectation are usually different. The information offered by an IoT system is the main carrier of business values. So, effective and efficient information integration is the foundation for the success of an IoT solution.

8.5 Componentized Architecture

The main components, which build out an IoT architecture, are as follows:

1. A Hardware element – This is the sensory part of the architecture made up of embedded computing, actuators, sensors with different types of abilities like sensing temperature, heat, light, motion detection, change in current, change in pressure, etc.
2. The data aggregator – This is the on-demand information repository which has capabilities and flexibilities of storing any type of data models at a very large scale. As mentioned earlier the scale applies to volume or repetition of the same type of data yet massive amounts of it. So scale storage, fast retrievals, faster searches and accesses to the variations, etc. are important at this level.
3. Information Presentation – This applies to the way information from the data is presented to the vertical segment that the IoT is targeting. Every element that is already connected and those that are going to be connected must be identified by their unique identification, location and functionalities. The current IPv4 may support to an extent where a group of cohabiting sensor devices can be identified geographically, but not individually. The Internet Mobility attributes in the IPV6 may alleviate some of the device identification problems; however, the heterogeneous nature of wireless nodes, variable data types, concurrent operations and confluence of data from devices exacerbates the problem further. Data centers that run on harvested energy and are centralized will ensure energy efficiency as well as reliability. The data have to be stored and used intelligently for smart monitoring and actuation. It is important to develop artificial intelligence algorithms, which could be centralized or distributed based on the need. Novel fusion algorithms need to be developed to make sense of the data collected. State-of-the-art non-linear, temporal machine learning methods based on evolutionary algorithms, genetic algorithms, neural net- works, and other artificial intelligence techniques are necessary to achieve automated decision-making. These systems show characteristics such

as interoperability, integration and adaptive communications. They also have a modular architecture both in terms of hardware system design as well as software development and are usually very well suited for IoT applications. More importantly, a centralized infrastructure to support storage and analytics is required.

The component-architecture suits the IoT systems very well due to the model in which the system builds out needs to scale. Scaling is not a re-engineering problem. It depends of systems that can be added with relative ease to extend the vector on which it operates. Scale could be applied to processing power, which albeit could small in quantum but huge in volume. It could mean scaling the information gathering layer, which although receives very small chunks of data per transaction but expects several millions of them per second. It could also mean that it deals with smaller number of data types being aggregated, filters per application and displayed but the sheer volume can cripple the local area network as well as the wide area network through which it traverses. User presentation or information display is a massive scale problem as it does not only take the challenge to summarize from a very large set, but it also summarizes on a set that is constantly changing or being added too. The motivations and technology demands on an IoT network applies creates challenge in repetitiveness and constant change.

While these challenges are being architected and many types of domain-focused applications of IoT are evolving, we do see innovations in the areas of new protocols. Some of them do cross the boundary of IoT and more into transportation of data, medium of traversal and optimizations linked to them.

8.6 Conclusion

IoT is evolutionary research problem. It takes into account several market drivers to build out technology to be researched in areas that were proposed impractical or non-existent. These were considered non-existent due to the fact that level of maturing in protocols, hardware architecture, communicating interfaces, and application build outs were not deriving the value-chain. Every technology vision arises from the need for consumption at some level, whether the consumption is for pure research point of view, which could be transformational or transitory. Transformational research falls into the segment of new category being created within an existing market place. IoT drives in the transformational segment. It makes possible systems and solutions that is research oriented from its value-added applications but also brings to light aspects of research that could not have been possible if the market did not reach a level of demanding more. Today we sit among a vast number of IoT applications and participate in the ecosystem, unknowingly.

Growth in this arena is going to see a massive upheaval for researchers and well as businesses. The cardinality at which this segment is going to operate is going to be quite high and that would lead to transformational changes in our lives linked to our health, food, transportation, energy consumption, resource usage alterations, public utilities, etc. We are not only learning but also participating in this today. IoT helps are learn more, be smarter about things that we do daily, things that impact us at various levels and helps us.

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CHAPTER 9

Some Considerations Regarding the Phenomenological Relationship Between Music And Mathematics

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This chapter explores the phenomenological relationship between music and mathematics. The chapter starts by giving some examples that may clearly validate the contribution of math's intuitive dimension to some of the most important historical discoveries of this discipline. We will try to show how these intuitive visions present an order that we might associate with the idea of beauty: we are talking about an aesthetic way of thinking. Afterwards we will suggest that this reasoning-commonly attached to music and mathematics- is not a mere abstract construct, but it has practical consequences: beauty contributes to truth and truth contributes to beauty. Finally, we will argue that what essentially unites both disciplines is the process of creative research and the constructions of metaphors, a process that permits the translation of symbolic codes.

Keywords*:* music, mathematics, intuitive reasoning, phemomenology, truth, beauty, metaphors.

9.1 Introduction

One would not consider the argument regarding the formal relationship between music and mathematics to be extremely complicated nor excessively original. Since Pythagoras we have evidence of the analytical relationship between both fields of knowledge. Physical science has mathematically coded the sonic experience. There are studies that try to explain a few musical compositions through mathematical operations. It is to some extent evident that these two fields are somehow related and that they organize their elements in a hierarchy: the numerical series, for example, are organized in a similar way to sound series..

Nevertheless, the descriptive or analytical procedures cannot completely explain the true essence of the musical experience. In this point you can start to think that mathematical enterprises are now totally the opposite to that of mathematics, and that there's nothing more distinctive than music (an unexplicable experience) and mathematics (a deductive building). Is this true? We know that music can be formalized – can math be experienced in an intuitive way? And if this is so, which ideas can be useful in order to trace the connections between these two disciplines?

In the pages that follow I would like to develop some conjectures as means of trying to give an answer to these questions. I will start by giving some examples that may clearly validate the contribution of math's intuitive dimension to some of the most important historical discoveries of this discipline. I will try to show how these intuitive visions present an order that we might associate with the idea of beauty: we are talking about an aesthetic way of thinking. Afterwards I will suggest that this reasoning- commonly attached to music and mathematics- is not a mere abstract construct, but it has practical consequences: beauty contributes to the truth and truth contributes to beauty. Finally, I will argue that what essentially unites both disciplines is the process of creative research and the constructions of metaphors, a process that permits the translation of symbolic codes.

1. Let's start with a historical example. Henri Poincaré, the French mathematical celebrity, described in a conference about mathematical creations the existence of certain functions referred to as "fuchsians".

"I left Caen, where I lived, for a geological expedition sponsored by the Mines School. The episodes during the travel made me forget my mathematical work. When we passed Coutances, we went deep into some unknown fields until we finally made a stop. In the exact moment that I put my feet on the ground, with no apparent connection to what I was thinking during my trip, the thought that the mathematical transformations that I have used to define the fuchsians functions were identical to that of non euclidean geometry. I didn't verify the idea (nor had the time to, I started an ordinary conversation with a fellow traveler), but I had the perfect certainty about its validation. As soon as I got back to Caen, I verified the results during my free time".

This story of "illumination" or revelation is more interesting because it's not atypical. Carl Friedrich Gauss tells a similar story of how he found the demonstration of a theorem which proof he has been looking for years:

"Finally, after two days, I found it, and it wasn't because of my daring efforts, it was merely God's grace. As if a sudden light shook me, and suddenly the problem was solved. I am not capable of understanding which was the thread that organized my previous thoughts and made my success possible."

Jacques Hadamard, in an influential book titled An Essay on The Psychology of Invention in the Mathematical Field, compares the ability of some mathematicians to instantaneously seek the solution to a problem with a Mozart's letter where he describes how he is capable of seeing his symphonies completed in his head before translating them to paper. The act of "seeing" is not literal, nor pictoric. It is an aptitude of comprehending in its totality.

Poincaré explained that the capacity of "seeing" implicated a series of rules that are "extremely delicate and subtle. It is nearly impossible to define them; you can only feel them, you can't formulate them". Poincaré considered the capacity of mathematical creation as a certain "emotional sensibility".

"It may result surprising to observe how the emotional sensibility is invoked in mathematical demonstrations, but it is only appealing to the intellect. But to think of it that way would imply to neglect the sense of beauty in mathematics, the sense of harmony within the forms and the numbers, the sence of geometrical elegance. We are talking about a true authentic aesthetic sentiment that belongs to the realm of emotional sensibility."

2. We may add that this "vision" that provides completion and certainty has something to do with our ideas of beauty. And while in music the idea of beauty occupies a prominent place; perhaps we should learn a bit more about its place in mathematics. Let's suggest, for a start, that a mathematical test, if it's successful, has some kind of "rhythm". This rhythm is evident in the ways that the ideas are presented, in the types of punctuation that are being used, in the imitations of generic models. We can say that there are moments of drama, of suspense and surprise, that there are different styles of compositions in mathematical tests. Let's see what Ludwig Boltzmann has to say about his great colleague J.C. Maxwell:

"The same way a musician is able to recognize within a few seconds the music of Mozart, Beethoven or Schubert, a mathematician is able to recognize Cauchy, Gauss, Jacobi, Helmholtz, or Kirchhoff by just reading the first few pages. French writers exhibit great formal elegance, whereas the English writers, especially Maxwell, exhibit their great dramatic sense. Who doesn't recognize Maxwell's descriptions of the dynamic theory of gases?

The variations within velocity majestically appear; then later, it makes way for the state equations and then on another side, the equations of a central field movement. That's how chaos is born. Suddenly, we listen to some distant drums, four hits: "add n=5". The diabolical spirit V (the relative velocity of both molecules) disappears; and like in music, a dominant figure in the bass is silenced, and what seemed unsurmountable is surmounted, like a work of magic... It is not time to question ourselves about this or that substitution. If you have not been swept by the development of the events, leave the paper aside. Maxwell doesn't write programmed music with explicative notes. A result is followed by another one very rapidly until finally, as an unexpected climax, we reach to the conditions of the thermical equilibrium combined with the expressions of the transpositions of coefficients. Suddenly the curtain falls in."

One does not have to understand the details of Maxwell's argument to appreacite the spirit of the explanation, it appears as if a romantic spirit were behind the descriptions of those equations, and it may not be chance the imagery of Romantic music that Boltzmann used to describe it with. In effect, it is possible to perceive the rhythm even in the evolution of the simplest mathematical operations, once we are familiar with them. This style is a dimension of the emotional sensibitlity of mathematics and beauty, one of their goals. Bertrand Russell who, together with A.N. Whitehead, dedicated his energies to the systematization of the arythmetics through the usage of symbols of mathematical logic, stated that: "Mathematics, correctly conceived, possess not only truth value, but also supreme beauty –a cold and austere beauty, like that of a sculptur...The authentic spirit of pleasure, of exaltation, the power of being more human, which is the primary characteristic of supreme excellence, can be found in mathematics as much as in music."

What has been said about the literary style of some of the greatest mathematicians in history can also be said about the particular tutoring style in which great masters transmit the teachings of the great creators. If we are talking about "style", this is clearly revealed in their pedagogic ways, that is to say, in the speech presentation of these arguments and in the – expected – elegant way of showing their solutions. Here – and thousands of students know this – the teachings in mathematics can fail rapidly due to "aesthetic" reasons: lack of performance. It is not exaggerated to say that the rhythm of a presentation about mathematical topics affects their comprehension completely. And it is not rare to compare the experience and expectations of a class audience in Calculus class with that of, for example, a visit to a museum. In both cases we are facing objects of knowledge (the work of art, the mathematical demonstration) whose comprehension goes beyond the mere description or anaylisis: the mistery, the beauty, the rhythm, the vision are resulting primary components that will help us understand in an intimate and lasting way what we have before our hands.

Let's think of any logic game. The intrinsic sense of a game does not rest too much on the description of their rules (the ones that are internalized) but in the comprehension of the proportions, the recognition of behavioral patterns and the typical results associated to those models. The "texture" of a logic game is a net of cognitive expectations through which we build a "vision", seeming and effective, of its development.

The beauty of the game consists in the simplicity of the reasonings that we are capable of developing, and in our capacity to avoid embroiling ourselves in detail calculations. This is a typical way of thinking in mathematics. The emotional sensibility and the beauty embroiled in the great sense of freedom and elegance given to us by the fact of guessing a method of rapid solution while facing the enormity of the task that comes rushing over us. As Lord Rayleigh said in the 19th Century: "Some demonstrations provoke assent. Others appeal to the intellect; they evoke pleasure and inspire an unstoppable desire of saying "Amen, Amen".

3. I would add that this aesthetic line of thinking has strong repercussions in the way of knowing. The elegance and beauty as creating behaviors imply a clarification of something essencial in the object of knowledge, and this also implies a change in our conception of the object. This point is rather important; it means that we are not only talking about the intuitive comprehension of the mathematical beauty, but also its observation in real life. In other words, we speak of the beauty of what is true, and we can speak this way because we assume that that specific beauty is revealing something generic, attributed to a type of objects, not only to a specific or one in particular. The most eloquent example of this mathematical debate between reality and creation, between intervention and interpretation, is the *pi number*.

Pi expresses the reason between a circumference and its diameter: a constant reason independently from the size of the circumference and the length of its diameter. Besides, we're speaking about a number that *can never be calculated with absolute exactitude*. *Pi* is more than an irrational number: it's a transcendental number. This inaccuracy in which we are permitted to approximate to Pi's calculus has not prevented the creation of mathematical formulas of this elegant number throughout history. Leibniz found a relationship between pi and a numerical series; and Euler was able to express it in relation to the imaginary number *e*. There is an establishing harmony in both cases by which all of the elements are connected with each other; this is the origin of mathematical beauty.

Stated differently, the mathematical argument is beautifully constructed when you can say it has a purpose, a design, clearly different from the processes of reasoning that originated it. This way, and only this way, we have the intimate impression that the nature of things is constructed for our own contemplation and enjoyment. The discovery's objective and the scientific creativity, particularly that of mathematics, is an aesthetic objective: to express the harmonies existing in nature which, as Barrow said, are far from being evident and directly observables. In this sense we can confirm that to the extent that science lacks artistic sense is an incomplete science. Or, with Kant, we can say that science develops by analogy with art.

We have proposed the idea that truth contributes to beauty – the idea that what's true is beautiful since it reveals non-evident connections among real elements. There are those who have suggested an inverse relationship – the idea that beauty contributes to the truth of things and that it takes precedence over them. Thereby, Paul Dirac stated with clarity: "It's more important to find beauty in the equations themselves than to be able to explain an experiment. The experiments, after all, may be wrong". There's not a doubt that this statement may result controversial, especially because it indicates a subordination of ethics to aesthetics. We can also start to think with ease about examples of beautiful things – beautiful theories – that aren't true: without going any further, the Ptolemaic model of the universe.

Even though it looks extremely difficult to be established, as shown in the comments made above, there is an essential connection between art, nature and mathematical thinking – we are referring to the quality of expressing the general, which is shared by aesthetic judgement and mathematical reasoning. Naturally, we are not stating that aesthetic judgement owns a universal character (we would have to prove this); but we are not proposing either to treat any notion of beauty as a statement related to taste, in the postmodern sense. We simply say that the judgement towards beauty can be treated as if it were universal and sensed as objective.

Unlike social constructionists, for whom there is no essence outside of speech, nor speech not socially constructed, we think that aesthetic attitudes of thinking as the ones given in mathematics exhibit the virtue of risking an attempt to define relations and essential structures that are objectively existing. The feeling of beauty in mathematicas has to do with the revelation of the universal, the discovery of the similar, the construction of order, the establishment of reasoning and proportions, the articulation of a whole and its parts, and the parts inside of a whole. The idea of beauty in music obeys similar patterns.

4. It is possible to dig deeper in this phenomenological connection that we are trying to trace. Firstly, the idea of proportion (the establishing of relations between different eareas) is closely linked to the idea of analogy – this is not but a special case of that analogy that implies a consonance between the parts and the whole. This idea of analogy (or geometric proportion) as aesthetic construction is the solid base of harmony, common to the ways of thinking and operating in art and science. Secondly, the ideas of analogy and metaphors are intimately linked, for a metaphor is an unexpected and condensed analogy. Aristotles granted great importance to the metaphor:

"The greatest thing of all is to be a master of the metaphor. It's the only thing that one can learn from others; and it is a sign of genius and originality, because a good metaphor implies intuitive perception of similarities in dissimilar things."

The search of metaphors is what links music and mathematics. The constant search that both activities consist of, give a wide possibility of feeling an aesthetic joy, of experimenting beauty, simply because we use our imagination. In mathematics we treat nature as an analogy of art; in music we treat art as an analogy of nature. But what's common in both areas is that we can symbolically translate between two different worlds of knowledge. In the words of Kant, "the imagination is a powerful entity of creation of a second nature species from material provided by real nature."

