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Design of a Framework to Measure the Degree of Live Virtual Constructive (LVC) Simulation Interoperability

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DESIGN OF A FRAMEWORK TO MEASURE THE DEGREE OF LIVE VIRTUAL CONSTRUCTIVE (LVC) SIMULATION INTEROPERABILITY

by

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ABSTRACT

Accomplishment of the Live, Virtual and Constructive simulation interoperability has been a major goal and a challenge in the Modeling and Simulation (M&S) community. There have been efforts to interoperate individual Live, Virtual and Constructive simulations within a common synthetic environment through suitable technologies such as interface specifications, protocols, and standard middleware architectures. However, achieving interoperability of LVC simulation is a technologically complex since it is affected by multiple factors, and the characteristics are not yet satisfactorily defined and studied. A proper method is absent to measure the potential interoperability degree of LVC simulation. Therefore, there should be an appropriate systematic approach to measure the potential LVC simulation interoperability which includes technical, conceptual and organizational domains.

This research aims to design a preliminary systematic approach to measure the potential interoperability degree of an individual Live, Virtual and Constructive simulation and a relevant organization which plans to use the simulation system for simulation interoperability. Specifically, a framework that contains components such as a) LVC simulation interoperability domains, b) interoperability domain factors, c) interoperability maturity levels, d) interoperability determination method is proposed. To accomplish the goal, a set of factors that determine the interoperability degree in LVC simulation environment are identified, and the factors are used to build the key elements of the framework. The proposed methodology for the framework design is based on systematic literature reviews and a survey involving a number of relevant domain experts. A case study is demonstrated to prove the validity and effectiveness of the developed framework. The case study illustrates how the interoperability levels of a simulation system and a relevant organization are effectively measured. This research potentially contributes by providing an understanding of the factors that determine the interoperability degree of LVC simulation, improvement of the LVC simulation interoperability measurement process, and consequently, accomplishment of more effective LVC simulation interoperability.

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Finally, this paragraph has been reserved for my dear wife, Sujeong. I really thank for your love and support which made this research possible.

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LIST OF ACRONYMS

ADD	Agency for Defense Development
AddSIM	Adaptive distributed parallel Simulation environment for Interoperable and reusable Models
API	Application Programmers Interface
C2	Command and Control
CBSE	Component-based Simulation Environment
CGF	Computer Generated Forces
COTS	Commercial-Off-The-Shelf
CTIA	Common Training and Instrumentation Architecture
DARPA	Defense Advanced Research Projects Agency
DIS	Distributed Interactive Simulation
DLL	Dynamic Link Library
DM&S	Defense Modeling and Simulation
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DOE	Design of Experiments
FOM	Federation Object Model
GUI	Graphic User Interface
HLA	High Level Architecture
IAM	Interoperability Assessment Methodology

IOL	Interoperability Level
i-Score	The Interoperability Score
JCIDS	Joint Capability Integration and Development System
LAN	Local Area Networks
LCI	Layers of Coalition Interoperability
LCIM	Levels of Conceptual Interoperability Model
LISI	Levels of Information System Interoperability
LVC	Live, Virtual and Constructive
MCISI	Military Communications & Information Systems Interoperability
MOE	Measures of Effectiveness
M&S	Modeling & Simulation
NATO	North Atlantic Treaty Organization
NMI	NATO C3 Technical Architecture Reference Model for Interoperability
NTI	Non-Technical Interoperability
OIAM	Organizational Interoperability Agility Model
OIM	Organizational Interoperability Maturity Model for C2
OMT	Object Model Template
PAID	Procedures, Application, Infrastructure, and Data
PDU	DIS Protocol Data Unit
QoIM	Quantification of Interoperability Model
R&D	Research & Development
RTI	Run Time Infrastructure

SIMNET	SIMulation NETworking
SISO	Simulation Interoperability Standards Organization
SoIM	Spectrum of Interoperability Model
SOM	Simulation Object Model
SME	Subject Matter Expert
SoS	System of Systems
SOSI	System of Systems Interoperability
SoSE	System of Systems Engineering
SSA	Standard Simulation Architecture
TENA	Test and Training Enabling Architecture
UML	Unified Modeling Language
XML	Extensible Markup Language

CHAPTER ONE: INTRODUCTION

1.1 Background

1.1.1 Live Virtual and Constructive (LVC) Simulation

In the past, live type simulation and training were the predominant method to evaluate the weapon system design, tactics, and maintained personnel readiness (Bezdek, Maleport, & Olshan, 2008). Live simulation is military training events involve real people operating real systems (Joint Staff, 2001). The live simulation type employs a large number of operational assets, training, and support personnel to achieve the objectives (Bezdek et al., 2008).

However, the advent of modern networking technology and the development of supporting protocols and architectures have led to widespread use interoperation of distributed Live, Virtual and Constructive simulations (Lutz, 2012). There has been a migration toward a cost effective mixture of different simulation types operating in a common synthetic environment to rehearsal planed strategy, and to develop training scenarios (Bezdek et al., 2008). The combination of three types of distributed simulations and applications into a single distributed system is called "***LVC***". ***LVC Simulation*** is a broadly used taxonomy describing a mixture of live, virtual, and constructive simulations (Joint Staff, 2001). Figure 1 shows a graphical representation of an LVC synthetic environment.

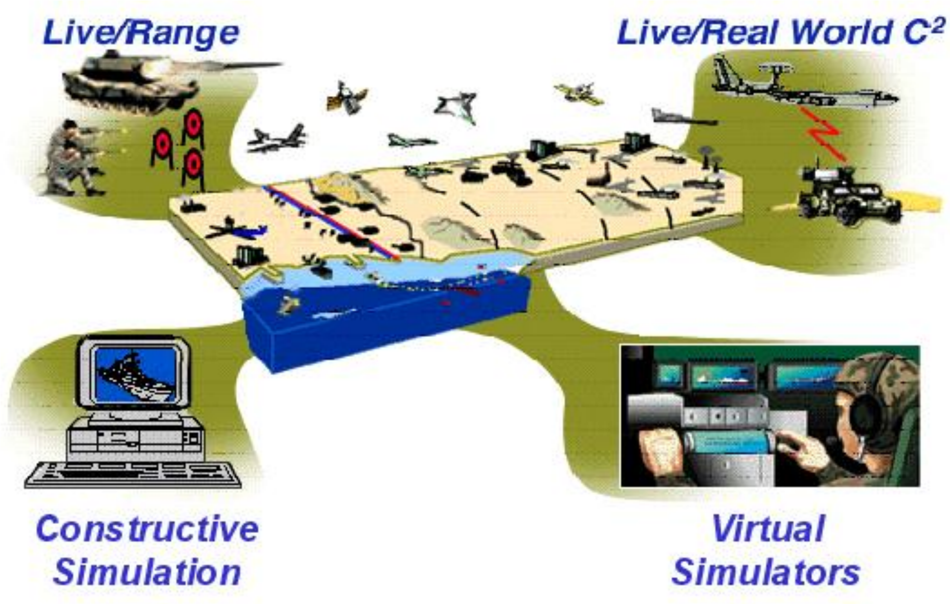

Figure 1: A Graphic of an LVC Synthetic Environment (Zalcman, Blacklock, Foster, & Lawrie, 2011)

1.1.2 LVC Simulation Interoperability and System Engineering Process

The strategy behind distributed simulation is to use networks and support simulation services to link existing M&S assets into a single unified simulation environment (Lutz & Drake, 2011). Legacy individual simulation systems are connected through medium such as middleware and gateways to guarantee logically correct interactions. Each simulation exchanges data through disparate middleware transport protocols, data exchange formats and applications (Gallant, 2010).

The distributed fashion of LVC simulation approach provides many powerful benefits compared to development and maintenance of large monolithic stand-alone simulation systems (Lutz, 2012).

1. First, it allows each individual simulation application to be co-located with its resident subject matter expertise rather than having to develop and maintain a large standalone

system in one location.

2. In addition, it facilitates efficient use of past M&S investments, as new, very powerful simulation environments can be quickly configured from existing M&S assets.
3. Finally, it provides flexible mechanisms to integrate hardware and/or live assets into a unified environment for test or training, and it is much more scalable than stand-alone systems.

It is no wonder that the benefits increased substantial attention on LVC simulation by the Department of Defense (DoD). As the interests continue to grow, there has been a consensus on the need for interoperability of LVC simulation models (DoD Directive, 1995). Also corresponding technology advances in supporting LVC environments are also necessary, and the efforts to develop new interoperability technology should continue to advance and mature.

However, despite of the powerful benefits of LVC simulation, there are many issues related to ***LVC simulation interoperability*** concerns. ***Interoperability*** is the ability of simulation systems to interact with other simulation systems and to exchange data in common interoperable simulation environment (Tolk, 2013). Interoperability causes the elements of a system to achieve a common understanding of each other and the environmental condition (Rezaei, Chiew, & Lee, 2014).

A common perception is that interoperability is synonymous with connectivity (Kosanke, 2006). But the paradigm of LVC simulation interoperability is far beyond of mere connection; it is related to all of the interoperability level (Wang, Tolk, & Wang, 2009). For example, because simulation systems fundamentally do not allow communication among them (Cellier & Kofman, 2006), there are technical issues including consistency of time advancement mechanisms, compatibility of supported services, data format compatibility, and even agreement on data element s semantics and ontology exchanges in simulation runtime (Lutz & Drake, 2011). For this reason, developing and implementing an assessment and measurement solution in the area is extremely complex and problematic (DoD Directive, 1995). Indeed, substantive interoperability between Live, Virtual and Constructive assets has long been a "Holy Grail" for the Modeling & Simulation (M&S) community (Bizub & Cutts, 2007).

To address such issues, many ***Simulation Standard Architectures (SSAs)*** have been developed. SSA allows coordinated runtime interaction among participating LVC simulations. Examples of such architectures include the Distributed Interactive Simulation (DIS) (IEEE, 1995), the Test and Training Enabling Architecture (TENA) (Noseworthy, 2008), and the High Level Architecture (HLA) (IEEE, 2000). For example, the DIS standard establishes a common data exchange environment, also known as a common messaging environment by using Protocol Data Units (PDU). PDU supports interoperability of heterogeneous, geographically-distributed live, virtual and constructive simulations (Dahmann & Morse, 1998).

Although the SSAs provide interoperable environments, SSAs cannot be the fundamental solution for true LVC simulation interoperability. Interoperability issues are much broader than simple SSAs (Bizub & Cutts, 2007). Current state-of-the-art research on LVC simulation interoperability only focuses on solving some specific interoperability problems at technological level (Chen, Vallespir, & Daclin, 2008).

The LVC simulation interoperability is not solely dependent on technical factors. Other factors such as conceptual and organizational factors must be considered. For example, successful simulation interoperability requires cooperation of simulation experts from diverse domains. The organization which implements simulation interoperability must have enough capabilities in terms of System Engineering (SE) perspective because simulation interoperability is determined by many factors from different domains.

The interoperability issues become much worse when the LVC simulation interoperability degree is measured and determined. Because the interoperability with using SSAs are heavily dependent on simulation implementers, the interoperability degree are different with using same SSA. For example, despite HLA is widely adopted within North Atlantic Treaty Organization (NATO) nations, HLA is not "plug and play". Some parts of the standards are left open to actual implementation (Zalcman et al., 2011).

Any successful development LVC simulation is heavily dependent on well-defined SE processes (Gallant & Gaughan, 2010). There have been system processes for distributed simulation development. They are the Federation Development and Execution Process (FEDEP) and the Distributed Simulation Engineering and Execution Process (DSEEP). They are aligned with specific simulation architecture such as Distributed Interactive Simulation (DIS), High Level Architecture (HLA), and Test and Training Enabling Architecture (TENA). FEDEP is a standardized process for developing interoperable HLA based federations. FEDEP is already designed as a framework into which lower level practices/procedures native to targeted user communities can be easily integrated.

DSEEP is for single, unifying SE process description for distributed simulation. It is ideal choice for SE Process task because a) It is based on existing distributed simulation processes, b) It is architecture/user community neutral, and c) It is already designed as a framework into which lower level practices/procedures native to targeted user communities can be easily integrated.

Systems engineering efforts for distributed simulation environments are typically based on the middleware transport used, the applications available and the constraints placed on the technical team including network, computer and personnel limitations (Gallant & Gaughan, 2010). Therefore, the LVC simulation interoperability can be determined and measured by the elements in the LVC simulation SE processes. For example, procured sufficient specialized experts and IT infrastructure will improve the potential interoperability of the simulation systems.

1.1.3 LVC Simulation Interoperability Measurement

To improve the LVC simulation interoperability in systems engineering process perspective, available interoperability measurement methods must be facilitated or new methods should be proposed. However, LVC simulation is necessarily composed of a set of operationally and managerially independent systems. The component systems are heterogeneous, changing and inconsistent, and are created by different people using different programming languages, in different conditions and are tuned for various platforms, are used and developed by many stakeholders with conflicting needs. Despite of the consistent efforts by the M&S community, all the attempts to develop a comprehensive interoperability assessment and measurement method acting on a systematic basis have been in vain (National Research Council, 1999).

Because most systems today need to interoperate with other systems, interoperability measurement and planning is a key part of systems engineering planning (Lane & Valerdi, 2011).

To measure the LVC simulation interoperability, a systematic approach that manages the interoperability measurement process through the simulation life cycle is needed (Leite, 1998). This process also can be seen in terms of SE. In this perspective, simulation interoperability degree must be manifested at the system requirements generation stage (Leite, 1998). Until recently, few interoperability requirements were identified, and often only after the system was deployed (Morris, Levine, Meyers, Place, & Plakosh, 2004).

When the efforts to measure the LVC simulation interoperability without systematic approach are made, the validity of the measurement is not good due to the characteristics of LVC simulation. The reasons are misunderstandings, incomplete requirements or there were unknown relationships between the requirements that were not captured (Bezdek et al., 2008). Therefore a systematic interoperability measurement process is needed to measure the LVC simulation interoperability.

1.2 Problem Statement

It is no doubt that the development of simulations interoperation requires very complex works and significant highly skilled effort (Dahmann, Salisbury, Barry, & Blemberg, 1999). Besides, interoperability measurement of simulations requires a highly integrated systematic approach. As explained in the previous section, the absence of the systematic approaches motivated this research. Detailed research problem is explained below.

"Several interoperability measurement methods have been presented to measure and improve the interoperability. However, there is no organized interoperability measurement framework focused on the LVC simulation domain due to the complexity, the unique characteristics and the design considerations of the domain. Therefore, there must be a LVC

simulation-specific systematic framework to measure the interoperability degree in technical, conceptual and organizational point of view."

1.3 Proposed Approach

This research focuses on development of a framework in the context of LVC simulation interoperability measurement. Specifically, an inaugural framework to measure the interoperability degrees of a single Live, Virtual, and Constructive Simulation systems and a relevant organization which implements simulation interoperability with the simulation system are established. The framework allows LVC simulation developers to measure the interoperability degree as the part of the SE process. The proposed framework is demonstrated in Figure 2.

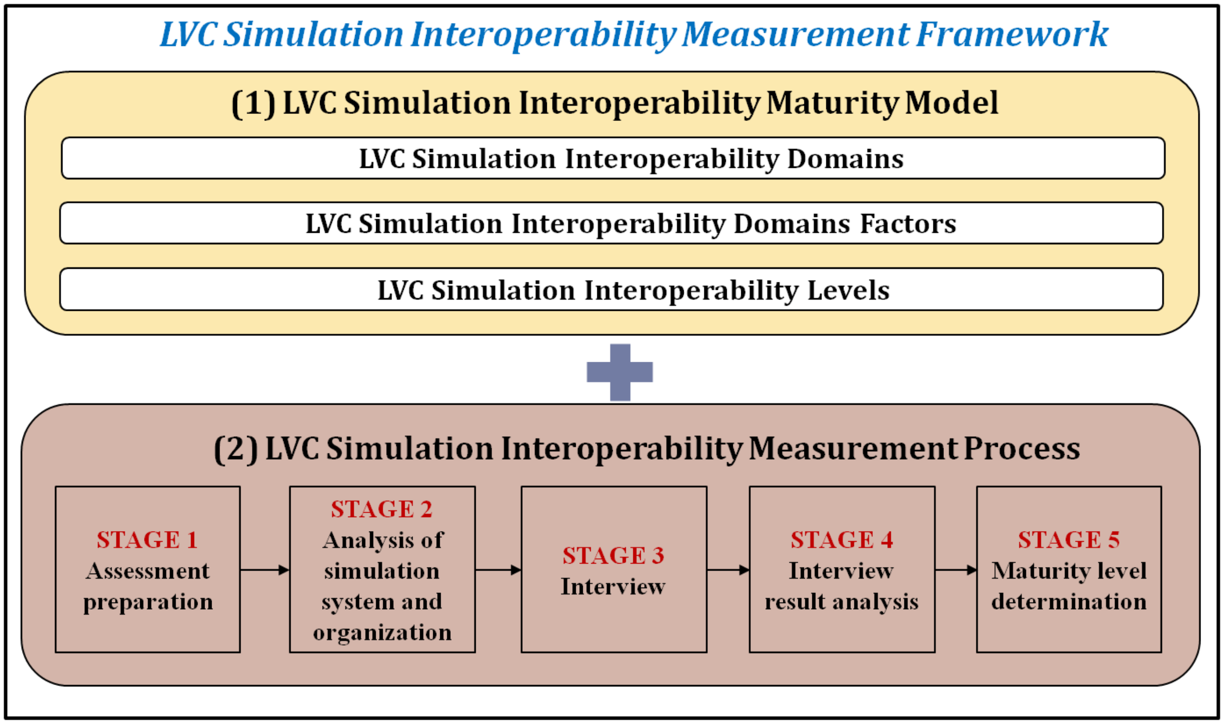

Figure 2: The Proposed Interoperability Measurement Framework

The framework consists of two parts: **a)** ***LVC simulation interoperability maturity model*** and **b)** ***LVC simulation interoperability measurement process***. The maturity model elements are necessary to establish maturity model which provides an accurate interoperability maturity status of a system. An well-formalized systematic interoperability measurement process contains a series of interoperability maturity model defining process (Rezaei et al., 2014). Specifically, the process includes interoperability domains, interoperability domains factors, interoperability maturity levels, and interoperability level determination method. In the process, LVC simulation developers can set an interoperability goal and then interoperability requirements are analyzed and reflected to the simulation objectives. Therefore, the LVC simulation interoperability maturity model is defined to formalize the framework.

As specific methods to collect data for the formalization of the framework, systematic literature reviews and an expert survey were conducted. Mainly, the fundamental framework continuant such as interoperability domains, interoperability domains factors, interoperability maturity levels, and defining scoring method were collected through the methodologies.

This research used the design science research method for information systems (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Figure 3 shows the design science research method by Peffers et al. (2007).

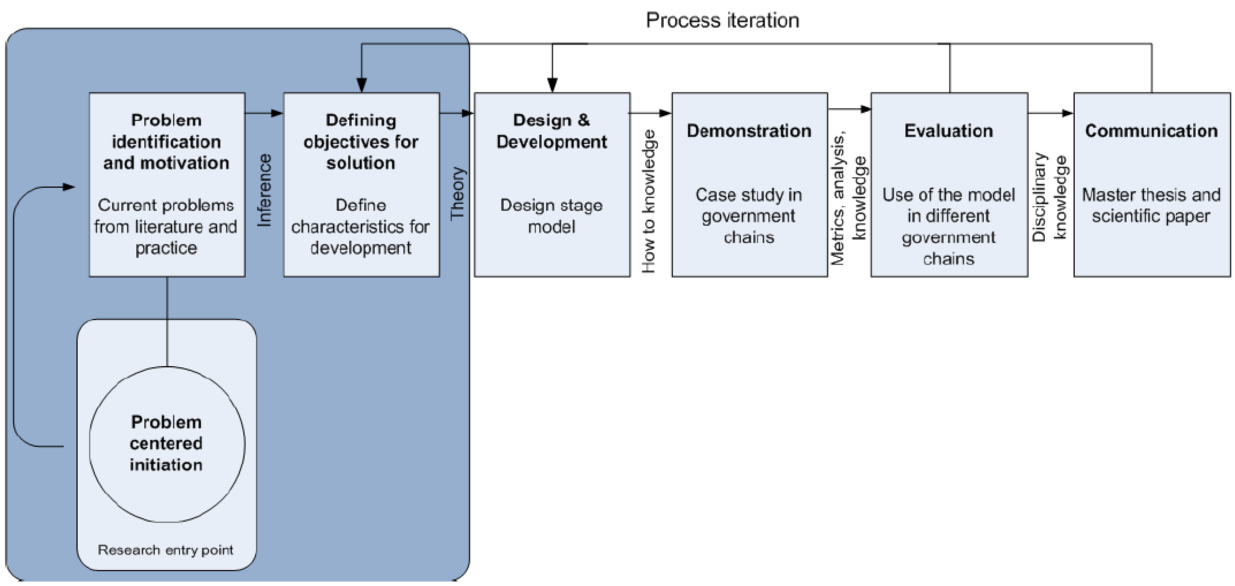

Figure 3: A Design Science Research Method by Peffers et al. (2007)

1.4 Research Question

When creating a framework, applicable criteria which prove the appropriateness of the framework are necessary. The criteria also guide the research direction to adopt appropriate techniques and tools to build the framework. The selection of the criteria incurs initial research questions. This thesis sought to answer the central research question. The set of research questions is shown in Table 1.

Table 1: Research Questions

Area	Question
Central Question	• **What is the framework to measure the LVC simulation interoperability levels?**
Other Questions	• **What are the elements for a successful LVC simulation interoperability measurement?** • What are the interoperability domains? • What are the interoperability domains factors? • What are the interoperability maturity levels? • What is the appropriate interoperability determination method?

1.5 Contribution

The contributions from this research work include the followings:

1. This research provides a new framework to plan and measure the interoperability levels of an LVC simulation and the relevant organization. The framework provides an environment in which simulation developers can predict and evaluate the interoperability degree of a single simulation system and an organization which implements simulation interoperability with the simulation system.
2. A case study with a Component-based Simulation Environment (CBSE) to validate proposed framework was implemented. Also architectural characteristics and core factors of the CBSE that determine the degree of interoperability were identified. In this research, the Adaptive distributed parallel Simulation environment for Interoperable and reusable

Model (AddSIM) developed by the Agency for Defense Development (ADD) was used. Also the Simulation Interoperability Laboratory in the University of Central Florida was a target organization for the case study. This validation effort found the current interoperability capability of the CBSE, and eventually the result from the case study contributed to enhance the interoperability capabilities of the CBSE.

1.6 Synopsis

In Chapter 1, the motivation and the context of the research were elaborated. The rationale of literature survey, the realm of the research, and gap analysis are presented in Chapter 2. In Chapter 3, research methodology on development of interoperability measurement framework of LVC simulation is detailed. Each component of the framework is described. The development of initial interoperability framework, systematic literature reviews and a survey to refine the framework, and the final framework are followed in Chapter 4. Chapter 5 presents a case study to prove the validity of the framework. The AddSIM and a research organization were used as key targets in the case study. Chapter 6 concludes the thesis with contributions, limitations and further research investigations and extensions.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter provides a review about existing research to answer the research questions mentioned in Chapter 1. The literature review consists of four basic research areas to provide basic knowledge background to the readers. The areas are selected according to the relevance of this research are: a) LVC simulation, b) Interoperability, c) Interoperability measurement and measurement models, and d) Systems Engineering. This chapter ends with a gap analysis that differentiates this research from other existing research related to interoperability measurements.

2.2 LVC Simulation

2.2.1 Simulation Classification

The military training using simulation is officially classified as ***Live, Virtual and Constructive simulation*** by U.S. Department of Defense (DoD). The commonly used definitions of Live, Virtual and Constructive simulation systems are shown in Table 2.

Table 2: The Definition of Live, Virtual, and Constructive Simulation (DoD Directive, 1995)

Classification	**Definition**
Live Simulation	A simulation involving real people operating real systems in a real environment.
Virtual Simulation	A simulation involving real people operating simulated systems. Virtual simulations inject human-in the- loop (HITL) in a central role by exercising motor control skills (e.g., flying an airplane), decision skills (e.g., committing fire control resources to action), or communication skills (e.g., as members of a C4I team).
Constructive Simulation	Models and simulations that involve simulated people operating simulated systems. Real people stimulate (make inputs) to such simulations, but are not involved in determining the outcomes.

Live simulation involves real people operating real systems in a real environment (DoD Directive, 1995). Daly and Thorpe (2009) differentiate live simulation training from Synthetic training which is executed with real people using real equipment in a virtual environment. The good example of live systems is the Air Combat Maneuvering Instrumentation (ACMI) system (Cronkhite & Kamhis, 1994). The system attached to real aircraft, for example can provide information such as location, speed, acceleration, system orientation and weapon status of the aircraft.

Virtual simulation is a simulation involving real people operating simulated systems (DoD Directive, 1995). Human is in Virtual simulation (human-in the- loop (HITL)) to exercise motor control skills, decision skills, and communication skills. These systems may have advanced distributed simulation capabilities that use simulation network protocols. However some form of common connection gateway device may be required to convert the simulation system protocols to corporate standard, synthetic range, interoperability protocols.

Constructive simulation involves simulated people using simulated equipment in a simulated environment (DoD Directive, 1995). Real people set scenarios in the simulations, but they are not involved in determining the outcomes. Constructive simulations show synthetic representation of both platforms and people. Constructive training can include personal computer and war game. This training focuses primarily on strategic, operational, or tactical decision-making.

Although there is a general classification, sometimes categorizing simulations into live, virtual and constructive categories is problematic because there is no clear division between these categories. The degree of human participation in the simulation is infinitely variable, as is the degree of system realism (DoD Directive, 1995). This is the reason why many simulations can be seen as hybrid systems that contain a mix of entity types (Hodson & Baldwin, 2009). For example, a virtual simulation routinely includes both virtual and constructive entities.

