A STUDY ON THE ANALYZING PRIORITY OF LIMITING FACTORS IN LIVE, VIRTUAL, AND CONSTRUCTIVE (LVC) SIMULATION INTEROPERABILITY USING ANALYTIC HIERARCHY PROCESS (AHP) METHOD

by

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A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Summer Term
2015

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ABSTRACT

Each Live, Virtual, and Constructive (LVC) simulation model has been developed and used with many benefits. When system developers created each simulation model, focused on specific standards to fit to their own respective purposes. Consequently, there have been interoperability issues among simulation models that have many limitations. To be specific, despite various efforts to achieve and maintain complete interoperability in LVC simulation environment, substantial limiting factors have remained in technical and managerial fields. Thus, analyzing and prioritizing limiting factors in LVC simulation is the effective way to solve interoperability problems while saving budget and time.

The purpose of this research is to analyze the priority of limiting factors in LVC simulation interoperability. Based on the identified limiting factors from the literature review, this study performed Analytic Hierarchy Process (AHP) survey to generate weights of experts' judgement for each limiting factor. Following the AHP survey targeted to LVC simulation experts, this researcher suggest the priority of limiting factors that are needed to be focused on as well as recommendations for future research.

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LIST OF ACRONYMS

AIJ	Aggregation of Individual Judgement
AIP	Aggregation of Individual Priorities
AHP	Analytic Hierarchy Process
BCS	Battle Command Systems
CCTT	Close Combat Tactical Trainer
CI	Consistency Index
CR	Consistency Ratio
DIS	Distributed Interactive Simulation
DSEEP	Distributed Simulation Engineering and Execution Process
FEDEP	Federation Development and Execution Process
HLA	High Level Architecture
INCOSE	International Council of Systems Engineers
JMETC	Joint Mission Environment Test Capabilities
LVC	Live, Virtual, and Constructive
LVC-IA	Live, Virtual, and Constructive Integrated Architecture
M&S	Modeling and Simulation
MILES	Multiple Integrated Laser System
OMT	Object Model Template
PEO STRI	Program Executive Office for Simulation, Training and Instrumentation
RI	Random Indices
RTI	Run-Time Infrastructure

SIM/STIM	Simulation / Stimulation
SoS	System of Systems
TENA	Test and Training Enabling Architecture

CHAPTER ONE: INTRODUCTION

1.1 Background

There have been numerous military trainings for developing combat capabilities. With this effort, many kinds of military technologies have been developed to support these trainings. On the other hand, real training has been needed with restrictions such as cost and the possibility of casualties. To manage these problems related communities are using training methods based on modeling and simulation. Modeling and Simulation (M&S) has long been recognized as an essential technology in the military (Henninger et al., 2008). The M&S assets are used to support the design and development of certain programs or systems as well as operational training. Because of the advantage of M&S technology, even other areas such as the medical field and the entertainment industry are using M&S assets in different ways.

Based on M&S technologies, in order to satisfy the needs of each user and the purpose of specified training, different types of simulation environments have been required and developed having its own purpose. The type of simulation that has been made to meet each requirements can be classified into Live, Virtual and Constructive simulation. Live simulation means combining real people with real systems. Live simulation was a prevalent type of simulation used for evaluating weapon system design and testing military personnel readiness in the past. Virtual simulation involves real people interacting with simulated systems. Constructive simulation combines simulated people or unit with simulated systems.

After the development of the simulations, people have wanted effective combination of simulation at different level of fidelity and the use of Live, Virtual, and Constructive (LVC) entities (Page & Smith, 1998). Also, with the beginning of networking technology, supporting architectures were developed for each simulation, leading to extensive use of distributed simulations. The combination of the 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).

Combining the different types of simulations can achieve more effective outcomes than a stand-alone simulation in a synthetic environment. This approach enables each of the systems to share their situation and assets in real time. In addition to this, simulation users can be given more flexibility, as well as scalable environments without additional steps.

However, while each type of simulation can be implemented effectively under specific environments, interoperability cannot be fully achieved under an integrated simulation environment, such as LVC simulation. Interoperability is the capability of systems to provide service to and accept services from other systems operating the systems effectively together (Dahmann, Fujimoto, & Weatherly, 1997). Indeed, substantive interoperability between Live, Virtual and Constructive assets has long been a "Holy Grail" for the Modeling and Simulation (M&S) community (Bizub & Cutts, 2007). However, one simulation system originally was made for its own objective and environment. It is common to have interoperability issues among systems. To be specific, each system not only has different technical factors such as support services, object models, testing environments, and systems engineering models, but also managerial factors, such as funding and leadership in order to develop new systems.

Unlike conventional systems, an LVC simulation system is the System of Systems (SoS), meaning a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities (Ackoff, 1971). Indeed, identifying the factors that can limit the interoperability is not restricted on technical issues. Achievement of complete interoperability cannot be localized to a single factor.

The effort of identifying limiting factors in LVC simulation interoperability attracts broad consensus in the literature. Many of the researchers who are relevant to LVC simulation have been attempting different types of methods in order to achieve interoperability in LVC simulation.

In this context, it is important to prioritize the limiting factors in LVC simulation in order to not waste cost and time. Awareness of the respective importance of these factors enables people who are in this field to define which characteristics that can be modified, improved, and or developed.

1.2 Problem Statement

The purpose of this research is to analyze the priority of limiting factors of interoperability in LVC simulations and contribute to future interoperability research. Despite diverse effort to achieve interoperability in an LVC simulation environment, there has been no research to set the priority among limiting factors. Also, the interoperability issue has remained a difficult problem. There is no doubt that eliminating limiting factors leads to an enhanced and integrated system. In order to determine the priority of limiting factors, this research requires the professional opinion from experts who have special knowledge and experiences using the Analytic Hierarchy Process (AHP) method. Analyzing the priority of limiting factors in the LVC simulation would suggest the goals that can create effective results without wasting effort.