But this process of symbolic translation, of metaphorical creation, it's produced by specific ways that are very differently in each case. Human beings experience the sonic material – and not mathematics – as a temporal experience. It's precisely this "being in time" – as Heidegger would say – which gives music a sensual presence that is lacking in mathematics. There may be beauty in sound itself even though it's not accompanied by a musical order because the beauty of sound is the same as that of a form – it has an internal harmony, it provokes presence and evokes absence; implies and complies. From a technical point of view, every sound is composed of harmonics that are mobilized and they accompany the original sound in its manifestation; even more, every sound can be organized as components of one or various close tonalities. From an orchestral point of view, every orchestra has or acquires a sound of its own as a musical (not strictly technical) project. From a socio-historical perspective, every sound involves a choice: the deployment of individual and collective identities, of the historical memory, future projects, or their absence.

Therefore, the sense of beauty in music, its sensual presence, is but the metaphorical construction (on the part of listener, composer, and interpreter) of networks of sonic relationships evoked by the sound currently being produced. A composition is a construction of models and proportions, of a determined musical form that will keep established conventions but will try to transcend hem meaningfully. The ear, like the mind that tries to understand mathematical arguments, operates in asimilar way, through means of relative constructions from the sounds you hear in reality. The ear does not exactly follow the sound flow in time: it anticipates and it lingers; progresses and returns; it sways. It establishes specific and original connections as much as in the structure of individual feeling of every listener as with the external contexts in which the individual experience develops. Occasionally, the connections can be so dense and vivid that the auditory attention gets lost and the process of symbolic translation acquires a life of its own – that is when the transformation of art in nature (of which we spoke earlier) occurs.

These phenomenological processes are virtually impossible to codify. And so the score is merely a two-dimensional and static representation unable to reflect every aspect of creation that we are sketching – the space of creation of the listener, and the listener that composes and the one that interprets. That's how we construct metaphor in music. That's how we can enjoy a musical piece, anticipating the memory of fragments and previous ideas to fragments and further ideas in which we can recognize what's similar and what's not.

The sound material is a pretext – although a very important one – in which we recognize the proportions of the foundation of the structure of a composition. The ear listens to those proportions in a similar way as the geometric shapes show structures of repeated reasoning. The proportions offer the composition a particular topology – the sense of internal space, its organization, its density, the distance between objects in that space, its continuity and the fragmentation in regions. Definitively, proportions establish a metaphorical meaning.

Inversely, even the most seemingly remote examples of this process of building proportions can be categorized by using a metaphor. If not with a metaphor of beauty, it could be with the metaphor of the sublime, as it occurs when we contrast the examples of compositions of the classic period to the ones of the romantic period. While the classic beauty seems to calm the conflicts of the rational mind – it also reveals, illuminates, affirms and charms – the experience of the romantic beauty seems to have more to do with the opposite. The classic beauty appears with such form that the object that we admire adapts perfectly to our aesthetic judgement and what it produces is mutual affirmation between the observer and the contemplated object. Classic beauty may seem to have a place out there, and a public meaning. Romantic beauty, on the other hand, doesn't seem to construct an objective world any further than the personal or individual interest. On the contrary, the romantic perception of beauty invites to a private meditation. Its proportions do not offer great satisfaction for themselves. The romantic music provokes uneasiness, and sometimes it bothers. The reason is that it doesn't invite objective coherence but only individual exploration and by doing so, it submerges us, it defies us, it confuses us. This is what the experience of the sublime consists of, an experience which is primarily subjective, non-existing in the exterior world with independence of the observer and the listener.

The construction of metaphors is key if we want to understand multiple connections, often hidden and historically silenced, in different fields of knowledge, like the ones we are discussing here. It is not a matter of strategic or heuristic procedure, we are not talking about "discoveries" nor "verifications" as the philosophers of science often do. Even though the metaphoric formulation has been defended in this field (as in the work of Mary Hesse), what is essential for us is that a formal procedure (building proportions) is naturally transformed into a phenomenological one (the experience of such proportions in two very different fields of knowledge) leading us to cognitive and emotional comprehension.

It's an eror to think of mathematics as the logical-deductive enterprise par excellence – a mistake so illogical as is to think of the etymology of the word "music" and believe that the activity to which the word refers to can only occur with the help of the muses. Both disciplines – music and mathematics – are closely linked, not by a formal perspective, but also – and this is what we wanted to show you in this chapter – from a phenomenological standpoint.

9.2 Conclusion

We have briefly explored the phenomenological relationship between music and mathematics. We have given some examples that may clearly validate the contribution of math's intuitive dimension to some of the most important historical discoveries of this discipline. We have been able to demonstrate how these intuitive visions present an order that we might associate with the idea of beauty, as we refer to an aesthetic way of thinking. We have also shown that this way of reasoning, commonly attached to music and mathematics, is not a mere abstract construct, but it has practical consequences, since beauty contributes to truth and truth contributes to beauty. Finally, we have argued that what essentially unites both disciplines is the process of creative research and the constructions of metaphors, a process that permits the translation of symbolic codes. We believe this is one of the keys of the transdisciplinary process of learning and cognition, that is, how to build symbolic codes through metaphors that are common to diverse disciplinary contexts. In the case of the cognitive and phenomenological overlaps between music and mathematics, transdisciplinarity rises as the binding material allowing a common understanding of both knowledge areas.

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CHAPTER 10

Protecting Human Capital through the Intersection of Architecture, Engineering and Worker Safety

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Prevention through Design (PtD) is intended to protect workers by eliminating hazards at work. Capital Project Planning is a process that businesses follow to improve facilities. Human capital is protected when safety management is given co-equal consideration with architecture and engineering throughout the capital planning process.

Keywords*:* Workers safety, Prevention through Design, occupational safety and health .

10.1 Introduction

The mission of the Prevention through Design (PtD) initiative is to protect workers at all stages of their career by designing out hazards and thereby reducing risks of injury, illness, and death. The Capital Project process presents a unique opportunity to fulfill this mission. The PtD initiative arose from discussions among industry, academic and government leaders about preventable deaths in the construction sector attributed to carelessness. The futility of blaming the victim was readily apparent. What could designers through the design process do to eliminate the root cause of these fatalities?

Administration of the initiative fell to the National Institute for Occupational Safety and Health (NIOSH), a division of the Centers for Disease Control and Prevention (CDC), which is part of the Department of Health and Human Services (HHS) in the United States. At the end of the seventh year of the initiative, almost 700 collaborators have published more than 3000 peer-reviewed journal articles, books and related safety materials.

In 2010, I joined the PtD team at NIOSH tasked with the development of safety training modules for undergraduate engineers. Thus began an extensive review of the safety literature, including risk management strategies, government regulations, and management philosophy. Working with experienced NIOSH industrial hygienists, I focused on understanding how PtD could influence the Capital Project Process. I became the interim PtD Coordinator in 2013 and served until the end of my appointment.

10.2 Including Occupational Safety and Health (OSH) in Design

PtD addresses occupational safety and health (OSH) issues by eliminating hazards and minimizing risks throughout the life cycle of work premises, tools, equipment, machinery, substances, and work processes, including their construction, manufacture, use, maintenance, and ultimate disposal or re-use. PtD involves including OSH considerations at each step of the design, re-design, and retrofit processes, including on-going operations and maintenance and ultimately, re-purposing or recycling. The earlier PtD concepts are introduced into the capital project process, the greater the protection of human capital, workers, through hazard elimination.

What is Capital Project Planning? This is a nine stage process that business entities follow to spend money on improvements to the business. The ten steps are: Project Initiation, Conceptual Design, Detail Design, Final Design, Procurement, Construction, Start-up & Commissioning, Project Close-out, Operations & Maintenance, and Decommissioning. A brief description of each of the steps follows:

Project Initiation — The process begins with a concept to satisfy a need. The customer/owner forms a team and invites them to a kick-off meeting. In this meeting, the budget and timeline are established and the project scope is defined. For facilities, the team consists of the owner, a financial expert, an architect, a project manager, one or more engineers and a safety and health (S&H) professional. The team identifies overarching policies such as PtD. They evaluate alternate locations for the facility, including zoning and environmental restrictions. The owner may have specific material preferences (steel, titanium, concrete, wood, glass, etc.) and these should be discussed.

Conceptual Design — The existing applicable literature, problems and successes associated with existing solutions, costs, and marketplace needs are evaluated during a feasibility assessment. Legal requirements including permits and regulations are identified for each design option. The conceptual design phase is principally concerned with the generation, evaluation and presentation of ideas for the Project Design Specification (PDS). Concept generation involves the development of whole product or sub-system concepts. These are normally presented in the form of sketches, layout drawings, or diagrams. The design team considers a broad range of concepts. The goal of the conceptual design phase is to identify the very general type of solution that will be pursued. By the end of the phase, a single concept will be proposed for further development. This chosen solution will be feasible and in keeping with the PDS.

During conceptual design, hazards are identified and goals are set to reduce worker exposures to noise; radiation; hot/cold stress; and chemical, biological, and/or ergonomic hazards. Operations and emergency procedures, fire safety, electrical demand, water usage, machinery, chemicals and chemical processes, animals and biological processes, instrumentation, maintenance, and security must all be considered. Permits are filed. An industrial engineer may recommend a specific workflow to reduce risk of ergonomic injuries or improve plant productivity. Geographic location, geologic composition, access to infrastructure, and other factors may influence facility siting. Applicable standards are identified.

The team considers ways to eliminate hazards; substitute less hazardous agents/ processes; establish risk minimization targets for remaining hazards; assess risk; and develop risk control alternatives. For example, a goal may be to limit noise exposure below a specific level to avoid the cost of providing hearing protection for workers. The PM works with the team to narrow design choices. The architect may construct models of the various design alternatives. Preliminary drawings are issued. The public may be asked to comment. The PM may solicit bids or otherwise identify subcontractors for the design of the structure, the building envelope, HVAC systems, site access and parking during construction.

PtD Activities during Conceptual Design —During conceptual design, occupational hazards that may be associated with building the project, installing or operating project-related equipment, and operating and maintaining the products of the project are anticipated. Occupational safety and health (OSH) goals should be established and provided to the design team to address these hazards. Many organizations have an established S&H policy statement. Specific S&H goals ensure that hazard elimination and substitution are considered and that risks from remaining hazards will be assessed and minimized as part of the design process. Examples of project goals include: reduce reliance on personal protective equipment to non-routine tasks, control exposures to noise to <85 dBA, minimize of the risk of falls from heights, achievability, and minimization of financial burden. OSH personnel can then formulate plans to accomplish the prioritized objectives.

Detail Design — At this stage of the project, the preferred concept has been identified and work can begin on the details. Drawings, diagrams and computer models are updated with locations, dimensions, elevations and other specific information required to manufacture the product or to build the facility. Specifications are written for purchased equipment and materials. Prototypes may be tested and evaluated. Every member of the design team has an assigned role. The S&H professional conducts process hazard reviews and recommends design interventions to eliminate chemical, biological or ergonomic hazards. Specific engineering and administrative controls are selected to reduce residual risks encountered during operations and under emergency conditions. Team members develop project specifications, including design life, facility dimensions, maintenance provisions, operating parameters and reliability requirements. The architect generates a set of drawings and specifications for each subcontractor. The PM monitors costs and tracks progress. Structural engineers, civil engineers, mechanical engineers, chemical engineers, and electrical engineers may all be involved at this stage. Depending on project complexity, each engineering firm may have several employees developing specifications and construction drawings for the project. Experienced trade contractors and others may be asked to review the detailed design for constructability, but this is not common in the United States.

PtD activities during Detailed Design —During this stage, risks should be eliminated by changing the design or by and avoiding processes that create hazards such as fumes, dust, vapors, vibration and noise. A risk analysis is conducted on hazards that cannot be designed or substituted out of the system. A variety of risk assessment methodologies are available from the American Industrial Hygiene Association (ANSI/AIHA Z10-2012) and the American Society of Safety Engineers (ANSI/ASSE Z590.3 – 2011). They include both a hazard analysis and a failure mode and effects analyses (Manuele 2013).

Minimal risk targets for remaining hazards are established and risk control alternatives are developed. During the preliminary design stage, environmental release permits and other regulatory documents are developed. Additionally, planning begins for the quantitative risk assessment that will occur during the final design phase.(http://www.fhwa.dot.gov/everydaycounts/projects/toolkit/design.cfm)

Final Design — The owner reviews all design decisions to date. Internal quality assurance checks are performed. During a final engineering review, the S&H professional may be required to justify specific risk control interventions. The S&H professional develops "checks and tests" for factory acceptance testing and commissioning. Final design documents are let for bid. The PM monitors costs, schedules, and progress. The Architect develops a traffic control and site access plan.

PtD activities during Detailed Design —During the final design stage, control systems are selected for use in mitigating hazards that could not be designed out in previous design stages. Consideration needs to be given to the type of work that will occur at the facility and what will happen in the event of an emergency. Equipment such as eyewash and emergency showers must be integrated into the project designs. A final hazard review and risk assessment ensures that mitigation strategies are addressed (Manuele 2008). Tests to ensure that equipment and processes meets the design specifications are developed.

Identified hazards or risks that were not eliminated in previous design stages are addressed through appropriate control systems. A maintenance and repair review should be completed. This review should examine the architectural and structural design to determine the risks associated with the design and select techniques to mitigate these risks. (Workplace Safety and Health Council)

Procurement — Procurement often occurs and overlaps multiple stages. Procurement describes the merging of activities undertaken by the client to develop the project. Procurement activities should be developed in the early stages of a project. During procurement, all design decisions are reviewed and internal quality assurance checks are performed. Checks and tests for factory acceptance testing and commissioning are developed.

PtD Activities during Procurement —During the procurement process, equipment purchase orders are reviewed to ensure that the purchased equipment is compliant with the S&H specifications for the facility. PtD activities can include the choice to specify quieter construction equipment as specified in NASA's "Buy Quiet" initiative (ANSI/AIHA 2012). Every piece of equipment is tested to ensure that the equipment meets the S&H specifications. A construction safety plan is developed, approved, and continually reevaluated. Additional construction and environmental permits are obtained as needed.

The practice of prequalifying bidders protects project integrity, promotes overall efficiency in the conduct of work, and ensures a helpful and safe working environment (AIHA 2001). Prospective bidders are required to submit financial and OSH performance history. These are reviewed. Only qualified contractors are allowed to submit bids.

Construction — The owner retains financial control of the project and may approve or deny proposed changes to the design. Employers are responsible for construction crew safety. The construction superintendent is responsible for site safety, although a subcontractor may be hired to enforce the traffic control and site access plan. Various engineers inspect the work in progress and note "as-built" deviations from their drawings. The PM monitors costs, schedules equipment and crews, and tracks progress.

PtD Activities during Construction —The overall health and safety of persons on the site is the objective. All contractors should have an approved S&H plan. The standards established in the S&H plan should be followed (ANSI/AIHA 2012). The Construction Superintendent informs all contractors of site-specific risks and hazards. Specific work processes can influence erection times. Parts of the structure can be prefabricated on the ground and then lifted into to place to reduce the amount of time workers are working at heights (AIA 2007). As a last resort, the use of safety equipment such as Personal Protective Equipment, harnesses, guardrails and procedures such as securing ladders and inspecting scaffolding can curtail the risk of occupational injuries in the construction industry.

Start-up & Commissioning — Commissioning is a systematic process of quality control and assurance, and is required for all capital projects. It is a formal process which is used to verify and document that the systems are designed and constructed in accordance with design specifications. The main function of this stage is to confirm, through functional testing, that the interactive operation of processes and systems comply with the capital projects design criteria. Preceding operation start-up, the pre-start-up OSH review is completed. Unacceptable items are resolved.

Final project acceptance and documentation of all design details and equipment files occurs in this stage. A project critique is held, closeout report prepared, and learning shared within and beyond the project team. Feedback is solicited from project team members as to standards and requirements for which changes are needed

The owner conducts a walk-through to identify incomplete items or omissions. The engineer prepares a punch list of items to resolve before final payment is made. The S&H professional and others conduct tests on equipment and processes to demonstrate compliance with design intent and specifications. PtD Activities during Startup & Commissioning

During the startup and commissioning stage, preliminary industrial hygiene monitoring is conducted. A comparison of residual risks versus risk targets is made. A walkthrough and industrial monitoring occurs to ensure that hazard control measures have been installed and operating effectively. This includes pre-start up safety reviews and the development of standard operation procedures (SOPs). Acceptance testing of equipment is conducted along with any retrofits that are necessary. The S&H professional consults with project team members regarding standards and requirements when changes are needed.

Project Close-out — The owner takes possession of the facility/product. The architect may be hired to perform a post-occupancy inspection to confirm that the facility meets design intent. A set of as-built drawings may be created. The PM resolves any outstanding invoices and change orders. The S&H professional completes all OSH-related documentation, including the development of checklists for operations & maintenance.

Operations & Maintenance — The facility is open for business. The Facility Manager (FM) oversees all operations and conducts periodic inspections. Production and productivity goals are established. The FM manages both the operation of the facility and the staff required to run it. The Maintenance Crew attends to routine maintenance and makes repairs as needed. Extraordinary repairs may be contracted out. Environment, Health and Safety (EHS) staff conduct training for new and existing personnel. They prepare reports as required by permit, such as an emissions inventory. They document all accidents and incidents.