2.2.2 Integrated Live Virtual and Constructive Simulations

The simulation systems are usually standalone, but they can be interoperated as a distributed simulation system using a network that runs different simulations simultaneously. A *distributed simulation* is simply one that is executed on multiple computers that are geographically distributed, whereas a *federated simulation* is a system-level virtual experiment in which multiple sub-system or federate simulation models participate (Rathnam, 2004).

To create a distributed and interoperated simulation environment, a hybrid simulation is assembled from a set of independent distributed simulations which is called as a *'LVC* *simulation'*. LVC simulation is a System of Systems (SoS) which provides an environment where multiple heterogeneous simulation systems interoperate with each other in real-time (Hodson, 2009). Within the environment, simulated entities, and weapon systems are generated, and current state information are shared through a network infrastructure and standard simulation architectures.

2.2.3 Standard Simulation Architecture (SSA)

To achieve interoperability among LVC systems within a common scenario requires compliance with an agreed set of interoperability standards including network infrastructure, data, interoperability protocols, platform and environment representation, etc (Zalcman et al., 2011). This requires the development of ***Standard Simulation Architectures (SSAs)*** that have been developed in order to achieve interoperability among independently developed simulations.

SSAs are intended to allow independently executing models to interoperate via a network to collaboratively simulate a common scenario or environment. SSAs can include definitions of message formats to be exchanged at runtime. There are a number of different names of SSA: a) Distributed Simulation Architecture (Fujimoto, 1999; Henninger et al., 2008; Loper & Cutts, 2010), b) Modeling and Simulation (M&S) Interoperability Standards (Tolk, 2012), c) M&S Interoperability Protocol (Gustavsson, Björkman, & Wemmergård, 2009), d) Distributed Simulation Protocols (Seo & Zeigler, 2009) or e) Distributed Simulation Architecture (Wu, 2005), etc.

A number of SSAs have been used include: DIS, HLA and TENA. The presence of several SSAs allows users to select the SSA that best meets their needs. The SSAs have contributed to establish distributed simulation environments such as geographically distributed joint training, mission rehearsal, and exercises. In this research only major SSAs are explained in the next section.

2.2.3.1 High Level Architecture (HLA)

High Level Architecture (HLA) is a general purpose technical architecture for distributed simulation systems which is used by simulation developers and users to create simulation applications (J. Dahmann, Fujimoto, & Weatherly, 1998). HLA suggest a framework in which developers can structure their simulation systems to interoperate with other simulation systems and assets. HLA facilitates interoperability among different types of models and simulation applications. Using HLA, computer simulations can interact with other computer simulations regardless of the computing platforms. HLA also promotes reuse of simulation software modules (Fujimoto, 1999).

HLA is intended to provide a general purpose distributed simulation architecture suitable for any type of model and broad range of application including training, logistics planning, analysis, and simulation-based acquisition (Rabelo, Eskandari, Shaalan, & Helal, 2007). HLA is not "plug and play". Some parts of the standards are left open to the RTI implementer, thus different RTIs are not guaranteed to interoperate each other (Blacklock & Zalcman, 2007).

HLA consists of three main components: the Framework and Rules, Interface Specifications, and the Object Model Template (OMT). Table 3 shows the main components of HLA.

Table 3: The Main Components of HLA (IEEE, 2000)

Components	Description
The Framework and Rules	Capstone document for a family of related HLA standards. It defines the components and the rules that outline the responsibilities of HLA federates and federations to ensure a consistent implementation.
The Federate Interface Specification	Defines the standard services of the HLA Runtime Infrastructure (RTI). These services are used by the interacting simulations to achieve a coordinated exchange of information when they participate in a distributed federation.
The Object Model Template	Describes object models that define the information produced or required by a simulation application, and for reconciling definitions among simulations to produce a common data model for mutual interoperation

The ***Runtime Infrastructure (RTI)*** is a software implementation of the HLA Interface Specification. RTI defines the common interfaces for distributed simulation systems during the federation execution of the HLA simulation (Rabelo, Eskandari, Shaalan, & Helal, 2007). It is the architectural foundation that promotes portability and interoperability. All shared information exchanged during a federation execution must be passed through the RTI.

Figure 4 shows a logical view of an HLA federation. In the figure, multiple federates exchange data with each other during simulation execution. The simulation data exchange follows a Federation Object Model (FOM). The RTI provides a general set of services that support the simulations in carrying out these federate-to-federate interactions and federation management support functions (Lee, 2011).

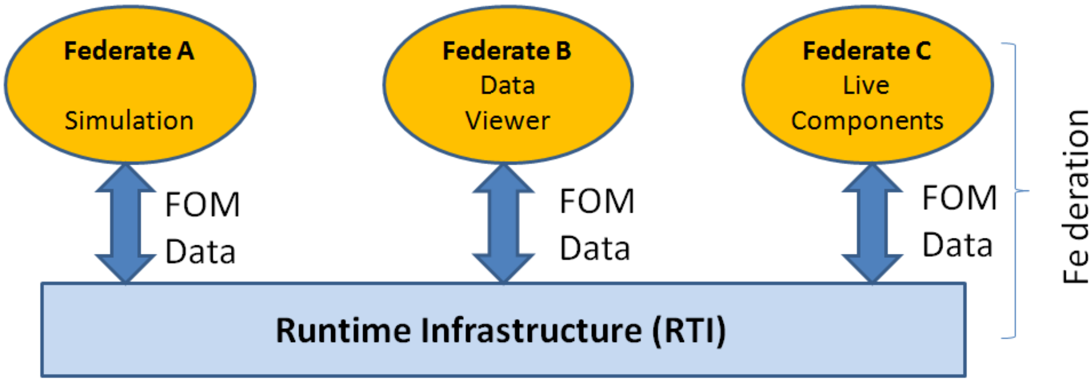

Figure 4: Functional Overview of HLA

2.2.3.2 Distributed Interactive Simulation (DIS)

In the early 1990's, ***<u>Distributed Interactive Simulation (DIS)</u>*** standard architecture was created to support virtual battles involving Semi-Automated Forces (SAF) (Steinman & Hardy, 2004). Distributed Interactive Simulation (DIS) is an IEEE standard for conducting real-time platform-level war gaming across multiple host computers and is used worldwide, especially by military organizations but also by other agencies such as those involved in space exploration and medicine. The goal of DIS is to interoperate various types of different simulations in distant locations to create highly interactive integrated simulation environment. Military exercises interoperability through DIS is intended to support a mixture of live, virtual and constructive entities. The standard architecture is used to interoperate simulation systems, products from different vendors.

Simulation state information and interactions are encoded into messages known as Protocol Data Units (PDUs). All interaction between simulations applications occur using the PDU format. PDUs are exchanged between hosts using existing transport layer protocols. DIS normally uses User Datagram Protocol (UDP) to broadcast information and interactions (Hofer & Loper, 1995).

2.2.3.3 Test and Training Enabling Architecture (TENA)

In the late 1990, after the HLA initiative was in progress, the ***Test and Training Enabling Architecture (TENA)*** emerged. The TENA was developed by the TENA Software Development Activity (SDA) to provide the architecture and the software implementation necessary to do three things: a) TENA enables interoperability among range systems, simulation systems, and C4ISR systems quickly and economically, b) TENA promotes reuse for range asset utilization and for future developments, and c) TENA provides composability to rapidly assemble, initialize, test, and execute a system from a pool of reusable, interoperable elements (Tolk, 2012). The SSA can be used to interoperate live, virtual and constructive simulations.

The core of TENA is the TENA Common Infrastructure, including the TENA Middleware, the TENA Repository and the TENA Logical Range Data Archive. TENA also specifies the existence of a number of tools and utilities, including those necessary for the efficient creation of a logical range (TENA, 2002). Range instrumentation systems and all of the tools interact with the common infrastructure through the medium of the TENA object model. The TENA object model encodes all of the information that is transferred between systems during a range event (TENA, 2002). Figure 5 depicts an overview of TENA.

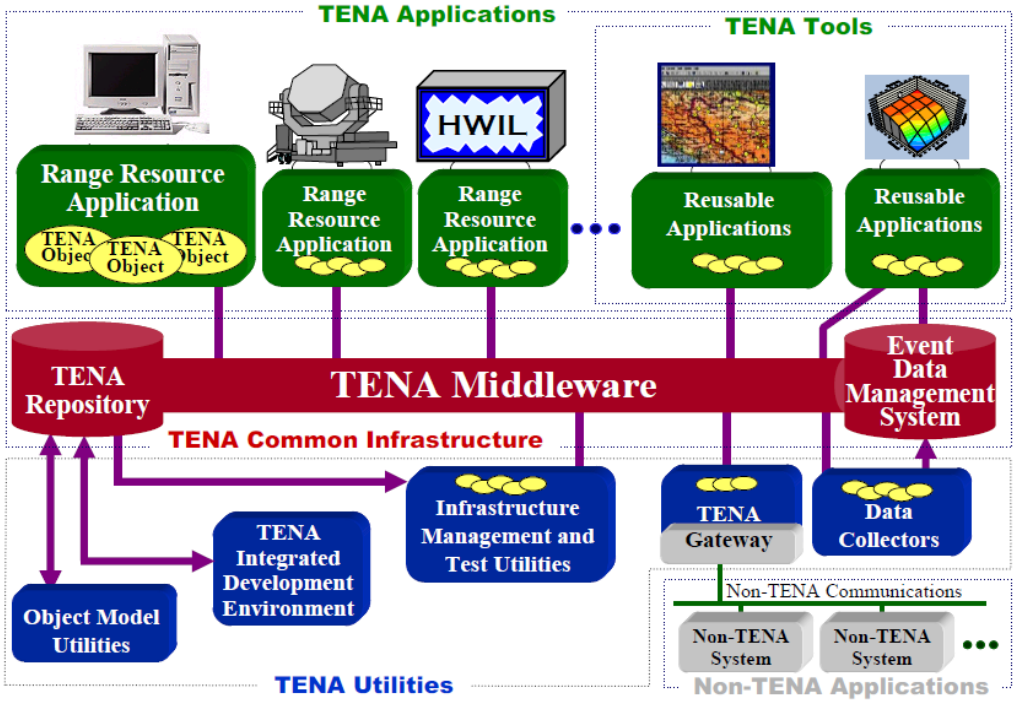

Figure 5: Overview of TENA

2.3 Interoperability

2.3.1 The Definition of Interoperability

Interoperability is the central concept of this research. Interoperability has been an important and widely discussed topic over the past decade, and the concept continues to draw attention within the Department of Defense (DoD) (Ford, Colombi, Jacques, & Graham, 2009a). The popular perception is that interoperability is synonymous with connectivity. However, true interoperability is much more than just connectivity (Kasunic & Anderson, 2004).

Although there is no universal definition for interoperability, there exist widely accepted definitions by diverse organizations. The popularly adopted definitions were proposed by the

Institute of Electrical and Electronics Engineers (IEEE) and US Department of Defense (DoD). Table 4 shows the definitions of interoperability.

Table 4: The Definitions of Interoperability

Organization	**Definition**
IEEE (Radatz, Geraci, & Katki, 1990)	(1) The ability of two or more systems or elements to exchange information and to use the information that has been exchanged
	(2) The capability for units of equipment to work efficiently together to provide useful functions
	(3) The capability achieved through joint conformance with a given set of standards, that enables heterogeneous equipments, generally built by various vendors, to work together in a network environment
	(4) The ability of two or more systems or components to exchange and use the exchanged information in a heterogeneous network
US Department of Defense (Staff, 2001)	(1) The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces, and to use the services so exchanged to enable them to operate effectively together.
	(2) The condition achieved among communications-electronics systems or items of communications- electronics systems equipment when information or services can be exchanged directly and satisfactorily between them and/or their users. The degree of interoperability should be defined when referring to specific cases.
	(3) (a) Ability of information systems to communicate with each other and exchange information; (b) Conditions, achieved in varying levels, when information systems and/or their components can exchange information directly and satisfactorily between them; (c) The ability to operate software and exchange information in a heterogeneous network (i.e., one large network composed of several different local area networks); (d) Systems or programs capable of exchanging information and operating together effectively.

Although there are many useful definitions, for the purposes of this research, a new interoperability definition is proposed as:

"Interoperability is the ability of a set of heterogeneous communicating systems or tools/applications capable of effectively exchanging information, and operating together according to specified state data and interaction rules."

This definition is adopted because a) interoperability occurs between a set of heterogeneous systems or applications, b) the definition describes interoperability as a relationship between systems, c) the definition implies that interoperation follows specified and agreed rules, and d) interoperability implies effective exchanging information and operation. Therefore, the definition of LVC simulation interoperability is:

"LVC simulation interoperability is the ability of a set of heterogeneous Live Virtual Constructive simulations capable of effectively exchanging information and operating together according to specified state data and interaction rules."

2.3.2 Interoperability Levels

Measuring interoperability requires interoperability maturity resolution at several distinct levels. Interoperability measurement approach defines a set of maturity levels (Ford, 2008). There have been a number of defined interoperability levels. However, only four levels are considered major levels. Heiler (1995), Carney and Oberndorf (2004), Munk (2002), Levine, Meyers, Morris, Place, and Plakosh (2003), Kasunic and Anderson (2004) defined four levels of interoperability: technical, syntactic, semantic, and organizational interoperability. Table 5 shows the definitions and the characteristics of the interoperability levels.

Table 5: Interoperability Levels

Levels	**Description**
Technical	• Achieved among communications-electronics systems or items of communications-electronics equipment when services or information can be exchanged directly and satisfactorily between them and their users (Novakouski & Lewis, 2012). • Typically associated with hardware/software components, systems, and platforms that enable machine-to-machine communication. • Focuses on communication protocols and the infrastructure required for the protocols to function (Veer & Wiles, 2008).
Syntactic	• Generally associated with data formats. The messages transferred by communication protocols should possess a well-defined syntax and encoding, even if only in the form of bit-tables (Veer & Wiles, 2008).
Semantic	• The ability to operate on the data according to the agreed-upon semantics (Lewis & Wrage, 2006). • Related to the definition of content, and deals with the human, rather than machine, interpretation of this content. • Denotes that a common understanding exists between people regarding the definition of the content (information) being exchanged (Hall & Koukoulas, 2008).
Organizational	• Capability of organizations to effectively communicate and transfer meaningful data (information), despite the use of a variety of information systems over significantly different types of infrastructure, possibly across various geographic regions and cultures. • Relies on the successful interoperability of the technical, syntactic, and semantic aspects (Veer & Wiles, 2008).

2.4 Interoperability Measurement Models

Literature survey found many current interoperability measurement approaches including mathematical representation and system classification. This section describes the concept of interoperability measurements and several abstract models of interoperability. A summary of each method as well as the significant contribution is presented. The analysis of the literatures provides key concepts and principal theoretical backgrounds related to interoperability measurement

2.4.1 History of Interoperability Measurement Models

A number of papers have been published specifically on interoperability measurement. The papers provide very broad definition of the term "interoperability measurement". They propose a new interoperability measurement method, or an improvement to existing methods. Ford et al. (2007) provided a detailed survey of the aforementioned interoperability methods as shown in Figure 6. Total sixteen interoperability measurement models were identified.

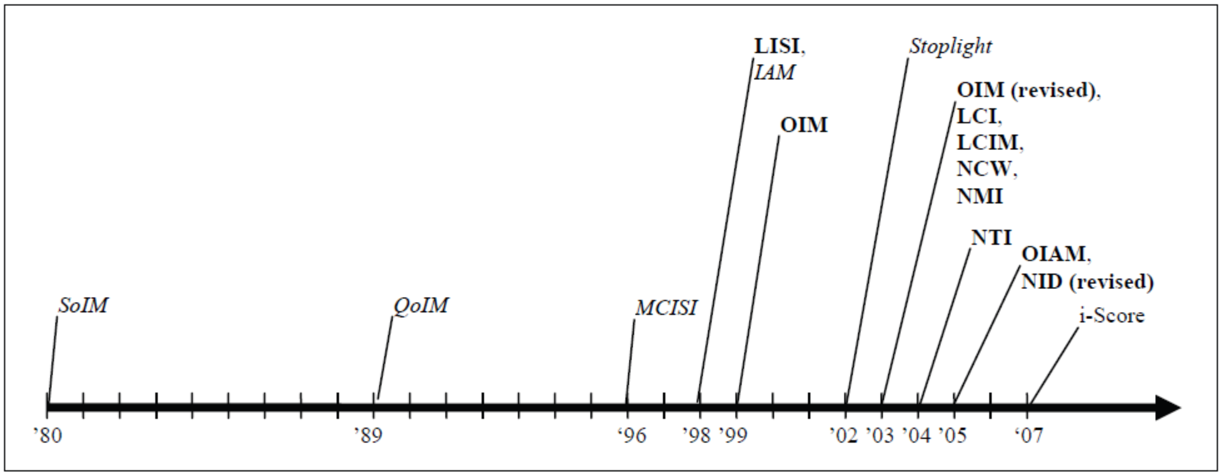

Figure 6: Status of Interoperability Measurement Models

2.4.2 Maturity and Non-maturity Models

The interoperability measurement models can be classified as maturity or non-maturity model. Maturity models can be applied to general systems whereas non-maturity models generally are applicable to only one system and interoperability type. Details on each models are explained in the following sections.

2.4.2.1 Maturity Models

Maturity model defines a basic set of interoperability maturity levels. The model was originally designed as a management tool to assess contractor software engineering ability. The concept of maturity model describes the interoperability maturity stages which a process progresses (Ford, 2008). Maturity model became the basis of the first maturity model-based interoperability measurement model called Levels of Information System Interoperability (LISI) (Ford, 2008). LISI was the template for numerous maturity model and maturity model-like interoperability measurement models designed to measure both information and non-information system interoperability. Table 6 shows the identified maturity models.

Table 6: Maturity Models

Organization	Model (Year)
Department of Defense	LISI (1998)
Australian Defense Science & Technology Organization (DSTO)	OIM (1999) OIAM (2005)
Old Dominion Univ. Virginia Modeling Analysis & Simulation Center (VMASC)	LCI (2003) LCIM (2003)
North Atlantic Treaty Organization (NATO)	NMI (2003)
DoD Command and Control Research Program	NCW (2003)
Carnegie Mellon Software Engineering Institute (CMU-SEI)	SoSI (2004)
Defense Science & Technology Lab. (DSTL) Contractor, QinetiQ	NTI (2004)
Research Establishment for Applied Science (FGAN)	NID (2005)
Air Force Institute of Technology (AFIT)	i-Score (2007)

2.4.2.2 Non-maturity Models

Non-maturity model-based interoperability measurement methods are not generalized methods of measuring interoperability. The models are specialized to a particular type of system. The earliest model, the Spectrum of Interoperability Model (SoIM), was designed as a program management tool, and defined seven levels of interoperability to measure the technical systems interoperability (LaVean, 1980). In 1989, Mensh, Kite, and Darby (1989) published the Quantification of Interoperability Methodology (QoIM) which assigned a measure of effectiveness (MOE) logic equation to each of seven interoperability-related components. Amanowicz (1996) made an important observation that the distance between systems is a degree of interoperability. The Interoperability Assessment Methodology (IAM) provided an eclectic mix of interoperability attributes and assorted equations applied by a flowcharted interoperability assessment process (Leite, 1998). Hamilton Jr, Rosen, and Summers (2002) who criticized the complexity of LISI offered a simplified stoplight model (2002) which lacks specific guidelines for color mapping to systems. Finally, Ford (2008) proposed the Interoperability Score (i-Score) to measure the operational interoperability of military systems. Table 7 shows the identified non-maturity models.

Table 7: Non-maturity Models

Organization	Model (Year)
Defense Information Systems Agency (DISA)	SoIM (1980)
MITRE Corporation	QoIM (1989)
Military University of Technology, Warsaw, Poland	MCISI (1996)
Joint Theater Air & Missile Def. Org. (JTAMDO) Contractor SIM	IAM (1998)
Joint Forces Cmd (JFCOM) Joint Forces Program Office (JFPO)	Stoplight (2002)

2.4.3 Interoperability Measurement Models

This section provides brief summaries of the models.

2.4.3.1 Spectrum of Interoperability Model (SoIM)

In 1980, Gilbert LaVean in the Defense Information Systems Agency (DISA) acknowledged that inter-system interoperability degree was very low because of the absence of interoperability measurement by which to state goals for specific systems (LaVean, 1980). Thus he developed the Spectrum of Interoperability Model (SoIM). The model combines a technical level (1-4) with a management/control level (1-6) to determine an interoperability level ranging from 1 to 7. The interoperability levels are shared resources, separate systems, multiple entry points, gateways, compatible systems, completely interoperable systems, and same system

(LaVean, 1980). Table 8 shows the seven levels of interoperability which are the combination of the two measures.

Table 8: SoIM Levels of Interoperability

Number	**Name**	**Technical Measure**	**Management/Control Measure**
1	Separate Systems	1	1
2	Shared Resources	1	2
3	Gateways	2	3
4	Multiple Entry Points	2	4
5	Conformable/Compatible Systems	3	4
6	Completely Interoperable Systems	3	5
7	Same System	4	6

2.4.3.2 Quantification of Interoperability Methodology (QoIM)

Mensh et al. (1989) presented the Quantification of Interoperability (QoIM) in 1989. The approach to interoperability measurement is unique because the model associated interoperability with Measures of Effectiveness (MOE). The goal of the model was to assess interoperability issues for three mission areas: Wide Area Surveillance (WAS), Over-The-Horizon Targeting (OTH-T), and Electronic Warfare (EW) by quantifying seven interoperability components (Mensh et al., 1989). They stated that interoperability of systems, units, or forces can be factored into a set of components that can quantify interoperability and identified the seven components as media, languages, standards, requirements, environment, procedures, and human factors (Ford, 2008).

2.4.3.3 Military Communications and Information Systems Interoperability (MCISI)

MCISI models communications and information system (CIS) interoperability using "level of command", "CIS services", and "transmission medium" using red, yellow, or green to indicate none, partial, or full interoperability in a 3D matrix. Further mathematical analysis views systems as points in a multi-dimensional space and calculates an interoperability measure between two features in different systems by computing their "distance" from each other.

2.4.3.4 Levels of Information System Interoperability (LISI)

The Levels of Information System Interoperability (LISI) is perhaps the most prominent interoperability maturity model within the Department of Defense. Even though it was developed in 1998, LISI continues to be referenced today. It began development at the MITRE Corporation in 1993 and was published in 1998 by the C4ISR Architecture Working Group (AWG) (C4ISR Architecture Working Group, 1998). LISI is a system focused vice mission focused method applicable only to information systems.

Like SoIM, LISI describes levels of interoperability called maturity levels. Whereas SoIM has seven levels, LISI has five—Level 0 (Isolated), Level 1 (Connected), Level 2 (Functional), Level 3 (Domain), and Level 4 (Enterprise). However, LISI improves upon SoIM by giving four attributes of the levels described by the acronym PAID—Procedures, Applications, Infrastructure, and Data. The LISI Reference Model is shown in Figure 7.

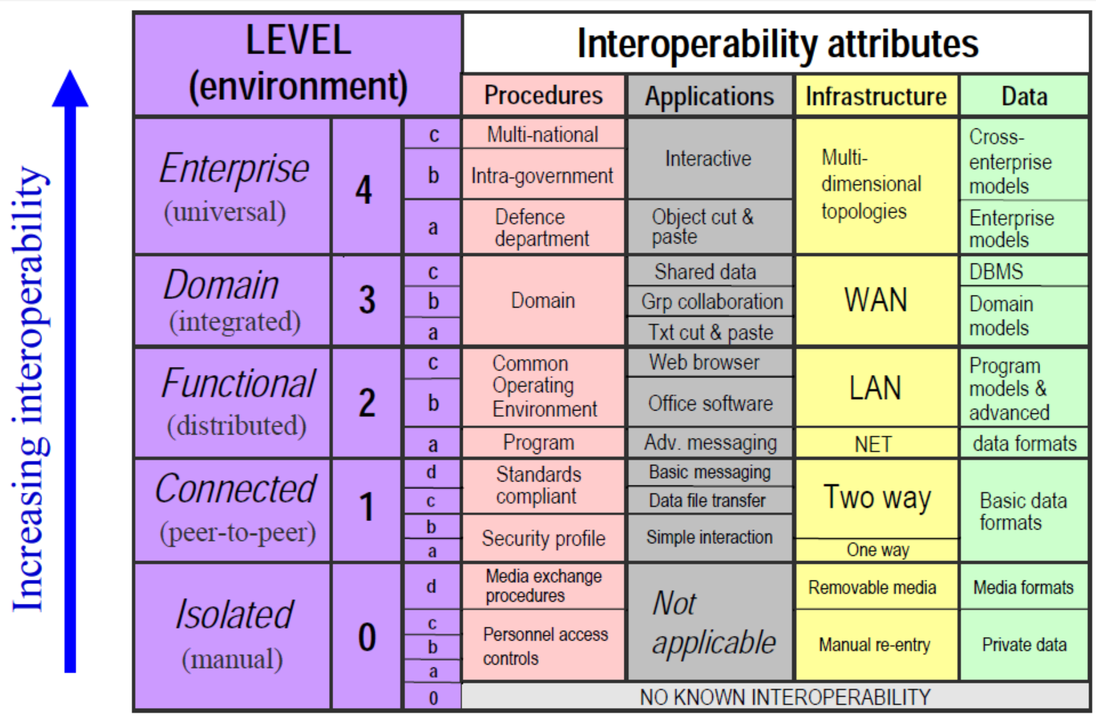

Figure 7: LISI interoperability maturity model

A web-based questionnaire is completed in order to generate the Interoperability Profile which contains information about a system for all four interoperability attributes. From the profile, an Interoperability Metric can be obtained which is a triplet of metric type (Generic, Expected, & Specific), Level (0…4), and Sub-level (a…z). The metric describes the level of interoperability for one system (generic) or a pair of systems (expected and specific) (Ford, 2008). The generic metric is the best level of interoperability a single system is capable of whereas the expected metric describes the highest common level of interoperability for a system pair. The specific metric describes the highest common level of interoperability between two information systems across all PAID attributes (Ford, 2008).