1.3 Potential Contribution

The potential contributions from this research work include the following:

1. This research will propose efficient directions for other research in order to resolve the barrier of achieving complete interoperability.
2. The trend of current interoperability problem among LVC simulation systems will be identified by experts who are in diverse fields. The result of this research will be useful to understand the priority of limiting factors in LVC simulation interoperability based on objective point of view.

1.4 Thesis Overview

This research has five overall chapters. The motive of this research and detailed problem are described in Chapter 1. Chapter 2 explains background of topic and critical issue in LVC simulation interoperability. In Chapter 3, research methodology is described explaining how to design and process the survey to identify priority of limiting factors in LVC simulation based on Analytic Hierarchy Process (AHP). In Chapter 4, results of survey are analyzed by calculating the weight. At last, a recommendation related to problems and future research are discussed in Chapter 5.

CHAPTER TWO: LITERATURE REVIEW

2.1 Chapter Overview

This chapter introduces a review about existing research to offer basic background to the readers and draw the important limiting factors in LVC simulation interoperability. This chapter deals with a) LVC simulation, b) Interoperability, c) Systems Engineering for LVC simulation, d) Limiting factors in LVC simulation interoperability, and e) Analytic Hierarchy Process.

2.2 Area 1: Live Virtual Constructive (LVC) Simulation

2.2.1 Definition of LVC simulation

Each Live, Virtual, and Constructive simulation has been classified by the U.S Department of Defense (DoD). Table 1 contains the commonly used definitions about Live, Virtual, and Constructive simulation.

Table 1 : The Definition of Live, Virtual, and Constructive Simulation(Hodson & Baldwin, 2009)

Classification	Definition
Live Simulation	Real people operate real systems
Virtual Simulation	Real people operate simulated system or simulated people operate real systems
Constructive Simulation	Simulated people operate simulated systems

Live simulation involves real people operating real systems in a real environment. Live simulation environment is comparable to required real operational environment. Through this live simulation, we can get an effective measurement of training while keeping the user safe. An example is a rifle soldier shooting his rifle using MILES (Multiple integrated Laser System) equipment at real targets to achieve training and testing objective.

Virtual simulation is the combination of environments between equipment and operational conditions. One of the general example of Virtual simulation is a CCTT (Close Combat Tactical Trainer) used by U.S. Army. Soldiers can do their operation from simulators representing different roles such as infantry and armor troops. Multiple users can share a common environment while interacting with other users.

Constructive simulation involves simulated people using simulated equipment in a simulated environment (DoD Directive, 1995). Real people make scenarios in the simulations, but the outcome of simulated action is not related to real people. For example, in war gaming models real people are operating input devices such as a computer and control, but the status of operations in war gaming models can be seen only as icons.

Figure 1 shows LVC synthetic environment from a military point of view. Like below, in some situation, the user may need to align with more than one simulation model for integrated and combined surroundings.

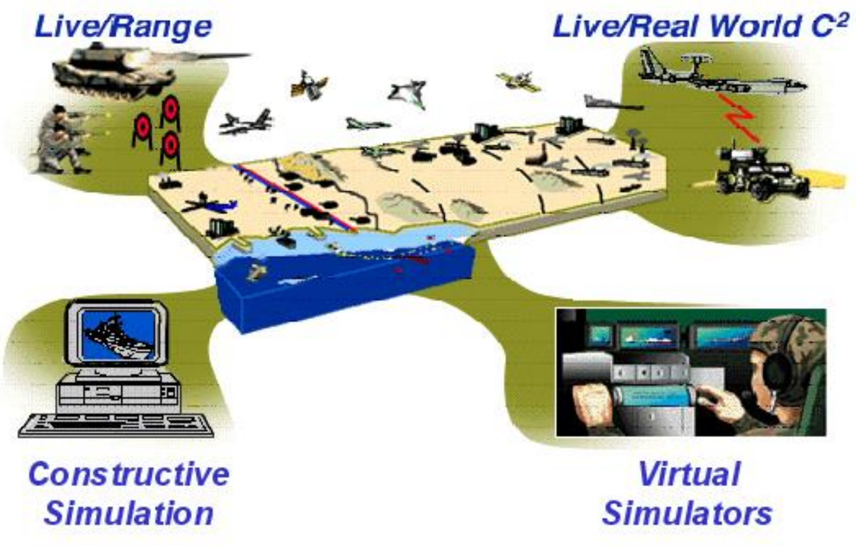


Figure 1 : A Graphic of an LVC Synthetic Environment (Zalcman, Blacklock, Foster, & Lawrie, 2011)

As stated above, each Live, Virtual, and Constructive simulation has its own feature. However, because there is no clear division among these categories, categorizing simulations into discrete classes such as live, virtual, or constructive could be ambiguous (Hodson & Hill, 2014). For instance, the level of human participation in a simulation is infinitely unsteady, as is the level of equipment realism. The categorization of simulations also lacks a category for simulated people interacting with real equipment (Dahmann et al., 1997).

LVC simulations discriminate themselves from the discrete classes by containing various degrees of all aspects of the defined classes. Based on these, there have been several definitions of LVC simulation by researchers. The following Table 2 shows the widely used definitions among simulation communities.

Table 2 : Major Definition of LVC Simulation

Definition	**Source**
“A broadly used taxonomy for classifying simulation types.”	(DoD Pub 5000.59-P)
“System of Systems (SoS) which provides an environment where multiple heterogeneous simulation systems interoperate with each other in real-time”	(Hodson, 2009)
"LVC simulations consist of a set of entities that interact with each other within a situated environment each of which are represented by a mixture of computer-based models, real people, and real physical assets”	(Hodson & Hill, 2014)

2.2.2 Standard Architecture of LVC simulation

Each of Live, Virtual and Constructive simulation has been developed and used with many benefits. However, when system developers made each simulation model, they just had considered specific standards to fit to its unique purpose. Because of this point, there have been coordination problems among simulation models with limitations. In order to overcome these issues, DoD and related agencies have been organizing several standard simulation architecture standards over the past few years. Architecture is defined as “the structure of components in a program or system, their interrelationships, principles, and guidelines governing their design and evolution over time” (Bass, 2007).