PtD Activities during Operations & Maintenance —From time to time, accidents happen. All incidents are examined in depth to establish root cause of the failures that affect the design or operation of the facility (ANSI/AIHA 2012, Manuele 2013,Manuele 2008). Training on safety equipment, processes, and policies should be conducted to enhance employee awareness and encourage safer behavior (Manuele 2008). The formation of a facility safety team is recommended. This team should consist of individuals at all levels of responsibility, including hourly employees and management, to encourage ownership of solutions. Approximately six months after close-out, a post-occupancy evaluation can be conducted to compare design intention with space utilization and to identify obvious opportunities to design out hazards.

Decommissioning — Decommissioning is the planned shut-down or retirement of a facility, system or process in a manner that does not endanger personnel or harm the environment. It entails planning waste, management security and protecting the worker and the public. It may also entail razing structures and dismantling building components and equipment. If buildings are left in place, decommissioning may involve converting them for alternate uses.

Planning is an important factor in decommissioning. Ideally, planning for decommissioning should begin during the design sages. During the design stage a cost/benefit evaluation should be used to determine the best strategy for decommissioning. This early planning will allow timely allocation of funding and infrastructure.

The purpose of decommissioning planning is to identify the resources that will be needed when they will be needed. The decommissioning plan should include at least a rough of cost estimate, a schedule of activities and a waste estimate by type and volume (Reisenweaver 2010).

The following information should be included in the decommissioning plan:

- Facility Information
- Administrative Details
- Detailed Cost Estimate
- Radiological Details
- Waste Management Plan

- Safety/Risk Assessment
- Environmental Assessment
- S&H Plan
- Quality Assurance
- Emergency Plan
- Physical Security & Safeguards

PtD Activities during Decommissioning —PtD activities during decommissioning are similar to those of the Construction phase. The decommissioning plan organizes the work to reduce the risk to the employees doing the work. Quieter construction equipment may be ordered, per NASA's "Buy Quiet" initiative (ANSI/AIHA 2012). It may be advantageous to disconnect and lower sections of the structure to the ground for disassembly to reduce the amount of time workers are working at heights (AIA 2007). As always, safety equipment, guardrails and standard operating safety procedures can reduce the risk of worker injuries. Health and safety on the site is essential to completing a project on time and under budget. All contractors should have a health and safety plan that covers routine and emergency situations. The standards established in the health and safety plan should be followed (ANSI/AIHA 2012).

10.3 Conclusion

Workers are human capital. The costs to train and protect skilled workers are minimal compared to the costs of replacing them. Accidents occur either when people are unaware of danger or when systems or equipment fail. The first step is to identify which hazards are present. Are they always present or are they the result of circumstances? Can the hazards be eliminated? Whenever an incident occurs, determine the root cause and document the solution. Keep a log. When the opportunity presents itself, perhaps through the acquisition of a new facility, be proactive to eliminate the hazard. Manage risks by controlling exposures. New equipment may be required. Employees must be trained. Consider "what if" scenarios and plan for each contingency. Develop an emergency plan and practice emergency procedures. Companies that protect their human capital save money. Keeping workers safe is a good business decision.

10.4 Acknowledgements

The author thanks Donna Heidel and Patricia Clegg for assistance with the literature research for this chapter.

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Prior to NIOSH, Dr. Heckel's work experience includes design and manufacturing of nuclear reactors and construction of nuclear containment facilities. She designed a laminar drill platform used to manufacture the stainless steel internal structure of a nuclear reactor. She worked as a field engineer on the Trans-Alaska Pipeline where she managed the steel yard and supervised a union crew of Boilermakers, Teamsters and Operators. She was a pioneer in developing computerized inventory-control systems at Boeing and later worked on the Customer Engineering Sales Support team for the 737. At General Electric, she performed life cycle analysis on the CFM56 engines that power the 737 aircraft and wrote the LM1600 engine test manual. She supervised the contract employees from Essig Research. This year, she joined the Board of the international Air & Waste Management Association. Dr. Heckel applied for patents on two Type II medical devices: an ergonomic grip and a device to treat hammertoes. In addition to journal publications and conference presentations, she has published a play (Uncle Doc), two textbooks (Putting People First – the Theory of Universal Design and Environmental Mercury Exposure of Terrestrial Life Forms), and musical scores for Psalms 1 & 2. She is the President and CEO of the Five Minute Church, Inc. a web-based ministry. Dr. Heckel and her husband Walter recently celebrated their Silver Wedding Anniversary. They have four adult children.

CHAPTER 11

Comparative Quality Evaluation of Internet Banking Applications Case Study of Three Romanian Banks

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This chapter constitutes the initial experiments with the WebQEM[1] method applied to the Internet banking applications of three renowned Romanian banks, for the purpose of the comparative evaluation of their quality. The first part comprises a statement of purpose and objectives, after which we succinctly highlight some reference points in the context of the research. The WebQEM method is then adapted to our purpose. We continue by presenting the application phases, and the procedures and algorithms used within this method. The following sections describe the experiment in detail: the conditions, the experimentation methodology and the results, as well as the findings and the conclusions. The work method presented in this chapter is currently perfected for use in a much larger and more complex study, dedicated to the Internet banking applications of a target number of 26 Romanian banks; the study will be published by Lambert Academic Publishing. At a later stage, our intention is to improve the comparative evaluation method in the context of valuing the benefits brought by the methodology of transdisciplinarity.

Keywords*:* internet banking, WebQEM method, ergonomics, usability of software applications, methodology of transdisciplinarity.

11.1 Introduction

Electronic remote-access financial solutions have become a daily need for millions of users around the world. Quality design for a financial software application intended for the general public is very complex and not an easy thing to do. Multiple issues

[1] WebQEM is a method of quantitative evaluation and comparison of website quality, developed between 1998 and 2000 by a group of researchers from the National University of La Pampa in Argentina, led by Professor Luis Olsina.

need to be considered, such as an efficient navigation structure, pleasant appearance, ease of use, etc.

For a wider target audience in the design and development of such applications, a number of additional aspects must also be considered related to the characteristics of different types of customers these applications must service (for instance, users who have PCs with monitors of a specific resolution; unstable Internet connections; some obsolete equipment; different types of Internet browsers etc).

Although in theory the notion of "universal-use software application" exists, translating this concept into practice is and will be a challenge for all the developers of software applications in general, and for the developers of finance-banking applications in particular [1].

The goal of this study is to develop an efficient "modus operandi" for the quality evaluation of electronic remote-access financial solutions and the objectives are:

- To identify a minimal set of necessary criteria for the evaluation of electronic remote-access financial solutions in terms of ergonomics and usability;
- To adapt the WebQEM method (for website quality evaluation) to the requirements of the process of evaluation of electronic remote-access financial solutions;
- To apply the adapted formula of the WebQEM method to a number of three Internet banking solutions present on the specific Romanian market (BT 24; BRD Net; and Raiffeisen Online);
- To formulate a set of concrete suggestions that would be useful for the professional development of electronic remote-access financial solutions on the specific Romanian market.

11.2 Context for Case Study

Most studies conducted to date on Romanian electronic remote-access financial solutions by different stakeholders in this field (forums in the communications and banking area, representatives of various financial institutions and banks, the media, educational and research institutions etc) are limited not only in numbers, but also in terms of scientific content and substance.

Such aforementioned stakeholders mainly confined their analyses to comparative statistical data pertaining to issues such as: the number of users, the number and volume of operations with the analyzed applications, or the costs involved, while showing less interest in issues related to the ergonomics and usability of such systems.

In the context that quite recent studies conducted by professionals in this field show that the number of customers of electronic remote-access financial solutions depends more on the development of new and better services than on lower prices for their supply, we can say that the approach to the study, i.e. the analysis, made by the aforementioned interested parties is incorrect.

However, based on the bibliographic documentation done during the preparation of this chapter, we can include in the "similar achievements" category a series of analytical endeavors that touch tangentially upon the issues to address here, namely:

- The study conducted in 2007 by TreeWorks[2], which aimed to analyze the

[2]TreeWorks is a company specialized in developing web-based communication and inter-

online presence of Romanian banking institutions, emphasizing the manners in which they use the Internet to promote their offers[3];

- Diploma thesis – Avantajul Competitiv în Serviciile Internaţionale de Internet (Competitive Advantage in International Internet Services) [2];
- Master's thesis - Studiu comparativ al serviciilor de Internet-Banking în contextul dinamicii pieţei de profil din România (Comparative Study of Internet Banking Services in the Context of the Dynamics of the Specific Romanian Market) [3];
- Article in "Ghişeul Bancar" ("Bank Counter"): "Ce bănci mizează pe Internet Banking" ("Which Banks Stake on Internet Banking")[4];
- Article in "Ghişeul Bancar": "Tot mai mulţi utilizatori de Internet Banking" ("More and More Internet Banking users")[5];
- Web article: Banca Comercială Română are cel mai bun serviciu de Internet banking (Banca Comerciala Romana has the Best Internet Banking Service)[6];
- Web article: Soluţiile eBanking din România (Romanian eBanking Solutions)[7].

11.3 Premises of the Case Study

11.3.1 Presentation of the WebQEM Method [4]

WebQEM is a method of quantitative evaluation and comparison of website quality, developed between 1998 and 2000 by a group of researchers from the National University of La Pampa in Argentina, led by Professor Luis Olsina [5]. The method has adapted the ISO 9126 quality model and the ISO 14598 evaluation process to websites, and comprises four closely correlated phases:

1. Defining and specifying the quality requirements;
2. Basic evaluation;
3. Global assessment;
4. Analyzing and documenting the results, and drawing the conclusions.

11.3.2 Conditions for the Experiment and Experimentation Methodology

After the prior study of some specialized papers on the same subject (WebQEM method experimentation) [4], for the purpose of acquiring the investigation means,

active solutions. TreeWorks was founded in 2002, and has developed so far more than 100 projects for domestic and international (US, Japan) clients, many of which are extremely complex.

[3]http://www.baniinostri.ro/stiri/stiri.php?ContentID=10298, last accessed November 11, 2012.

[4]http://www.ghiseulbancar.ro/articole/54/1102/Ce_banci_mizeaza_pe_internet_banking.htm, last accessed November 12, 2012.

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[6]http://www.9am.ro/stiri-revista-presei/Business/12085/Banca-Comerciala-Romana-are-cel-mai-bun-serviciu-de-Internet-banking, last accessed November 11, 2012.

[7]Source: http://www.ebanker.ro/Despre_noi.aspx, last accessed November 13, 2012.

experiment objectives, WebQEM concepts and procedures, the evaluation process specific to the above-mentioned method was applied to a number of three Internet banking services in the portfolio of some banks that we consider representative for the specific Romanian market. The three banks are:

1. Banca Transilvania
2. Banca Română de Dezvoltare (BRD - Groupe Societe Generale)
3. Raiffeisen Bank

The choice of the above-mentioned banks for this study was based on several considerations related to the fact that all three banks:

- Belong to the category of major banking players in the Romanian retail banking sector;
- Have a tradition of supplying Internet banking services in Romania (BRD Net was launched onto the market on September 1, 2004[8] ; Banca Transilvania and Raiffeisen Bank have provided Internet banking services since 2002);
- Are among the only 5 banks in the top 10 Romanian banks that provide a demo Internet banking account[9];
- Obtained close scores in usability evaluations conducted so far[10] (average scores obtained: Raiffeisen Bank – 7.38; BRD – 6.23; Banca Transilvania 6.53);
- Have client portfolios of comparable size in the Internet banking sector[11].

The experiment was conducted over one week, and involved the use of multiple investigation means, such as: content analyses, comparative analyses, direct testing (banking operations, queries, reports), and performance monitoring over different time intervals/on different days of the week.

In order to collect the data, we compiled lists of criteria that include both the definition of criteria, and a number of additional explanations (related to criteria significance), where required. The outcomes of observations have resulted in the assigning – for each considered criterion – of a score (between 0 and 100), a Yes/No response, and an evaluation, which were summarized in an enclosed list.

11.3.3 Data Collection

The evaluation form includes:

- Tree structure of features, sub-features, and measurable attributes;

[8] http://www.bizwords.ro/stiri/povesti_de_success/1133/ Internet-Banking-tranzactii-din-fotoliul-de-acasa.html, last accessed November 18, 2012.

[9] http://www.ghiseulbancar.ro/articole/7/5705/Studiu_priv ind_serviciile_de_e-banking.htm, accessed: November 12, 2012.

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- The type de response expected by the evaluator:
  - A score on a scale of 0 to 100, which represents the assessment of the measured attribute;
  - Yes/No evaluation, which indicates whether the measured attribute satisfies/does not satisfy the requirement;
  - A value chosen from a list, which indicates the degree to which the requirement is satisfied.

Evaluation was performed by individual observation / inspection / monitoring of the applications and by filling in the evaluation form according to the outcomes of observations. Data was collected manually, due to the numerous Yes/No questions, which involve visual inspection; furthermore, in the case of the attributes measurable directly by a preference criterion, the only way to obtain an assessment was the judgment of the evaluator.

The collected data were summarized and analyzed in a Microsoft Excel document, and the WebQEM method was applied to all the collected values.

11.4 Stages of the Case Study

In order to quantitatively and qualitatively evaluate and compare the Internet banking applications, we went through each of the 4 phases of the WebQEM method.

11.4.1 Defining and Specifying the Quality Requirements

In this stage, we created, the tree structure of the features, sub-features, and measurable attributes, called "Specification of quality requirements" [2]. For the creation of such specification, we considered the following quality features: usability, functionality, reliability, efficiency, and security (Table 11.1).

11.4.2 Basic Evaluation

Establishing the elementary criteria: Each quantifiable attribute is associated a variable X_i, which can receive a real value through an elementary function [4]. The final result is the transposition of the value of the function into a quality elementary preference Eqi, which can take values in the interval (0,1).

The EQ_i values are interpreted as follows:

- $EQ_i = 0$, when X_i does not satisfy the requirement;
- $EQ_i = 1$, when X_i satisfies the requirement;
- $0 \leq EQ_i \leq 1$, when X_i partially satisfies the requirement.

This article only gives the criteria established for usability (Table 11.2). We established criteria in a similar way for:

- Functionality
- Reliability
- Efficiency
- Security

Applying the calculus formulas for the measurable attributes: The partial results of the elementary preferences for the five features are given in Tables 11.3, 11.4, 11.5, 11.6, and 11.7.

11.4.3 Global Assessment

Logical aggregation of elementary preferences: The aggregation method used in the experiment consisted of the LSP (Logic Scoring of Preference[12]) model and the CLP (Continuous Logic Preference) operators.

In the process of global preference aggregation, the importance weights of the five features taken into account (usability, functionality, reliability, efficiency, and security) were determined by the evaluator based on a number of considerations, such as:

- The direct dependence between the level of usage, and the quality and manner of implementation of an Internet banking service. Consequently, the "usability" feature was given the highest weight (0.3);
- The importance of the security of the Internet banking systems for the customers' decision to buy / use. Consequently, the "security" feature was assigned the second largest weight (0.2);
- The increasing requirements of users in terms of the wide range of functions that the Internet banking applications must offer. Consequently, the "functionality" feature was assigned a weight equal to that of the "security" feature (0.2);
- The findings of the three years of experience in the field about the relatively low importance attached by clients to the aspects included in the categories of the "efficiency" and "reliability" features. Consequently, these two features were assigned a lower weight (0.15).

Calculation of partial and global quality preferences: Once the process of aggregation was finalized and the global scheme was obtained, the partial and global indicators were calculated for each Internet banking application analyzed using the formula:

$$e_0 = (W_1 E_1^r + ... + W_r E_k^r)^{1/r}\,, \quad W_1 + ... + W_k = 1$$

where

e_0 partial preference.
W weight of a certain attribute.
E elementary preference of an attribute.
k number of attributes in the aggregation block.
r conjunctive/disjunctive factor of the aggregation block[13].

The obtained results are given in Table 11.8. During the three previous phases, we recorded all the results of evaluations and calculations, and now we are moving on to the analysis and interpretation of such results, and the drawing of the conclusions.

[12]http://www.cs.auckland.ac.nz/ emilia/publications/ICWE2 005LSP.pdf, accessed: November 17, 2012.

[13]http://www.cs.auckland.ac.nz/ emilia/publications/ICWE2 005LSP.pdf, last accessed October 25, 2012, and http://gidis.ing.unlpam.edu.ar/downloads/pdfs/Olsina_ NRHM.pdf, accessed: October 25, 2012.