Numerous interoperability maturity models used LISI as a template to measure information and non-information system interoperability such as the Organizational

Interoperability Model for C2 (OIM) (Clark & Jones, 1999; Clark & Moon, 2001; Fewell & Clark, 2003, the Levels of Conceptual Interoperability Model (LCIM) (Tolk & Muguira, 2003), NATO C3 Technical Architecture Reference Model for Interoperability (NMI) (NATO, 2003), Layers of Coalition Interoperability (LCI) (Tolk, 2003), the Network Centric Warfare Maturity Model (NCW) (Alberts & Hayes, 2003), the Non-Technical Interoperability Framework (NTI) (Stewart, et. al., 2004), the Organizational Interoperability Agility Model (OIAM) (Kingston et. al., 2005), and a modification of the NATO Interoperability Directive (NID-revised) (Schade, 2005).

2.4.3.5 Interoperability Assessment Methodology (IAM)

The Interoperability Assessment Methodology was published three months after LISI was published by Leite in 1999 (Leite, 1998) . Leite revised the model in 1999 and 2003. IAM is based on the idea of measurement and quantification of a set of interoperability between system components (Levine et al., 2003). IAM identified nine components: requirements, standards, data elements, node connectivity, protocols, information flow, latency, interpretation, and information utilization. Leite also defines interconnection degrees: connectivity, availability, interpretation, understanding, utility, execution, and feedback. The model was referenced by Kasunic who state that the quality attributes of IAM can be used to extend the LISI at the mission slice level (Kasunic, 2001).

2.4.3.6 Organizational Interoperability Model for C2 (OIM)

Clark and Jones (1999) introduced Organizational Interoperability Maturity Model (OIM) to create an organizational extension to LISI. They pointed out that LISI focuses strongly on system and technical compatibility, and does not address C2 support. Fewell and Clark (2003) stated that OIM was used to identify problems and evaluate interoperability in a coalition operation. From 1998 to 2006, LISI was the template for numerous maturity model and maturity model-like (leveling) interoperability measurement models designed to measure both information and non-information system interoperability such as the Organizational Interoperability Model for C2 (OIM) (Clark & Moon, 2001).

OIM defined five levels of interoperability: independent, cooperative, collaborative, combined, and unified interoperability. Fewell and Clark (2003) provided detailed descriptions about the attributes of the interoperability levels, and analyzed the operational interoperability with case scenarios. A mapping between OIM and LISI taken from Clark is provided in Figure 8 (Clark & Jones, 1999).

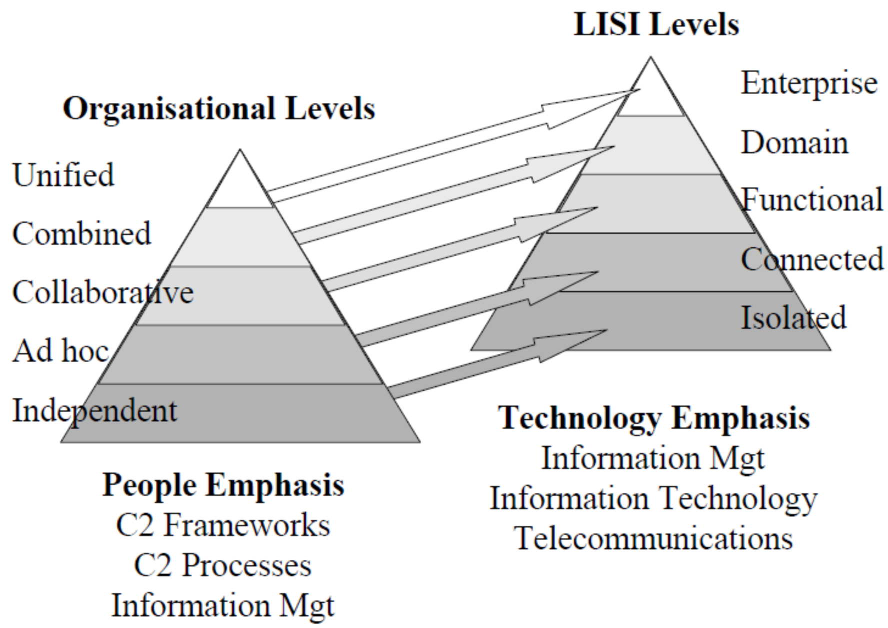

Figure 8: Alignment between Organizational Model and LISI

2.4.3.7 Stoplight

Hamilton Jr et al. (2002) published an Interoperability Roadmap for C4ISR Legacy Systems which included a simple interoperability measurement model which they simply called a Stoplight model. Stoplight is a simplified model used to help decision makers determine if legacy systems meet operational and acquisition interoperability requirements. It is implemented as a 2D matrix with "yes/no" responses in the matrix. It can also be used to track interoperability improvements over time (Hamilton Jr et al., 2002).

2.4.3.8 Level of Conceptual Interoperability Model (LCIM)

Tolk and Muguira (2003) introduced the Levels of Conceptual Interoperability Model (LCIM) which identified seven levels of interoperability among participating systems as a method to describe technical interoperability and the complexity of interoperations (2003). They stated that the model can be used as a framework to determine whether meaningful interoperability between systems is possible in the early stages of the federation development process. LCIM provides a conceptual model as a means to discuss integration, interoperability and composability. Figure 9 shows the LCIM model.

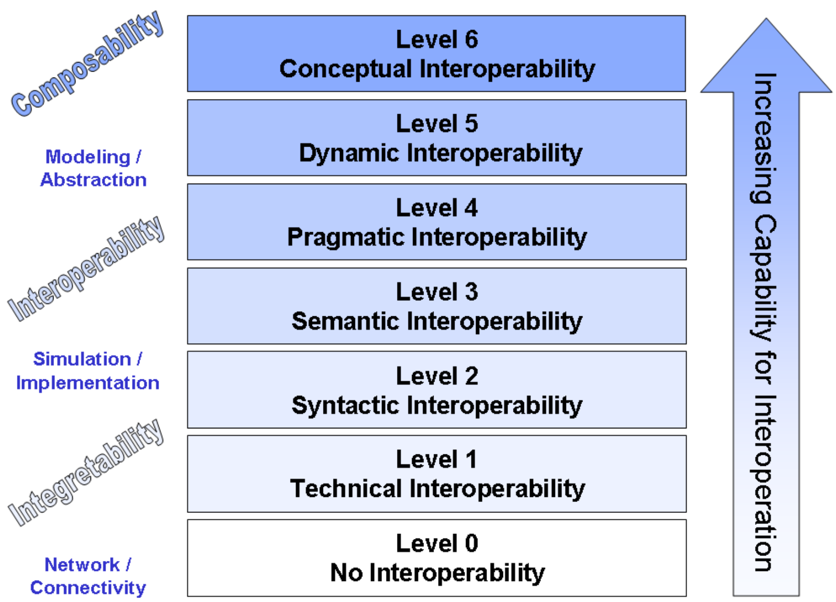

Figure 9: The Levels of Conceptual Interoperability Model (LCIM)

The LCIM associate the lower layers with the problems of simulation interoperation while the upper layers relate to the problems of reuse and composition of models. Zeigler, Praehofer, and Kim (2000) present a theory of modeling and simulation which provides a conceptual framework and an associated computational approach to methodological problems in M&S. The framework provides a set of entities and relations among the entities that, in effect, present ontology of the M&S domain (Zeigler et al., 2000).

2.4.3.9 Layers of Coalition Interoperability (LCI)

Tolk (2003) introduced the Layers of Coalition Interoperability (LCI) model similar to LCIM model. LCI is intended to facilitate discussion on technical and organizational support required for interoperable solutions. He shows that operational interoperability is an extension of technical interoperability. LCI defines nine layers of interoperability, from lowest to highest, a) Physical Interoperability, b) Protocol Interoperability, c) Data/Object Model Interoperability, d) Information Interoperability, e) Knowledge/Awareness, f) Aligned Procedures, g) Aligned Operations, h) Harmonized/Strategy Doctrines, and i) Political Objectives. Figure 10 shows the LCI model.

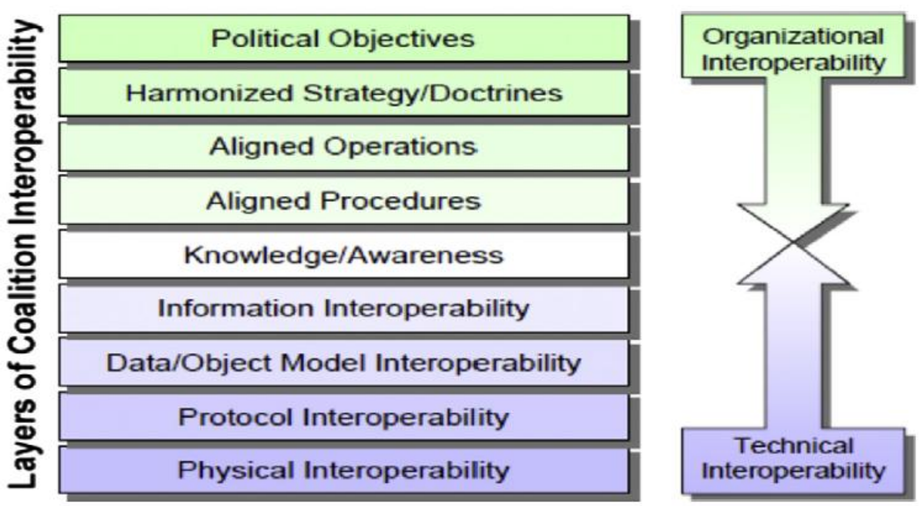

Figure 10: Layers of Coalition Interoperability (LCI) model

2.4.3.10 NATO C3 Technical Architecture Reference Model for Interoperability (NMI)

NMI originally intended to describe technical interoperability based on four degrees of interoperability: Degree a) Unstructured Data Exchange, Degree b) Structured Data Exchange, Degree c) Seamless Sharing of Data, and Degree d) Seamless Sharing of Information. The degrees were to categorize how to enhance operational effectiveness by structuring and automating the interpretation and exchange of data element. The four degrees maps directly to LISI's top four levels and is closely reflects the LISI model (Morris et al., 2004).

2.4.3.11 System-of-Systems Interoperability (SoSI) Model

Carnegie-Mellon University Software Engineering Institute (CMU-SEI) developed to facilitate system-of-systems interoperability research . The model addresses technical interoperability and operational interoperability and concerns between organizations building and maintaining interoperable systems. While it is a useful way of developing and integrating systems-of-systems, SoSI lacks interoperability matrix to specifically measure interoperability (Ford, Colombi, Jacques, & Graham, 2009b). Instead, the model provides a framework in which analysts can use their own matrix.

2.4.3.12 Non-Technical Interoperability Framework (NTI)

Stewart, Clarke, Goillau, Verrall, and Widdowson (2004) introduced the Non-Technical Interoperability (NTI) framework in 2004 to "understand these aspects of interoperability better and to mitigate potential frictional factors in multinational forces." They developed the model after interviewing of 45 United Kingdom military officers ranging from Army Captain to three-star General. The basic idea is that OIM model did not cover social, personnel, and process interoperability. NTI framework provides a more detailed breakdown of interoperability attributes than the four enabling OIM attributes.

2.4.3.13 Organizational Interoperability Agility Model (OIAM)

Kingston, Fewell, and Richer (2005) in the Australian Defense Science and Technology organization (DSTO) published the Organizational Interoperability Agility Model (OIAM) in 2005. The goal of the model is to capture the dynamic aspects of working in coalitions including the ability of an organization to contribute to the rapid formation and reformation of coalitions, including novel ones (Kingston et al., 2005). OIAM uses five levels of organizational agility (Static, Amenable, Accommodating, Open, and Dynamic) as well as the four OIM attributes, combining preparation and understanding.

2.4.3.14 Interoperability Score (i-Score)

The Interoperability Score (i-Score) is a quantitative method to measure the interoperability of general types of systems in the context of an operational process (T. Ford, J. Colombi, S. Graham, & D. Jacques, 2007). The model uses existing architecture data and accommodates more than one type of interoperability. The model is unique because the interoperability measurements are operational process specific. The i-Score method accommodates custom layers which allow the analyst to compensate the i-Score measurement for any number of interoperability-related performance factors such as bandwidth, protocols, mission capability rate, probability of connection, or atmospheric effects, among others (T. Ford et al., 2007). The method can be used assess organizational or policy interoperability which are non-traditional interoperability.

2.4.4 Summary of Existing Interoperability Models

Total sixteen interoperability measurement models were identified and reviewed. Table 9 presents a summary of existing interoperability models.

Table 9: Summary of Existing Interoperability Models

Organization	**Model (Year)**
Defense Information Systems Agency (DISA)	SoIM (1980)
MITRE Corporation	QoIM (1989)
Military University of Technology, Warsaw, Poland	MCISI (1996)
Department of Defense	LISI (1998)
Joint Theater Air & Missile Def. Org. (JTAMDO) Contractor SIM	IAM (1998)
Australian Defense Science & Technology Organization (DSTO)	OIM (1999) OIAM (2005)
Joint Forces Cmd (JFCOM) Joint Forces Program Office (JFPO)	Stoplight (2002)
Old Dominion Univ. Virginia Modeling Analysis & Simulation Center (VMASC)	LCI (2003) LCIM (2003)
North Atlantic Treaty Organization (NATO)	NMI (2003)
DoD Command and Control Research Program	NCW (2003)
Carnegie Mellon Software Engineering Institute (CMU-SEI)	SoSI (2004)
Defense Science & Technology Lab. (Dstl) Contractor, QinetiQ	NTI (2004)
Research Establishment for Applied Science (FGAN)	NID (2005)
Air Force Institute of Technology (AFIT)	i-Score (2007)

Previous section described the general overviews of the exising interoparbility maturity models. Since the models have diverse purposes in each domain, their contributions are different and useful to discuss. Table 10 lists the main contributions of the interoperability models.

Table 10: Main Contributions of Interoperability Models (Ford, 2008)

Method	**Main Contribution**
SoIM	Interoperability can be measured in levels
QoIM	Interoperability can be correlated to measures of effectiveness via simulation
MCISI	The distance between systems modeled as points in space indicates their interoperability
LISI	Systems possess interoperability attributes
IAM	Same as LISI
OIM	Organizations interoperate, but have different interoperability attributes than technical systems
Stoplight	Operations and acquisitions both have interoperability requirements
LCI	Operational interoperability is an extension of technical interoperability
LCIM	Conceptual interoperability bridges system interoperability
NMI	Same as LISI
NCW	Interoperability occurs in the physical, information, cognitive, and social domains; lack of interoperability impedes mission accomplishment
SoSI	System-of-system research is founded upon operational, conceptual, and programmatic interoperability
NTI	Social, personnel, and process interoperability are valid types of non-technical interoperability
OIAM	There are levels of ability of organizations to be agile in their interoperations
NID	Levels of interoperability can be described in linguistic terms
i-Score	Interoperability measurements are operational process-specific and have a maximum value

2.4.5 Elements for Interoperability Measurement

The literature reviews on interoperability measurement models showed that the identified models have common key elements to measure systems interoperability degree. Although their approaches are slightly different, they have general elements. The identified elements are a) Systems Architectural Modeling, b) Systems Interoperability Domains, c) Systems Interoperability Maturity Levels, d) Systems Interoperability Maturity Matrix, and e) Interoperability Degree Scoring Method. The proposed LVC simulation interoperability measurement framework has the elements to appropriately measure the interoperability degree.

2.5 Systems Engineering for Interoperability Measurement

2.5.1 System

A ***system*** is defined in this research to be a "functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements; that group of elements forming a unified whole" (Griendling, 2011). The elements may include physical, behavioral, or symbolic entities. Elements may interact physically, mathematically, and/or by exchange of information (Rouse, 2003). A system generally consists of a large number of subsystems, are geographically dispersed over large distances and are operating in heterogeneous computing environments (Ghosh & Lee, 2000). Thus, to predict system-level behavior when exploring the solution space for coupled subsystems, *distributed* and *federated* simulation systems are often useful (Rathnam, 2004). The group of such subsystems is often considered systems of systems.

2.5.2 System of Systems (SoS)

The DoD defines an ***System of Systems*** as "set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities" (Systems and Software Engineering Deputy, 2008) or, alternately, "Groups of systems, each of which individually provides its own mission capability, that can be operated collectively to achieve an independent, and usually larger, common mission capability" (Air Force Studies Board, 2008). SoS have been classified into four general categories, virtual SoS, acknowledged SoS, collaborative SoS, and directed SoS (Systems and Software Engineering Deputy, 2008).

The ISO/IEC/IEEE 42010 standard uses a similar definition, with the addition of the environment, defining architecture as the fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution. However, the word architecture did not originate in the field of engineering. Historically, architecture has referred to the art and practice of designing and constructing buildings (Simpson & Weiner, 1989).

An SoS is considered to have an underlying architecture, which is defined by ANSI/ IEEE 1471-2000 (Hilliard, 2000) to be the fundamental organization of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution." An important characteristic of a SoS is interoperability among its constituent systems (Lane & Valerdi, 2011).

Architecture of a System is the structure or structures of the system that comprise the components, the externally visible properties of those components, and the relationships among them (Bass, 1998). Using measurement to assess the behavior of the key attributes of these components, an architectural perspective helps to organize the complexity of the interoperability challenge in ways that can lead to more coherent treatments (Kasunic, 2001).

2.5.3 Systems Engineering for LVC Simulation Development

There also have been numerous definitions of *Systems Engineering (SE)* presented over the years. The definition used in this research is the one provided by The International Council of Systems Engineers (INCOSE). INCOSE defines SE as an "interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and proceeding with design synthesis and system validation while considering the complete problem: Operations, Cost & Schedule, Performance, Training & Support, Test, and Disposal & Manufacturing".

LVC simulation is regarded as a SoS. Each Live, Virtual and Constructive simulation is a system. If a many systems are integrated to a system, the system is a system of systems. Well-defined SE processes are a key element of any successful development LVC simulation (Coolahan, 2012). In the distributed simulation community, there are several such processes in wide use today, each aligned with specific simulation architecture such as Distributed Interactive Simulation (DIS), High Level Architecture (HLA), and Test and Training Enabling Architecture (TENA) (Coolahan, 2012).

2.5.4 Systems Engineering Processes for Distributed Simulation Development

There have been system processes for distributed simulation development. They are the ***Federation Development and Execution Process (FEDEP)*** and the ***Distributed Simulation Engineering and Execution Process (DSEEP)***. FEDEP is already designed as a framework into which lower level practices/procedures native to targeted user communities can be easily integrated.

In spring 2007, SISO started revising the FEDEP. It has been renamed to Distributed Simulation Engineering and Execution Process (DSEEP) and is now an active standard IEEE 1730–2010 (Lutz, 2012). DSEEP represents a tailoring of best practices in the systems and software engineering communities to the M&S domain. DSEEP is simulation architecture-neutral, but it does contain annexes that map this architecture-neutral view to DIS, HLA, and TENA terminology. A top-level view of the DSEEP is provided in Figure 11 (Lutz, 2012).

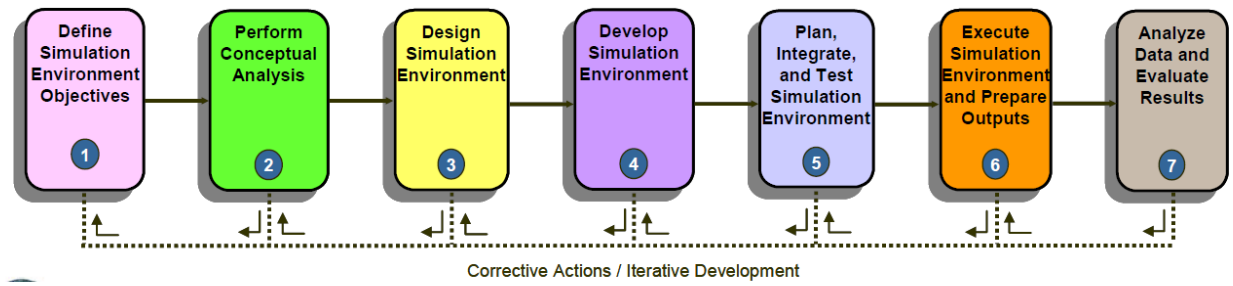

Figure 11: Distributed Simulation Engineering & Execution Process (DSEEP), Top-Level View

DSEEP is for single, unifying SE process description for distributed simulation. It is ideal choice for SE Process task because a) It is based on existing distributed simulation processes, b) It is architecture/user community neutral, and c) It is already designed as a framework into which lower level practices/procedures native to targeted user communities can be easily integrated. A short description of the seven major steps is described in Table 11.

Table 11: Distributed Simulation Engineering and Execution Process (DSEEP) Steps

Step	Description
Step 1	**Define Simulation Environment Objectives** The user, the sponsor, and the development team define and agree on a set of objectives and document what must be accomplished to achieve those objectives.
Step 2	**Perform Conceptual Analysis** Based on the characteristics of the problem space, an appropriate representation of the real world domain is developed.
Step 3	**Design Simulation Environment** Existing members that are suitable for reuse are identified, design activities for member modifications and/or new members are performed, required functionalities are allocated to the members, and a plan is developed for the development and implementation of the simulation environment.
Step 4	**Develop Simulation Environment** The information exchange data model is developed, simulation environment agreements are established, and new members and/or modifications to existing members are implemented.
Step 5	**Integrate and Test Simulation Environment** All necessary integration activities are performed, and testing is conducted to ensure that interoperability requirements are being met.
Step 6	**Execute Simulation** The simulation environment is executed and the output data from the execution is pre-processed.
Step 7	**Analyze Data and Evaluate Results** The output data from the execution is analyzed and evaluated, and results are reported back to the user/sponsor.

In this research, DSEEP is a reference SE process model for the proposed framework. For example, the interoperability measurement activity accounts for a part of whole DSEEP. In the systematic process, LVC simulation developers can set interoperability maturity goals, assess the current maturity state, and define a roadmap to achieve enhanced interoperability goals.

2.6 Gap Analysis

2.6.1 Gap Analysis Rationale

From the literature review, key elements that consist of proposed framework were identified. Gap analysis criteria were selected based on the elements to differentiate this inaugural research from other exiting research. Literature review showed that there are elements consisting systems interoperability measurement method. The elements are a) Systems Interoperability Domains, b) c) Systems Interoperability Maturity Levels, d) Systems Interoperability Maturity Matrix, and e) Interoperability Degree Scoring Method.

However, although the elements are enough to measure general systems interoperability, other elements are necessary to focus interoperability measurement on LVC simulation domain. To formalize an effective framework, the interoperability measurement activity is conducted in SE process with focused on LVC simulation domain. The key elements are: a) Simulation Interoperability Domain, b) Maturity model, c) SE (systems lifecycle) Process. Therefore, the gap analysis verifies whether existing research appropriately cover the selected key elements or not.

2.6.2 Analysis of Existing Research

This section provides an analysis of existing interoperability measurement approaches. Also limitations of the approaches as well as identified gaps with this research are discussed.

Kasunic and Anderson (2004) presented practices for measuring systems interoperability and assisting military planners in the acquisition, development, and implementation of command, control, communications, computers, and intelligence (C4I) systems. The motivation of the research was the acknowledgement of no method for tracking interoperability on a comprehensive or systematic basis. They used the Levels of Systems Interoperability (LISI) model as reference model to measure the interoperability degree of the C4I system with structured and systematic approach throughout the systems life cycle. They also addressed potential systems interoperability and operational interoperability issues. However they used LISI model which is generally only applicable to information systems interoperability.

Fewell and Clark (2003) presented an application of the Organizational Interoperability Model for C2 (OIM) to measure an organizational interoperability. They used OIM to analyze the International Force East Timor (INTERFET) coalition between two military forces for peace operation in East Timor in 1999. The model has been used to provide a useful framework for evaluating organizational interoperability. They also identified major organizational interoperability problems such as legal and doctrinal framework, command issues, trust and culture. Even though they showed usefulness of the model by focusing on the sharing of information and the exchange of knowledge, the research is irrelevant to simulation interoperability and system lifecycle, and system architecture modeling.

Morris et al. (2004) introduced the System of Systems Interoperability (SOSI). The research was based on the belief that interoperability must occur at multiple levels within and across programs, and not solely in the context of a system construction. The Software Engineering Institute looked at the full range of barriers to achieving interoperability between systems, including programmatic, constructive, and operational barriers. They adopted three activities for research method: review of related research, conducting of small workshops, and interviews with experts. Although they address SoS interoperability measurement approach based on LISI, proper maturity matrix and detailed interoperability scoring method in their research were not found.

Clark and Moon (2001) used the Levels of Systems Interoperability (LISI) model to assess the technological interoperability for Air Combat System interoperability. They also used Organizational Interoperability Model (OIM) to assess the organizational interoperability of a coalition forces. They stated that both approaches are necessary to provide a comprehensive coverage of the interoperability issues that will need to be considered when future capability options are assessed and when future joint and combined operations are proposed or undertaken. Their approach is irrelevant to simulation interoperability and system architecture modeling.

Chen et al. (2008) proposed an approach to measure the enterprise interoperability. Their research is unique because no approaches have been found in the literature on interoperability compatibility measure, potentiality measure, and interoperability performance measure. Although the research is new approach, they did not address interoperability maturity model which is the core concept of this research.

Cornu, Chapurlat, Quiot, and Irigoin (2012) proposed a framework to assess enterprise systems interoperability. They also designed an interoperability matrix to measure intrinsic and extrinsic interoperability between enterprise resources involved in a process during entire life cycle. Enterprise systems were classified into three different systems: Human systems, Non-Human systems and Heterogeneous group of systems. Also the characteristics of the systems were defined to analyze the collaborations between the systems. Even though the approach covered most of the gap analysis areas, the framework is not intended to simulation interoperability.

Diallo, Tolk, Graff, and Barraco (2011) described how the Levels of Conceptual Interoperability (LCIM) as the theoretical backbone for developing and implementing an interoperability framework that supports the exchange of XML-based languages used by M&S systems across the web. The research integrated the Model-based Data Engineering (MBDE) within the framework to support the interactions between the layers of the LCIM. They also presented a case to demonstrate the framework supports a set of heterogeneous military systems interoperability. Their research is not closely related to simulation interoperability and the measurement methodology proposed in this research.