These simulation architectures have been made to perform capabilities for each simulation model while simulating scenarios or environments simultaneously. Archetypal simulation architectures are the Distributed Interactive Simulation (DIS), High Level Architecture (HLA), and Test and Training Enabling Architecture (TENA).

2.2.2.1 Distributed Interactive Simulation (DIS)

Distributed Interactive Simulation (DIS) standard architecture was developed to define an infrastructure for connecting different types of simulations in the early 1990's. The DIS architecture provides flexible arrangements between computational loading, positional error, and network bandwidth (Fullford, 1996). DIS was intended to harmonize computer-controlled action with virtual entities. Algorithms of DIS can reduce large amounts of network information traffic. In addition, nodes that consist of different type can communicate with each other within synthetic environment.

2.2.2.2 High Level Architecture (HLA)

High Level Architecture (HLA) has been developed to support interoperation and the reuse of simulations by US DoD. Regardless of computing platform, it is possible to communicate among simulation models by HLA.

The basic definition of the HLA includes three main components: HLA Rules, HLA Interface Specification, and HLA Object Model Template. Table 3 shows the main components of HLA.

Table 3 : The Main Components of HLA

Components	Description
The Framework and Rules	Defines the rules and component that draft the responsibilities of HLA federates and federations to make sure a consistent implementation. (IEEE, 2000)
The Federate Interface Specification	Defines the standard services of the HLA Runtime Infrastructure. Specifies the interfaces implementation for exact operation of federations
The Object Model Template	HLA object models are specification of sharable elements of the simulation or federation in "object terms". The HLA are intended to focus on explanation of the essential aspects of the simulation and federations (Dahmann et al., 1997)

The Runtime Infrastructure (RTI) is the baseline software that is used in federation. The federation means entire simulation systems that are made by combining each simulation. RTI provide services to support simulation functions. Only one RTI exists in each federation. Because of this, all exchanged information must pass through the RTI.

RTI defines the common interfaces for distributed simulation systems during the federation execution of the HLA simulation. The functional point of view of HLA federation is described in Figure 2. In the Figure 2, all objects are in the federates. A federate could be a simulator. HLA allows all objects to be coordinated through data exchange provided by RTI. RTI is independent factor that not be interrupted by specific object models.

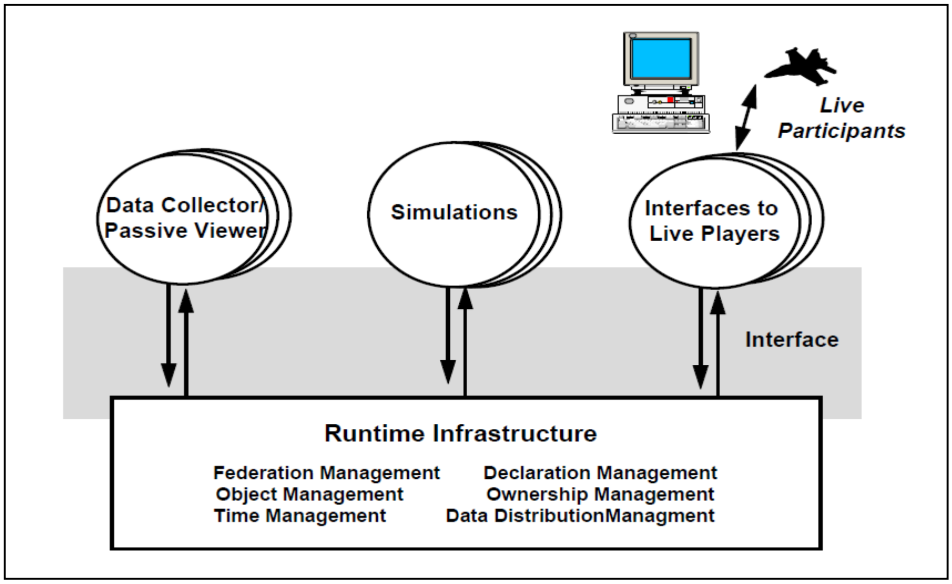


Figure 2 : Functional Overview of HLA

2.2.2.3 Test and Training Enabling Architecture (TENA)

Test and Training Enabling Architecture (TENA) was developed to accommodate simulation-based acquisition and system testing using real-time synthetic environment.

Main objective of TENA is to provide architecture to support composability, interoperability among simulations and C4I systems in a proper ways.

As you can see in Figure 3, the major components of TENA are the TENA Middleware, the TENA Repository, and the TENA Logical Range Data Archive. Capabilities of TENA Repository are extensive documentation and collaboration. Real time data exchange and data management is implemented by TENA Middleware. The TENA common infrastructure does an important role for achieving a system’s goal.

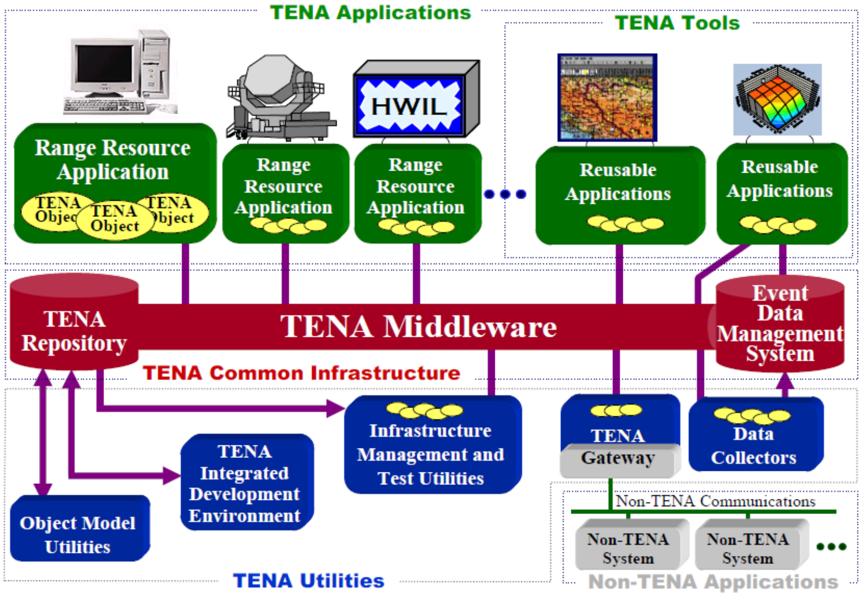


Figure 3 : Overview of TENA(Powell & Noseworthy, 2012)