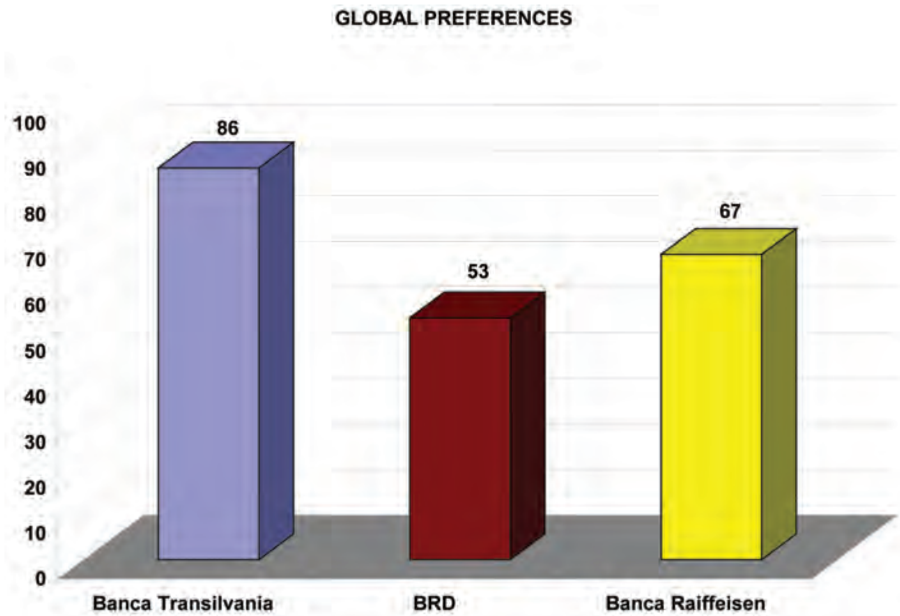

Figure 11.1: Global preferences of internet banking applications.

11.5 Results of the Case Study

Based on the obtained results, we will now present the findings, and draw the conclusions.

11.5.1 GLOBAL Feature

The final evaluation of the obtained quality features is given in Table 11.9, and the global values obtained for each of the three Internet banking applications are shown in the graph in Figure 11.1.

The analysis of the evaluation results shows that:

- Banca Transilvania's BT 24 application obtained high scores for all the 5 features considered (between 65.57 and 99.09
- Raiffeisen Bank's application obtained satisfactory scores for all the 5 features considered (between 16.86 and 97
- The BRD Net application obtained variable scores (between 6.86 and 89.31

11.5.2 USABILITY Feature

The results obtained by the Usability feature in the case of each of the Internet banking applications are given in the graph in Figure 11.2.

Banca Transilvania's Internet banking application, BT 24, stands out in terms of usability, since it includes a number of additional elements as compared to the other

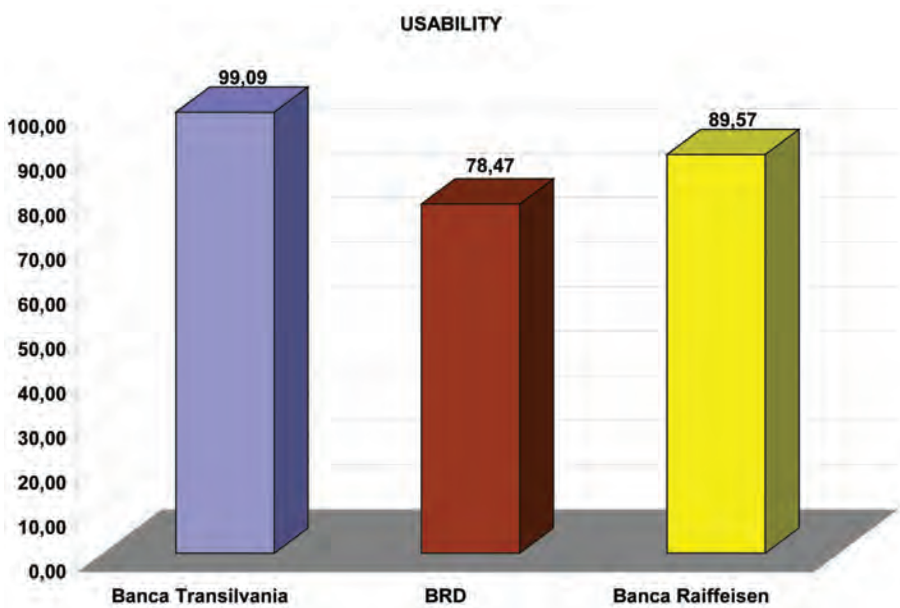

Figure 11.2: Results obtained by the usability feature.

two applications that were analyzed. Some of them are: contextual help, downloadable user's manual, balance report, and the wide range of communication channels available for the clients in order to keep in touch with the specific department.

Raiffeisen Bank's application also obtains a good usability score, since it stands out, despite the above-mentioned deficiencies, by a report option that is very useful to clients (i.e. the contracted loan report), report which is not present on the platforms of the other analyzed applications.

As compared to Raiffeisen Bank's application, the BRD Net application adds the order status report to its own list of deficiencies; it is the only application (among the analyzed ones) that does not provide such feature.

11.5.3 FUNCTIONALITY Feature

The results obtained by the Functionality feature in the case of each of the Internet banking applications are given in the graph in Figure 11.3.

In terms of functionality, the results of the applications that also obtained good scores on the previous criterion (usability) are very close. Nevertheless, both Banca Transilvania, and Raiffeisen Bank still need to improve some of the aspects (ex: BT 24 should introduce the recurrent payment option, while Raiffeisen Bank should introduce the order import option).

The deficiencies of the BRD Net application in this area refer to aspects such as: liquidation of savings accounts, order import, and recurrent payments.

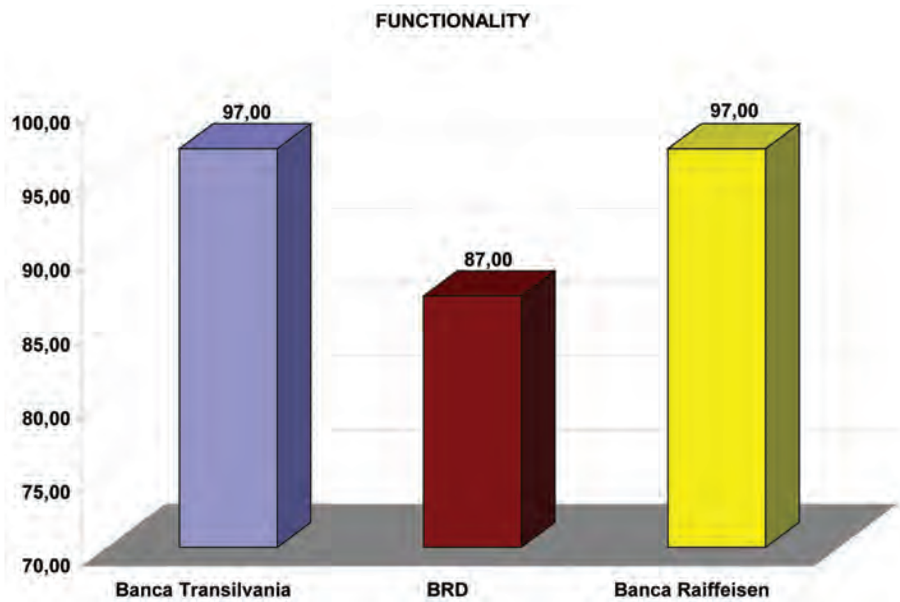

Figure 11.3: Results obtained by the functionality feature.

11.5.4 RELIABILITY Feature

The results obtained by the Reliability feature in the case of each of the Internet banking applications are given in the graph in Figure 11.4.

Banca Transilvania's application, BT 24, obtained the highest reliability score; the only important aspect that this application fails to satisfy in this area (of the considered aspects) is the fact that the only browser the application runs on is Internet Explorer.

Although the BRD Net application obtained a good score in this area, one of its deficiencies is the fact that some of the web nodes present on its platform are non-answering, or their response is determined by the existence or absence of some settings / specific programs.

Raiffeisen Bank's application also shows similar deficiencies; a compelling example is the application's demonstrative section, which cannot be accessed unless Macromedia Flash Player is installed on the client's PC. In terms of the reliability of Raiffeisen Bank's application, we should also mention the less efficient display of the application's menu and links, which allows cases of isolated links to occur.

11.5.5 EFFICIENCY Feature

The results obtained by the Efficiency feature in the case of each of the Internet banking applications are given in Figure 11.5.

In terms of efficiency, Raiffeisen Bank's application is the undisputed leader; the very high score it obtained in this area is mainly due to the fact that the update

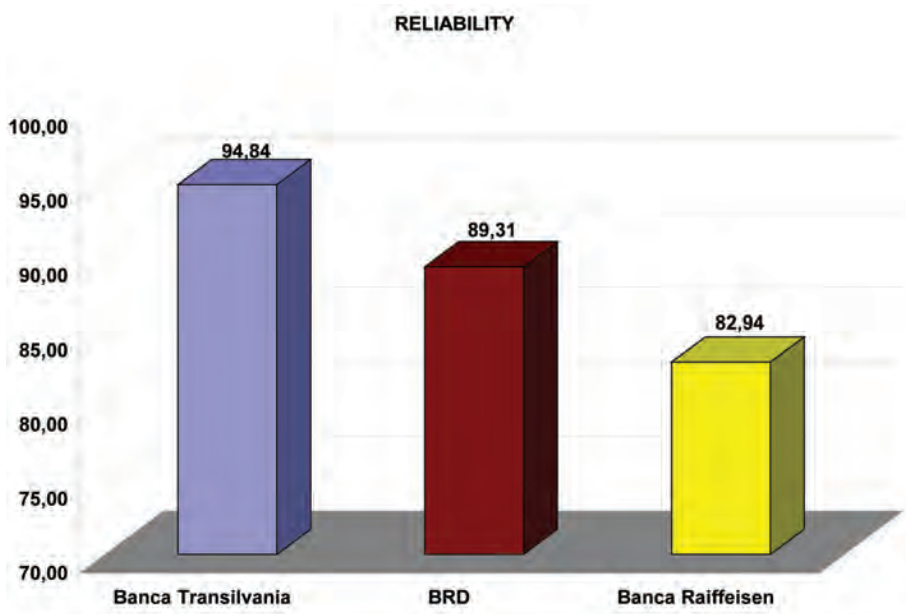

Figure 11.4: Results obtained by the reliability feature.

frequency of order processing and balance information is very high, since all such updates are practically performed online, which is not the case with the other two applications analyzed. Nevertheless, in the case of all the analyzed applications there is room for some improvement in this area in terms of the number of clicks needed to send an order to the bank.

11.5.6 SECURITY Feature

The results obtained by the Security feature in the case of each of the Internet banking applications are given in Figure 11.6.

Banca Transilvania's application, BT 24, stands out in the security area through a carefully developed procedure of sending to the clients the confidential data required for access to the application, which the other two applications lack. As far as this aspect is concerned, BRD is a complete opposite, since there are cases when the confidential data required for access to the BRD Net application is sent by e-mail, which is an extremely insecure channel.

In terms of security of access to the application, BT 24 ranks first again; this application has two levels of access security:

- 1^{st} level, ensured by the digital authentication certificates;
- 2^{nd} level, ensured by the user ID and password-based authentication.

However, digital authentication certificates also have disadvantages; the main disadvantage is that they can only be installed on Windows operating systems and Internet Explorer browsers, affecting the addressability of the solution.

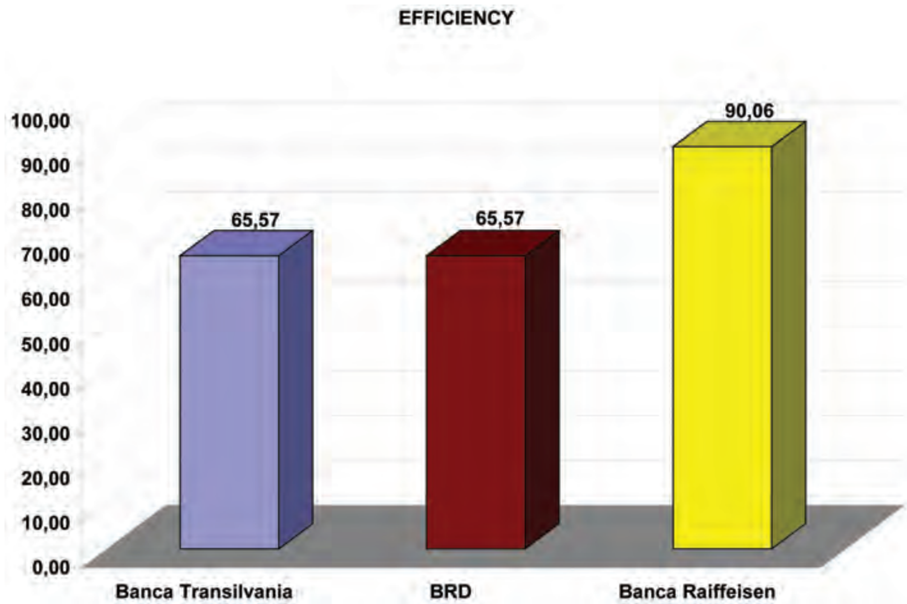

Figure 11.5: Results obtained by the efficiency feature.

Although Raiffeisen Bank's application has a similar structure, on two security levels, it has deficiencies in terms of security; thus, one of the authentication steps depends on data that can be easily lost by users (identification data of cards). The BRD Net application ranks last as far as this aspect is concerned, because it has only one security level, by user ID and Password.

11.6 Conclusion

Considering the research objectives, we can draw the following conclusions:

- The WebQEM method's applicability to the qualitative measurement and evaluation of Internet banking applications has been demonstrated;
- Based on the model of the criteria used within the WebQEM method, which was applied to the analyzed websites, we identified a minimal set of criteria necessary for the evaluation of Internet banking solutions (usability, functionality, reliability, efficiency, and security);
- We were able to adapt the WebQEM method to the requirements of the process of evaluation of Internet banking solutions by considering a number of parameters, whose numerical values were established according to the value intervals provided by the specialized literature. A possible source of error in the mentioned approach could be the lack of clear criteria for associating the blocks of the LSP (logic scoring of preference) diagram and the value of the conjunctive/disjunctive factor of the aggregation block ("r").

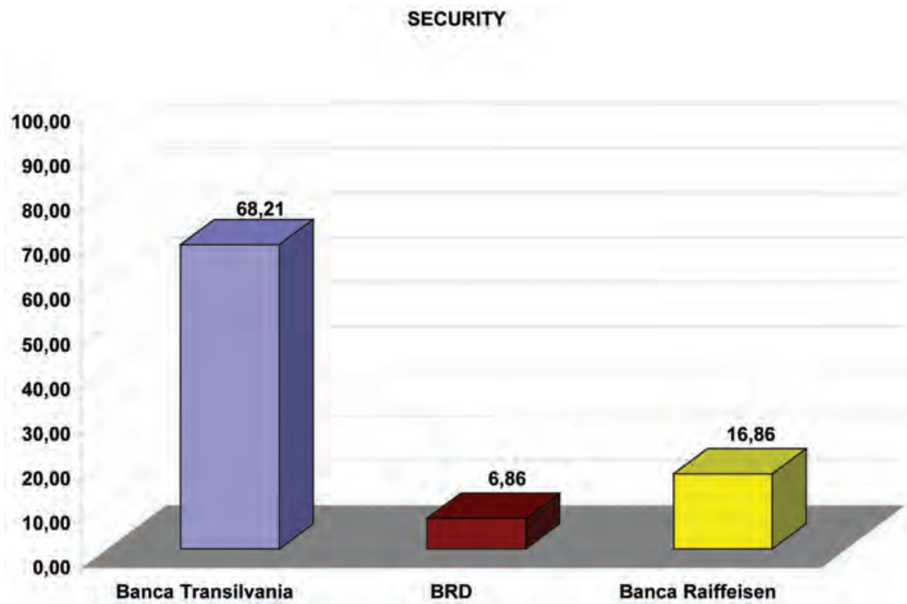

Figure 11.6: Results obtained by the security feature.

Another conclusion of this study is that the analyzed banks still have deficiencies in their manner of keeping in touch with the clients who have subscribed to the Internet banking applications.

Consequently, the results of this study can be considered as a promising beginning for supporting the – quite difficult – process of developing methodologies specific to the financial and banking industry and necessary for an adequate evaluation of Internet banking solutions.

11.7 New Directions for Development

The new directions for the development of the three Internet banking applications analyzed could be the following:

- To improve access security;
- To eliminate the single points of failure;
- To route the client traffic between different locations and/ or geographical regions automatically and in a balanced manner;
- To increase the applications' number of functions;
- To improve the manner of keeping in touch with subscribers by creating some online video help-desk offices, since it has been proven that Internet banking services lack the so-called "human touch".

Therefore, the three Romanian banks could consider implementing some modern solutions for communicating with clients, solutions intended to minimize the above-mentioned deficiencies.

Last but not least, from our point of view, such a complex comparative analisys can be, at a later stage, considerably developed by adapting a new approach, based on the transdisciplinary methodology. This methodology “comprises three axioms: multiple Levels of Reality, knowledge as complex and emergent and the Logic of the Included Middle”[14]. In this way, the analisys will be more accurate, with more benefits, because: “Transdisciplinarity complements disciplinary approaches. It occasions the emergence of new data and new interactions from out of the encounter between disciplines. It offers us a new vision of nature and reality. Transdisciplinarity does not strive for mastery of several disciplines but aims to open all disciplines to that which they share and to that which lies beyond them[15] .