Ford (2008) presented the *i-Score* method to measure the interoperability degree between a heterogeneous set of military weapon systems in the requirements definition or early system design phases. He modeled military systems according to their interoperability-related features in the context of an operational process. *i-Score* method accommodates custom layers which allow the analyst to compensate the *i-Score* measurement for any number of interoperability-related performance factors such as bandwidth, protocols, mission capability rate, probability of connection, or atmospheric effects, among others (Ford et al., 2009a).

Rezaei et al. (2014) proposed a framework to assess the ultra large scale systems interoperability. They presented a maturity model for the interoperability of ultra large scale systems. Then one ultra large scale system its maturity level was determined by using the interoperability level of the component system. The framework eventually provided systematic process to increase the interoperability of the component systems in ultra large scale systems based on the interoperability maturity levels. Their research covers most of the gap analysis areas except simulation interoperability.

Vida, Stoicu-Tivadar, and Bernad (2012) used LISI model to measure the interoperability maturity and degree between healthcare information systems. They presented an algorithm to determine the message exchange rate between healthcare information systems. The algorithm computes the interoperability degree from the technical interoperability point of view. They developed a tool which calculates the technical interoperability of a healthcare information system automatically based on the algorithm. They only covered technical interoperability, and their research is not closely related to simulation interoperability.

Wang et al. (2009) used the Levels of Conceptual Interoperability Model (LCIM) as a framework for conceptual modeling and its descriptive and prescriptive uses. Although they discuss SE approach for conceptual modeling and descriptive and prescriptive uses of LCIM, the research focuses on HLA and Base Object Model (BOM) based simulation federation. He described maturity model, system architectural modeling, interoperability domain, and maturity model. But their research lacks maturity matrix and detailed interoperability scoring method.

Yahia, Aubry, and Panetto (2012) proposed a mathematical formalization of the semantic relationships between Cooperative Information Systems (CIS) conceptual models. The resultant model was used to evaluate the lack of interoperability implications to the global information systems shared goals. They demonstrated the approach through a case study dealing with interoperability requirement between an Enterprise Resource Planning (ERP) system and a Manufacturing Execution System (MES) application. Their research is only closely related with semantic interoperability, and does not cover most of the gap analysis areas.

Lane and Valerdi (2011) presented approached to characterize and quantify the interoperability influence on SoS engineering effort in terms of cost. They analyzed fourteen interoperability models and presented two approaches that can be used as SoS cost models. However they did not provide details about the interoperability measurement framework elopements such as system architecture modeling, interoperability domains, and maturity levels.

Vida et al. (2012) presented an algorithm to measure the interoperability between healthcare information systems. This algorithm computes the interoperability degree from the technical interoperability point of view. They developed a tool to calculate the technical interoperability of a healthcare information system automatically. The algorithm provides an interoperability degree measurement environment as well as the degree of intercommunication in a certain healthcare environment. They used LISI model to build the algorithm, but their approach is irrelevant to simulation interoperability and system architecture modeling.

Guo and Wang (2012) also proposed a quantitative interoperability measurement method of combat mission using the system executable Petri net model at architecture level. They assigned quality attribute to the interoperation, and the quality matrix of system interoperation is determined by the process net of Petri net model. Then the correlation matrix of interoperation between systems is obtained based on Petri net model structure, thus completing the interoperability measurement of a heterogeneous set of integrated systems. They demonstrated the proposed methodology with the Missile Defense Systems as an example. Although they invented new approaches, their research does not have measurement methods such as maturity level and matrix.

Yang et al. (2013) measured interoperability degree of the internet-based information systems. They defined the architecture of the information systems at various layers from infrastructure to platform, to information, and to applications. The research identified interoperation elements for different layers of the information systems, and ranks the capability into levels and sub-levels. Finally, they calculated the system layers with Analytical Hierarchical Process (AHP) and Analytical Network Process (ANP) method. Although they provided detailed interoperability measurement process, they did not build maturity model. Also their research is irrelevant to simulation interoperability measurement.

Palomares, Campos, and Palomero (2010) introduced a framework to develop a set of questionnaire to assess the enterprise interoperability degree. The framework provides an environment in which researcher determines the level of interoperability achieved by the enterprise systems. They only covered the enterprise layers, enterprise interoperability domains, system architecture, enterprise modeling, and ontology.

Soares and Amaral (2011) proposed the Information Systems (IS) interoperability in Public Administration (PA). They identified the factors that influence IS interoperability initiatives in PA by using Delphi study. The study provides an understanding of the complex forces acting in IS interoperability. The research also contributes to improve the research, management, and implementation of PA interoperability measurement issues. Even though they found a set of forces and ranked them based on the level of importance, they did not provided specific interoperability measurement methodology.

2.6.3 Gap Analysis Summary

This section summarizes the identified gaps between the existing approaches and the proposed LVC simulation interoperability measurement framework with a gap analysis table. Total twenty one existing interoperability measurement approaches were identified. This research is differentiated by proposing a holistic LVC simulation interoperability measurement framework. Table 12 exhibits the summarized research gaps.

Table 12: Gap Summary from Literature Reviews

Existing Researches	Comparison Criteria						
	Simulation Interoperability	Systems Engineering	Interoperability Maturity Model Elements				
			Interoperability Domains	Interoperability Domains Factors	Interoperability Maturity Level	Maturity Matrix	Interoperability Degree Determination method
Clark & Moon (2001)	Not covered	Weakly covered	Weakly covered	Strongly covered	Strongly covered	Strongly covered	Strongly covered
Fewell & Clark (2003)	Not covered	Not covered	Moderately covered	Moderately covered	Moderately covered	Moderately covered	Moderately covered
Kasunic & Anderson (2004)	Not covered	Weakly covered	Moderately covered	Moderately covered	Moderately covered	Moderately covered	Moderately covered
Morris et al. (2004)	Not covered	Not covered	Weakly covered	Weakly covered	Weakly covered	Weakly covered	Not covered
Chen et al. (2008)	Not covered	Not covered	Not covered	Moderately covered	Moderately covered	Moderately covered	Strongly covered
Ford (2008)	Not covered	Moderately covered	Strongly covered	Not covered	Not covered	Not covered	Strongly covered
Wang et al. (2009)	Moderately covered	Strongly covered	Strongly covered	Weakly covered	Weakly covered	Weakly covered	Not covered
Ford (2009)	Not covered	Moderately covered	Strongly covered	Not covered	Not covered	Not covered	Strongly covered
Palomares et al. (2010)	Not covered	Not covered	Moderately covered	Moderately covered	Moderately covered	Moderately covered	Not covered
Vida et al. (2010)	Not covered	Weakly covered	Moderately covered	Moderately covered	Moderately covered	Moderately covered	Moderately covered
Guo et al. (2011)	Not covered	Moderately covered	Strongly covered	Weakly covered	Weakly covered	Weakly covered	Strongly covered
Diallo et al. (2011)	Weakly covered	Not covered	Not covered	Moderately covered	Moderately covered	Weakly covered	Weakly covered
Soares & Amaral (2011)	Not covered	Not covered	Strongly covered	Strongly covered	Moderately covered	Moderately covered	Not covered
Staden & Mbale (2012)	Not covered	Weakly covered	Moderately covered	Strongly covered	Strongly covered	Strongly covered	Strongly covered
Cornu et al. (2012)	Not covered	Moderately covered	Strongly covered	Strongly covered	Strongly covered	Strongly covered	Strongly covered
Guo & Wang (2012)	Not covered	Weakly covered	Strongly covered	Not covered	Not covered	Not covered	Strongly covered
Vida et al. (2012)	Not covered	Not covered	Moderately covered	Moderately covered	Moderately covered	Moderately covered	Moderately covered
Yahia et al. (2012)	Not covered	Not covered	Moderately covered	Not covered	Not covered	Not covered	Moderately covered
Lane & Valerdi (2012)	Not covered	Moderately covered	Not covered	Not covered	Not covered	Not covered	Not covered
Yang (2013)	Not covered	Moderately covered	Strongly covered	Strongly covered	Strongly covered	Strongly covered	Strongly covered
Rezaei et al. (2014)	Not covered	Moderately covered	Strongly covered	Strongly covered	Strongly covered	Strongly covered	Strongly covered
LVC Simulation Interoperability Measurement Domain							
Kim (2015)	Strongly covered	Moderately covered	Strongly covered	Strongly covered	Strongly covered	Strongly covered	Strongly covered

Legend: Not covered; Weakly covered; Moderately covered; Strongly covered

As shown in the figure, there are only two existing researches that are focused on simulation interoperability. Wang et al. (2009) used the LCIM for conceptual modeling and descriptive and prescriptive uses of HLA and Base Object Model (BOM) based simulation federation. Also Diallo et al. (2011) weakly covered the simulation interoperability domain.

The SE issues in interoperability measurement process are not covered in many of the approaches. Wang et al. (2009) only strongly addressed the issues. Ford (2008), Guo et al. (2011), Cornu et al. (2012), Yang (2013), and Rezaei et al. (2014) proposed approaches moderately consider SE issues.

Most of the existing researches have interoperability maturity model elements. However, Ford (2008, 2009), Guo & Wang (2012), Yahia et al. (2012), and Lane & Valerdi (2012) have unique interoperability measurement approaches which do not propose or use maturity model. The researches do not cover some of the interoperability maturity model elopements. Also Morris et al. (2004), Wang et al. (2009), Palomares et al. (2010), Soares & Amaral (2011), and Lane & Valerdi (2012) did not provided proper interoperability degree scoring methods.

This research strongly covers all criteria except the SE issues. This is because the proposed framework only accounts for a part of LVC simulation development and execution process. The framework explains how to measure the degree of interoperability in the SE process. As explained in Chapter one, each interoperability measurement step is linked to a particular step in LVC simulation development process.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

When there is a need for development of new framework, employing opinions of Subject Matter Expert (SME) is highly recommended. Also the published literatures are good sources to obtain required information to formalize the proposed framework. After considering a series of literature reviews on accessible research methodologies, the relevance to research areas, identified level of importance, and characteristics of the LVC simulation interoperability measurement domains, it was concluded that systematic literature reviews and an expert survey are the most adequate to build the basis of the proposed framework. The detailed methodology details are demonstrated in Figure 12.

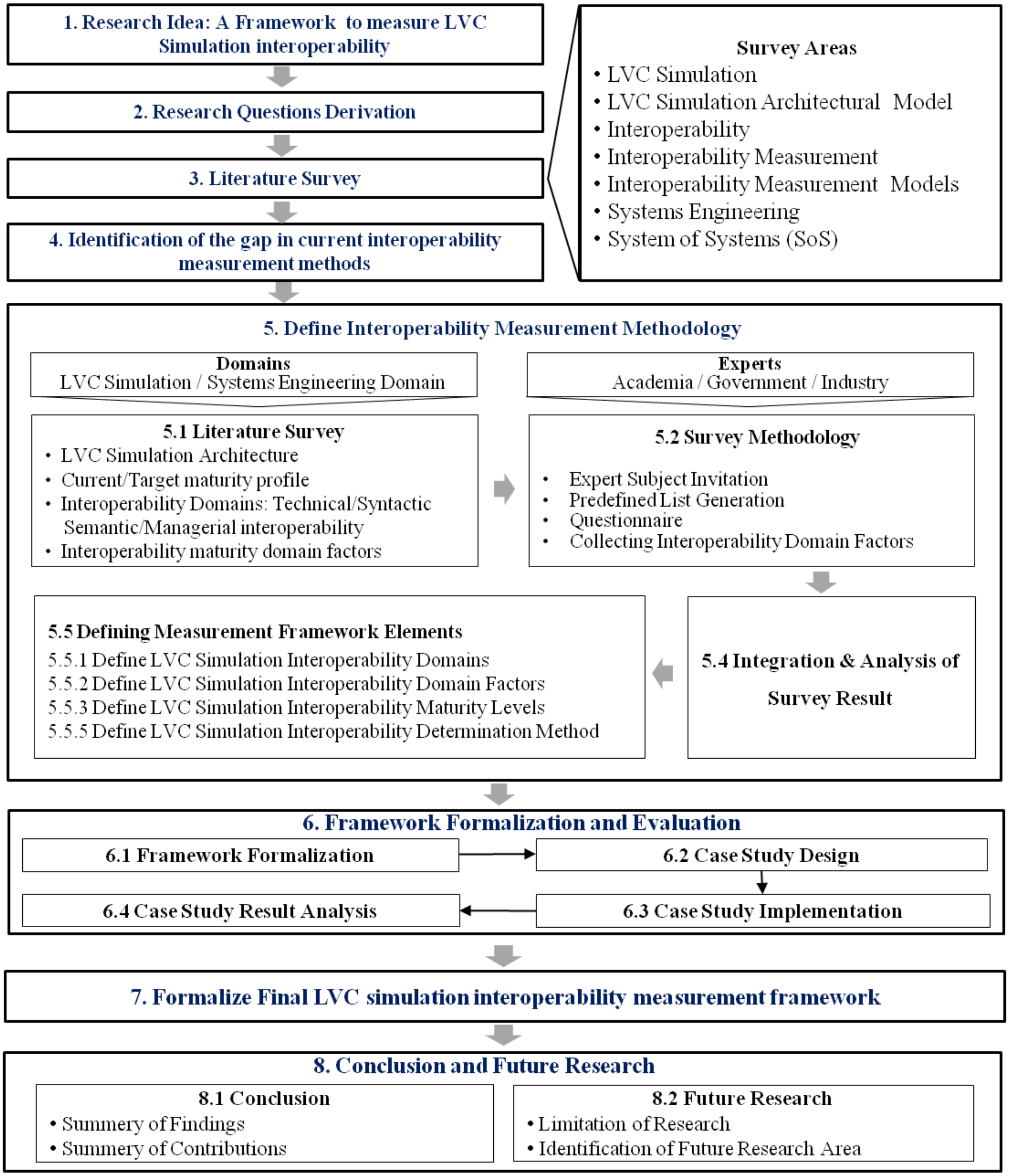

Figure 12: Proposed Research Methodology

3.2 Research Methodology Steps

This section presents details of the proposed research methodology.

3.2.1 Step1, 2, 3 and 4: Initial Steps

The first four steps in the proposed methodology are ***initial steps*** which were covered in Chapter one and two. The initial steps include the research idea, the research question derivation, the literature survey and the gap analysis. The steps are regarded as preliminary work to design the initial interoperability measurement framework. Specifically, research questions are derived from the research idea, and related research domains are reviewed to obtain information on LVC simulation interoperability measurement. The architectural characteristics of Distributed Simulation as well as LVC simulation are defined and collected based on the literature review. Finally research gaps are identified from the existing interoperability measurement methods.

3.2.2 Step 5: Define LVC Simulation Interoperability Measurement Framework Elements

This step is very important to create the framework. In this step, elements of the LVC simulation interoperability measurement framework are defined. This step consists of four sub-steps. First, a literature review is conducted to identify architectural characteristics of LVC simulation, interoperability domains and relevant domain factors. Secondly, a survey is conducted to validate the collected domain factors. Thirdly, the survey result is integrated and analyzed to define the main elements of the framework. Lastly, the elements are defined from the previous steps. The main elements are: a) LVC simulation interoperability domains, b) LVC simulation interoperability domains factors, c) LVC simulation maturity levels, d) LVC simulation interoperability maturity determination method. Details about each sub steps are explained in the following section.

3.2.2.1 Step 5.1~5.4: Literature Review and Survey

A systematic literature review is conducted to survey information related to the candidate interoperability maturity model. The survey areas are architectural characteristics of LVC simulation, interoperability maturity profile, interoperability domains, interoperability domain factors, etc. The information from the literature review accounts for fundamental elements of the survey questionnaire. A set of questions are presented to selected domain experts to initiate the survey. The expert areas are Academia, Government and Industry. These individuals primarily represent a technical, operational, and managerial perspective of LVC simulation and SE domains. The experts are selected based on interviews, publication and experience. The results from the survey is analyzed and coded into the parameters of the interoperability measurement framework. Based on the analysis, following defining activities are conducted.

3.2.2.2 Step 5.5: Define LVC Simulation Interoperability Maturity Model Elements

The result from survey is used to define the key elements of the maturity model. The interoperability measurement framework is formalized by organizing identified key elements. Next section describes details on the elements.

3.2.2.3 Step 5.5.1: Defining LVC simulation Architectural Model

The first sub-step is to define the architectural model of LVC simulation. The architectural model is intended to present the key interoperability characteristics of LVC simulation and the relationship among them that determine the interoperability degree of the simulation systems. Also the architectural model provides the structure of the simulation systems and the key properties of the design principal (Kumar, 2010). The analysis of architectural characteristics can be adopted to determine system interoperability degree. This is to appropriately explain the core element classes and the relationship between continuant classes of the architecture model. Each class specifies the elements and their interaction hierarchy to shows how the elements are related to or with each other.

3.2.2.4 Step 5.5.2: Defining LVC Simulation Interoperability Domains and Domain Factors

The goal of this sub-step is to collect and determine required LVC simulation interoperability domain classification. The interoperability domain is categorized to different types of interpretabilities such as technical, syntactic, semantic and organizational interoperability. The reason of this activity is because LVC simulation has very complicated and unique architectures which require a broad spectrum of domains to achieve effective interoperability. The selected domains are applied to the LVC simulation interoperability maturity levels which are explained in the next section.

3.2.2.5 Step 5.5.3: Defining LVC Simulation Interoperability Maturity Levels

In this step, LVC simulation interoperability maturity levels are defined. The LVC simulation maturity levels provide a basis to measure the interoperability maturity degree of targeted systems. The levels explain how much the interoperability of the targeted systems is matured to be interoperated. The maturity level presents the system ability to interoperate to other systems by exchanging and sharing information (Widergren, Levinson, Mater, & Drummond, 2010). Generally a system with higher maturity level represents higher potential interaction capability between systems than a system that has lower maturity level (Clark & Jones, 1999).

3.2.2.6 Step 5.5.4: Defining LVC Simulation Interoperability Maturity Model Matrix

The maturity model matrix provides a ground to define system requirements to improve the systems interoperability level. System requirements such as adaptability, flexibility, and composability that are relevant to interoperability degree can be defined based on the maturity matrix. The maturity matrix also suggests ideal status of interoperability that a system should reach to enough maturity of interoperability capabilities. The matrix has predefined numerical parameters for each interoperability domain at each maturity level. Using the completed maturity model matrix, a system interoperability capability status can be evaluated.

3.2.2.7 Step 5.5.5: Defining LVC Simulation Interoperability Maturity Determination Method

This sub-step is to define a determination methodology of LVC simulation interoperability maturity level. To evaluate the interoperability maturity level of a system with qualitatively measurable fashion, the interoperability measurement framework must have a parameterization methodology in terms of interoperability maturity levels. The determination methodology provides appropriate process representation of the interoperability level.

3.2.3 Step 6: Framework Formalization and Evaluation

Next step is the final sub-step in which previously explained sub-steps are integrated to formalize the interoperability measurement framework. The framework has specific guidelines and course of actions to successfully measure the LVC simulation interoperability degrees. In this step, the framework is evaluated to prove the validity by implementing a case study. The case study is designed to be best suited for LVC simulation interoperability measurement.

The implementation of the case study requires the utilization of specific tools and software products. The configured LVC simulation consists of diverse federates including Live, Virtual and Constructive simulations, component based simulation engines, parallel/distributed simulation engines, and other supporting components. Figure 13 shows the configured federation. The interoperability between the simulations is facilitated by using the standard simulation architectures such as HLA, DIS and TENA.

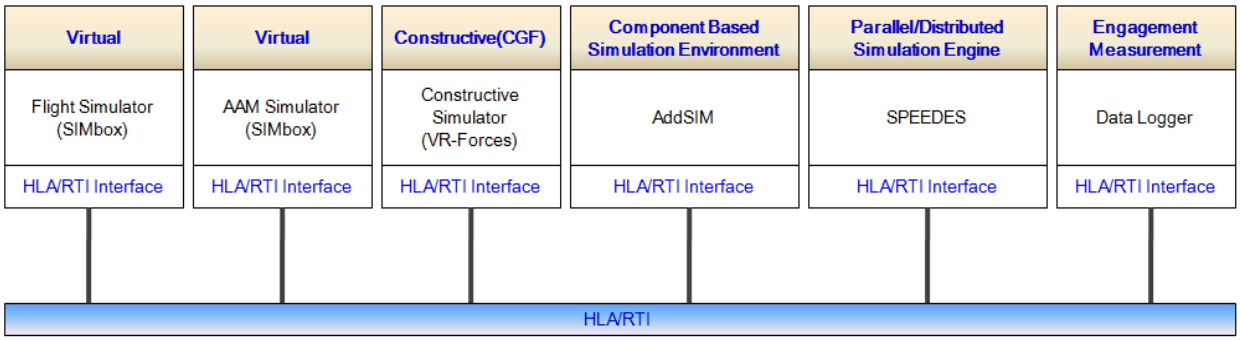

Figure 13: LVC Simulation Configuration for Case Study

3.2.4 Step 7: Final Formalization

This step analyzes the lessons learned from the previous steps including the initially formalized LVC simulation interoperability measurement framework. The lessons from the analysis are reflected to build the second-phase case study. When the framework shows valid outputs in terms of historical data of case studies, the framework is regarded as valid. This means that the modified framework through the expert feedbacks and experiment result analysis show more precise interoperability measurement results. Finally, the LVC simulation interoperability measurement framework is completely formalized.

3.2.5 Step 8: Conclusion and Future Research

This section summarizes the finding and contributions from the research activity. The summary of the process to develop the LVC simulation interoperability measurement framework is briefly explained. Summary of findings as well as contributions during the development are stated. Also the limitations on the research are discussed, and future research areas to enhance the developed framework are identified.

CHAPTER FOUR: AN LVC SIMULATION INTEROPERABILITY MEASUREMENT FRAMEWORK

4.1 Introduction

Before implementation of LVC simulation interoperability, the readiness of the simulation interoperability and the interoperability strategy must be assessed. This activity can be realized through LVC simulation interoperability maturity measurement framework. The assessment activity is necessary and allows the simulation developer to analyze the potential strength and the weakness of the LVC simulation before the implementation. The measurement also provides guidelines for existing LVC simulation to reach improved interoperability degrees.

The purpose of this chapter is to define an LVC simulation interoperability maturity measurement framework which created from a combination of relevant existing maturity models elements and opinions from domain experts. An interoperability measurement methodology which uses the proposed maturity model is also described in the next section.

4.2 Classification of Interoperability Measurement

Yahia (2012) stated that the interoperability measurement methods are classified to four categories:

1. Leveling and Non-leveling Method
2. Qualitative and quantitative methods
3. Black box and white box methods
4. A priori and a posteriori methods

4.2.1 Leveling and Non-leveling Methods

The leveling methods are based on maturity model-based interoperability measurement methods. This approach defines a set of interoperability maturity levels and associated attributes (Ford, 2008). This research is a leveling method because the interoperability measurement process is based on a maturity model which is defined in the next sections. Table 13 shows a generalized interoperability maturity model.

Table 13: A Generalized Interoperability Maturity Model

Interoperability Levels	Interoperability Attributes			
	A1	A2	A3	A4
Level 4				
Level 3				
Level 2				
Level 1				
Level 0				

In the other hand, the non-leveling methods are non-maturity model based interoperability measurement methodology. They are not generalized to maturity models, but specialized to particular types of system interoperability (Ford, 2008).

4.2.2 Qualitative and quantitative methods

Interoperability measurement can be either qualitative or quantitative. Most of qualitative approaches are subjective and defined on the basis of general criteria of evaluation by associating a maturity level to a specific kind of interoperability (Yahia, 2011). Most existing interoperability measurement methods use qualitative approach. Quantitative approaches adopt numeric values to assess interoperability degree. In this research, qualitative approach is used.

4.2.3 Black box and white box methods

Any type of system can be seen as black boxes or white boxes in terms of measurement (Bertalanffy, 1968). The black box considers only inputs and outputs of systems, and does not worry about the internal interactions and properties of the systems. On the other hand, the white box approach explains the internal mechanism of the systems by showing input-output mapping of the systems components. A schematic representation of black box and white box systems can be seen in Figure below (Heylighen, 2002).

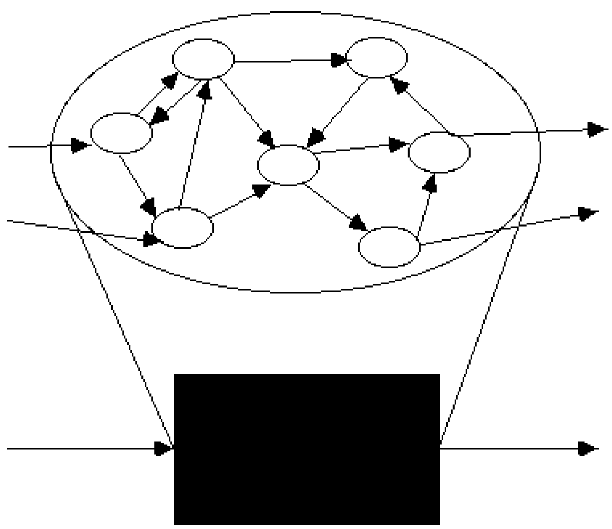

Figure 14: Black and White Box Approaches

4.2.4 A priori and a posteriori methods

LVC simulation interoperability maturity can be assessed in two ways: 1) potential interoperability measurement and 2) compatibility and/or performance measurement. The potential measurement is related to the potential interoperability of systems with other existing and/or future systems. The compatibility and/or performance measurement is related to compatibility and/or performance measurement of existing and known systems.

4.2.5 Research scope and positioning

First, this research is a leveling method because an LVC simulation interoperability maturity model is proposed, and the model is used to determine maturity levels. For the qualitative or quantitative approaches, qualitative approach is used. This research adopted white box approach, and framework users can see inside mechanism of the process as well as the input-output mapping of the systems components. Lastly, this research measures the potential interoperability of an LVC simulation and a relevant organization. The research scope and position in this research are demonstrated in Table 14.