2.2.2.4 Live-Virtual-Constructive Integrated Architecture (LVC-IA)

The LVC-IA is the specific classification of standard architecture for military LVC simulation. LVC-IA was developed from the military point of view. It is a combination of software and hardware, which is for Army program supporting protocol standards. The LVC-IA has been developed by the US Army Program Executive Office for Simulation, Training and Instrumentation (PEO STRI). The LVC-IA is a network-centric linkage that collects, retrieves and exchanges data among Live Instrumentation, Virtual Simulators, and Constructive Simulations as well as Joint and Army Battle Command Systems (BCS) (Allen, Lutz, & Richbourg, 2010). This architecture provides the common protocols, specifications, standards and interfaces that help standardize common LVC components and tools required for interoperability of LVC components for simulation/stimulation (SIM/STIM) of unit Battle

Command Systems for mission rehearsals and training. LVC-IA is next-generation Army multi-echelon, integrated, joint training and mission rehearsal environment. (Goad, 2008).

LVC-IA defines "how" information and data is exchanged and used among the LVC domains and Battle Command Systems. As shown in Figure 4, the main goal of LVC-IA is offering an operating environment which is very similar to a real combat situation and providing value-added training opportunities to commanders and units.

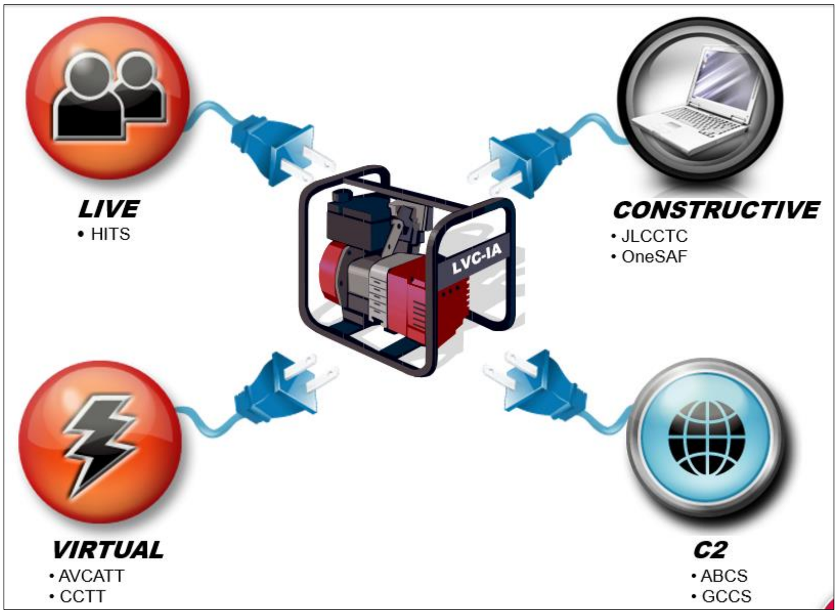


Figure 4 : Concept of LVC-IA

2.3 Area 2: Interoperability

2.3.1 The Definition of Interoperability

The term, interoperability, can be interpreted by various ways depending on the point of view. The meaning of interoperability is very broad. Individuals and organizations have been confronting interoperable issues to achieve diverse purposes. Thirty-five definitions of interoperability have been mentioned over the past 30 years as shown in Table 4.

Table 4 : Number of Interoperability Definitions per year
(Ford, Colombi, Graham, & Jacques, 2007)

year	**Number of Interoperability Definitions**
1977	1
1978	1
1980	3
1987	1
1990	1
1995	1
1996	2
1997	1
1998	1
1999	1
2000	4
2001	3
2003	6
2004	4
2005	3
2006	1
Total	35

According to these definitions, it is clear that many definitions of interoperability have been interpreted from technical point of view. However, as techniques have been complicated and non- technical factors such as organization, culture have been involved; thus, one can recognize that the area of interoperability is getting broader and broader.

“What is the most commonly used definition of interoperability?” Based on number of citations about interoperability, it is possible to infer that the definition made in 1977 from U.S. DoD is the most general definition. That definition is repeated below.

"The ability of systems, units, or forces to provide services to and accept from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together."

The definition of interoperability stated above is the oldest definition, and it is still commonly used in DoD document today (Ford et al., 2007), which means this definition contains essential factors to describe the interoperability.

Although this definition covers the major concept of interoperability, there still needs to be a one more specific to this research. Unlike traditional systems, each interaction in a LVC simulation cannot be explained by a single element, but instead produces a complicated and cumulative effect of contributions from all involved elements (Ondimu & Muketha, 2012). For example, a combination of computer-based model, real people, and physical facilities should be considered for achieving complete interoperability.

In this research, a new definition of LVC interoperability is proposed that states that: the ability of the entire Live Virtual Constructive simulation system is to provide services and accept from other systems, and to use the services to exchange data to enable them to operate effectively together considering non-technical elements.

2.3.2 Classification of Interoperability

Throughout the definitions of Interoperability, we can be aware that interoperability is not achieved by a simple element. The more complex systems are developed, the more interoperability element should be considered to achieve complete interoperability. Considering this point, many researchers have already agreed upon various definitions for interoperability.

Researchers and other users agree that technical interoperability has been the main issue. For example, information systems, database, and electronic application interoperability are typical technical interoperability. However, other aspects of interoperability; such as culture, organization, and training impact interoperability issues. Over the past few decades, sixty-four interoperability types have been defined based on different purpose (Ford et al., 2007).