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Table 11.1: Specification of all the quality features.

1. USABILITY:	2.1.5 Establishment of savings accounts
	2.1.6 Liquidation of savings accounts
1.1 General presentation of the application	
1.1.1 Intro page (including the main links)	**2.2 Related features**
1.1.2 Commercial and informative pages	2.2.1 Multiple signature masks
1.1.3 Operational interface	2.2.2 Order import
1.2 Interface and esthetic appearance	2.2.3 Recurrent payments
1.2.1 Grouping coherence of main controls	2.2.4 Programmed payments
1.2.2 Presentation permanence and stability of main controls	2.2.5 Predefined orders
1.2.2.1 Permanence of direct controls	2.2.6 Export of statements of account
1.2.2.2 Permanence of indirect controls	2.2.7 Order printing
1.2.2.3 Stability	2.2.8 Password change
1.2.3 Esthetic preferences (including customization according to corporate identity)	2.2.9 Entering and saving new beneficiaries
1.2.4 Uniformity of style	
1.3 Feedback and help	**3. RELIABILITY:**
1.3.1.Quality of help components	**3.1 Nontechnical (context) errors**
1.3.1.1 Contextual Help	3.1.1 Link errors
1.3.1.2 Downloadable user's manual	3.1.1.1 Isolated links
1.3.2 Contact data list	3.1.1.2 Invalid links
1.3.2.1 E-mail addresses	3.1.1.3 Non-implemented links
1.3.2.2 Phone & Fax numbers (including Green Line)	3.1.2 Various errors and inconveniences
1.3.2.3 Postal address	3.1.2.1 Number of deficiencies or absent features due to browsers
1.3.3 Demo component	3.1.2.2 Number of site deficiencies or unexpected results, independent of browser
1.3.4 FAQ component	3.1.2.3 Number of non-answering web nodes
1.3.5 Contact form component	3.1.2.4 Eloquence of error messages
1.3.5.1 Contact form over secured communication channel	
1.3.5.2 Contact form over ordinary communication channel (e-mail)	**4. EFFICIENCY:**
1.3.6 Report component	**4.1 Information accessibility**
1.3.6.1 Order status report	4.1.1 Accessible format of specialized information
1.3.6.2 Order execution report	4.1.2 Update frequency of balance information
1.3.6.3 Balance report	4.1.3 Presence of operations / balances history
1.3.6.4 Statements of account	**4.2 Complexity of operating procedures**
1.3.6.5 Account movements	4.2.1 Number of clicks needed to send an order to the bank
1.3.6.6 Savings account report	4.2.2 Order form complexity
1.3.6.7 Contracted loan report	**4.3 Processing time for operations ordered by users**
1.3.7 Foreign language support	
	5. SECURITY:
2. FUNCTIONALITY:	
2.1 Types of operations	**5.1 Security of communication between the user's PC and the bank's server**
2.1.1 RON payments	5.1.1 Digital authentication certificates
2.1.2 Foreign currency payments	5.1.2 Token / digipass devices
2.1.3 Sale of foreign currencies	5.1.3 User ID and password-based authentication
2.1.4 Purchase of foreign currencies	**5.2 Security of sending confidential data required for access**

Table 11.2: Criteria established for usability.

Code	Elementary preference function	Formula
1.1.1	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.1.2	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.1.3	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.2.1	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.2.2.1	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.2.2.2	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.2.2.3	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.2.3	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.2.4	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.1.1	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.1.2	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.2.1	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.2.2	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.2.3	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.3	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.4	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.5.1	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.5.2	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.6.1	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.6.2	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.6.3	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.6.4	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.6.5	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.6.6	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.6.7	D = 0 (no), D = 1 (Yes)	X = 100 * D
1.3.7	Ni - no. of foreign languages supported Si - level of language support, [0,2 - minimum support, 1 - medium support, 2 - total support]	X = 30 * SUM(Si)*Ni, if X>100 => X=100

Table11.3:Partial results for usability.

USABILITY	**Banca Transilvania**	**BRD**	**Raiffeisen Bank**
1.1.1 Intro page (including the main links)	100	100	100
1.1.2 Commercial and informative pages	100	100	100
1.1.3 Operational interface	100	100	100
1.2.1 Grouping coherence of main controls	100	100	100
1.2.2.1 Permanence of direct controls	100	100	100
1.2.2.2 Permanence of indirect controls	100	100	100
1.2.2.3 Stability	100	100	100
1.2.3 Esthetic preferences (including customization according to corporate identity)	100	100	100
1.2.4 Uniformity of style	100	100	100
1.3.1.1 Contextual Help	100	0	0
1.3.1.2 Downloadable user's manual	100	0	0
1.3.2.1 E-mail addresses	100	0	100
1.3.2.2 Phone & Fax numbers (including Green Line)	100	100	100
1.3.2.3 Postal address	100	0	0
1.3.3 Demo component	100	100	100
1.3.4 FAQ component	100	100	100
1.3.5.1 Contact form over secured communication channel	100	0	100
1.3.5.2 Contact form over ordinary communication channel (e-mail)	100	100	0
1.3.6.1 Order status report	100	0	100
1.3.6.2 Order execution report	100	100	100
1.3.6.3 Balance report	100	0	0
1.3.6.4 Statements of account	100	100	100
1.3.6.5 Account movements	100	100	100
1.3.6.6 Savings account report	100	100	100
1.3.6.7 Contracted loan report	0	0	100
1.3.7 Foreign language support	90	6	90

Table 11.4: Partial results for functionality.

FUNCTIONALITY	**Banca Transilvania**	**BRD**	**Raiffeisen Bank**
2.1.1 RON payments	100	100	100
2.1.2 Foreign currency payments	100	100	100
2.1.3 Sale of foreign currencies	100	100	100
2.1.4 Purchase of foreign currencies	100	100	100
2.1.5 Establishment of savings accounts	100	100	100
2.1.6 Liquidation of savings accounts	100	0	100
2.2.1 Multiple signature masks	100	100	100
2.2.2 Order import	100	0	0
2.2.3 Recurrent payments	0	0	100
2.2.4 Programmed payments	100	100	100
2.2.5 Predefined orders	100	100	100
2.2.6 Export of statements of account	100	100	100
2.2.7 Order printing	100	100	100
2.2.8 Password change	100	100	100
2.2.9 Entering and saving new beneficiaries	100	100	100

Table 11.5:Partial results for reliability.

RELIABILITY	**Banca Transilvania**	**BRD**	**Raiffeisen Bank**
3.1.1.1 Isolated links	100	100	50
3.1.1.2 Invalid links	100	100	100
3.1.1.3 Non-implemented links	100	100	100
3.1.2.1 Number of deficiencies or absent features due to browsers	50	50	50
3.1.2.2 Number of site deficiencies or unexpected results, independent of browser	100	100	100
3.1.2.3 Number of non-answering web nodes	100	50	100
3.1.2.4 Eloquence of error messages	100	100	100

Table 11.6:Partial results for efficiency.

EFFICIENCY	**Banca Transilvania**	**BRD**	**Raiffeisen Bank**
4.1.1 Accessible format of specialized information	100	100	100
4.1.2 Update frequency of balance information	50	50	100
4.1.3 Presence of operations / balances history	100	100	100
4.2.1 Number of clicks needed to send an order to the bank	50	50	50
4.2.2 Order form complexity	100	100	100
4.3 Processing time for operations ordered by users	50	50	100

Table 11.7:Partial results for security.

SECURITY	**Banca Transilvania**	**BRD**	**Raiffeisen Bank**
5.1.1 Digital authentication certificates	100	0	0
5.1.2 Token / digipass devices	0	0	0
5.1.3 User ID and password-based authentication	100	100	100
5.2 Security of sending confidential data required for access	100	0	50

Table 11.8: Results obtained for the Usability criterion.

Features / Sub-features	Partial and global preferences		
	Banca Transilvania	**BRD**	**Raiffeisen Bank**
1. USABILITY:	**99.09**	**78.47**	**89.57**
1.1 General presentation of the application	100.00	100.00	100.00
1.2 Interface and esthetic appearance	100.00	100.00	100.00
1.2.1 Grouping coherence of main controls	100.00	100.00	100.00
1.2.2 Presentation permanence and stability of main controls	100.00	100.00	100.00
1.2.3 Esthetic preferences (including customization according to corporate identity)	100.00	100.00	100.00
1.2.4 Uniformity of style	100.00	100.00	100.00
1.3 Feedback and help	97.00	42.28	68.55
1.3.1.Quality of help components	100.00	0.00	0.00
1.3.2 Contact data list	100.00	25.00	75.00
1.3.3 Demo component	100.00	100.00	100.00
1.3.4 FAQ component	100.00	100.00	100.00
1.3.5 Contact form component	100,00	46,84	65,52
1.3.6 Report component	90.00	60.00	90.00
1.3.7 Foreign language support	90.00	6.00	90.00
2. FUNCTIONALITY:	**97.00**	**87.00**	**97.00**
2.1 Types of operations	100.00	90.00	100.00
2.2 Related features	90.00	80.00	90.00
3. RELIABILITY:	**94.84**	**89.31**	**82.94**
3.1 Nontechnical (context) errors	94.84	89.31	82.94
3.1.1 Link errors	100.00	100.00	80.00
3.1.2 Various errors and inconveniences	87.50	75.00	87.50
4. EFFICIENCY:	**65.57**	**65.57**	**90.06**
4.1 Information accessibility	76.69	76.69	100.00
4.2 Complexity of operating procedures	71.60	71.60	71.60
4.3 Processing time for operations ordered by users	50.00	50.00	100.00
5. SECURITY:	**68.21**	**6.86**	**16.86**
5.1 Security of communication between the user's PC and the bank's server	60.26	8.58	8.58
5.2 Security of sending confidential data required for access	100.00	0.00	50.00
GLOBAL PREFERENCES	**86.00**	**53.00**	**67.00**

Table 11.9: Final evaluation.

Features / Sub-features	Partial and global preferences		
	Banca Transilvania	**BRD**	**Raiffeisen Bank**
1. USABILITY	**99.09**	**78.47**	**89.57**
2. FUNCTIONALITY	**97.00**	**87.00**	**97.00**
3. RELIABILITY	**94.84**	**89.31**	**82.94**
4. EFFICIENCY	**65.57**	**65.57**	**90.06**
5. SECURITY	**68.21**	**6.86**	**16.86**
GLOBAL PREFERENCES	**86.00**	**53.00**	**67.00**

CHAPTER 12

Legacy Interface Adapter Design Modeling

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Technology is changing at a very rapid rate. Many deployed/fielded information systems are aging and becoming "legacy" systems that continue to operate and perform as required. However, as time goes by, maintainability of these systems is becoming an increasing issue. Also, the dissemination of information and data from the legacy systems to modernized systems is becoming more prominent within industry. With the technology evolution, there is a need to adapt legacy systems to modern architected systems. The objective of this project is to educate the reader about available design considerations and processes to consider when developing an "adaptor" type interface with a legacy system. An interface adapter example is utilized throughout this chapter to provide the reader with sufficient information to get started on their own design. This chapter is intended to visit several design topics and processes; component-oriented axiomatic design, architectural considerations, and project planning. Through the survey of these topics, the reader will have a framework and a model in which to get a head start. Many of these topics are cross disciplinary in nature and may be used with a variety of systems.

Keywords*:* Legacy system, adapter software design, axiomatic design .

12.1 Introduction

Customers who operate existing legacy data processing systems often have a need to interface those existing legacy systems to new or replacement subsystems. Legacy systems often provide stable low cost processing, but they may need to interface with new/replacement subsystems.

These new or replacement subsystems by their nature utilize more current technology than the legacy system. However, attempting to modify the legacy system directly to interface with the newer subsystem causes an undesirable and often unaffordable ripple of change in the legacy system. Hence, a need arises for an Interface Adapter that fits between the legacy system and the newer subsystem. The adapter can absorb the ripples of change so the newer subsystem can be designed taking advantage of the newest available technology and the legacy system is either not impacted or minimally impacted by this interface modification.

This chapter leverages the axiomatic design of the Interface Adapter Software Design (IASD) project. The set of customer needs, Functional Requirements (FRs), Design Parameters (DPs) and Constraints applicable to an IASD were developed and will be utilized to the fullest extent. The full design process, description of customer needs (CNs), Functional Requirements decomposition process, associated Design Parameters and Requirements traceability matrix are described in Chapter III.

The vertical requirement decomposition method/tool is utilized to decompose the system design requirements. The first level requirements are developed to describe the highest level of the design description, and an initial/high level design matrix is developed and decoupled to start the hierarchical vertical decomposition approach. An iterative decomposition analysis approach is utilized to refine the various levels after analyzing coupling in the design matrices.

Although this chapter is based around the IASD design using component oriented axiomatic design techniques, architectural considerations are leveraged in order to validate the design and to systematically develop the design to a level that could lead directly to implementation.

12.2 Interface Adapter Software Design (IASD)

12.2.1 Component Oriented Axiomatic Design

Component Oriented Axiomatic Design is an approach that utilizes specific processes to develop a system design to the component level while checking for missing components. Identifying missing components early in the design process is crucial to maintain cost, stay on schedule and enhance performance on the project. Also, missing a component may be detrimental to the success of the project. The earlier missing components are found during the design process, the less time and money that are spent later in the project lifecycle. The design team should consider keeping the customer informed throughout the design process or, better yet, have them actively participate on the team.

12.2.2 Architectural Considerations

The second approach described in this chapter utilizes an architectural design approach that combines contextual, operational, logical and physical data to provide a base architecture. This approach, similar to the axiomatic design approach, uses customer needs and requirements as a basis for the architecture of the system. The difference between the two methods is the detailed processes utilized to describe each part of the system. These details allow a smooth transition to system hardware and software development.

12.2.3 Project Planning

Project planning occurs throughout all stages of project and is considered an evolving process. However, it is important to put together an initial project master plan and integrated master schedule. This is essential to successful project start up and initial project execution. Although it is highly probable that changes will occur during project execution for various reasons, continual adaptation of the master plan and schedule are essential for project completion. The IASD project Integrated Master Plan (IMP) and Integrated Master Schedule (IMS) are developed in this chapter so that the reader may gain an understanding of how to approach project planning in a systematic manner.

12.3 Component Oriented Axiomatic Design

This chapter uses axiomatic design techniques to present such an Interface Adapter Software Design (IASD). The report iteratively develops a list of customer needs, Functional Requirements, Design Parameters and Constraints applicable to an IASD and analyzes the design steps pointing out desirable and undesirable characteristics. The axiomatic design approach is presented in Figure 12.1.

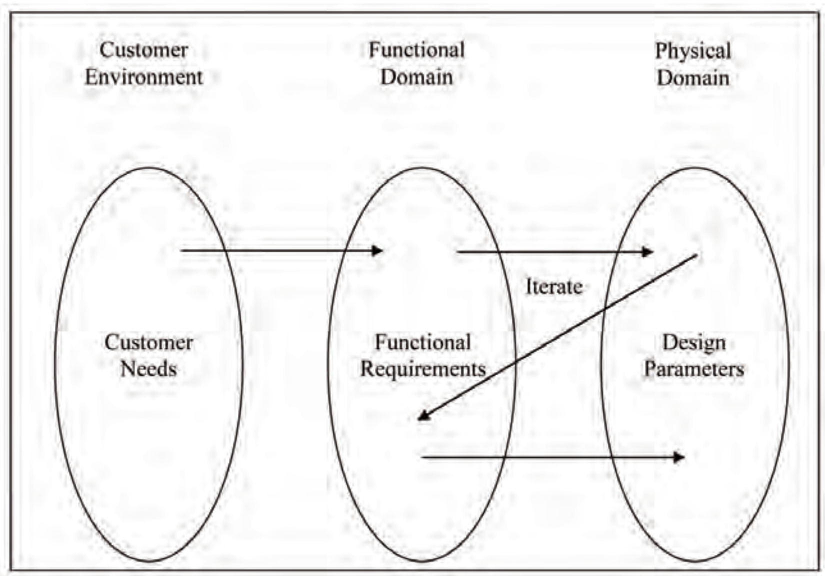

Figure 12.1: *Axiomatic design domains involved in the IASD design [Tate, 2006].*

12.3.1 Defining Customer Needs

The project objective is to design an interface between an existing legacy data system and multiple modernized data systems with specific interface requirements. This project utilizes the Component-Oriented Axiomatic Design (COAD) process to provide the best possible design decisions based upon customer needs and decomposed functional requirements. The customer vision is to, "provide a reliable, cost effective mechanism to interface a legacy data system to a modernized data system with minimum disruption to ongoing operations."

The customer needs were identified through brainstorming sessions and reviewing past industry project experiences. Customer needs would normally be determined in projects of this category by a consortium of personnel including:

- System design engineers
- Legacy knowledgeable systems engineers
- New subsystem design team
- Software engineers and architects
- Network engineers
- Field personnel who operate or maintain legacy systems
- Program management, scheduling, budgeting, etc.