Table 14: Research Scope and Position of the Research

Criteria	**Classification**
Leveling or Non-Leveling	Leveling
Qualitative or Quantitative	Qualitative
Black box or White box	White box
Priori or Posteriori	Priori (Potential Interoperability)

4.3 The LVC Simulation Interoperability Maturity Model (LSIMM) Formalization

As explained, the proposed framework consists of two main components: 1) Simulation Interoperability Maturity Model (LSIMM) and 2) LVC simulation interoperability measurement process. This section describes the formalization of LSIMM.

LSIMM consists of four main components: 1) interoperability domains, 2) interoperability domain factors, 3) interoperability levels, and 4) interoperability level labels. Figure 15 illustrates the main components of LSIMM.

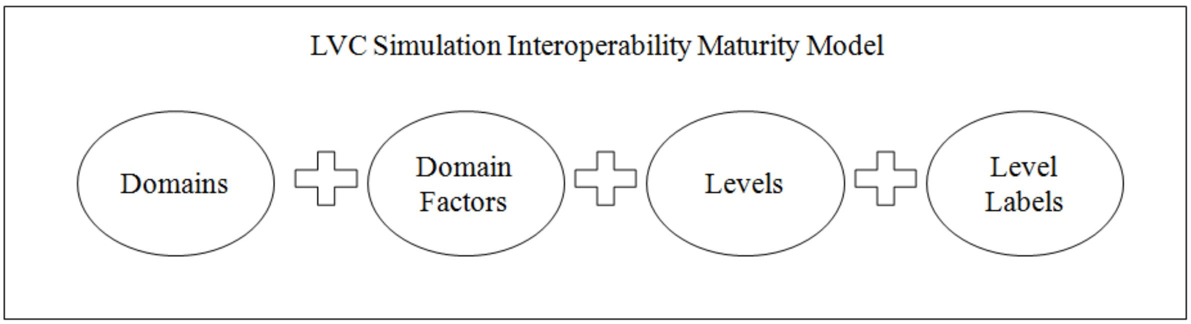

Figure 15: LVC Simulation Interoperability Maturity Model Components

The research methodology explained this research uses an expert survey and literature review to obtain the main components. Interoperability domains, levels and level labels are determined by the literature reviews, only the domain factors are collected by the expert survey. The process of defining LSIMM is demonstrated in Figure 16.

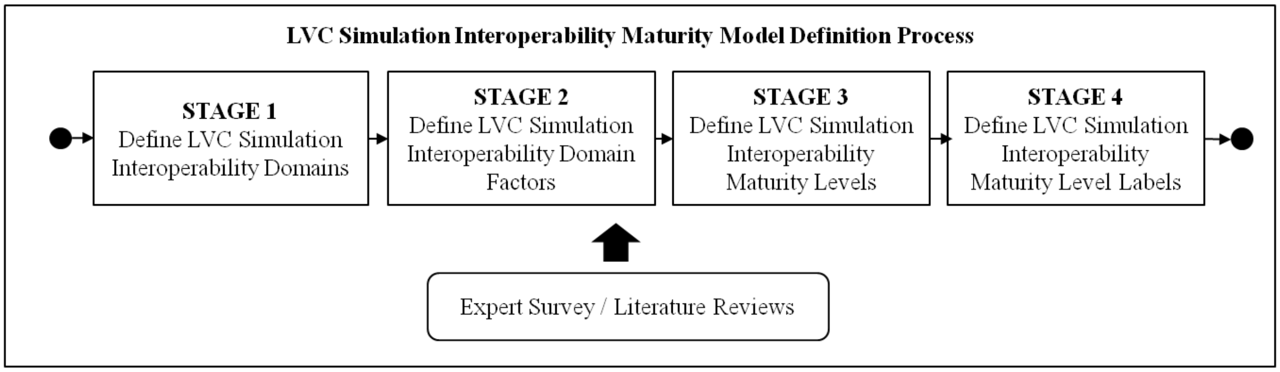

Figure 16: The process of defining LSIMM

4.3.1 Interoperability Domains

The first step to design LSIMM is to determine the interoperability domains. From the literature review, several domains are significant for the model and finally determined.

1. Technical domain: technical domain is an important domain to consider because LVC simulation interoperability is realized through multi-dimensional technical point of view. This domain primarily focuses on the physical technology to connect multiple heterogeneous simulations with different technologies.
2. Conceptual domain: this domain is important because it describes information and data layers between different simulations. The domain has common area with technical domain, but was determined to be independent because it has significant area.
3. Organizational domain: Organizational interoperability in practice means the seamless integration of business process and the exchange of information that they manage between the organizations (Vernadat, 2007). In this research an organization means an organization which includes a simulation interoperability team that practically executes simulation interoperability with a target simulation system. For the success of simulation

interoperability, the organization needs enough managerial skills and structure. The organizational interoperability domain in this research means managerial capabilities in Systems Engineering of LVC simulation. Thus for the managerial domain, DSEEP and FEDEP were used to identify the important factors that determine managerial interoperability.

4.3.2 Interoperability Domain Factors

The second stage is to define the important factors that determine LVC simulation interoperability level for each interoperability domains. The domain factors are the most important component in the LSIMM because the domain factors provide a set of specific criteria to assess the interoperability maturity level for each domain.

4.3.2.1 Literature Reviews

In order to formalize the survey questions, identification and collection of the critical factors that determine the interoperability level of LVC simulation is needed. The survey method used partially closed survey which means the survey questions have sample answers, and the subjects need to choose answer from a set of multiple choices. Therefore, a list including initial factors should be given to the expert subjects to facilitate the survey process.

A systematic literature review process introduced by Brereton, Kitchenham, Budgen, Turner, and Khalil (2007) was used to generate the list. Figure 17 illustrates the systematic review process. Systematic literature review is primarily related to aggregating evidences and factors which are critically relevant to LVC simulation interoperability level.

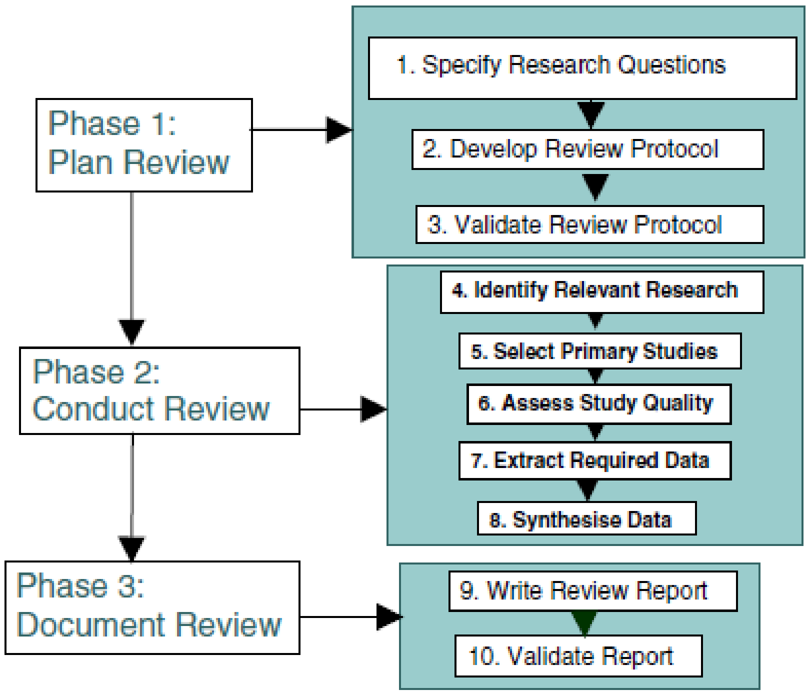

Figure 17: Systematic Literature Review Process (Brereton et al., 2007)

Performing a systematic review consists of 10 activities. They can be grouped into three phases which are 1) planning, 2) conducting the review, and 3) reporting the review. The review process was applied to this research and each phase is explained in Table 15.

Table 15: The Systematic Literature Review Process Phases

Phase		Description
1	Plan Review	• Research Question: *"What are the critical factors that determine the level of simulation interoperability in terms of technical, conceptual and organizational (managerial/Systems Engineering) prospects?"*
		• Review Protocol Search engines: IEEExplore, Google Scholar, Google, Yahoo, ACM Digital library, Citeseer library • LVC simulation and interoperability keywords Types of literatures: Journals, books, white papers, technical reports, conference proceedings, dissertation, thesis, and Journal archives
2	Conduct Review	• Identified many research • Selected primary research according to the relevance, quality, and achievement. • A set of factors were identified and collected • The collected data were synthesized considering the similarity
3	Document Review	• Write review report • A list of literatures • A list of factors

Multiple papers regarding LVC simulation domain were collected and reviewed. An extensive literature review process which encompassing multiple areas were conducted. Specifically, the areas include journals, conference papers in the LVC simulation development, technical issues, policy, management and system engineering. Also technical reports, project reports, white papers as well as government reports were reviewed. Finally, a list of factors that determines LVC simulation interoperability degree was obtained. Table 16 shows a list of elements from the literature review process.

Table 16: A List of Factors from Literature Review

Domain	Factors
I. Technical	• Communication networking resources and configuration • Compliance to the Standard simulation architectures(HLA, TENA, DIS) • Common middleware/gateway/bridge capbilities • Simulation performance measurement/monitoring tools/equipments • Define human or hardware in-the-loop requirements in simulation systems • Computer hardware/platform/tools and configurations • Functionality and fidelity of simulation application to represent required entities, events, phenomena and natural environment • Supporting databases/database storage and algorithms • Time management • Data management and distribution • Security • Support for IT infrastructure
II. Conceptual	• Unambiguous semantics • Conceptual model definition and structure • Data structure and format compatibility • Meta-model for data exchanges • Object modeling standard • Documentation of meaning/content of data • Adaptive data models in both syntax and semantics
III. Organizational	• Available Funding • Database management capability • Support and policy for simulation conceptual model • Organized/trained subject matter expertise for development/integration/operation/maintenance • Time and scheduling coordination capability • Performance and reliability measurement/capability • Systems Engineering(SE) processes/policy/capabilities (consistent development and execution process) • Testing processes/policy/capabilities • Interoperability guidance/policy/capabilities • Documentation of unambiguous terminology • Ability to introduce new interoperability technology • Flexible (agile) organizational structure • Simulation development and execution capabilities

Domain	Factors
	• Tools and capabilities for to support scenario development, conceptual analysis, Verification, validation, and accreditation (VV&A), and configuration management • Facility services for hardware/software integration and test • Security standard/policy/ procedures for hardware, network, data, and software

4.3.2.2 The Survey

This section explains information about decisions made for the plan and execution of the survey. The survey process must be formalized to obtain effective data. Decisions during the plan and execution of survey method are very important to use the method as a scientific validation point of view. Therefore, decisions regarding the survey study were determined according to validated matter. The decisions include: expert subject constitution, expert invitation, survey process, and questionnaire structure.

4.3.2.3 Expert Subject Constitution

The expert subject constitution is the most critical issue in this study. The design of the exert subject was inspired by a set of guidelines proposed by Okoli and Pawlowski (2004). They defined an iterative process to identify experts used in survey. The detail of the step includes:

1. Step 1: Define inclusion criteria
2. Step 2: Define key searching niches
3. Step 3: Populate niches with names
4. Step 4: Invite experts and request indication of new experts
5. Step 5: Invite new experts

For Step 1, a criterion was verified to indentify expert individuals who are included in the survey subjects. The individual is an expert and/or a specialist who has experiences closely related to LVC simulation domain more than five years. Specifically, the individuals have been involved in the planning and implementing of the LVC simulation interoperability.

In Step 2, three main niches were found: M&S industry, government agencies, and academia. Since LVC simulation was originated from military domain, government agencies particularly military agencies were core niches for Step 2. In addition, M&S industry who supplies simulation systems to the government agencies was also regarded as a core niche. Researchers from academia who have been involved in M&S projects were also eligible as LVC simulation domain experts.

The third step is to collect experts in each niche to invite the individuals. The primary method to identify the experts is reviewing publication. Publications relevant to LVC simulation and interoperability domains were collected and reviewed. After a list of experts was created, an invitation letter was sent to inform the experts about the survey participation by email. Also the Rolling stone method was applied in a way each individual indicated another individual.

After whole expert panel constitution process, total 196 individual were invited as of the fourth step. The individuals were asked to introduce other experts who want to participate in the study. Finally, in Step 5, total 167 individuals responded to participate in the survey process. The constituted expert subjects of 59 (35%) government personnel, 72 (43%) industry professionals and 36 (22%) academic researchers. Table 17 demonstrates the expert subject constitution result.

Table 17: Expert Subject Constitution Result

Domain	Number of Subject	Percentage (%)
Government	59	35
Industry	72	43
Academy	36	22
Total	167	100

4.3.2.4 Structure of Questionnaire

The structure of questionnaire was a critical issue in the process because it gathers the data needed to formalize the LSIMM. Specifically, systematically designed questionnaire structure allows a collection of essential elements of the maturity model.

As previously explained, the survey method has a predefined list approach. Although a blank sheet approach is ideal for the study, this approach requires great number of round implementation. However, the questionnaire had an open structure to allow the experts to add new elements that were not included in the pre-defined list. The method to collect new elements was simple; the questionnaire has a free texting space.

4.3.2.5 Survey Result

The survey was conducted. The overall duration of the execution was 34 days. The questionnaire was sent to 167 experts, and the response rate was 28%. Total 43 subjects responded with valid survey answers. Table 18, 19 and 20 show the results of the survey result.

Table 18: The Survey Result

Category	Result
Duration	34 days
Subject Size	167
Response Size	43
Response Rate	26 %

Table 19: Expert Domain

Domain	Number of Subject	Percentage (%)
Government	21	49
Industry	12	28
Academy	10	23
Total	43	100

Table 20: Expert Experience

Experience	Number of Subject	Percentage (%)
1~5 years	4	9
6~10 years	10	23
11~15 years	11	26
16 years or more	18	41
Total	43	100

The performed survey produced an ordered list of LSIMM elements. Table 21 explains a list of LSIMM elements.

Table 21: A Result of LSIMM Factors from Survey

Domain		Factors	Agree	Neutral	Disagree
Technical	1	Communication networking infrastructure and configuration	40	2	1
	2	Compliance to the Standard simulation architectures(HLA, TENA, DIS)	37	5	1
	3	Common middleware/gateway/bridge capbilities	36	6	1
	4	Simulation performance measurement/monitoring tools/equipments	30	11	2
	5	Define human or hardware in-the-loop requirements in simulation systems	24	13	6
	6	Computer hardware/platform/tools and configurations	39	4	0
	7	Functionality and fidelity of simulation application to represent required entities, events, phenomena and natural environment	35	7	1
	8	Supporting databases/database storage and algorithms	40	2	1
	9	Time management	33	7	3
	10	Data management and distribution	37	4	0
	11	Security	33	8	2
	12	Support for IT infrastructure	30	9	4
Conceptual	1	Unambiguous semantics	40	3	0
	2	Conceptual model definition and structure	38	3	2
	3	Data structure and format compatibility	38	4	1
	4	Meta-model for data exchanges	22	18	3
	5	Object modeling standard	31	11	1
	6	Documentation of meaning/content of data	18	14	11
	7	Adaptive data models in both syntax and semantics	20	19	4
Organizational	1	Available Funding	30	9	4
	2	Database management capability	15	13	15
	3	Support and policy for simulation conceptual model	36	5	2
	4	Organized/trained subject matter expertise for development/integration/operation/maintenance	38	2	3
	5	Time and scheduling coordination capability	39	3	1
	6	Performance and reliability measurement/capability	18	16	9
	7	Systems Engineering(SE) processes/policy/capabilities (consistent development and execution process)	36	6	1
	8	Execution and testing processes/policy/capabilities	38	3	2
	9	Interoperability guidance/policy/capabilities	38	5	0
	10	Documentation of unambiguous terminology	37	5	1
	11	Ability to introduce new interoperability technology	11	19	13
	12	Flexible (agile) organizational structure	39	4	0
	13	Simulation development and execution capabilities	39	2	2
	14	Tools and capabilities for to support scenario development,	36	7	0

Domain		Factors	Agree	Neutral	Disagree
		conceptual analysis, Verification, validation, and accreditation (VV&A), and configuration management			
	15	Facility services for hardware/software integration and test	36	6	1
	16	Security standard/policy/ procedures for hardware, network, data, and software	37	4	2

4.3.2.6 Validation of Factors

This section describes the validation method used in the survey result analysis. When more than 50 percent of the domain experts answered "Agree" to a question for a specific factor, the factor is regarded as a factor that determines the LVC simulation interoperability. The answers were analyzed using a hypothesis test. In addition to the hypothesis test, a 95 percent confidence interval was calculated for each factor. The hypothesis for validation of each factor is:

$$H0: p = 0.5$$

$$H1: p > 0.5$$

The analysis for proportions is implemented using binomial probabilities. A normal approximation to the binomial can be used when p "is not extremely close to 0 or 1" (Walpole and Myers, 1978). The equation to calculate the normal z value is

$$z = \frac{p - 0.5}{\sqrt{(p)(q)/n}}$$

The probability that $Z \leq z$ is in the two-tail normal probability distribution table. The significance level chosen to determine if a factor was validated is 0.05. When the significance level is 0.05 or smaller than 0.05, the null hypothesis is rejected, and we can conclude that more than 50 percent of the survey experts agree with a specific factor.

Using same method, 35 factors were validated, and eight factors were determined to be invalid. Invalid factors were removed from the framework. A 95 percent confidence interval for the participants answered "Agree" in the survey was also calculated. Walpole and Myers (1978) showed that a (1 - α) 100 percent confidence interval for the binomial parameter *p* when the sample size n ≥ 30 is approximately

$$\hat{p} - z_{a/2}\sqrt{\frac{\hat{p}\hat{q}}{n}} < p < \hat{p} + z_{a/2}\sqrt{\frac{\hat{p}\hat{q}}{n}}$$

Where $p\hat{}$ is the proportion of successes in a random sample of size n, $q\hat{} = 1 - p\hat{}$, and $z_{\alpha/2}$ is the value of the standard normal curve. In this case, the 95 percent confidence interval is given by

$$\hat{p} \pm 1.96\sqrt{\frac{\hat{p}\hat{q}}{n}}$$

The significance level for the factor that were validated is usually much greater than 0.05. After the validation process, the technical, conceptual and organizational factors were all validated. Table 22 shows the validation result.

Table 22: Validation Result

Domain		Factors	p value	Valid
Technical	1	Communication networking infrastructure and configuration	0.000	Valid
	2	Compliance to the Standard simulation architectures(HLA, TENA, DIS)	0.000	Valid
	3	Common middleware/gateway/bridge capbilities	0.000	Valid
	4	Simulation performance measurement/monitoring tools/equipments	0.000	Valid
	5	Define human or hardware in-the-loop requirements in simulation systems	0.184	Not valid
	6	Computer hardware/platform/tools and configurations	0.000	Valid
	7	Functionality and fidelity of simulation application to represent required entities, events, phenomena and natural environment	0.000	Valid
	8	Supporting databases/database storage and algorithms	0.000	Valid
	9	Time management	0.000	Valid
	10	Data management and distribution	0.000	Valid
	11	Security	0.000	Valid
	12	Support for IT infrastructure	0.940	Not valid
Conceptual	1	Unambiguous semantics	0.000	Valid
	2	Conceptual model definition and structure	0.000	Valid
	3	Data structure and format compatibility	0.000	Valid
	4	Meta-model for data exchanges	0.302	Not valid
	5	Object modeling standard	0.000	Valid
	6	Documentation of meaning/content of data	0.874	Not valid
	7	Adaptive data models in both syntax and semantics	0.695	Not valid
Organizational	1	Available Funding	0.000	Valid
	2	Database management capability	0.996	Not valid
	3	Support and policy for simulation conceptual model	0.000	Valid
	4	Organized/trained subject matter expertise for development/integration/operation/maintenance	0.000	Valid
	5	Time and scheduling coordination capability	0.000	Valid
	6	Performance and reliability measurement/capability	0.901	Not valid
	7	Systems Engineering(SE) processes/policy/capabilities (consistent development and execution process)	0.000	Valid
	8	Execution and testing processes/policy/capabilities	0.000	Valid
	9	Interoperability guidance/policy/capabilities	0.000	Valid
	10	Documentation of unambiguous terminology	0.000	Valid
	11	Ability to introduce new interoperability technology	1.000	Not valid
	12	Flexible (agile) organizational structure	0.000	Valid
	13	Simulation development and execution capabilities	0.000	Valid
	14	Tools and capabilities for to support scenario development, conceptual analysis, Verification, validation, and accreditation (VV&A), and	0.000	Valid

Domain		Factors	p value	Valid
		configuration management		
	15	Facility services for hardware/software integration and test	0.000	Valid
	16	Security standard/policy/ procedures for hardware, network, data, and software	0.000	Valid

To formalize the LSIMM, all the identified factors need to be mapped to factors that represent all the characteristics of the factors. Table 23 demonstrates the mapping of the factors.

Table 23: Mapping of Factors for Technical Domain

Domain	Factors
Technical	Computer and Network Infrastructure
	Standard Simulation Architecture (SSA) Compliance
	Simulation application and configuration
	Technical Simulation Management
Conceptual	Unambiguous Semantics
	Conceptual Model Definition and Structure
	Object Modeling Standard
	Data Format Compatibility
Organizational	Supporting Documentation
	Capable Experts
	Development and Execution Capabilities
	Development and Execution Infrastructure

4.3.3 Interoperability Levels

The next step is to define the interoperability maturity levels to measure the level of simulation interoperability. The maturity levels represent the intensity of interoperability in terms of three interoperability domains mentioned above.

4.3.3.1 The Number of Levels

There is no literature specifically requires the number of interoperability levels in a maturity model. However, practically, the number can be determined based on the previous defined maturity models. In the literature review, most of the identified models maintained a number of five levels. In addition, five-level can be statistically practical when the levels are applied to a five point Likert scale to determine certain capabilities (Huijsman, Plomp, & Batenburg, 2012). Therefore, LCIMM uses a five-level interoperability.

4.3.3.2 Labeling the Levels

The literature reviews were analyzed to name each interoperability level. The names were selected based on two requirements.

1. Requirement 1: the name should properly represent an interoperability level at which the simulation is exactly located.
2. Requirement 2: the name should be limited to an exact level to avoid confusing between levels.

Because LCIMM uses five levels in the model, the first level should describe an interoperability level where there is no potential interoperability (totally isolated), and the fifth level should be a level where simulation has a complete potential interoperability (totally interoperable). Other three levels should be named to represent the gradual difference of interoperability level.

4.3.3.2.1 Review of Primary Existing Interoperability Maturity Models

This section reviews existing maturity models that provide the factors that the LSIMM is based on. The maturity models are closely related to LSIMM in term of technical, organizational and conceptual domains. The literature survey focused on legacy interoperability maturity models which successfully addressed associated interoperability measurement issues.

After literature review, appropriate models for development LSIMM was identified and collected. They are LISI, OIM, NMI, LCIM and EIMM. LISI has been used to measure the technical interoperability domain (Tolk, 2003). Although the model was originally intended to measure Information Technology interoperability, it was adopted as a basic template for numerous maturity models (Ford, 2008). Table 24 shows the interoperability levels and associated description of LISI model.

Table 24: LISI Maturity Levels

Maturity Level	Description
Enterprise	Data and applications are fully shared and distributed. Data has a common interpretation regardless of format.
Domain	Information is exchanged between independent applications using shared domain-based data models.
Functional	Logical data models are shared across systems
Connected	Simple electronic exchange of data.
Isolated	Manual data integration from multiple systems.

OIM was proposed by Clark and Jones (1999) because LISI does not focus on organizational interoperability. OIM is an extended version of LISI to address organizational maturity levels. There are five levels in the OIM.

Table 25: OIM Maturity Levels

Maturity Level	Description
Unified	The organization is interoperating on a continuing basis. Command structure and knowledge basis are shared.
Integrated	Shared value systems and goals, a common understanding to interoperate however there are still residual attachments to a home organization
Collaborative	Recognized interoperability frameworks are in place. Shared goals are recognized. Roles and responsibilities are allocated but the organizations are still distinct.
Ad hoc	Some guidelines to describe how interoperability will occur but essentially the specific arrangements are still unplanned. Organizations remain entirely distinct.
Independent	Organizations work without any interaction. Arrangements are unplanned and unanticipated. No formal frameworks in place.

NMI was originally intended to address the data exchange flows between enterprise organizations. NMI was updated to reflect LISI model in 2003 (Morris et al., 2004). Table 26 depicts the NMI maturity levels.

Table 26: NMI Maturity Levels

Maturity Level	Description
Seamless sharing of information	Universal interpretation of information through cooperative data processing
Seamless sharing of data	Automated data sharing within systems based on a common exchange model
Structured data exchange Functional	Exchange of human-interpretable structured data intended for manual and/or automated handling, but requires manual compilation, receipt, and/or message dispatch
Unstructured data exchange Connected	Exchange of human-interpretable, unstructured data such as the free text found in operational estimates, analysis, and papers.

LCIM was selected because the model assesses conceptual interoperability level of exchanged data which goes beyond technical models. LCIM is intended to bridge conceptual design and technical design (Tolk and Muguira, 2003).

Table 27: LCIM Maturity Levels

Maturity Level	Description
Harmonized data	Semantic connections are made apparent via a documented conceptual model underlying components.
Aligned dynamic data	Use of data is defined using software engineering methods like UML.
Aligned static data	Common reference model with the meaning of data unambiguously described.
Documented data	Shared protocols between systems with data accessible via interfaces.
System specific data	Black boxes components with no interoperability or shared data.

EIMM was developed by the ATHENA (Advanced Technologies for interoperability Heterogeneous Enterprise Networks and Applications) project (Athena, 2005). The model defines general interoperability level of between enterprises. Table 28 shows the EIMM maturity levels.