To be specific, from a technical point of view, there have been two well-known interoperability types, syntactic and semantic interoperability, used.

First, syntactic interoperability is generally associated with data formats. The data transferred by communication protocols should include a well-defined syntax and encoding, even if only in the form of bit-tables (Veer & Wiles, 2008). Examples of tools of syntactic interoperability could be SQL or XML. Representing syntactic interoperability means that two or more systems are capable of exchanging and communicating data.

Another type of interoperability is semantic interoperability. This is about the ability to operate on the data according to the agreed-upon semantics (Lewis & Wrage, 2006) and to automatically interpret the information exchanged accurately and meaningfully in order to generate useful results as defined by the end users of each systems (Ide & Pustejovsky, 2010).

These interoperability classifications are broadly used to deal with the technical field of interoperability. However, as described in section 2.3.1, in order to accomplish the highest level of interoperability in complicating systems, classification of interoperability has extended its range including non-technical factors.

Considering this limitation, Organizational Interoperability Maturity model (OIM) was proposed in 1999. OIM extends technical interoperability measurement model into the more abstract layers of command and control support. Also, Advanced Technologies for interoperability of Heterogeneous Enterprise Networks and their Applications(ATHENA) classified interoperability into six different management sectors, such as a) business, b) process, c) knowledge, d) information, e) software, and f) data (Berre et al., 2007).

These efforts clearly show that the classification of interoperability is not limited to technical issues. Especially, since LVC simulation systems is a set of different systems, then managerial factors could work toward the achievement of positive results.

2.4 Area 3: Systems Engineering for LVC simulation Interoperability

2.4.1 System of Systems (SoS)

What is the “system”? The majority of people in this world may have heard the word “system” at least several times. However, people from different backgrounds have different perspectives of what a “system” is. Since LVC simulation also consists of a Live system, Virtual system, and Constructive system, the defining of “system” and “system of systems” is a critical process in order to understand LVC simulation.

“System” is defined as a set of different elements or aggregation of elements connected to perform a unique function not performable by the element alone (Harrington, Carr, & Reid, 1999). The elements may include physical, behavioral, or symbolic entities. Elements may interact physically, mathematically, and/or by exchange of information (Rouse, 2003). Then, what is the “system of systems”? “System of systems” is defined as a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities (Ackoff, 1971). In addition to this, system of systems are simultaneous and distributed systems, the element of which are complex systems themselves (Kotov, 1997). The characteristics of “system of systems” are classified into operational independence of constituents, managerial independence of constituents, geographic distribution, emergent behavior, and evolutionary development (Sage & Cuppan, 2001). Taken together, all these definitions and characteristics suggest that “system of systems” is a concurrent and complex process that enhances the performance; and an important characteristic of a SoS is interoperability among its constituent systems (Lane & Valerdi, 2011).

2.4.2 Systems Engineering for LVC simulation

The systems engineering focuses on how to design and manage projects or programs throughout their entire life cycles. People use systems engineering to solve complex problems and handle the issue effectively. The systems engineering deals with many work-processes, optimization methods and risk management tools (Klatt & Marquardt, 2009). In addition to this, The International Council of Systems Engineers (INCOSE) defines systems engineering as an “interdisciplinary approach and means to accommodate the realization of complete 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".

Based on the definition mentioned above, the systems engineering techniques have been used for distributed simulation, which means different kind of systems engineering processes have been applied to develop standard architecture such as HLA and TENA. For example, Federation Development and Execution Process (FEDEP) was developed for constructing and executing HLA federation. FEDEP is an overall framework overlay that can be used together with many other, commonly used development methodologies. Every step of FEDEP is shown at figure 5.

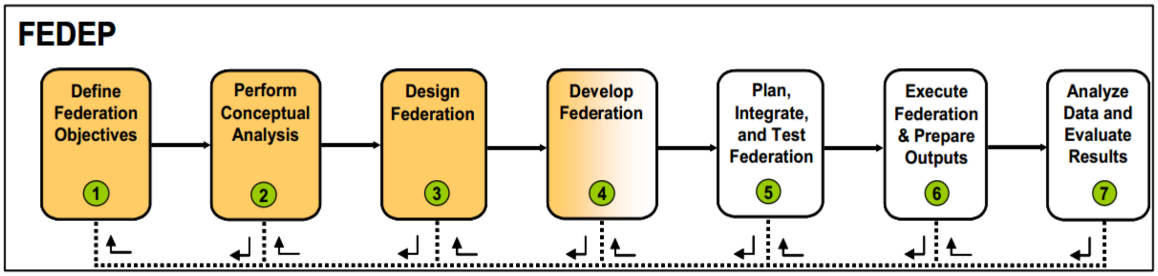


Figure 5 : Federation Development and Execution Process (Cutts, Gustavson, & Ashe, 2006)

FEDEP has been renamed to Distribute Simulation Engineering and Execution Process (DSEEP) and is the current active standard instead of FEDEP. An overview of the DSEEP is provided in Figure 6. DSEEP is unifying a single systems engineering process. However, the assumption of DSEEP is that only one simulation architecture will be used (Gallant & Gaughan, 2010).

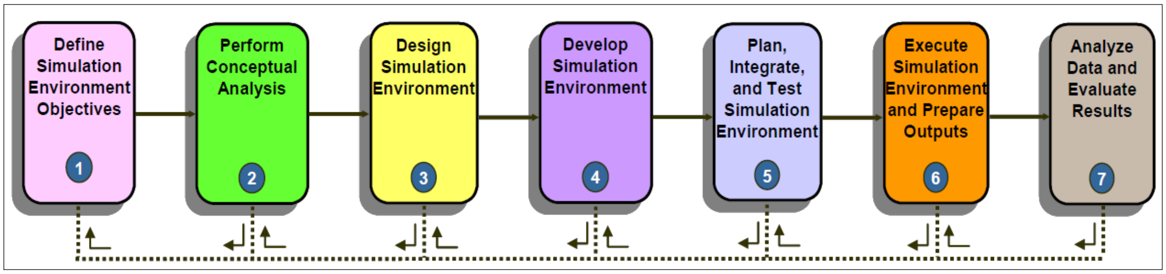


Figure 6 : Distributed Simulation Engineering & Execution Process (DSEEP)

Also, a systems engineering process similar to FEDEP was introduced in TENA Architecture Reference Document(Powell, 2002). In addition to this, a modified and renamed TENA system engineering model was adopted by the Joint Mission Environment Test Capability (JMETC).