The scenario under examination is a legacy system in which a subsystem is identified and replaced. This new, replacement subsystem uses current communication technology and protocols but the legacy system operates older technology. The primary desire is to develop a testable adapter to translate the two communication protocols (old and new).

12.3.2 Customer Needs and Constraints

The following information describes an initial list of customer needs, known or agreed constraints and definitions/declarations.

1. Adapter shall access subsystem replacement.
2. Adapter shall interface legacy system to subsystem replacement using specified communication protocols.
3. Customer needs a subsystem replaced because manufacturers are not supporting aging parts of system and/or customer needs to migrate parts of system to newer and more flexible technology and make software based.
4. Customer needs more functionality but the legacy system contains subsystems that are functionally limited.
5. Limited funding exists for overhauling the entire system so focus is on subsystem replacement which is more cost effective.
6. Customer needs additional functionality added to the system.
7. The customer needs more current technology for the resulting functionality improvement.
8. Various stakeholders need to be able to test the new subsystem in a stand alone configuration (without access to the legacy system).
9. Various stakeholders need to be able to verify requirements of a new subsystem by having visibility to data-flow within the adapter.
10. Customer needs to utilize standardized technology to make development more cost effective and gain more functionality (get more for less).
11. The current legacy system is incompatible with newer COTS products.
12. The Customer needs data flow improvement to take advantage of increased bandwidth and capacity of communication equipment, (i.e. network switches).
13. Customer needs to reduce equipment footprint size to use less space.
14. Customer needs reduced power requirements.
15. Customer needs reduced heat generation.

16. Customer needs improved reliability.
17. Customer needs improved maintainability.
18. Customer needs system availability to be at least as good as the current system (24x7 with scheduled maintenance periods - 1000 hours or better continual uptime).
19. Adapter shall be considered part of legacy system.
20. If one subsystem channel's connectivity is lost, the system considers all are lost.
21. If no response is received from the subsystem or connection is lost on any of the multiple communication channels, all communication with the subsystem is halted.
22. Legacy interface is TCP-IP socket based.
23. Secondary interface shall be Service Oriented Architecture (SOA).
24. Adapter shall be software based running on a standard computer platform.
25. Adapter shall maintain SOA connectivity with Naming Service to resolve single server.
26. Adapter shall provide a sustainable TBD commands per second commanding rate.
27. Adapter design shall scale to match available hardware.
28. For operational mode, adapter does not have to operate if legacy system is not available.
29. Publicly exposed data references in the adapter should be protected (not deleted).
30. Adapter shall trace events to provide diagnostic access to processing.
31. Test scenarios shall utilize the legacy interface of the adapter to test the adapter and subsystem.

The list of customer needs is then grouped into higher level categories. These categories are areas of interest that describe the higher level needs by the customer. This method also helps flush out constraints that may affect the overall design of the final system. Figure 12.2 shows the KJ diagram related to the Customer Needs described above. It is often helpful to view the relationships between the customer needs and the categories into one diagram for quick identification of customer needs and constraints.

12.3.3 Mature Domain

Using knowledge from experience and technology used in similar systems, the following diagrams were developed to show possible mature domains that could be incorporated into the design. These domains will be used to further develop requirements and design parameters. The platform technologies listed in Figure 12.3 and the COTS and Software technologies listed in Figure 12.4 show mature domain components that map to the IASD requirements. This provides a component relationship of the IASD requirement so existing mature domain components already available in the industry. These mature domains change over time due to the rapid changes in technology, so taking a snapshot in time may lead to changes down the road. As in

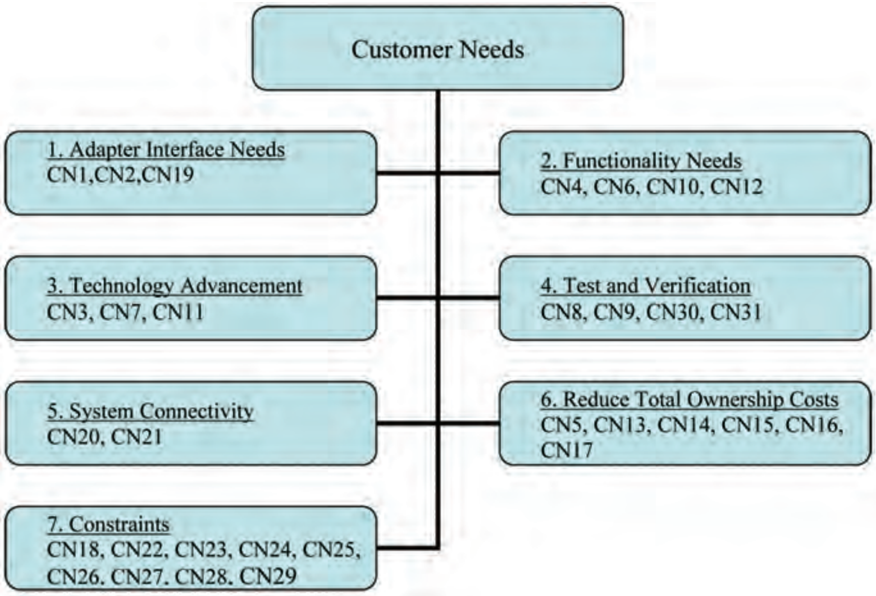

Figure 12.2: *Grouped customer needs.*

the description of “legacy system”, today’s mature domains are tomorrow’s legacy domains.

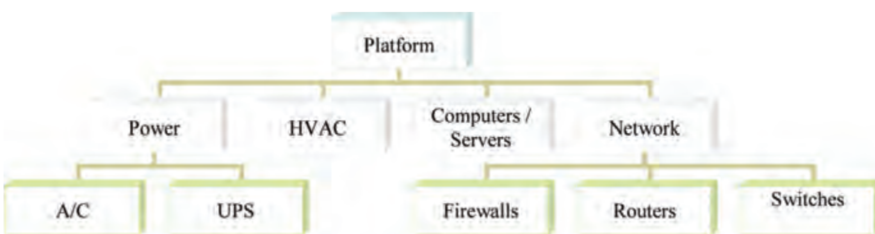

Figure 12.3: *Mature domains (platform).*

The following Constraints emerged during the initial stage of the axiomatic design process. The constraints are derived through the analysis of customer needs and act of mapping them to the mature domain components categorized for this application. Constraint C10 emerged later in the design process.

- C 1 Legacy interface shall be TCP-IP socket based.
- C 2 Secondary interface shall be SOA.
- C 3 Adapter shall be software based running on a standard computer platform.
- C 4 Maintain SOA connectivity with Naming Service.
- C 5 Provide a sustainable TBD commands per second commanding rate. C 6 Provide for 24 hour, 7 day per week duty cycle with a MTBF (Mean Time

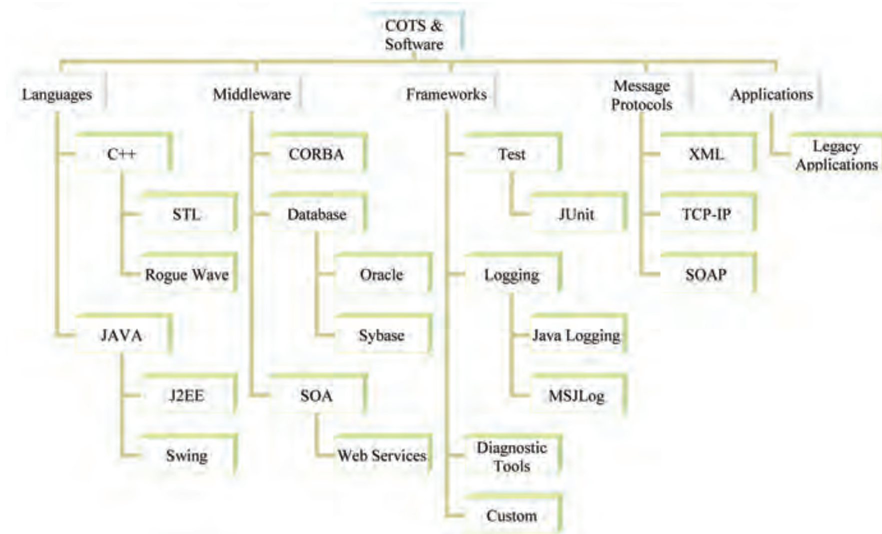

Figure 12.4: *Mature domains (COTS & Software).*

Between Failure) of 1000 hours or better.

- C 7 Scalable to match available hardware.
- C 8 In operational mode, adapter does not have to operate if legacy system is not available. C 9 Protect (do not delete) publicly exposed data references in adapter.
- C10* Event log service is available to all parts of the adapter for logging trace events.

These system constraints define the adapter's functional bounds. They also define the inputs for which the adaptor is responsible.

12.3.4 Functional Requirements and Design Parameters Decomposition

The adapter is assumed to operate between the legacy and the new subsystem where it can translate data transmitted in either direction. This position also allows a legacy driver to be connected to this adapter for testing and operation without the need for the legacy system. Figure 12.5 shows the relationship between the legacy system, adapter (IASD) and a new subsystem.

As shown in Figure 12.1, Functional Requirements (FRs) are developed from Customer Needs (CNs) and Design Parameters (DPs) are developed from the FRs. Each FR captures the concise scope of functions for the given level. Keeping a focus on customer needs insures all system needs are accounted for.

In this case, DP development evolves easily from FRs with the perspective that a DP satisfies everything within the scope of the FR. When the Design Matrix is used to examine coupling, the scope of DPs is made much clearer. This exposes the DP to multiple FR mappings. This process reveals additional information about the

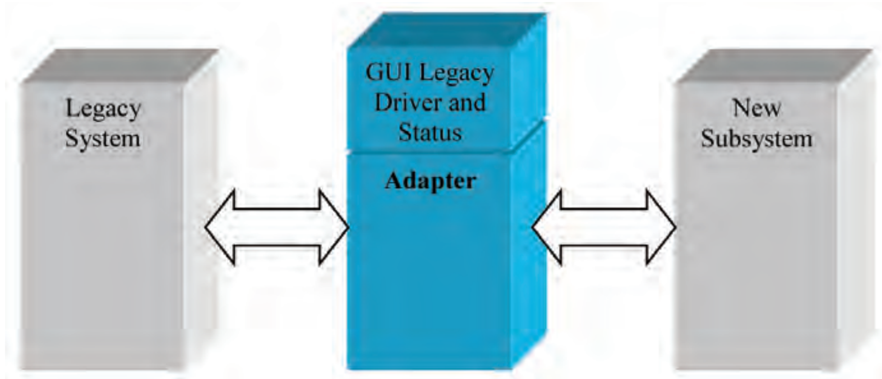

Figure 12.5: *Base IASD design.*

FRs (i.e. definition is too broad, functionality is excessive, or that the definition is optimal). By iteratively going over a level of FR/DP development based on Design Matrix analysis, a more sound design is realized as more concise FRs/DPs are realized.

Note: In the next sections, the FR and DP numbering scheme is formed as follows; $< Level\_1 > . < Level\_2 > . < Level\_3 >$. The sub-level numbers are sequential for the entire level to reflect a FR or DP at the given level, not within the higher level's FR/DP. This numbering scheme is preferable when working with design matrices, specifically when a matrix needs to be manipulated into lower triangular form.

Level 1 FRs/DPs

The following FRs are derived for the first level. The primary function of the adapter is to translate data between two interfaces and secondarily provide a user interface for testing the new subsystem.

- FR 1 Interface a legacy system to an upgraded subsystem.
- DP 1 Data Translator Adapter.
- FR 2 Provide a user driven stand-in legacy driver for testing and verifying new subsystem.
- DP 2 Legacy Interface Test Driver and Status GUI.

This matrix shown in Table 12.1 represents the decoupled relationship between FR1/DP1 and FR2/DP2. This could have been a completely uncoupled matrix (Xs only in diagonal locations), except to satisfy the legacy interface test driver requirement, FR2; the GUI must have access to the Adapter.

Level 2 FRs/DPs

The following level 2 FR/DP pairs are derived by analysis of the customer needs. In this case, the foundational functionality emerged from brainstorming the logical separations. Since it is assumed the implementation of the adapter is completed using a standard software language, the level 2 DPs are envisioned as primary functional components in a software design framework.

Table 1: Level 1 FR/DP Design Matrix

Level 1	DP1	DP2
FR1	X	
FR2	X	X

Table 2: Level 2 FR/DP Initial Design Matrix

Level 2	DP 1.1	DP 1.2	DP 1.3	DP 1.4	DP 2.5
FR 1.1	X		X		
FR 1.2		X	X		
FR 1.3			X		
FR 1.4		X	X	X	
FR 2.5			X		X

- FR 1.1 Provide legacy interface to receive and transmit data with legacy system.
- DP 1.1 Legacy Interface.
- FR 1.2 Provide Subsystem interface to receive and transmit data with the new subsystem.
- DP 1.2 Subsystem Interface.
- FR 1.3 Translate/manage entire adapter functionality
- DP 1.3 Adapter Manager
- FR 1.4 Data needs to be inspected and checked against state of data on subsystem interface to determine where a message should be routed (message dependent or independent of current state)
- DP 1.4 Data Marshaller to determine routing to subsystem
- FR 2.5 Operate adapter via legacy driver without legacy system being available
- DP 2.5 Legacy Driver / GUI Portal

Reworking the matrix into lower triangular form in Table 12.2, the following decoupled version shown in Table 12.3 is obtained. The Adapter Manager obviously has a lot of coupling to the rest of the system, but this is by intent to try to keep other parts focused on specific functions. This coupling and others may be reduced during the level 3 FR/DP analysis.

Level 3 FRs/DPs

The following level 3 FR/DP pairs are also derived by analysis of the customer needs.

- FR 1.3.1 Configure adapter using a configuration input
- DP 1.3.1 Configuration File

Table 3: Level 2 FR/DP Decoupled Design Matrix

Level 2	DP 1.3	DP 1.2	DP 1.1	DP 1.4	DP 2.5
FR 1.3	X				
FR 1.2	X	X			
FR 1.1	X		X		
FR 1.4	X	X		X	
FR 2.5	X	X			X

- FR 1.1.2 Interface with Legacy System to transfer data to/from adapter
- DP 1.1.2 Legacy Interface
- FR 1.2.3 Interface with Subsystem to transfer data to/from adapter
- DP 1.2.3 Subsystem Interface
- FR 1.3.4 Manage conversion of data in both directions via defined protocols
- DP 1.3.4 Adapter Manager Data Converter
- FR 1.4.5 Route data to/from multiple channels on subsystem interface
- DP 1.4.5 Data Marshaller
- FR 1.2.6 Initialize when legacy interface is triggered to be active against legacy subsystem or test driver
- DP 1.2.6 Legacy Interface Initializer
- FR 1.3.7 Trace events
- DP 1.3.7 Event Log
- FR 1.2.8 Subsystem Interface will input configuration for a given number multiple channels
- DP 1.2.8 Subsystem Interface Initializer
- FR 1.5.9 Manage/coordinate initialization sequence of all adapter functions
- DP 1.5.9 Adapter manager Initializer FR 1.3.10 Sequence/coordinate fault recovery/response
- DP 1.3.10 Adapter Manager Fault Handler

Table 12.4 shows the Design Matrix realized from the first iteration of FR/DP pairs. Tight coupling between FR1.3.7 and DP 1.3.7 is created because of the event tracing via an event log. This FR/DP is removed from the matrix by defining a new constraint. The new constraint is added as (C10) to ensure this need is covered and to reduce coupling in the matrix. Since the adapter is a software based application, a common software log service can be made available to all parts of the system. See the results below in Table 12.5.

The level 3 design matrix is then manipulated toward lower triangular form to produce Table 12.6.

Before going further, the design matrix reveals coupling that is difficult to account for in the current level 3 FR/DP definitions. The FR/DPs involving the Legacy Interface and the Subsystem Interface are coupled to other parts of adapter. The single fault handler function is a contributor to this coupling as well as the data conversion being handled in one location.