Table 28: EIMM Maturity Levels

Maturity Level	Description
Optimizing	Enterprise systems are systematically traced to enterprise models and innovative technologies are continuously researched and applied to improve interoperability.
Interoperable	Enterprise models support dynamic interoperability and adaptation to changes and evolution of external entities.
Integrated	The enterprise modeling process has been formally documented, communicated and is consistently in use.
Modeled	Enterprise modeling and collaboration is done in a similar way each time, the technique has been found applicable. Defined meta-models and approaches are applied, responsibilities are defined.

All the introduced maturity models are analyzed and Table 29 shows the interoperability domain and associated model, and Table 29 shows the interoperability levels of existing models respectively.

Table 29: Interoperability Domain and Associated Models

Maturity Level	Maturity Model
Technical	• LISI (Levels of Information Systems interoperability) • NMI (NC3TA reference Model for Interoperability)
Conceptual	• LCIM (Level of Conceptual Interoperability Model)
Organizational	• OIM (Organizational Interoperability Model) • EIMM (Enterprise Interoperability Maturity Model)

Table 30: Interoperability Levels of Existing Models

Maturity Model	Interoperability Levels
LISI	Enterprise, Domain, Functional, Connected, Isolated
NMI	Seamless sharing of information, Seamless sharing of data, Structured data exchange, Unstructured data exchange
LCIM	Harmonized data, Aligned dynamic data, Aligned static data, Documented data, System specific data
OIM	Unified, Integrated, Collaborative, Ad hoc
EIMM	Optimizing, Interoperable, Integrated, Modeled

4.3.3.2.2 Analysis of Existing Models

Given that LSIMM is intended to focus three interoperability domains (technical, conceptual and organizational), also the interoperability elements for each interoperability domain must be defined. Each interoperability domain must be divided to multiple sub-domains to precisely measure the associated interoperability.

This research focuses on three mentioned interoperability domains. For conceptual and technical interoperability, existing models which are LISI, LCIM, EIMM and NMI were reviewed and contributed to formalize LSIMM. The organizational interoperability domain in this research means managerial capabilities in Systems Engineering of LVC simulation. Thus for the managerial domain, DSEEP and FEDEP were used to identify the important factors that determine managerial interoperability.

4.3.3.2.3 Labels Description

From the literature review process explained in the previous sections, each label was determined. Table 31 below provides detailed descriptions for each level.

Table 31: Overview of LSIMM Levels

Level	Label	Description
Level 0	Isolated	• No interoperability
Level 1	Ad-hoc	• Capability of ad-hoc connecting with multiple heterogeneous simulation systems
Level 2	Connected	• Capability of connecting with multiple heterogeneous simulation systems
Level 3	Standard	• Capability of standard connecting with multiple heterogeneous simulation systems
Level 4	Interoperated	• Capability of interoperating with multiple heterogeneous simulation systems

4.4 The LVC Simulation Interoperability Maturity Model (LSIMM): Specification

4.4.1 LSIMM levels – Level 0 (Isolated)

This level is stand-alone level. In this level, simulation system and relevant organization are stand-alone or isolated and not prepared to interoperate with other simulation systems. For the technical perspective, no reliable computer and network infrastructure and Information Technology (IT) support are provided. The simulation system is not compliant to SSAs and the simulation system has no capabilities. For the conceptual perspective, there are not conceptual model and data model. There is not organizational structure and management plan for interoperability of simulation. For the organizational and managerial perspective, there is not organizational structure and flexibility of the organization. Table 32 shows the description of the level.

Table 32: Description of LSIMM Level 0

I. Technical	**Computer and Network Infrastructure**	**Standard Simulation Architecture (SSA) Compliance**	**Simulation system Capabilities**	**Technical Simulation Management**
Level 0	No or unreliable infrastructure	No compliance to SSA	No capabilities	No technical simulation management
II. Conceptual	**Unambiguous semantics**	**Conceptual Model Definition and Structure**	**Object Modeling Standard**	**Data Format Compatibility**
Level 0	No document zed semantics	Undefined conceptual model	No object modeling standard	No data format compatibility
III. Organizational	**Supporting Documentation**	**Capable Experts**	**Development and Execution Capabilities**	**Development and Execution Infrastructure**
Level 0	No supporting documentation	No capable experts	No development and execution capabilities	No flexible organization

4.4.2 LSIMM levels – Level 1 (Ad-hoc)

The simulation system is considered prepared to interoperate with other simulation systems from this level. The simulation system and the organization have basic capabilities, and implementation of ad-hoc level interoperability is possible in this level.

Technically, the interoperability environment including the simulation system and network infrastructure is limited. Conceptually, all the conceptual model, object modeling and data format were modeled and documented. The organization has organized experts but has a limited development and execution capabilities. Table 33 shows the description of the level.

Table 33: Description of LSIMM Level 1

I. Technical	**Computer and Network Infrastructure**	**Standard Simulation Architecture (SSA) Compliance**	**Simulation system Capabilities**	**Technical Simulation Management Capabilities**
Level 1	Basic IT infrastructure	Connectable and Ad hoc information exchange	Limited capabilities	Limited technical management
II. Conceptual	**Unambiguous semantics**	**Conceptual Model Definition and Structure**	**Object Modeling Standard**	**Data Format Compatibility**
Level 1	Modeled or documented			
III. Organizational	**Supporting Documentation**	**Capable Experts**	**Development and Execution Capabilities**	**Development and Execution Infrastructure**
Level 1	Limited documentation	Organized experts	Limited development and execution capabilities	Defined organization structure

4.4.3 LSIMM levels – Level 2 (Connected)

This level is connected level. The simulation system and the organization have basic connected level of interoperability capabilities from this level. The simulation system and the organization have basic capabilities, and implementation of a basic level interoperability is possible in this level.

Technically, the interoperability environment including the simulation system and network infrastructure has defined infrastructure. Conceptually, all the conceptual model, object modeling and data format use defined formats, structure and configuration. The organization has defined supporting documentation, and trained experts who have a defined development and execution capabilities.

Table 34: Description of LSIMM Level 2

I. Technical	**Computer and Network Infrastructure**	**Standard Simulation Architecture (SSA) Compliance**	**Simulation system Capabilities**	**Technical Simulation Management Capabilities**
Level 2	Defined IT infrastructure	Defined compliancy to SSA	Defined capabilities	Defined technical management
II. Conceptual	**Unambiguous semantics**	**Conceptual Model Definition and Structure**	**Object Modeling Standard**	**Data Format Compatibility**
Level 2	Use of Defined format/structure and configuration			
III. Organizational	**Supporting Documentation**	**Capable Experts**	**Development and Execution Capabilities**	**Development and Execution Infrastructure**
Level 2	Processes / Procedures defined	Trained experts	Defined development and execution processes/procedures	Trained organization for processes/procedures

4.4.4 LSIMM levels – Level 3 (Standard)

This level is standard level. The simulation system and the organization have basic standardized capabilities, and implementation of a standardized level interoperability is possible in this level.

Technically, the interoperability environment including the simulation system and network infrastructure has open and organized computer and network IT infrastructure. A collaborative technical management is possible in this level. Conceptually, all the conceptual model, object modeling and data format are meta-modeled. The organization has listed supporting documentation, and specialized experts who have a collaborative and specialized development and execution capabilities.

Table 35: Description of LSIMM Level 3

I. Technical	**Computer and Network Infrastructure**	**Standard Simulation Architecture (SSA) Compliance**	**Simulation system Capabilities**	**Technical Simulation Management Capabilities**
Level 3	Standard IT infrastructure	Standard compliance to SSA	Collaborative capabilities	Collaborative technical management
II. Conceptual	**Unambiguous semantics**	**Conceptual Model Definition and Structure**	**Object Modeling Standard**	**Data Format Compatibility**
Level 3	Meta-modeled format/structure and configuration			
III. Organizational	**Supporting Documentation**	**Capable Experts**	**Development and Execution Capabilities**	**Flexible Organization**
Level 3	Processes / Procedures listed	Specialized experts	Collaborative and specialized development and execution processes/procedures	Flexible organization structure

4.4.5 LSIMM levels – Level 4 (Interoperated)

This level is agile and adaptive level. The simulation system and the organization have adaptive and agile simulation capabilities, and implementation of dynamic and adaptive level interoperability is possible in this level.

Technically, the interoperability environment including the simulation system and network infrastructure has adaptive IT infrastructure. Conceptually, all the conceptual model, object modeling and data format use adaptive format, structure and configuration. The organization has fully developed supporting documentation, and agile experts who have high level of development and execution capabilities.

Table 36: Description of LSIMM Level 4

I. Technical	**Computer and Network Infrastructure**	**Standard Simulation Architecture (SSA) Compliance**	**Simulation system Capabilities**	**Technical Simulation Management Capabilities**
Level 4	Adaptive IT infrastructure	Adaptive compliance to SSA	Dynamic and adaptive capabilities	Real-time management
II. Conceptual	**Unambiguous semantics**	**Conceptual Model Definition and Structure**	**Object Modeling Standard**	**Data Format Compatibility**
Level 4	Adaptive format/structure and configuration			
III. Organizational	**Supporting Documentation**	**Capable Experts**	**Development and Execution Capabilities**	**Flexible Organization**
Level 4	Adaptive processes / procedures	Agile/dynamic/adaptive experts	Agile/dynamic/adaptive development and execution processes/procedures	Agile/dynamic/adaptive organization

4.4.6 The Finalized LVC Simulation Interoperability Maturity Model

From the previous formalization process, the LSIMM was formalized.

Table 37: The LVC Simulation Interoperability Maturity Model

I. Technical	**Computer and Network Infrastructure**	**Standard Simulation Architecture (SSA) Compliance**	**Simulation application Capabilities**	**Technical Simulation Management**
Level 0	No or unreliable infrastructure	No compliance to SSA	No capabilities	No technical simulation management
Level 1	Basic IT infrastructure	Connectable and Ad hoc information exchange	Limited capabilities	Limited technical management
Level 2	Defined IT infrastructure	Defined compliancy to SSA	Defined capabilities	Defined technical management
Level 3	Standard IT infrastructure	Standard compliance to SSA	Collaborative capabilities	Collaborative technical management
Level 4	Adaptive IT infrastructure	Adaptive compliance to SSA	Dynamic and adaptive capabilities	Real-time management
II. Conceptual	**Unambiguous semantics**	**Conceptual Model Definition and Structure**	**Object Modeling Standard**	**Data Format Compatibility**
Level 0	No documentized semantics	Undefined conceptual model	No object modeling standard	No data format compatibility
Level 1	Modeled or documented			
Level 2	Use of standard format/structure and configuration			
Level 3	Meta-modeled format/structure and configuration			
Level 4	Adaptive format/structure and configuration			
III. Organizational	**Supporting Documentation**	**Capable Experts**	**Development and Execution Capabilities**	**Flexible Organization**
Level 0	No supporting documentation	No capable experts	No development and execution capabilities	No flexible organization
Level 1	Limited documentation	Organized experts	Limited development and execution capabilities	Defined organization structure
Level 2	Processes / Procedures defined	Trained experts	Defined development and execution processes/procedures	Trained organization for processes/procedures
Level 3	Processes / Procedures listed	Specialized experts	Collaborative and specialized development and execution processes/procedures	Flexible organization structure
Level 4	Adaptive processes / procedures	Agile/dynamic/ada ptive experts	Agile/dynamic/adaptive development and execution processes/procedures	Agile/dynamic/adapti ve organization

4.5 The LVC Simulation Interoperability Measurement Process

This section describes a process how to measure the potential interoperability level of a simulation application based on the developed LSIMM.

4.5.1 Interoperability Measurement Process Overview

The measurement process is a part of the interoperability measurement framework. The measurement is an activity either determines the current interoperability level of a simulation system and relevant organization, or an activity as an initiative to continuously improve the interoperability levels. Figure 18 depicts the process.

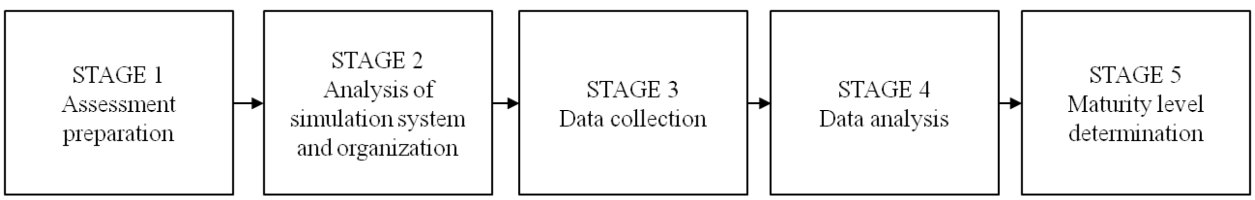

Figure 18: Interoperability Measurement Process

This process defines multiple stages and associated methodology to determine the interoperability maturity level of a simulation system. Table 38 depicts descriptions of each process.

Table 38: Descriptions of Each Process

Stage		Description
1	**Measurement preparation**	Stage 1 is to prepare the measurement process. This stage defines the interoperability measurement goal, detailed process and constraints. This stage also used to gather general information about the overall measurement process. The assessor needs to collect information such as relevant documentation and interview subjects, etc.
2	**Analysis of simulation system and organization**	Stage 2 is to define and analyze target simulation system and the organization that implements the interoperability, and to identify the system elements that determine interoperability level. The assessors review all accessible information related to the target simulation system.
3	**Data collection**	Stage 3 is to interview with relevant domain experts to collect enough information about the target simulation system and the organization. This stage is also to ensure if the gathered information from previous stage is accurate. Assessors can obtain other information sources and past measurement results. The interview is conducted according to a developed interview process framework.
4	**Data analysis**	Stage 4 is to analyze interview result and obtain feedbacks from the interoperability organization. The result is used and process to determine the final interoperability maturity level of targeted simulation system and the organization. Each assessor assigns interoperability level based on the assessors' judgment. In this stage the initially determined interoperability levels are subjective.
5	**Maturity level determination**	This stage is to finalize the interoperability maturity level. The team of assessors reaches an agreement and determines the maturity level. This stage extends with providing a roadmap to improve the interoperability maturity level of the target system and the organization.

4.5.2 Stage 1: Measurement Preparation

Stage 1 is to prepare the measurement process. In this stage, the assessor defines the interoperability measurement goal, the scope and gathers general information about the overall measurement process. The assessors can be originated from outside. The assessors may be originated from an organization which implements the simulation interoperability, or other external organization, or combination of the two.

Stage 1 is mainly for interview preparation. The goal of the interview is to obtain all collectable information to evaluate the potential interoperability level of a target simulation system and a relevant interoperability organization. The interview is conducted according to a developed interview process framework. Figure 19 depicts the interview process adapted from Giachetti (2010).

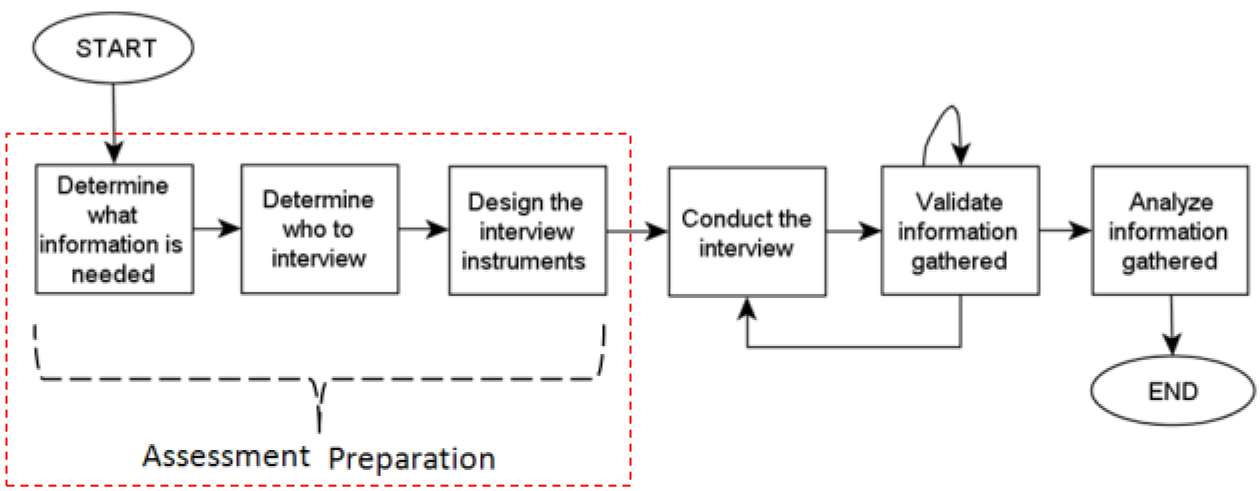

Figure 19: Interview Process (Giachetti, 2010)

In Stage 1, the first three stages of the interview process are conducted. As the interview process is initiated, the measurement team determines what information is needed. The identification of the information is very important because there should be limited number of interview sessions.

Next step is to find interviewees. The interviewees should be any domain experts who have enough experiences in the simulation system interoperability domain. Suitable interviewees have enough knowledge and clear understanding of the target simulation system and the organization.

The measurement team also needs to prepare interview questionnaire to avoid any confusion and misunderstanding of meaning of words during the interview sessions. Table 39 demonstrates the interview questionnaire.

Table 39: Partial Interview Questionnaire

Interview Questionnaire
I. General
Simulation System
1. What is the objective of simulation system? 2. What is the functionality of the simulation system? 3. What are the identified constraints of the simulation system?
Organization
1. What is the organization structure? 2. What are the levels of capabilities?
II. Technical
1. Is there reliable computer and network infrastructure? 2. Is the simulation system compliant to the Standard Simulation Architecture (SSA) Compliance? 3. What are the capabilities of the simulation system? 4. Does your organization have technical simulation management capabilities?
III. Conceptual
1. Does your simulation system have unambiguous semantics? 2. Does your simulation system have structured conceptual model definition and structure? 3. Does your simulation system have object modeling standard? 4. How is the data format compatibility of your simulation system?
IV. Organizational
1. Does your organization have enough supporting documentation? 2. Does your organization have capable experts? 3. Does your organization have enough development and execution capabilities? 4. Does your organization have enough development and execution infrastructure?

4.5.3 Stage 2: Analysis of Simulation System and Organization

Stage 2 is to define and analyze target simulation system, and identify the system elements that determine interoperability level. Specifically, the assessor needs to understand the overall objective, constraints, and functionality of the target simulation system which are important for simulation interoperability.

4.5.4 Stage 3: Data Collection

Stage 3 is to interview with relevant experts to collect enough information about the target simulation system and the organization. This stage is also to ensure if the gathered information from previous stage is accurate. Assessors can obtain other information sources and past measurement results. Also assessors need a systematic interview process to obtain effective interview result. The measurement team meets the interviewee and should be active to listen to the interviewees. The assessors should determine appropriate length of interview time. An interview process was adopted for this framework. Figure 20 shows the designed interview process.

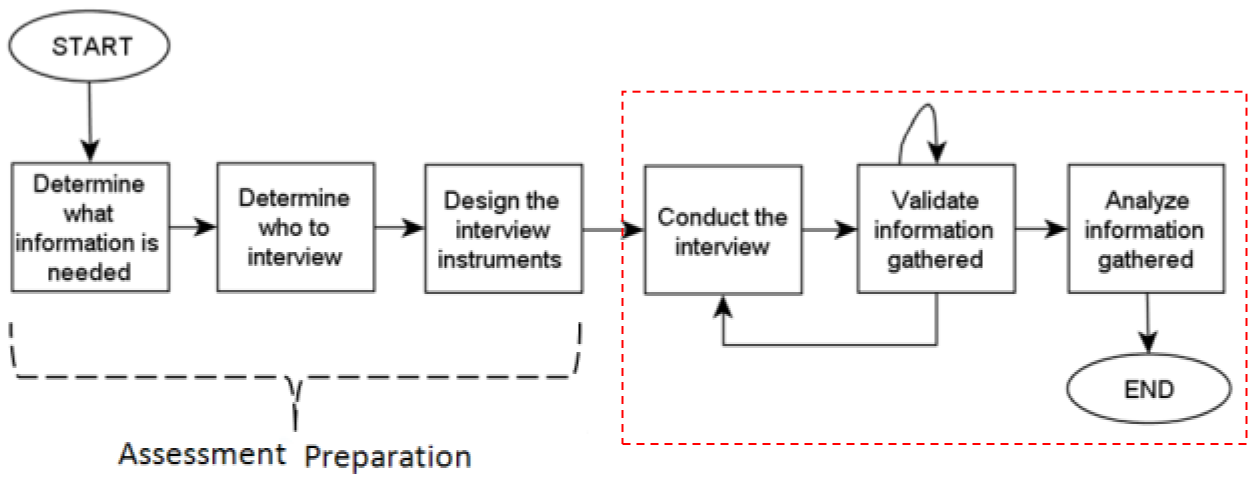

Figure 20: Interview Process (Giachetti, 2010)

4.5.5 Stage 4: Data Analysis

In this stage, the assessor validates the information from the interview activity. The validation is to increase the understating level about the obtained information. The assessor analyzes the interview result and completes an interview result analysis form. Table 40 shows the form.

Table 40: Interview Result Analysis Form (Sample)

Case: AddSIM and SIL					
I. Technical	Level 0	Level 1	Level 2	Level 3	Level 4
A. Computer and Network Infrastructure				V	
B. Standard Simulation Architecture (SSA)				V	
C. Simulation application and configuration			V		
D. Simulation management					V
Determined Technical Maturity Level					
II. Conceptual	Level 0	Level 1	Level 2	Level 3	Level 4
A. Unambiguous semantics			V		
B. Conceptual model definition and structure				V	
C. Object modeling standard			V		
D. Data format compatibility				V	
Determined Conceptual Maturity Level					
III. Organizational	Level 0	Level 1	Level 2	Level 3	Level 4
A. Supporting Documentation				V	
B. Capable Experts					V
C. Development and Execution Capabilities					V
D. Flexible Organization				V	
Determined Organizational Maturity Level					

4.5.6 Stage 5: Maturity Level Determination

The final interoperability maturity level is determined by an agreement among the assessors or measurement team. This framework uses discussion and agreement method to reach an agreement. This stage extends with providing a roadmap to improve the interoperability maturity level of the target system and the organization.

CHAPTER FIVE: CASE STUDY

5.1 Introduction

This section explains the validation method of the proposed framework. The framework proves the validity in measuring LVC simulation interoperability maturity by conducting a case study. The primary objective of this case study is to validate the developed framework by using a real simulation application and a relevant organization. The result of the case study can be used to measure the current interoperability status of the simulation system and the organization, and furthermore to improve the potential interoperability them.

5.2 Theoretical Background

The main benefit of conducting a case study is the particular details and holistic understanding that researchers gain from a specific case. Case study allows researchers to fully understand how an intervention worked, or why an intervention had an effect in a particular case (Silver Pacuilla, Brown, Overton, & Stewart, 2011).

Case study is also considered as useful when the research topic is broad and highly complex, when there is not enough available theoretical background or when the context is highly important (Dul & Hak, 2008). The knowledge can contribute to the knowledge of individual, group, organizational, social, political and related phenomena (Yin, 2014). In the measuring interoperability degree of LVC simulations, the topic can be regarded as broad and complex due to the characteristics such as a large number of organizations involvements, and multiple domains and focuses.

5.3 Case Study Design

Case studies can be used for descriptive, explanatory, or exploratory purposes (Yin, 2014). For any of these purposes, there are two distinct case study designs: multi-case design and single-case design. Although multi-case designs of case study is analytically powerful and can lead to more successful validation than single-case design (Yin, 2014), this research utilizes a single-case design because this research is a part of a specific project named the 'AddSIM Project'. This project case was purposely selected because the case is an atypical case. AddSIM is a being developed simulation model. The detailed information is introduced in the following sections. Also the relevant organization which implements simulation interoperability using AddSIM is the target organization for the case study.

A case study process was designed base on Yin (2014). Figure 21 depicts the designed case study.

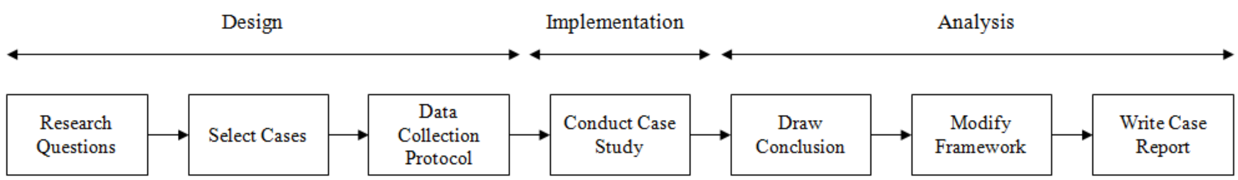

Figure 21: Case Study Process

The case study process consists of three main sub stages. In the first *design* stage, research questions which ask the goal of the case study are designed. Also cases which are applied to the case study are selected and explained. Finally, data collection protocol is designed and documented. In the *implementation* stage, the designed case study is conducted. In the *analysis* stage, a conclusion from the implementation is drawn. This conclusion is used to modify the proposed framework because the case study is a part of a framework validation process. Finally the process ends with providing a case study document. Table 41 describes detailed description of each case study process.

Table 41: Case Study Process Description

Stage		Description
1	**Research questions**	• Goal and objectives of the case study
2	**Select cases**	• Cases selection and rationale • A simulation system and an organization
3	**Design data collection protocol**	• Data collection methods such as documentation, interviews, and website, etc.
4	**Conduct case study**	• A single case implementation of case study
5	**Draw conclusion**	• Case study conclusion and initial report
6	**Modify framework**	• Modification of the framework based on the finding and conclusion from the implementation
7	**Write case report**	• Final case study report with modified framework

5.3.1 Research Questions

The research questions for the case study are:

1. What are the interoperability levels of AddSIM in terms of technical and conceptual domains?

2. What are the interoperability levels of the Simulation Interoperability Laboratory (SIL) in terms of organizational domain?

The case study is implemented to draw the interoperability levels of the target simulation system and the relevant organization.