Consequently, it can be suggested that since each of the systems engineering models have been developed for its own purpose. However, there are some differences restraining interoperability among systems engineering models. So, a single and interoperable systems engineering approach would be critical and influential for entire LVC simulation systems.

2.5 Area 4: Limiting Factors in LVC Simulation interoperability

2.5.1 Technical Limiting Factors

Several limiting factors in LVC simulation interoperability have been introduced by researchers. As stated previous chapters, LVC simulation systems are not composed of simple factors. Especially, in technical point of view, there are so many technical factors to be considered and resolved toward improvement of interoperability.

There is no doubt that the development of a gateway has been successful. However, there have been reported some problems because there is no “common” gateway. Each gateway was developed only for their specific program without considering potential reuse (RR Lutz & Drake, 2011). Even if better a gateway is developed, the costs for transitioning to a new gateway could be enormous.

Also, object modeling has been a severe inhibitor to interoperability and composability and as is likewise other simulation systems. The object modeling features in both the HLA and TENA are unique to their specific protocol or architecture (Cutts et al., 2006). This specialty doesn’t offer flexibility for exchanging data or solving complex problems.

The problem of a different systems engineering model has been identified by many researchers. Focusing on how to manage a complex problem and efficient design is implemented by a systems engineering model. Sometimes part or whole systems need to be mixed or integrated for the desired function. When making this integration, a different step or terminology could be a big barrier for everything (Zalcman et al., 2011).

Another substantial limiting factor is the lack of understanding of interoperability issues between TENA and HLA. Providing reusable modeling and simulation assets was the intended purpose of making HLA while providing test resources was the main goal of TENA (Zimmerman, 2001). Lack of understanding of essential characteristic have made errors.

In addition to the problems stated above, time advancement mechanisms, data format compatibility, compatibility of supported services, semantic mismatches for runtime data elements were identified (Dong, Zhu, Di, & Meng, 2013).

2.5.2 Managerial Limiting Factors

Usually very little incentives for integration among different systems have been a problem. Developers have a tendency to focus on immediate outcome within a limited budget and time because potential use makes that project more complex. Even if they consider interoperability when they develop the system, only a small portion of budget or incentive would be allocated to that project (Ondimu & Muketha, 2012).

Also, there is no standard guidance on how developers or managers can resolve the problems in a more standardized way that can enhance the interoperability (Zalcman et al., 2011).

In order to achieve interoperability, the cost of a project would be increased. For example, users need to be trained to be familiar with new systems and have increased time and budget to become familiar with the new system. As a side note, actions for interoperability are directly related to money. Funding is another managerial limiting factor in LVC simulation systems as well as for other common projects.

2.6 Area 5: Analytic Hierarchy Process (AHP)

2.6.1 Overview of AHP

We can think of the world as a large and complex system interacting among different elements. Due to these complexities, it is very difficult to locate optimal solutions for specific problems. Thus, prioritizing possible alternatives can be an effective approach to solve certain problems.

Analytic Hierarchy Process (AHP) was developed by Thomas Saaty in 1980. This method has been broadly used for decision making in many areas. AHP is intended to catch participant knowledge, experience, and intuition based on “pairwise” comparisons of alternatives; especially, when there is not enough data, time or discussions with various opinions. AHP is the best method to analyze opinions making the information related to the problems simple and specific.

In other words, AHP classifies alternatives according to hierarchy level and provides a reasonable comparison method using mathematical approaches. There are four axioms about AHP as described in Table 5.

Table 5 : The axioms for AHP

Axioms	**Description**
Reciprocal	• if $P_C(A, B)$ is a paired comparison of factors A and B in relation to their parent factor C, representing how many times more the factor A possesses a property than does factor B, then $P_C(B, A) = 1/ P_C(A, B)$. For example, if A is 5 times larger than B, then B is one fifth as large as A
Homogeneity	• The elements being compared should not differ by too much in the property being compared. If this is not the case, large errors in judgment could occur.
Dependency	• the elements in a hierarchy do not depend on lower level elements
Expectations	• individuals who have reasons for their beliefs should make sure that their ideas are adequately represented for the outcome to match these expectations

An advantage of AHP is that the systematic approach allows different individuals to participate equally in a process that is quantitative and non-biased, rather than subjective and value-laden (Schmoldt, et. al. 1994).

The AHP method has three main assumption: a) possible to accommodate representative members of each specific group; b) the number of participants should be small enough to be systemically manageable; and c) the participants should be expected to contribute in an objective manner (Schmoldt, Peterson, & Smith, 1995).

The important main concept of AHP method to be considered is that this method is not based on statistical methodology (Duke & Aull-Hyde, 2002). A sample size of 1 is enough to get reasonable results. In other words, there is no minimum requirement for the number of experts (T. L. Saaty, 1989) . AHP method was developed to allow a single decision maker to choose among a number of alternatives.

2.6.2 The Process of AHP

As mentioned above, the AHP method provides a mathematical process using an individual's preferences. The AHP method is implemented by following these steps.

2.5.2.1 Structuring Hierarchy of Alternatives

First step of AHP is structuring hierarchy of alternatives. Usually, hierarchy of AHP consist of a general goal, a group of alternatives, and criteria. The purpose of decision making has to be on the top of hierarchy. At the bottom, there are more specialized elements. The criteria is broken down into subcriteria. The following is the example of AHP hierarchy.