Table 4: Iteration 1 Level 3 FR/DP Initial Design Matrix

Level3	DP1.3.1	DP1.1.2	DP1.2.3	DP1.3.4	DP1.4.5	DP1.2.6	DP1.3.7	DP2.5.8	DP2.5.9	DP1.3.10
FR1.3.1	X	X	X				X			
FR1.1.2		X		X			X			X
FR1.2.3			X	X			X			X
FR1.3.4		X	X	X			X			X
FR1.4.5			X		X	X	X			X
FR1.2.6			X			X	X			X
FR1.3.7	X	X	X	X	X	X	X	X	X	X
FR2.5.8		X					X	X		X
FR2.5.9							X		X	
FR1.3.10		X	X				X			X

Table 5: Iteration 1 Level 3 FR/DP Design Matrix

Level3'	DP1.3.1	DP1.1.2	DP1.2.3	DP1.3.4	DP1.4.5	DP1.2.6	DP2.5.8	DP2.5.9	DP1.3.10
FR1.3.1	X	X	X						
FR1.1.2		X		X					X
FR1.2.3			X	X					X
FR1.3.4		X	X	X					X
FR1.4.5			X		X	X			X
FR1.2.6			X			X			X
FR2.5.8		X					X		X
FR2.5.9								X	
FR1.3.10		X	X						X

Table 6: Final Iteration 1 Level 3 FR/DP Design Matrix

Level3''	DP1.3.10	DP1.2.3	DP1.1.2	DP1.3.4	DP1.2.6	DP2.5.9	DP1.3.1	DP1.4.5	DP2.5.8
FR1.2.3	X	X		X					
FR1.1.2	X		X	X					
FR1.3.10	X	X	X						
FR1.3.4	X	X	X	X					
FR1.2.6	X	X			X				
FR2.5.9						X			
FR1.3.1		X	X				X		
FR1.4.5	X	X			X			X	
FR2.5.8	X		X						X

The analysis shifts back to reexamining the level 3 FR/DPs to more carefully look where functions are performed against the level 2 DPs. The fault handling is uncoupled by breaking out the respective types of fault handling required and assigning them to respective parts that deal with that portion of the adapter functions. Also, the data conversion is assigned to the respective interfaces so other parts of the adapter do not have to be a part of the specific data protocols.

Level 3 FRs/DPs (Revised and Grouped)

Legacy I/F

- FR 1.1.1 Communicate via legacy protocol on a sequential data channel
- DP 1.1.1 Legacy protocol interpreter (built to match spec)
- FR 1.1.2 Initialize when triggered
- DP 1.1.2 Legacy interface initializer
- FR 1.1.3 Provide interface to legacy driver
- DP 1.1.3 Legacy Driver / GUI Portal

SubSystem I/F

- FR 1.2.4 Communicate via subsystem I/F protocol
- DP 1.2.4 Subsystem protocol interpreter (built to match spec)
- FR 1.2.5 Initialize when triggered
- DP 1.2.5 Subsystem interface initializer

Manager

- FR 1.3.6 Input adapter configuration
- DP 1.3.6 Configuration reader
- FR 1.3.7 Manage/coordinate initialization sequence
- DP 1.3.7 Adapter Initializer
- FR 1.3.8 Sequence/coordinate fault recovery/response
- DP 1.3.8 Fault Handler
- FR 1.3.9 Collect system state
- DP 1.3.9 Status Collector

Marshaller

- FR 1.4.10 Manage parallel data channels. Assign work to appropriate channel based on configuration and the previous work handled
- DP 1.4.10 Data Dispatcher Channel Manager
- FR 1.4.11 Store message data while waiting status from subsystem
- DP 1.4.11 Waiting-Response-Queue
- FR 1.4.12 Reject unknown transmission
- DP 1.4.12 Data Dispatcher Xmit Handler
- FR 1.4.13 Reject transmissions when triggered
- DP 1.4.13 Data Dispatcher Xmit Handler

GUI

- FR 2.2.14 GUI interface for legacy driver
- DP 2.2.14 GUI Legacy System Application
- FR 2.2.15 Display status of interface states/configuration

Table 7: Final Level 3 Design Matrix

Level 3	1	2	3	4	5	6	9	11	14	15	16	8	12	13	10	7	17
1	X																
2		X															
3			X														
4				X													
5					X												
6						X											
9							X										
11								X									
14									X								
15										X	X						
16										X	X						
8		X			X							X					
10													X	X	X		
12													X	X	X		
13													X	X	X		
7		X			X									X		X	
17									X	X	X						X

- DP 2.2.15 GUI Application*
- FR 2.2.16 Perform diagnostics
- DP 2.2.16 GUI Application*
- FR 2.2.17 Authenticate GUI user
- DP 2.2.17 User Authentication

* These are defined further in the next section.

The Design Matrix shown in Table 12.7 represents the new level 3 version after altering the position of the rows and columns to get it into lower triangular form. Note that for readability, the following table has DPs as columns and FRs as rows and since the third level number of the FRs and DPs is unique, only the third level number is used. That is, DP 1.3.9 is listed as column 9 and FR 1.3.9 is listed as row 9.

The tight coupling revealed in this iteration is isolated to two respective parts of system, the Dispatcher and the GUI. The coupling in the Dispatcher's functionality (FRs 10, 12, 13) is expected and understandable since all data routing is done at this point. These FRs may be collapsed into a single FR. The breakout of the fault handling after the first level of FRs/DPs enabled helps to determine where that functionality is best served. The two fault handling functions (FRs 12 and 13) may be collapsed together.

The coupling with the GUI in FRs 15-16 is expected since all FRs are served from a single GUI. Collapsing these FRs into one removes coupling in the diagram, however the best solution is to modify the two respective DPs to clarify which function is for system status and which one is for diagnostic access.

The Adapter Manager's FRs (7, 8) that require configuration and initialization are coupled with other components. This coupling should not be intrusive to the

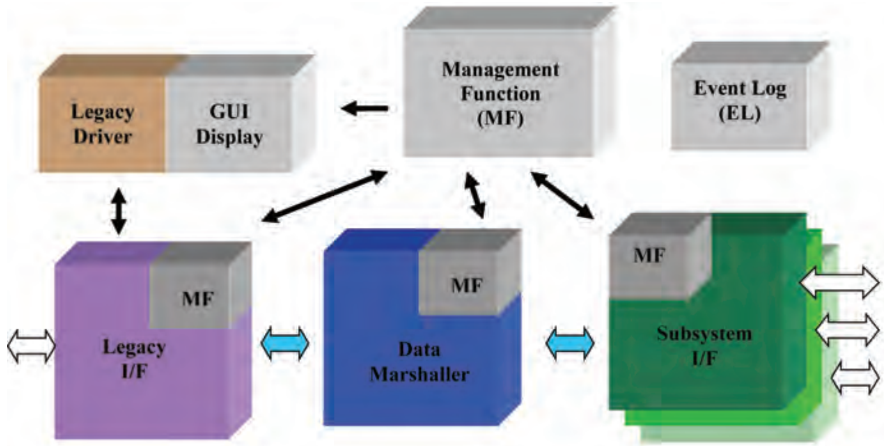

Figure 12.6: Major design component diagram.

overall design of the system. All level 3 FR/DP pairs define the scope of a design that may now begin to transition to functional physical components in a logical software design.

12.3.5 Resulting Module Definition

Figure 12.6 represents major components that emerged from the FR/DP and Design Matrix analysis. The level 2 DPs drive the primary functional components in the design. The level 3 DPs reveal more of the functions within and the relationships between the level 2 DPs. The configuration and initialization requirements are mapped to three other components as well as the Adaptor Manager as indicated by the Management Function (MF) subcomponents in the diagram.

Adapter Components

The association of major adapter components identified in Figure 12.6 may now be associated with more specific mature domains. This consists of using COTS products, middleware, and software languages and libraries as components of the adapter design.

- Management Function
  o Java package
  o XML (config file)
- Legacy Interface
  o Java package
  o TCP-IP
- Data Marshaller
  o Java package (algorithms)

- Subsystem Interface
  o Web Services
- Event Log
  o Java Logging
- Legacy Driver
  o Database to store data for test
- GUI Display
  o Java Swing for GUIs

Adapter Simulations

Simulations may be used to examine the relationships of components and begin to expose the design to the requirements and ensure completeness. The following scenarios are examined using collaboration diagrams to analyze the components and look for functionality completeness.

These scenarios were developed using the steps required for three threads of processing. These threads represent some basic processing paths. The “authentication” component was considered a missing component and is highlighted for discussion later. Figure 12.7 shows the collaboration diagram of the IASD initialization process.

All three collaboration diagrams (Figures 12. 7- 12.9) highlight the newly added “Authentication” component to show the relationship of the Authenticator in the respective system processes.

Missing Components (Identification)

The components’ relationships are defined as publishers (P) and/or corresponding subscribers (S) in Figure 12.6. The objects are shown as the ordered DPs from the final level design matrix shown in Table 8. The “Emergent” column captures the DPs that do not have a corresponding component to publish or subscribe to.

At this point, the publish-subscribe condition is broken and one emergent component is exposed. The component needed is an authenticator to validate the user access to the GUI. The missing Authenticator component is added and so the publish-subscribe conditions are satisfied.

Missing Components (Developed)

The missing component provides authentication of users accessing the system via the GUI to operate the legacy data driver and access diagnostic data. The authentication component is attached to the GUI since users will be required to have user ids and passwords entered for authentication. The missing component, “Authentication” is added to the component diagram (Figure 12.6) and is shown in Figure 12.9.

The authentication component is integrated into the system and the new functionality as shown in the sequence diagram represented in Figure 12.10. Since authentication involves validating user access and provides different access rules for testing, administrative, and trouble shooting, it will provide various levels of accessibility. These requirements can be covered using Lightweight Directory Access Protocol (LDAP). This protocol is a mature domain in itself and can be implemented by many different COTS products, typically web servers.

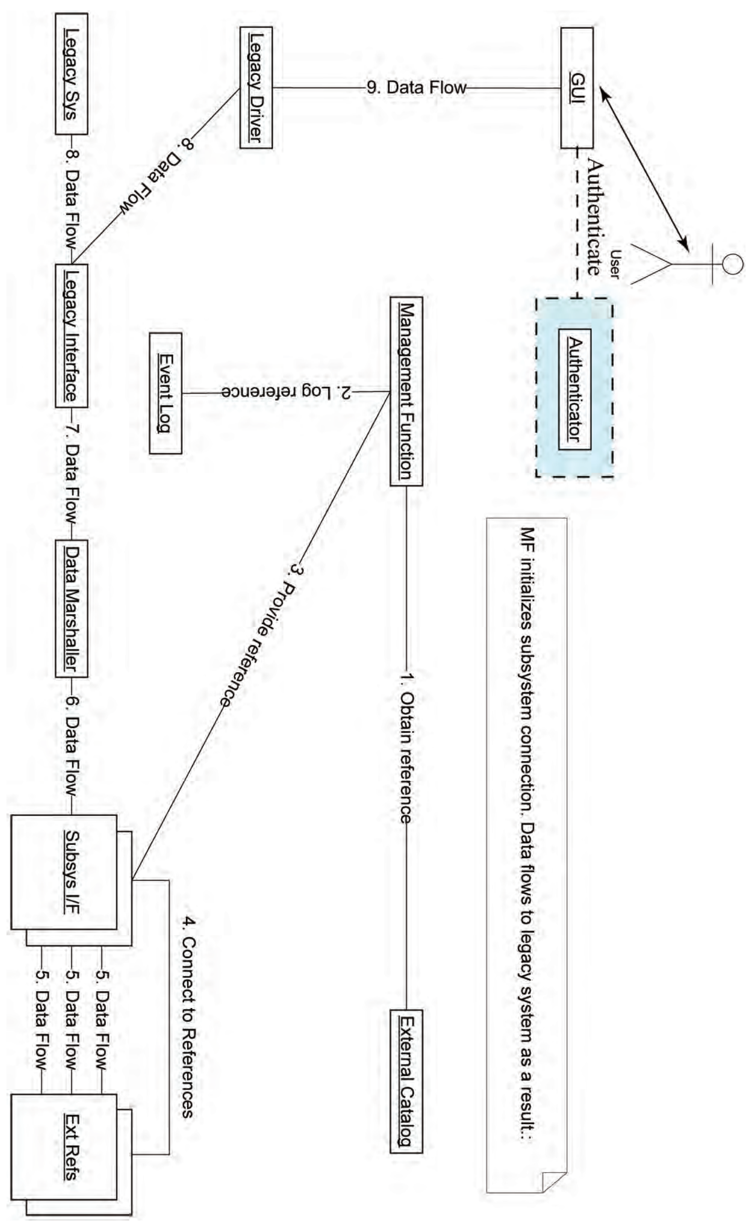

Figure 12.7: Collaboration diagram (Legacy System Data Process).

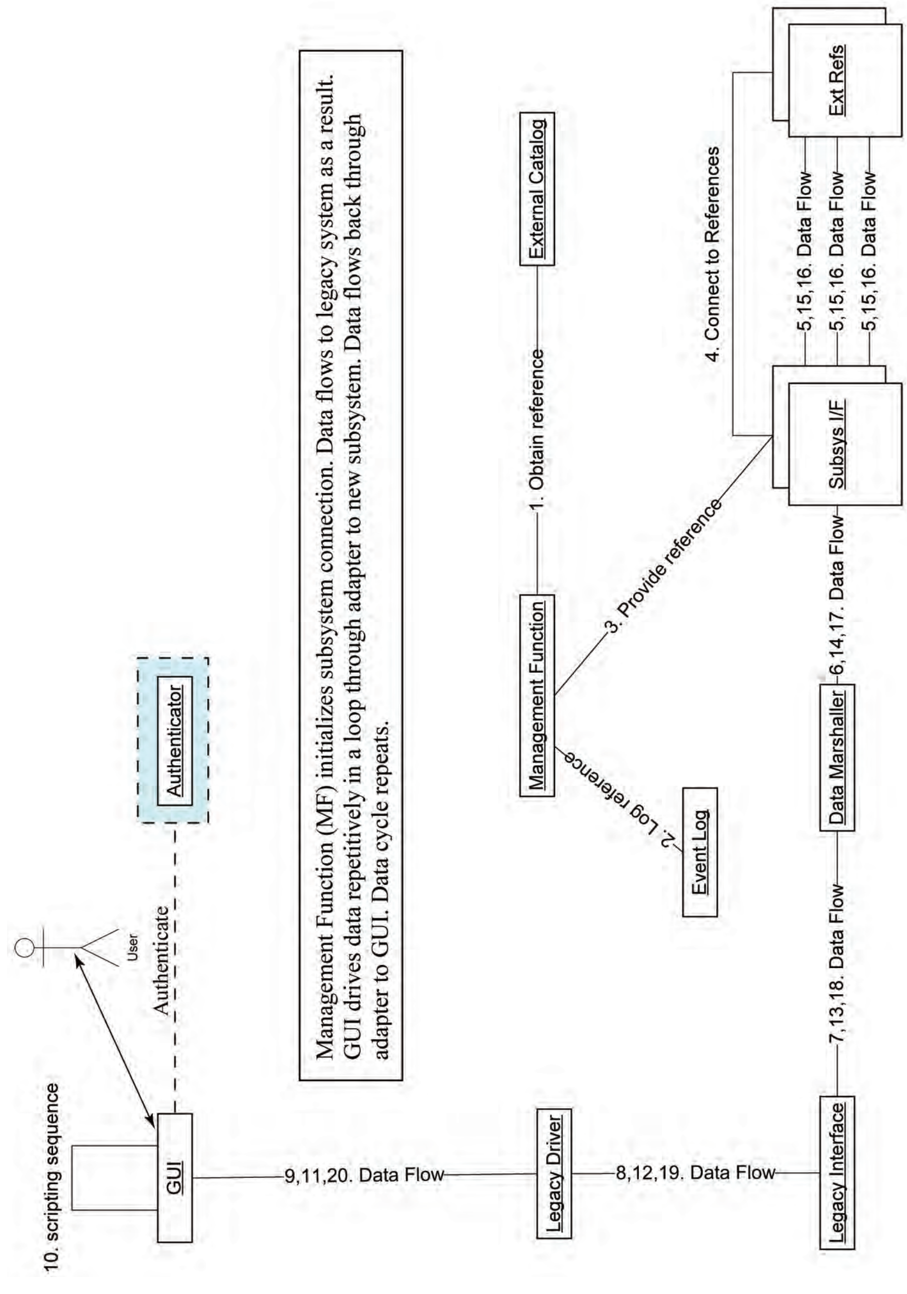

Figure 12.8: Collaboration diagram (Legacy Driver Guided Processing).

Table 8: Checking Integrated Components

Objects	Components						
	Legacy I/F	GUI	Mgmt Function	Legacy Driver	Data Marshaller	Subsystem I/F	Emergent
DP 1.1.1: Legacy Protocol interpreter	S				P		
DP 1.1.2: Legacy Interface initializer	S		P				
DP 1.1.3: Legacy Driver	S	P					
DP 1.2.4: Subsystem protocol interpreter					P	S	
DP 1.3.6: Configuration reader		P	S				
DP 1.3.9: Status collector		S	P				
DP 1.4.11: Waiting – response - queue					S	P	
DP 2.2.14: GUI Legacy system application		S		P			
DP 2.2.15: GUI Application		S	P				
DP 2.2.16: GUI Application		S	P				
DP 2.2.17: User Authentication		S					P
DP 1.3.8: Fault Handler		P	S				
DP 1.4.10: Data Dispatcher Channel Manager			S		P		
DP 1.4.12: Data Dispatcher Xmit Handler			S		P		
DP 1.4.13: Data Dispatcher Xmit Handler			S		P		
DP 1.3.7: Adapter initializer			P		S		

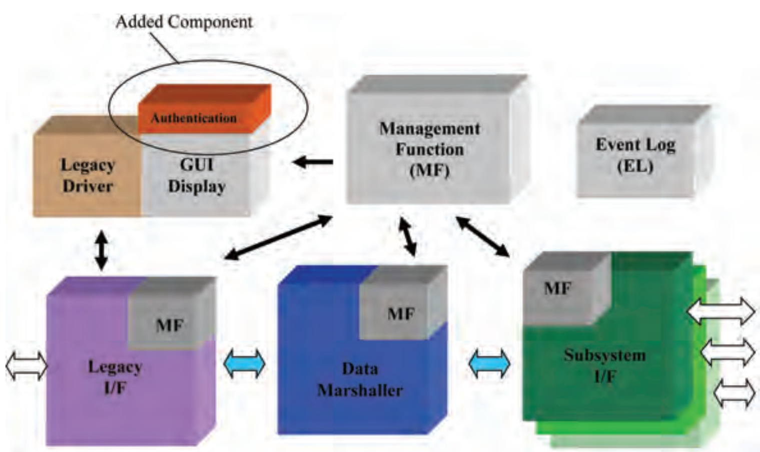

Figure 12.9: Major design component diagram (Missing Component Added).