5.3.2 Case Selection

Because the case study would be performed with a single-case design, a simulation model which is developed and operated by an organization was selected. The model is a component-based simulation environment which is the *Adaptive distributed parallel Simulation environment for Interoperable and reusable Model (AddSIM).*

The organization is the Simulation Interoperability Laboratory (SIL) in the Department of Industrial Engineering and Management Systems (IEMS) at the University of Central Florida (UCF). The SIL is working on a funded project relevant to AddSIM. The purpose of the project is to ensure that the component-based simulation environment (AddSIM) supports the interoperability function for LVC components. Table 42 gives the descriptions of the simulation system and the organization. More detailed description is provided in the next section.

Table 42: Selected Cases

Case	**Description**
I. AddSIM	• A simulation system • A component-based simulation environment
II. SIL	• A research lab that working on a funded project relevant to AddSIM

5.3.3 Data Collection Protocol

In order to collect enough data to analyze and determine the interoperability level of the selected simulation system and the relevant organization, a data collection protocol was designed. The data collection protocol consists of using available documents and interview. Figure 22 shows the data collection protocol.

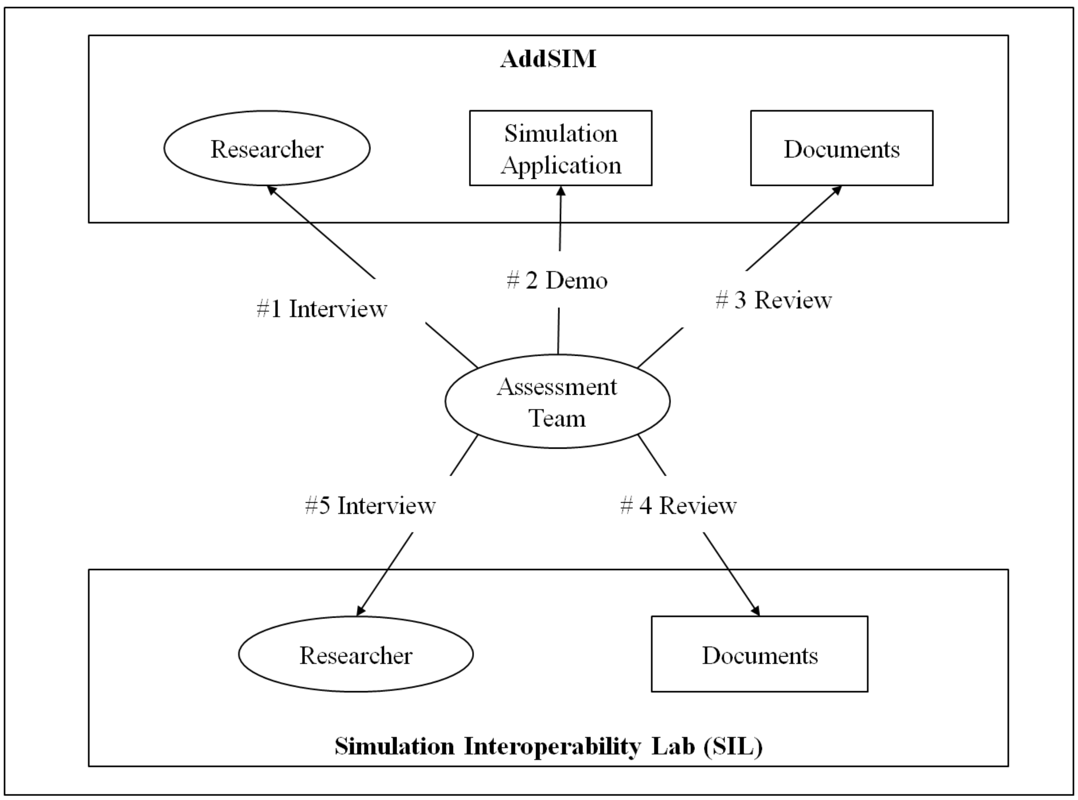

Figure 22: Data Collection Protocol

For AddSIM side, an interview to an AddSIM developer, a demonstration and document reviews are conducted. An interview to a simulation system researcher and document reviews are also conducted. The data from the collection activities are combined and analyzed.

5.4 Case Study Implementation

5.4.1 Measurement Preparation

The assessor defined the interoperability measurement goal, the scope and gathers general information about the overall measurement process. The assessor is a researcher in the SIL. The interview questionnaire was also prepared. The interview is conducted according to a developed interview process framework. As the interview process is initiated, the assessor determined what information is needed. The identification of the information is very important because there should be limited number of interview sessions. The interviewees are a developer of AddSIM and a researcher in SIL. They have enough knowledge and clear understanding of the target simulation system and the organization.

5.4.2 Data Collection

From the defined data collection protocol, information about the AddSIM and the SIL were collected. This section describes the detailed case study implementation process.

5.4.2.1 AddSIM

5.4.2.1.1 Introduction of AddSIM

AddSIM is a component-based weapon system simulation environment using engineering models of weapon systems to enhance interoperability, reusability, and composability of weapon simulation models. AddSIM was developed by the Agency of Defense Development (ADD), South Korea from 2009 to 2011 (Lee, Lee, Kim, & Baik, 2012).

AddSIM adopted layered architecture design to facilitate the model development and the maintenance of the software as depicted in Figure 23. The layered architecture also prevent from duplication of functions at each layer. For example, the kernel layer which is the core component of AddSIM consists of six functions including parallel/distributed management for parallel processing in distributed environment as well as the basic five functions of event management, time management and simulation management, run-time object management and persistence/rollback management.

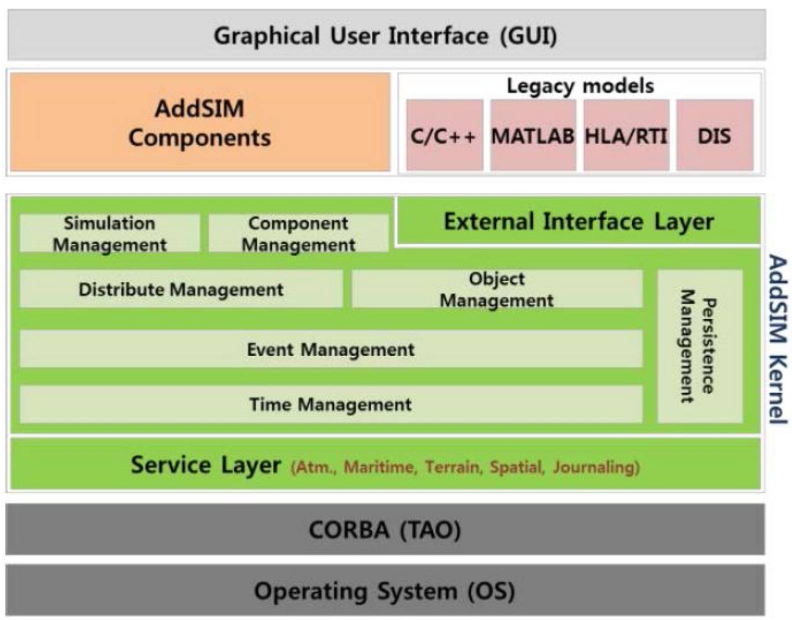

Figure 23: Architecture of AddSIM

The architecture consists of a tool & application layer, external interfaces layer, kernel layer, service layer, communications layer, and platform layer.

5.4.2.1.1.1 Tool and Application Layer

In a tool and application layer, component & player development, build & execution, and analysis of simulation, search and use of componentized models in distributed repositories are performed. The graphical editing framework (GEF) based on Eclipse is used as a development tool to increase the user convenience and efficiency of the components and player development. To support the reuse of components, an editing tool provides properties of components in EXtensible Markup Language (XML) format. The standard structure of component is referred to as Base Object Model (BOM) of SISO.

The web server for component model is linked with the xml file automatically when the component is shared. During the time the component is developed, the xml file that is used in the simulation configuration and operation for the model is made. AddSIM also provides the post-analysis module to analyze the simulation result and visualization module using SIMDIS 3-D Analysis and Display Toolset to play back the entire simulation execution (Lee et al., 2012).

5.4.2.1.1.2 Kernel Layer

Kernel layer that is a core layer of AddSIM consists of six functions, including parallel and distributed management for parallel processing in distributed environment as well as the five basic functions of event management; time management and simulation management, run-time object management and persistence & rollback management. The Procedure for executing the simulation in kernel layer is as follows. After loading componentized models stored in a local and remote repository based on created simulation file in tool & application layer, simulation object is created. Then, run-time objects of simulation are executed. After that, the kernel processes simulation events, which is communication with other runtime simulation objects through messages, stores properties of simulation objects and conducts relay of service for a service layer (Lee et al., 2012).

5.4.2.1.1.3 Service Layer

Service layer supports APIs for the high-fidelity models. Users can easily describe the weapon system by using environmental APIs of atmosphere, ocean, and geography.

The atmospheric and oceanic APIs is designed to treat the meteorological data format such as, GRIdded Binary (GRIB), Synthetic Environment Data Representation and Interchange Specification (SEDRIS) transmittal format (STF) and Network Common Data File (NetCDF) through transforming data into ASCII files. The geographical API is designed to handle the flat and ellipsoidal earth model as well as to manage the Digital Terrain Elevation Data (DTED) and Feature Database (FDB) format to extract the geographical feature. User can handle the simulation object's spatial information such as position, speed, and user defined data. Journaling API saves and extracts log data generated during the simulation execution and user defined variables (Lee et al., 2012).

5.4.2.1.1.4 External Interface Layer

In terms of the external interface layer, there are many simulation resources developed with C and C++ or Matlab in military simulation. Also, many simulation resources are federated through HLA/RTI. HLA is a de-facto SSA for now, and HLA compliancy is a necessary condition to meet current simulation environment requirements. Therefore, simulation environment has to support the interoperability with these legacy simulation resources to enhance the reuse of simulation. For these reasons, AddSIM provides three external interfaces such as C, C++, Matlab, DIS and HLA/RTI interface (Lee et al., 2012).

5.4.2.1.1.5 *Features of AddSIM*

AddSIM has several distinguishing features compared to existing conventional simulation environments.

<u>Separation between a Simulation Engine and Models</u>

The first of the distinguishing features is the separation between a simulation engine and models. Modeling framework in AddSIM has been developed upon *Open Simulation Architecture for Modeling and Simulation* (OSAMS) that is being studied as an open modeling framework in Parallel and Distributed Modeling & Simulation Standing Study Group (PDMS-SSG) of Simulation Interoperability Standards Organization (SISO) and Base Object Model (BOM), SISO standard for simulation object model (J. Steinman & Parks, 2007).

<u>Standardization of a Modeling Framework</u>

The second feature is the standardization of a modeling framework. A simulation model is designed to have a hierarchical structure as shown in Figure 24. The top level is the simulation model that includes some players. Each player consists of some components. Furthermore, each component can include sub-components recursively.

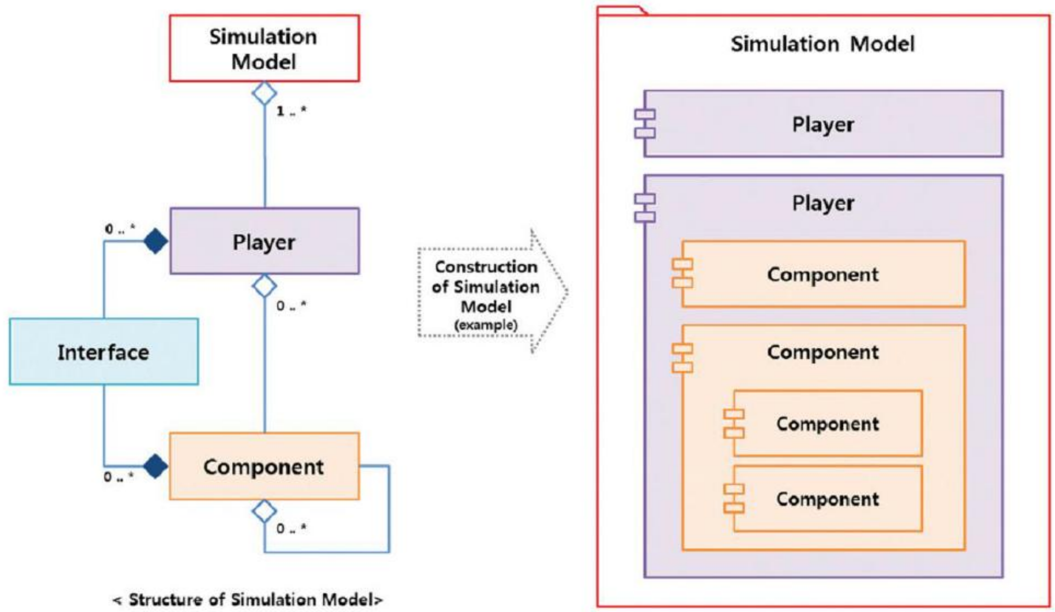

Figure 24: A hierarchical modeling structure of AddSIM

The definition of the, player, component and interface is as follows (Lee et al., 2012).

● Player: It is the top level component model configuring the simulation model. Usually, it represents a weapon system such as flight, tank or missile. The behavior of a player is modeled with a user defined code (UDC).

● Component: It is a building block (an element of a player or upper component) that executes a specific function independently. The behavior of an element is also modeled with a UDC. A component is compiled into a dynamic link library (DLL) and linked with AddSIM.

● Interface: It is a passage to process events of kernel, components and players. Components and players via the interface can communicate each other.

In the modeling procedure, common meta model is used to improve interoperability and reuse of the model. AddSIM also uses meta model for component and player modeling. In the AddSIM, meta-model defines the relationship between component, player, interface, member function, variable, and data type. Using the hierarchical structure and common meta model for component and player, AddSIM can enhance interoperability and reuse of components and players. Components and players are compiled by way of componentizing to configure the dynamic loading for simulation. Meta-information for a component such as configuration information, communication information, and control information is stored and controlled in XML style. While a simulation is executed, a kernel interprets that file for configuring simulation objects. As AddSIM provides dynamical loading of simulation objects, components stored in remote repositories are retrieved or used without any modification of components by downloading.

Web Service based on SOA Concept

The third characteristic is web service based on SOA concept. To support distributed simulation smoothly, the distributed resource repository based on web is provided. Through the web service, users can retrieve and reuse components stored in a remote repository. Figure 25 shows the operational concept of distributed repository.

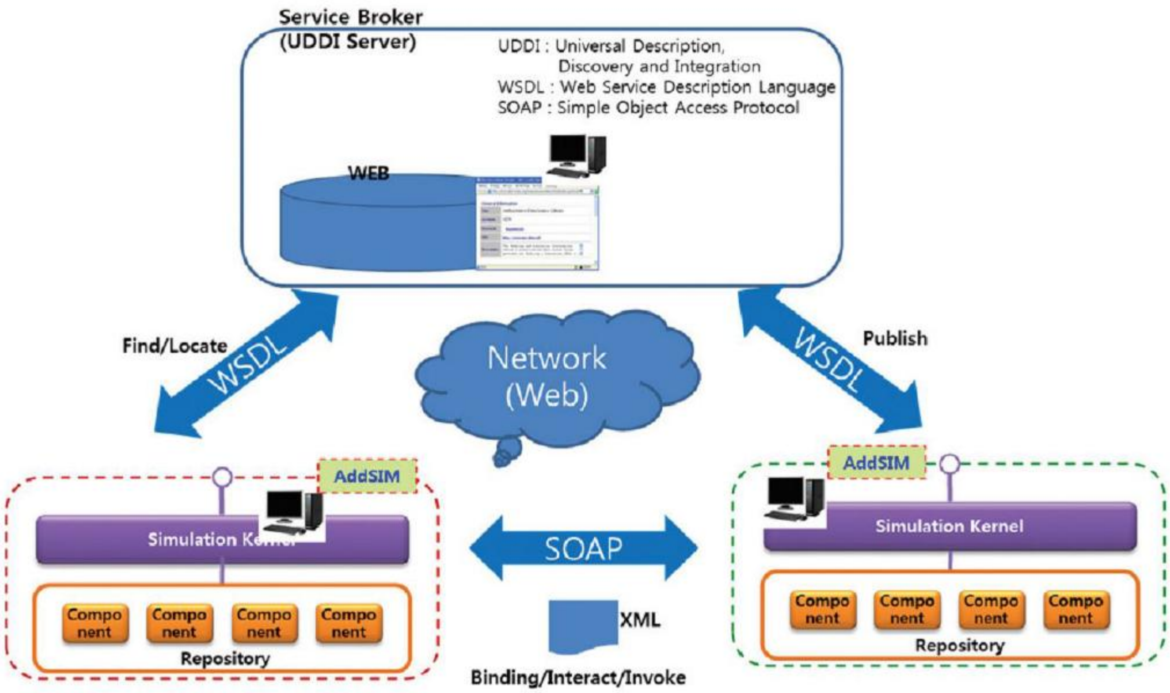

Figure 25: Operational concept of distributed repository.

<u>Time Synchronization Algorithm</u>

Finally, AddSIM engine provides the infrastructure and related functions capable of working number of event processes and synchronizing time between event processes in order to do parallel processing at the same time. Time synchronization algorithm for parallel processing can be divided into a conservative and optimistic way. In the optimistic way, there are time warps, breathing time bucket (BTB), breathing time warp (BTW), etc. Among the optimistic way, AddSIM engine is designed to utilize BTB algorithm and rollback handling for time synchronization between event processes when proceeding parallel processing.

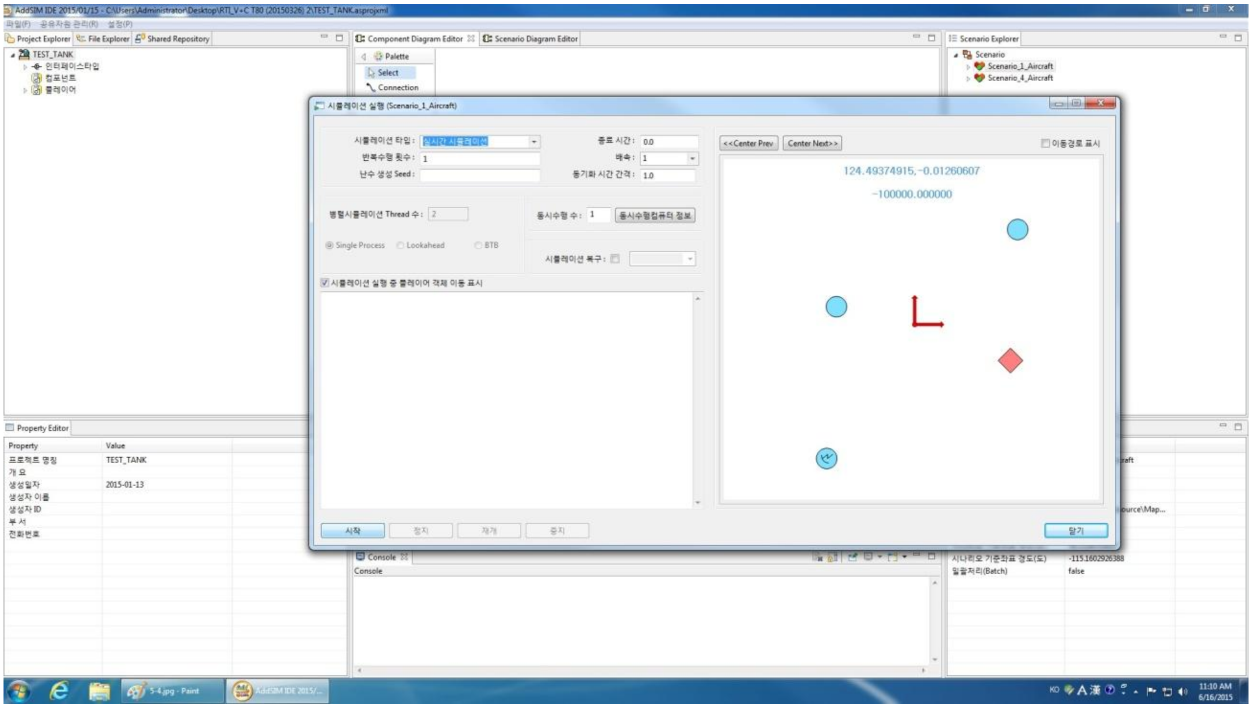

Figure 26: AddSIM Graphic User Interface

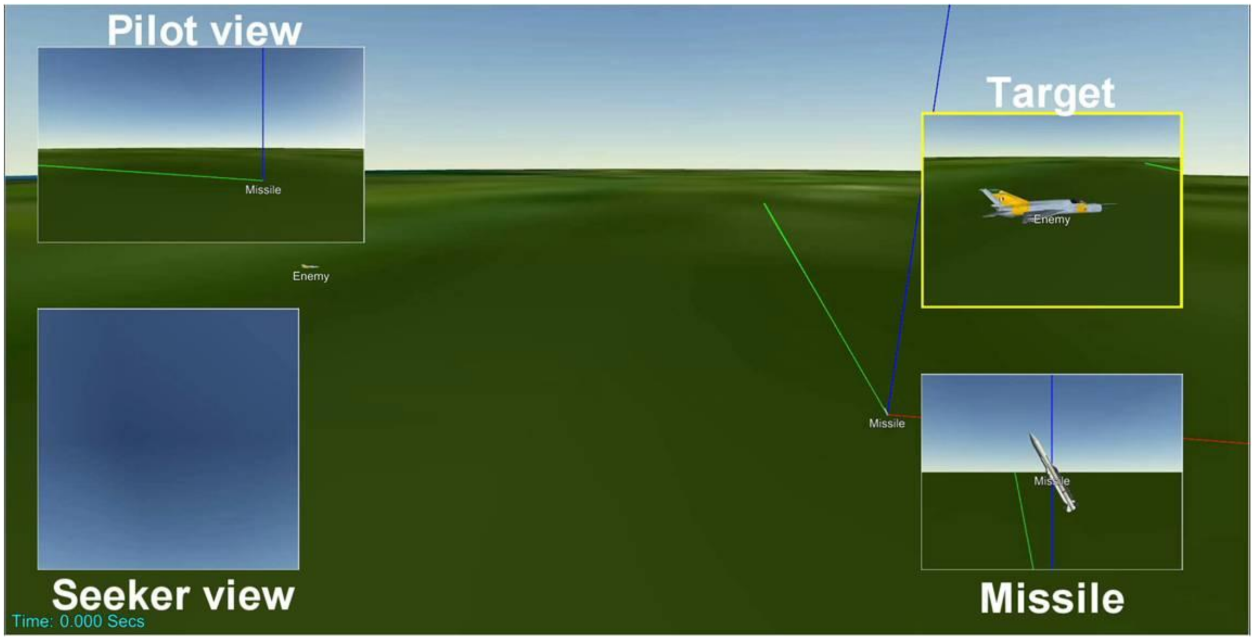

Figure 27: Visualization of AddSIM Simulation Result

AddSIM has capability to integrate other simulations developed using C/C++ or Matlab in distributed simulation environment. The purpose of the capability is to support reusability and interoperability with other legacy simulations resources. The interoperability is implemented through standard interoperability architectures such as the High Level Architecture (HLA). For this reason, AddSIM provides three external interfaces such as C/C++, Matlab, and HLA interface (Lee et al., 2012).

5.4.2.1.2 Application Demonstration

In order to assess the current interoperability maturity level, a series of demonstrations were implemented by a researcher in the SIL. The demonstration content details are explained in Table 43.

Table 43: AddSIM Demonstration Detail

Content		Description
1	Graphical User Interface (GUI)	✓ Main user interface ✓ Simulation operational interface ✓ Analysis / replay interface
2	Scenario Development	✓ Project creation ✓ Interface type definition ✓ Component / player development ✓ Scenario generation ✓ Simulation run ✓ Simulation result analysis
3	Application Programming Interface (API)	✓ User component/player functions ✓ User interface functions ✓ API services
4	Sample Project Development	✓ Development and implementation of sample scenarios

5.4.2.1.3 Document Review

The available document is the 'AddSIM Software User Manual' which describes how to use the simulation software and the APIs. The manual is for users who want to run the application with existing sample project or for who want to design and develop user specified components, players, scenarios. The document was reviewed and multiple sample scenarios were implemented using the document. Other available documents are published research papers regarding AddSIM.

5.4.2.1.4 Interview

One of the primary data collection methods is conducting interviews to an expert involved in the development of AddSIM. To conduct the interviews, an interview protocol was created. To analyze the capabilities of AddSIM, a questionnaire was developed. Table 44 shows a part of the main questionnaire. The questionnaire does not include the organizational domain because the domain is for the organization which implements simulation interoperability with AddSIM. The organization is introduced and the capabilities are analyzed in the next section. The full version of the evaluation spreadsheets can be found in Appendix B.

Table 44: A Part of Main Questionnaire

Interview Questionnaire
I. General
1. What is the objective of simulation system? 2. What is the general architecture of the simulation system? 3. What is the functionality of the simulation system? 4. What are the identified constraints of the simulation system? 5. What is the organization structure?
II. Technical
1. Is there reliable computer and network infrastructure? 2. Is the simulation system compliant to the Standard Simulation Architecture (SSA) Compliance? 3. What are the capabilities of the simulation system? 4. Does your organization have technical simulation management capabilities?
III. Conceptual
1. Does your simulation system have unambiguous semantics? 2. Does your simulation system have structured conceptual model definition and structure? 3. Does your simulation system have object modeling standard? 4. How is the data format compatibility of your simulation system?

5.4.2.2 The Simulation Interoperability Laboratory (SIL)

5.4.2.2.1 Introduction of the lab

The Simulation Interoperability Laboratory (SIL) is an academic research organization which implements mainly simulation interoperability in the Industrial Engineering and Management Systems (IEMS) at the University of Central Florida. There are total six team members in the organization: two professors, two researchers with Ph.D. degrees, and two doctoral students. The team is working on to accomplish Virtual and Constructive (VC) simulation interoperability using multiple legacy simulation systems based on the High Level Architecture (HLA) and Run-Time Infrastructure (RTI) as a part of a project with ADD.

Figure 28: Simulation Interoperability Laboratory (SIL) and Simulator

5.4.2.2.2 Document Review

The available documents were reviewed. The available document list includes 1) Introduction of the SIL, 2) Research Publications, 3) Technical Reports and 4) Research Proposals.