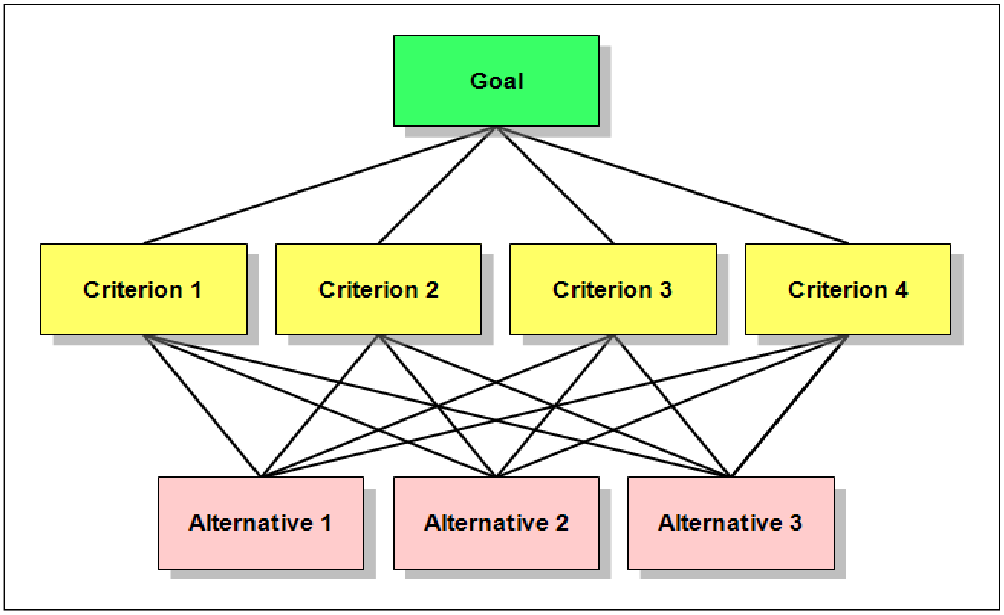


Figure 7 : AHP Hierarchy example

Structuring hierarchy has important meaning. Once the hierarchy setup is completed, decision makers can evaluate and compare each element and researchers can analyze according to the specified hierarchy.

2.5.2.2 Pair Wise Comparisons

It is very difficult to transform qualitative data to quantitative data. To overcome this difficulty, the AHP method use the relative importance between two elements. Pair wise comparisons are used to determine the relative importance. In this process, decision makers choose only one value at a time to represent their own opinion. The scale of value is usually from 1 to 9. According to Saaty’s original AHP theory, any scale can be used to determine the value. He suggested that best optimal upper bound is 9.

Table 6 : Scale for pairwise comparisons (R. W. Saaty, 1987)

Relative intensity	**Definition**	**Explanation**
1	Equal importance	Two elements are of equal value
3	Slightly more importance	Experience slightly favor one element over another
5	Essential or strong importance	Experience strongly favor on element over another
7	Very strong importance	An element is strongly favored and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between	When compromise is needed
Reciprocals of above nonzero	If the activity *i* has one of the above nonzero number assigned to it when compared with the activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
Rationale	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

Matrix $n \times n$ is made up of relative values, where n is the number of the elements. Defining which element is more important in each pair of elements is done by asking simple questions like; “How strongly important is element A than element B?” Example of relative value matrix is shown at Table 7. For instance, the highlighted number “3” in matrix means that A is three times more important than B. With this approach, every portion of matrix can be filled in.

Table 7 : Example of relative value matrix

	A	**B**	**C**
A	1	**3**	1/2
B	1/3	1	1/6
C	2	6	1

2.5.2.3 Calculate the relative priorities

Calculating priorities can be started with normalizing the matrix. First step of normalizing is adding each column's relative values. Then each relative value is divided by this sum. Based on the result of the first step, the next step is averaging the values in each row. After these two steps, the final result vector is the priorities vector. The sum of the result vector is 1, which means 100 percent.

2.5.2.4 Determine the consistency of the results

The key factor of this step is calculating the Consistency Index (CI) and Consistency Ratio (CR). The logical error of evaluating the score can be detected by these two factors. The CI is the indicator showing accuracy of the pairwise comparisons. The formula of CI is:

$$\mathrm{CI} = \frac{(\lambda_{\max} - n)}{(n-1)}$$

Where, λ_{max} *is the maximum eigenvalue of the matrix and n is the number of elements*

The CR is the ratio of the CI to Random Indices (RI). The values in RI are derived from a randomly chosen weight and corresponding reciprocals in a same size matrix.

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$$

If the CR is less than 0.1, this means that the comparison matrix has a consistency. If the CR is 0, this means the decision maker did the evaluation with complete consistency.

2.5.2.5 Aggregating individual judgements

The AHP method is effective for not only an individual but also for group decision making. Since the AHP method was developed, there has been research for aggregating individual judgements. According to the major research, two popular processes are used for aggregation.

The first process is called Aggregation of Individual Judgement (AIJ), which means aggregating individual judgements concerning each set of pairwise comparisons in order to generate aggregated hierarchy. The other process is called Aggregation of Individual Priorities (AIP), which means combining each of the individual hierarchies and then calculating the priorities (Forman & Peniwati, 1998). Actually decision makers and researchers can use any of these processes without special reason (Wu, Chiang, & Lin, 2008).

Researchers can use the arithmetic mean or geometric mean when aggregating the judgements. Initial research describes that the geometric mean is more applicable and reasonable (Aczél & Saaty, 1983). It has been proven that both the arithmetic and geometric mean are applicable, and if the number of judgement is large, then the geometric mean cannot be used for aggregation(Wu et al., 2008).

In this research, the geometric mean is used for aggregating the expert judgments while combining each set of comparisons.