Integration

Integration includes the development of components within the design. The UML diagrams show in Figure 12.11 and Figure 12.12 the integration of the java classes

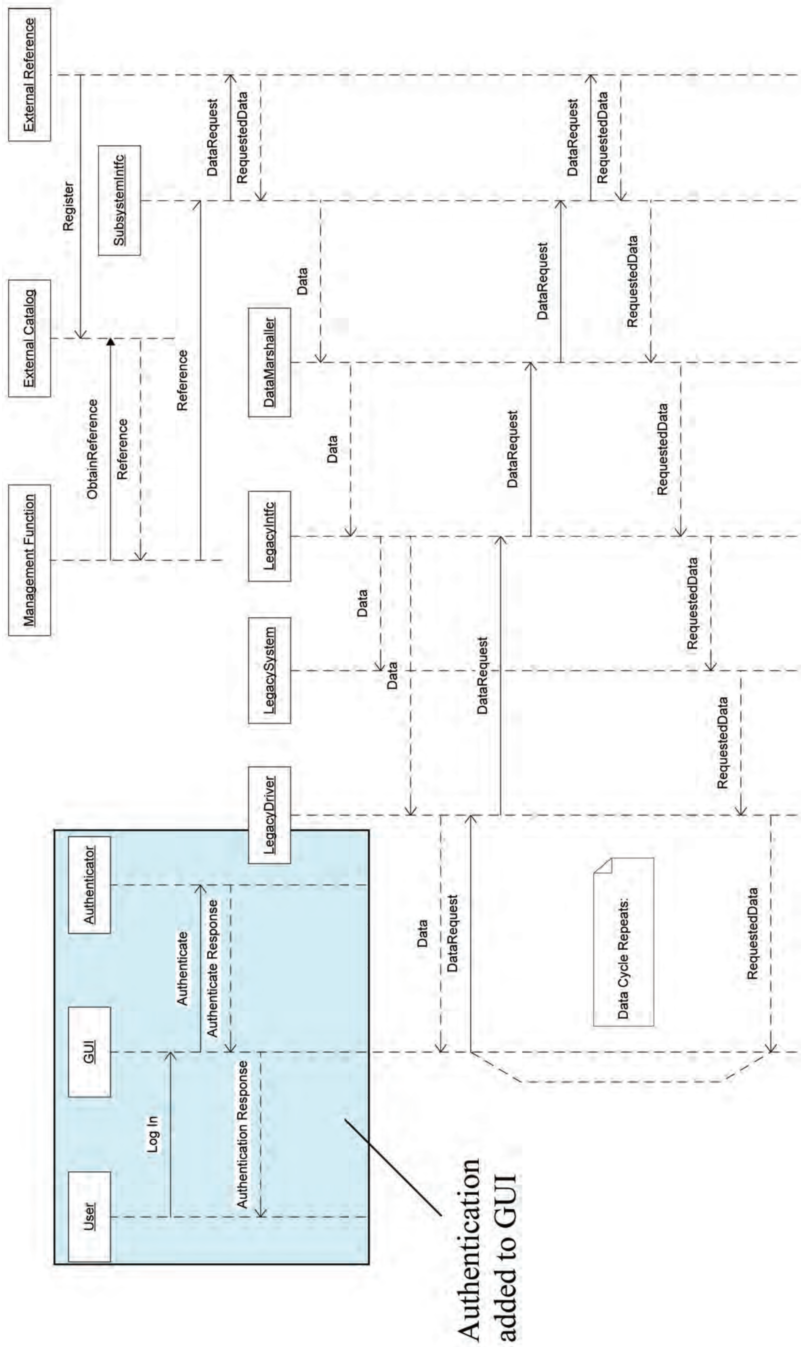

Figure 12.10: Sequence diagram with user Authentication.

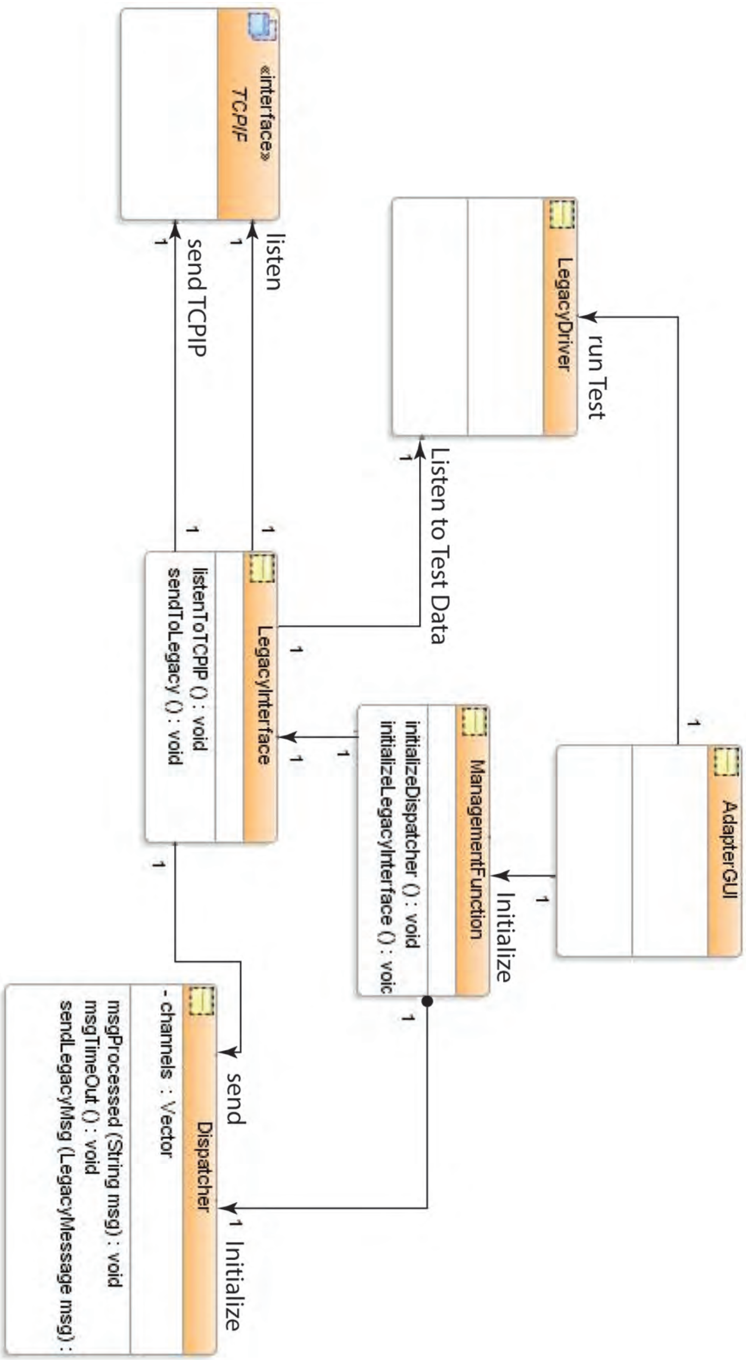

Figure 12.11: UML diagram (Legacy and GUI).

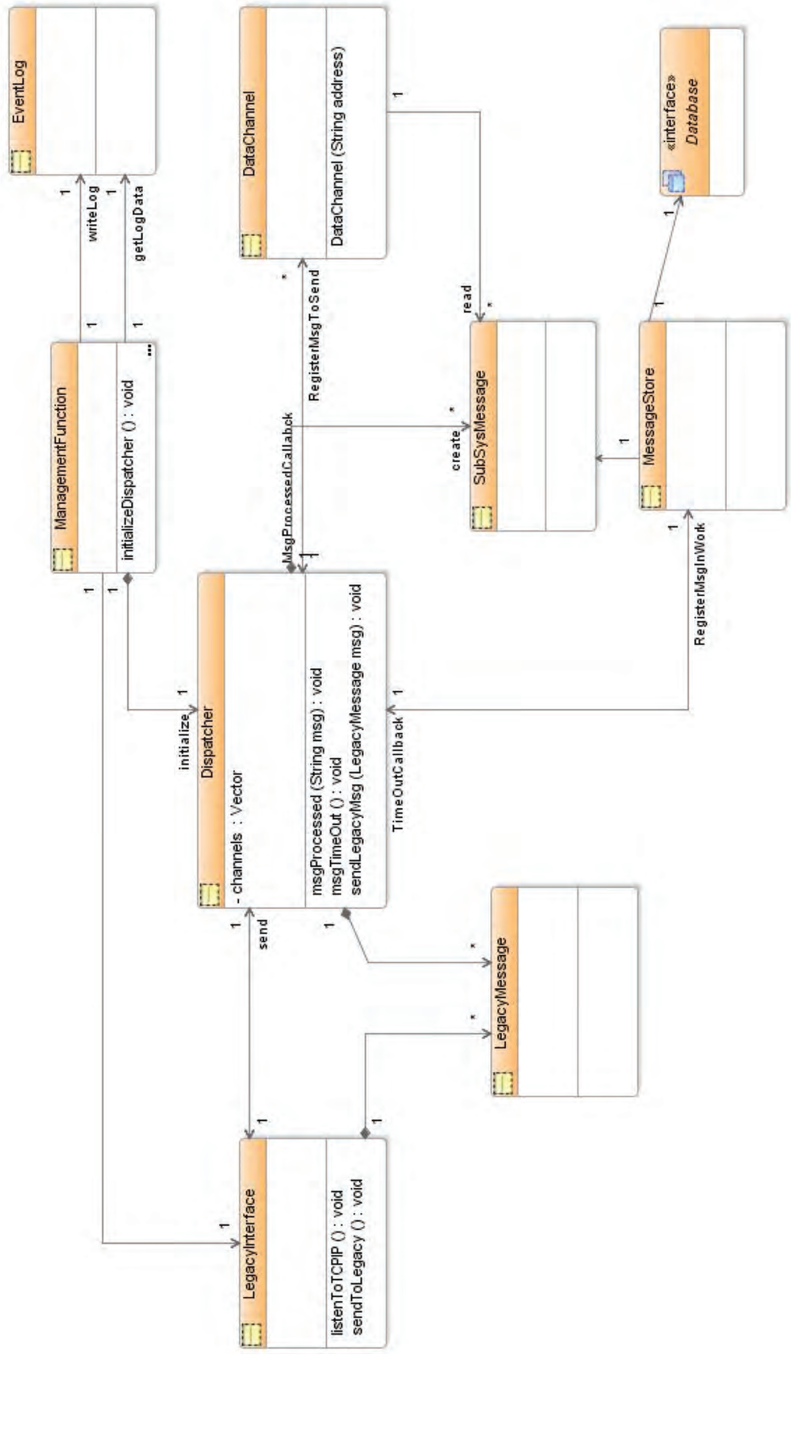

Figure 12.12: UML diagram (Dispatcher and Subsystem I/F).

that came from the design. These diagrams represent a start to the primary classes, operations, and attributes that will exist in the software system. The integration of these classes to domains like TCP/IP and Database are shown in the UML diagrams.

At this point the test cases may be used to check out functionality through the integration process. Low level unit tests may be developed to check out component functionality and interfaces. The functional requirements test cases validate overall system functionality as the system is further integrated.

Adding Components to Mature Domain

The missing authentication component that provides system security is common to both software systems operations and testing functions. The selection of LDAP for this design is a potential component that may be added to the list of mature domains originally identified in Figure 12.4.

Figure 12.13 shows an update to Figure 12.4 (Mature Domains) with security added to the mature domain components for the missing component, "Authentication".

Software Product (Execution)

The system execution phase of an application such as this Adapter begins when major component development is complete and full system testing may begin with the external interfaces. An application of this type may be deployed when all functional requirement test cases have passed test validation. Customer acceptance should come upon approval of all test results.

12.4 Axiomatic Design Concluding Comments

The Component-Oriented Axiomatic Design process provides a clear process to identifying design components. This chapter, Systematic Component-Oriented Development with Axiomatic Design, [Togay, Dogru, Tanik, Tate] presented the concept with the COAD process of discovering missing components in the design as seen by the missing user authentication component in the Adapter design.

By utilizing the COAD process, perceived customer confidence is heightened because the results of the final design meet the customer needs. The process brings a focus on the important functions of a system and how multiple functions best relate to each other. With the design process steps unique to COAD, the designer may identify missing components that are required to meet defined functional needs without altering the design dramatically.

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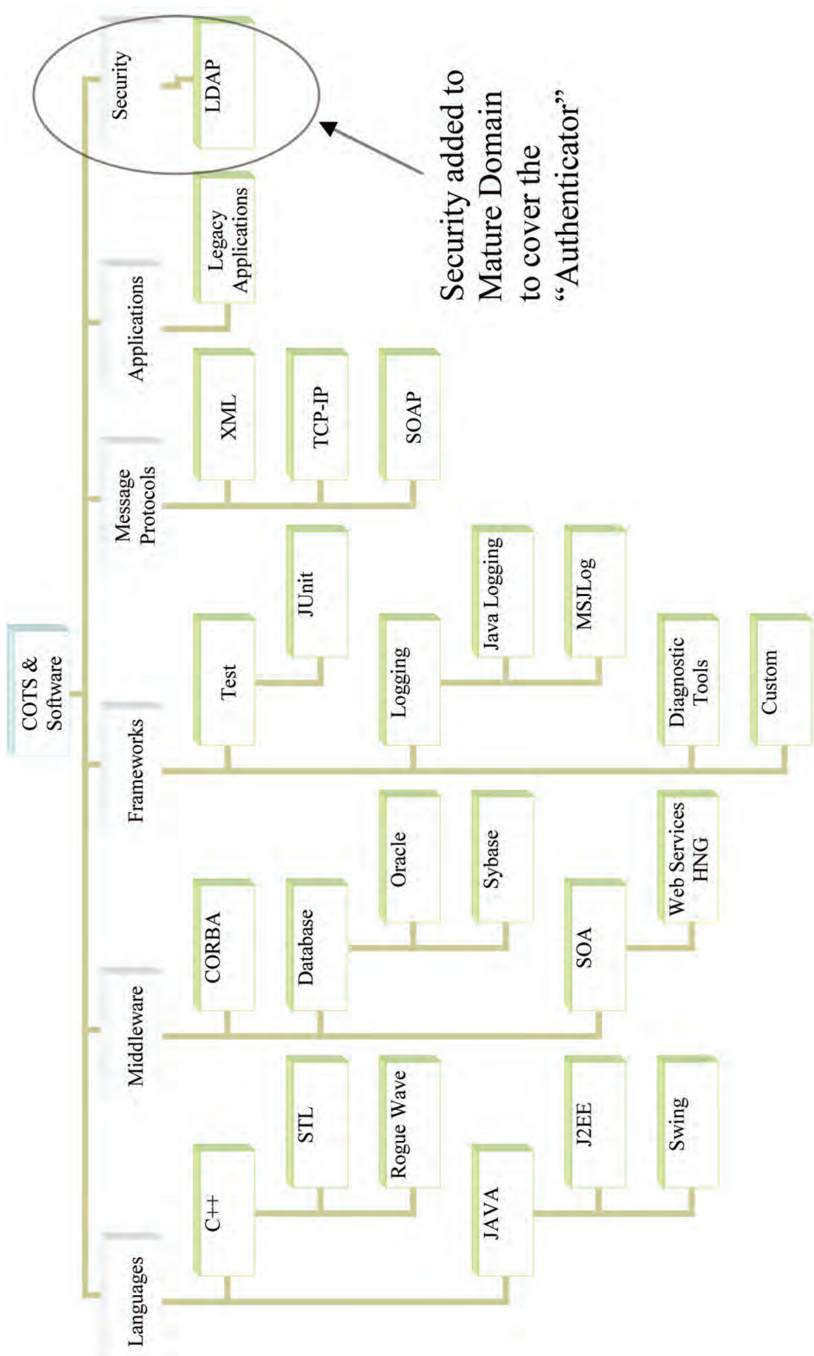

Figure 12.13: Revised mature domain with security.

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