5.4.2.2.3 Interview

The primary data collection method is conducting interviews to the experts involved in the development and operation of the simulation model in the SIL. To conduct the interviews, an interview protocol was created. To analyze the capabilities of SIL, a questionnaire was developed. An interview was conducted to a researcher who has operation experiences with AddSIM in prospect of interoperability with other simulation systems. Table 45 shows a part of the main questionnaire. The full version of the evaluation spreadsheets can be found in Appendix B.

Table 45: A Part of Main Questionnaire

Interview Questionnaire
IV. General
1. What is the objective of the organization? 2. What is the general structure of the organization? 3. What is the functionality of the organization? 4. What are the identified constraints of the organization?
V. Organizational
1. Does your organization have enough supporting documentation? 2. Does your organization have capable experts? 3. Does your organization have enough development and execution capabilities? 4. Does your organization have development and execution infrastructure?

5.5 Case Study Result Analysis

In this section, the result of the case study implementation is discussed in terms of the three interoperability domains. The interoperability level of the selected simulation for each domain is discussed separately. The final current interoperability maturity level of AddSIM and SIL is discussed and determined and conclusions are drawn.

5.5.1 Technical Domain

The current interoperability levels of AddSIM in technical domain were analyzed and determined from the analysis of the collected data. Table 46 shows detailed analysis result.

Table 46: Analysis of Collected Data: Technical Domain

1. Computer and Network Infrastructure
✓ Communication networking infrastructure and configuration
• AddSIM is installed in a desktop computer with standard performance. The capability is enough to run AddSIM without any latency. • A standard communication networking is available such as TCP/IP Local Area Network (LAN) without major modifications.
2. Standard Simulation Architecture (SSA) Compliance
✓ Compliance to the Standard simulation architectures
• AddSIM is developed to be compliant to SSAs such as HLA and DIS. Legacy model components can participate in scenarios in AddSIM through the 'External Interface'. • AddSIM can use legacy models developed based on other simulation applications such as Matlab and external C++ source codes.
✓ Common middleware/gateway/bridge capbilities
• AddSIM has capabilities to use common middleware such as RTI as well as gateways and bridges.
3. Simulation application Capabilities
✓ Functionality and fidelity of simulation application
• AddSIM has functionality and fidelity of simulation application to represent required entities, events, phenomena and natural environment. • AddSIM has parallel computing capabilities and the users can choose the computer processors configurations.
4. Technical Simulation Management
✓ Simulation performance measurement/monitoring tools/equipments
• SIL has specific simulation performance measurement software.
✓ Supporting databases/database storage and algorithms
• AddSIM has supporting databases/database storage and algorithms.
✓ Time management
• Time management scheme in AddSIM is heavily dependent on users.
✓ Data management and distribution
• Data management and distribution is heavily dependent on users.

From the analysis result discuss above, the interoperability maturity level in technical domain is deemed to be at Level 3 which is *standard*. Table 47 shows the technical interoperability levels of AddSIM. The finalized technical maturity level is Level 3. This means that technically AddSIM has a standard level of possible interoperability maturity. However, the simulation application and configuration and technical simulation management levels are all Level 1 which means AddSIM has limited capabilities in this particular area.

Table 47: Technical Interoperability Levels

I. Technical	**Case: AddSIM**
A. Computer and Network Infrastructure	Standard IT infrastructure (Level 2)
B. Standard Simulation Architecture (SSA)	Standard compliance to SSA (Level 2)
C. Simulation application and configuration	Limited capabilities (Level 1)
D. Technical simulation management	Limited technical management (Level 1)

5.5.2 Semantic and Syntactic Domains

The current interoperability levels of AddSIM in technical domain were analyzed and determined from the analysis of the collected data. Table 48 shows detailed analysis result.

Table 48: Analysis of Collected Data: Semantic and Syntactic Domains

1. Unambiguous Semantics
• AddSIM has meta-modeled format/structure and configuration
2. Conceptual model definition and structure
• AddSIM has meta-modeled format/structure and configuration
3. Object modeling standard
• The object model (player) in AddSIM was developed based on the Base Object Model (BOM) defined by the Simulation Interoperability Standard Organization (SISO).
4. Data format compatibility
• AddSIM has meta-modeled format/structure and configuration

From the analysis result discuss above, the interoperability maturity level in technical domain is deemed to be at Level 3 which is *standard*. Table 49 shows the technical interoperability levels of AddSIM.

Table 49: Semantic and Syntactic Interoperability Levels

II. Semantic and Syntactic	**Case: AddSIM**
A. Unambiguous semantics	Meta-modeled format/structure and configuration (Level 3)
B. Conceptual model definition and structure	
C. Object modeling standard	
D. Data format compatibility	

5.5.3 Organizational Domain

The current interoperability levels of SIL in Organizational domain were analyzed and determined from the analysis of the collected data. Table 50 shows detailed analysis result.

Table 50: Analysis of Collected Data: Organizational Domain

1. Capable Experts
✓ Organized/trained subject matter expertise for development/integration/operation/maintenance
• SIL has specialized experts in simulation interoperability standards such as HLA.
✓ Flexible (agile) organizational structure
• The structure of SIL is open and flexible which means the research member can be changed at any time.
2. Development and Execution Capabilities
✓ Database management capability
• The researchers have enough capabilities for the database management as well as software and hardware for database management
✓ Time and scheduling coordination capability
• The researchers are collaborative in the Time and scheduling coordination.
✓ Performance and reliability measurement/capability
• Limited performance and reliability measurement/capability
✓ Systems Engineering (SE) processes/policy/capabilities
• Limited documentations about systems Engineering (SE) processes/policy/capabilities
3. Supporting Policy Documentation
✓ Execution and testing processes/policy/capabilities
• Not enough documents for execution and testing processes/policy/capabilities
✓ Interoperability guidance/policy/capabilities
• Not enough documents for interoperability guidance/policy/capabilities
✓ Documentation of unambiguous terminology
• Not enough documents for terminology
✓ Support and policy for simulation conceptual model
• Not enough documents for support and policy for simulation conceptual model
4. Development and Execution Infrastructure
✓ Facility services for hardware/software integration and test
• Simulation performance measurement/monitoring tools/equipments
✓ Tools and capabilities for to support scenario development, conceptual analysis, Verification, validation, and accreditation (VV&A), and configuration management
• Multiple simulation systems, tools, and analysis software
✓ Support for IT infrastructure
• Enough support for IT infrastructure

From the analysis result discuss above, the interoperability maturity level in organizational domain is deemed to be at Level 3 which is *standard* except Supporting Documentation (Level 1). Table 51 shows the technical interoperability levels of SIL.

Table 51: Organizational Interoperability Levels

III. Organizational	**Case: SIL**
A. Supporting Documentation	Limited documentation (Level 1)
B. Capable Experts	Specialized experts (Level 3)
C. Development and Execution Capabilities	Adaptive development and execution processes/ Procedures (Level 3)
D. Development and Execution Infrastructure	Adaptive organization infrastructure (Level 3)

5.5.4 Maturity Level Determination

Based on the interviews and the analysis of the available documentation, the current level of technical, conceptual and organizational interoperability is determined. The current capabilities of AddSIM are compared to the capabilities and interoperability status in the LSIMM. The level is determined when all capabilities in each domain reach specific interoperability level. The overall level, therefore, only reach all the capabilities are met. The analysis result can be seen in Table 52.

Table 52: Case Study Result

Case: AddSIM					
I. Technical	Level 0	Level 1	Level 2	Level 3	Level 4
A. Computer and Network Infrastructure			v		
B. Standard Simulation Architecture (SSA)			v		
C. Simulation application capabilities		v			
D. Technical simulation management		v			
II. Conceptual	Level 0	Level 1	Level 2	Level 3	Level 4
A. Unambiguous semantics				v	
B. Conceptual model definition and structure				v	
C. Object modeling standard				v	
D. Data format compatibility				v	
III. Organizational	Level 0	Level 1	Level 2	Level 3	Level 4
A. Supporting documentation		v			
B. Capable experts				v	
C. Development and execution capabilities				v	
D. Development and execution infrastructure				v	

Table 53 shows the finally determined interoperability maturity levels of AddSIM and SIL.

Table 53: Interoperability Maturity Level of AddSIM and the Organization

I. Technical	**Computer and Network Infrastructure**	**Standard Simulation Architecture (SSA)**	**Simulation application and configuration**	**Simulation management**
AddSIM	Standard IT infrastructure	Standard compliancy to SSAs	Limited capabilities	Limited technical management
	Level 2	Level 2	Level 1	Level 1
II. Conceptual	**Unambiguous semantics**	**Conceptual model definition and structure**	**Object modeling standard**	**Data format compatibility**
AddSIM	Meta-modeled format/structure and configuration			
	Level 3			
III. Organizational	**Supporting Documentation**	**Capable Experts**	**Development and Execution Capabilities**	**Development and Execution Infrastructure**
SIL	Limited documentation	Specialized experts	Collaborative development and execution processes/procedures	Adaptive organization infrastructure
	Level 1	Level 3	Level 3	Level 3

Figures below show graphical representations of the finally determined interoperability maturity levels of AddSIM and SIL.

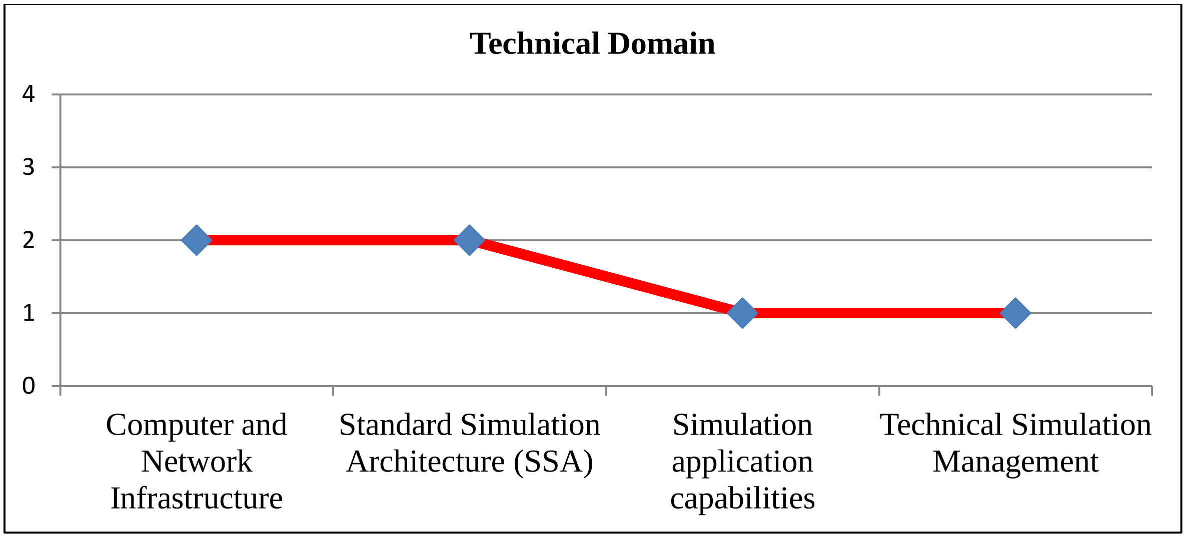

Figure 29: Technical Interoperability Levels of AddSIM

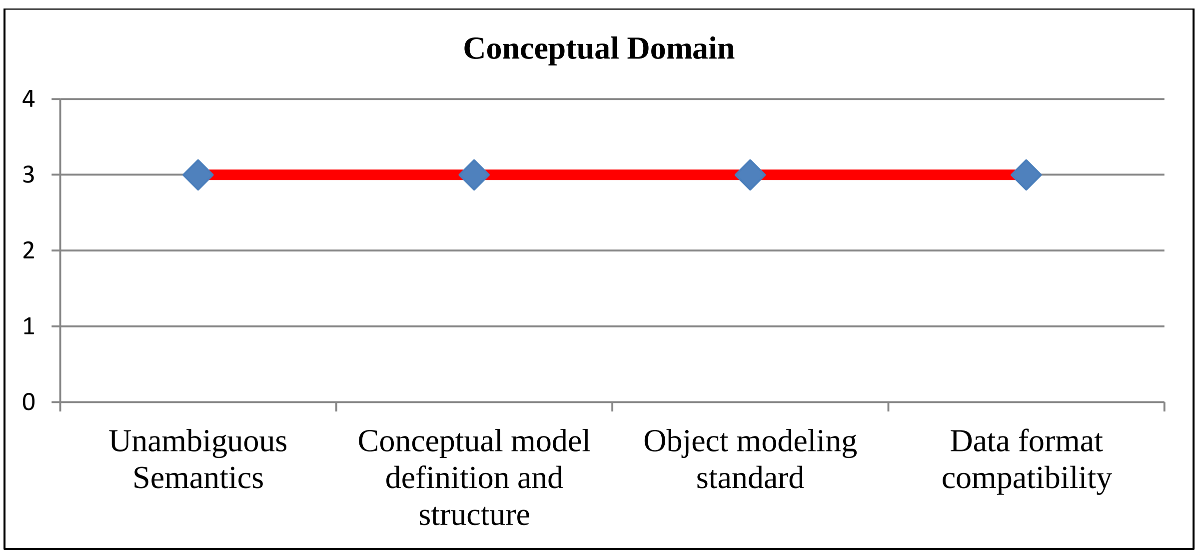

Figure 30: Conceptual Interoperability Levels of AddSIM

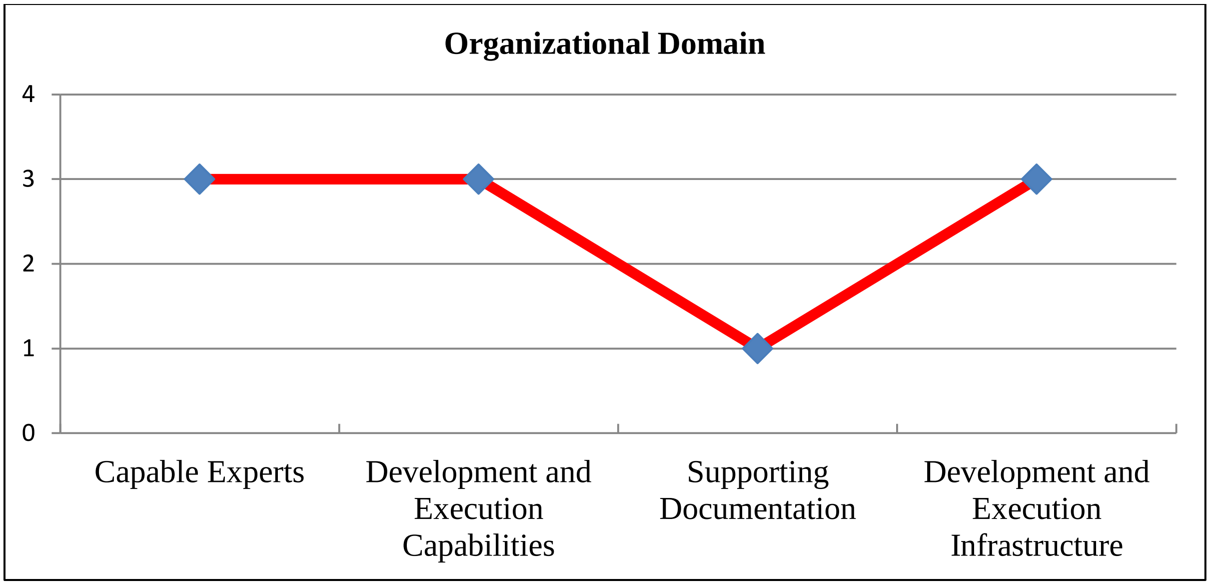

Figure 31: Organizational Interoperability Levels of SIL

CHAPTER SIX: CONCLUSION AND FUTURE RESEARCH

6.1 General Conclusion

This research contributed to develop a systematic method to measure the LVC simulation interoperability levels. An interoperability maturity model for measuring LVC simulation interoperability was proposed. The LSIMM is based on an analysis using other existing interoperability maturity models related to technical, conceptual and organizational interoperability domains. LSIMM was mainly formalized using a survey result from domain experts. LSIMM describes the interoperability levels in terms of technical, conceptual and organizational point of views.

Chapter 1 identified the background, problem, objectives and proposed approach of this research. In the background, the definition of LVC simulation interoperability and the measurement were studied. The problem described the absence of proper framework to measure the LVC simulation interoperability, and proposed approach to solve the problem is presented. Finally, research questions, potential contributions, and synopsis of this thesis were followed.

Chapter 2 focused on introducing background knowledge that the LVC simulation interoperability measurement framework is formalized. Also this chapter provides a scientific foundation for LVC simulation interoperability. The chapter introduces the concept and definition of LVC simulation, interoperability, and existing interoperability measurement models are introduced. The chapter is necessary to identify key LVC simulation interoperability concept that are required to define and guideline the possible solution.

Chapter 3 introduced the methodology used to define LSIMM. The methodology includes a survey from domain experts and a study of existing interoperability measurement framework and relevant models.

Chapter 4 presented the main contribution of this research which is the formalization of LVC simulation interoperability measurement framework. The framework consists of two elements: LSIMM and interoperability measurement methodology (process). The objective of LSIMM is to measure a Live, Virtual, Constructive simulation system interoperability with other future system before they are interoperated. The factors that determine interoperability level are technical, conceptual, and organizational considered. LSIMM is a new framework, but it is partially organized by existing models. Also the interoperability measurement methodology is a process in which interoperability measurement team can refer to measure and determine the interoperability level (degree) of targeted simulation system. This measurement activity also provides consultation how to improve the potential interoperability of the simulation system.

Chapter 5 provided a case study of a component-based simulation environment which is the AddSIM to demonstrate how the interoperability measurement framework can be applied to a simulation system. The case study showed that where AddSIM is located in LSIMM. The measuring activity was presented in detail. Based on the measurement, the current interoperability capabilities of AddSIM are highlighted and proper actions to improve the interoperability level are proposed.

The proposed framework successfully provided an answer to the interoperability measurement team to analyze current interoperability capabilities of AddSIM and SIL. Although the framework did not provide very specific the improvement method of interoperability level, the framework provides analysis results of strength and weakness of technical, conceptual and organizational interoperability domains.

The framework measures the interoperability of single simulation system instead of pair of interoperated systems or multiple systems. Therefore this is very useful even when the future simulation systems that will be interoperated are not known. Higher interoperability maturity level means higher possible interoperability with other simulation systems without major design modifications. Because the interoperability level is determined from consideration of overall capabilities for each interoperability domain, it is hard to say that same interoperability level means exact same interoperability capability meaning easy interoperability. There could be domain specific problems that hinder interoperability.

6.2 Future Research

Future research includes the interoperability measurement framework which can measure potential interoperability for paired simulation systems. If a pair of simulation systems is known and interoperability measurement team wants to integrate them, they can predict the interoperability level and know the strength and weakness of the interoperability capabilities of paired systems.

Other research includes the scientific method to determine interoperability level of a particular simulation system. This thesis concluded that an agreement among a interoperability measurement team can lead to proper determination of interoperability level, but there should be other more reliable methods to reach proper agreements.

APPENDIX A: SURVEY QUESTIONNAIRE

Introduction of Survey

We are studying the level of Live Virtual Constructive (LVC) simulation interoperability. Specifically, our goal is to measure the interoperability maturity level of a simulation application and an organization who implements the simulation interoperability. As you know, LVC simulation interoperability is not only matter of technology. Also conceptual (syntactic and semantic), organizational and managerial issues must be considered to accomplish successful LVC simulations interoperability. Therefore, we will identify important factors that determine the LVC simulation interoperability level in terms of Technical, Conceptual (syntactic and semantic) and Organizational point of view. Here are definitions of the interoperability types. Technical Interoperability covers the technical issues of linking computer systems and services which includes aspects such as interfaces, interconnection services, data integration, middleware, data presentation, data exchange and security. Semantic Interoperability denotes the aspects of interoperability that is concerned with ensuring that the precise meaning of exchange data is understood by the receiving system that was not initially developed for this purpose. Syntactical Interoperability represents the interoperability aspects that are associated with data formats and communication protocol syntax and encoding that would allow two or more systems to communicate and exchange data. Organizational (managerial) Interoperability focuses on managerial capabilities in an organization who wants to interoperate simulation systems.

1. Please indicate your work domain.

Academy Industry Government Other

2. How many years of experience do you have working with LVC simulation domain?

1~5 years 6~10 years 11~15 years 16 years or more

In LVC simulation, technical factors that cover technical issues of linking computer systems and services should be considered. Please select all important factors, from your experience, that determine the LVC simulation interoperability in Technical point of view.

Please indicate you agree or disagree with the following statements.

3. Communication networking infrastructure and configuration determine the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

4. Compliance to the Standard simulation architectures (HLA, TENA, and DIS) determines the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

5. Common middleware/gateway/bridge capabilities determine the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

6. Simulation performance measurement/monitoring tools/equipment determines the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

7. Define human or hardware in-the-loop requirements in simulation systems determines the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

8. Computer hardware/platform/tools and configurations determines the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

9. Functionality and fidelity of simulation application to represent required entities, events, phenomena and natural environment determines the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

10. Supporting databases/database storage and algorithms determines the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

11. Time management determines the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

12. Data management and distribution determines the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

13. Security determines the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

14. Support for IT infrastructure determines the LVC simulation interoperability in Technical point of view.

Disagree Neutral Agree

In LVC simulation interoperability, semantic and syntactic factors should be considered because simulations are heterogeneous and have different semantic / syntactic meaning of data. Please select all important factors, from your experience, that determine the LVC simulation interoperability quality in Syntactic and Semantic point of view.

15. Unambiguous meaning / content of data (semantics) determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

16. Conceptual model definition and structure determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

17. Meta-model for data exchanges determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

18. Object modeling standard determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

19. Documentation of meaning/content of data determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

20. Adaptive data models in both syntax and semantics determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

In LVC simulation interoperability, organizational (managerial) factors should be considered because the simulation interoperability is about collaboration in an organization and managerial capabilities. Please select all important factors, from your experience, that determine the LVC simulation interoperability quality in Organizational (managerial) point of view.

21. Available Funding determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

22. Database management capability determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

23. Support and policy for simulation conceptual model determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

24. Organized/trained subject matter expertise for development / integration / operation / maintenance determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

25. Time and scheduling coordination capability determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

26. Performance and reliability measurement/capability determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

27. Systems Engineering (SE) processes/policy/capabilities (consistent development and execution process) determine the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

28. Execution and testing processes/policy/capabilities determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

29. Interoperability guidance/policy/capabilities determine the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

30. Documentation of unambiguous terminology determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

31. Ability to introduce new interoperability technology determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

32. Flexible (agile) organizational structure determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

33. Simulation development and execution capabilities determine the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

34. Tools and capabilities for to support scenario development, conceptual analysis, Verification, validation, and accreditation (VV&A), and configuration management determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

35. Facility services for hardware/software integration and test determines the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

36. Security standard/policy/ procedures for hardware, network, data, and software determine the LVC simulation interoperability in Syntactic and Semantic point of view.

Disagree Neutral Agree

APPENDIX B: INTERVIEW QUESTIONNAIRE

1. What is the objective of simulation system?
2. What is the organization structure?
3. What are the identified constraints of the simulation system?
4. Does the SIL have communication networking infrastructure? What is the configuration?
5. Is AddSIM Compliance to the Standard simulation architectures such as HLA, DIS and TENA?
6. How are the middleware/gateway/bridge capabilities in AddSIM?
7. Does AddSIM have simulation performance measurement component?
8. What are the human or hardware in-the-loop requirements in AddSIM?
9. What are the Computer hardware/platform/tools and configurations?
10. What is the functionality and fidelity of AddSIM to represent required entities, events, phenomena and natural environment?
11. Does AddSIM have enough supporting databases?
12. What is the time management scheme in AddSIM?
13. What is the data management and distribution in AddSIM?
14. Does AddSIM have security features?
15. Is there enough support for IT infrastructure?
16. How are the semantic meaning and content of data in AddSIM? Are they unambiguous?
17. How are the conceptual model definition and structure in AddSIM?
18. How is the meta-model for data exchanges in AddSIM?
19. How is the Object modeling standard in AddSIM?
20. How are the meaning and content of data in your documentation?

21. Do you have adaptive data models in both syntax and semantics in AddSIM?

22. Do you have enough funding for the interoperability?

23. Does SIL have enough database management capability?

24. Does SIL have support and policy for simulation conceptual model?

25. Does SIL have organized/trained subject matter expertise for development/integration/operation/maintenance?

26. Does SIL have time and scheduling coordination capability?

27. Does SIL have performance and reliability measurement/capability?

28. Does SIL have Systems Engineering (SE) processes/policy/capabilities (consistent development and execution process)?

29. Does SIL have execution and testing processes/policy/capabilities?

30. Does SIL have interoperability guidance/policy/capabilities?

31. Does SIL have documentation of unambiguous?

32. Does SIL have ability to introduce new interoperability technology?

33. Do you think SIL has agile organizational structure?

34. What is your opinion about the comprehensive simulation development and execution capabilities of SIL?

35. Are there tools and capabilities for to support scenario development, conceptual analysis, Verification, validation, and accreditation (VV&A), and configuration management capabilities in SIL?

36. Are there facility services for hardware/software integration and test?

37. Do you have security standard/policy/ procedures for hardware, network, data, and software?

APPENDIX C: APPROVAL OF EXEMPT HUMAN RESEARCH

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Exempt Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Kiyoul Kim**

Date: **March 19, 2015**

Dear Researcher:

On 3/19/2015, the IRB approved the following activity as human participant research that is exempt from regulation:

Type of Review:	Exempt Determination
Project Title:	Identification of factors that determine LVC Simulation Interoperability Maturity Level
Investigator:	Kiyoul Kim
IRB Number:	SBE-14-10836
Funding Agency:	
Grant Title:	
Research ID:	N/A

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these changes affect the exempt status of the human research, please contact the IRB. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Patria Davis on 03/19/2015 10:14:27 AM EDT

IRB Coordinator

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