2.7 Summary

The main concepts of the LVC simulation and interoperability have been reviewed for identifying limiting factors based on the already published literature with the AHP method. From the reviews stated in previous section, it has been clear that the synergy effect of complete LVC simulation interoperability is powerful and useful with many advantages. Using these key concepts in this chapter, the next chapter will describe the detailed steps for obtaining priorities among limiting factors.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter describes the methodology that is used to identify the priority of limiting factors in the LVC simulation interoperability. As mentioned at Chapter 2, the main method for this research is AHP. The first step is to define the criteria and hierarchy for the AHP survey. After reading a series of literature review, six technical limiting factors and three managerial limiting factors are identified.

The second step is the survey design based on the refined limiting factors. This step includes some processes such as setting the hypothesis, identification of participants, and organization of questionnaire. Since a reasonable hypothesis is the basic of the research, three hypothesis was made and applied to this research. In order to collect reliable data, diverse experts who have special knowledge and experience participated to this survey.

The third step is the survey implementation and data analysis. The survey was done by using email. In order to get valid data, every data was tested by the consistency value. Then, analyses were done by using hierarchy levels.

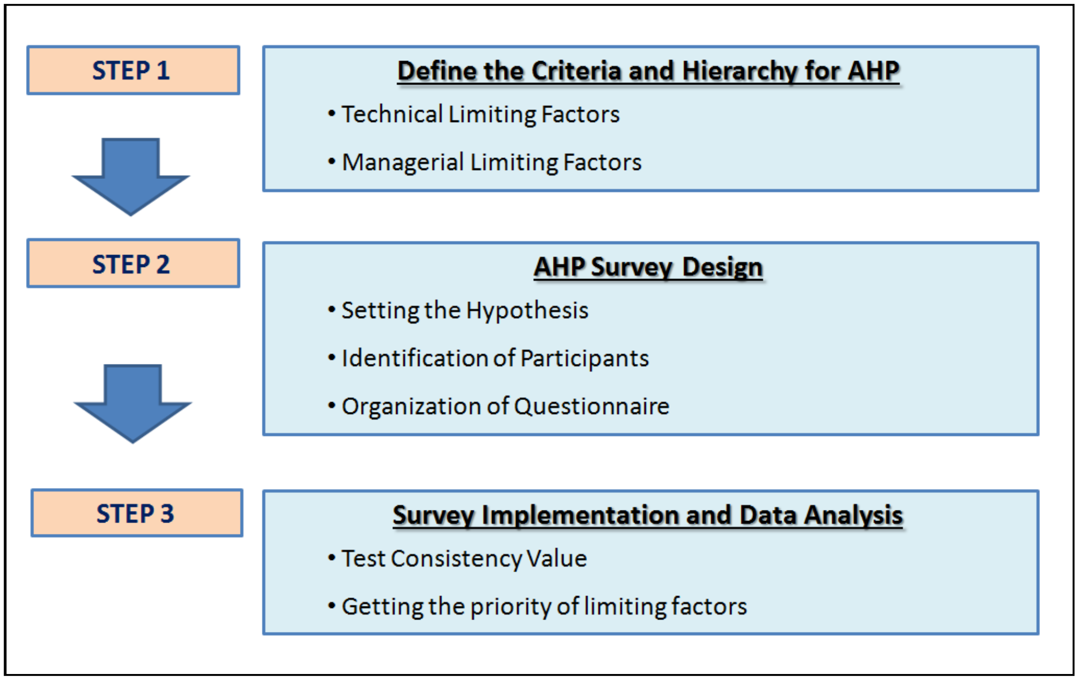


Figure 8 : Proposed Research Methodology

3.2. Step 1: Define the Hierarchy and Criteria for AHP

Step 1 is the most important part of this research. As mentioned above, the Analytic Hierarchy Process is the tool for evaluating which limiting factor is more important than others. Decision makers have to evaluate limiting factors only based on specific criteria. There are so many related factors in the LVC systems due to its complexity. So, understanding of the essential limiting factors of the LVC systems is a starting point for this step. We already discussed overview of LVC simulation systems and interoperability through literature review section. The following is the list of LVC interoperability limiting factors that have been published.

Table 8 : Summary of existing LVC interoperability limiting factor

LVC interoperability limiting factors	**Source**
• Middleware incompatibilities, Metamodels for data exchanges	(Dong et al., 2013)
• Lack of common gateway and bridge capbilities	(RR Lutz & Drake, 2011)
• Lack of understanding difference between HLA and TENA - Differences in Intended use - Differences in System Engineering Process - Business Process Incompatibilities • Inconpatibilities in Object Modeling • Middleware Incompatibilities	(Cutts et al., 2006)
• Design Problems - Different System Engineering Models - Disparity in the Services provided by each of the architectures • Reconsolidation Problems - Different standard Object model • Execute and Test Problems - No external Testing Environment - Existing Legacy System • Very little Incentive for the different architectures to interoperate • No source of Interoperability Guidance	(Zalcman et al., 2011)
• Lack of Ownership • Inconsistent Funding to support interoperability • Existing Legacy System • Security issue • Emergent Behavior • Lack of motivation • Ambiguous Terminology	(Ondimu & Muketha, 2012)
• No single organization for interoperability • Lack of program management • Increased time and cost • Security • Complexity of external interface • Lack of testing	(Starr, 2005)
• No general method for interoperability measurement	(Ford, 2008)

LVC interoperability limiting factors	Source
- Lack of Common Object model components - Differences in the protocol used by the various architectures	(R Lutz et al., 2009)

Based on limiting factors in LVC simulation interoperability mentioned above, the first hierarchy level can be classified as technical factors and managerial factors.

One of the key factors of successful application of AHP could be the number of factors included in the AHP survey (Lai et al, 2002). The decision-maker could be confusing when five or more criteria are involved in the questionnaire. Since AHP method is based on pairwise comparisons, more than five criteria could increase the possibility of inconsistency (Lirn, Thanopoulou, & Beresford, 2003). Therefore, using all factors described above would be inappropriate.

Considering the number of factors, all factors are abbreviated according to similarity of characteristic. As a result, the technical limiting factors are made up of six factors while the managerial limiting factors are made up of three factors. Figure 9 is the overview of hierarchy for limiting factors.

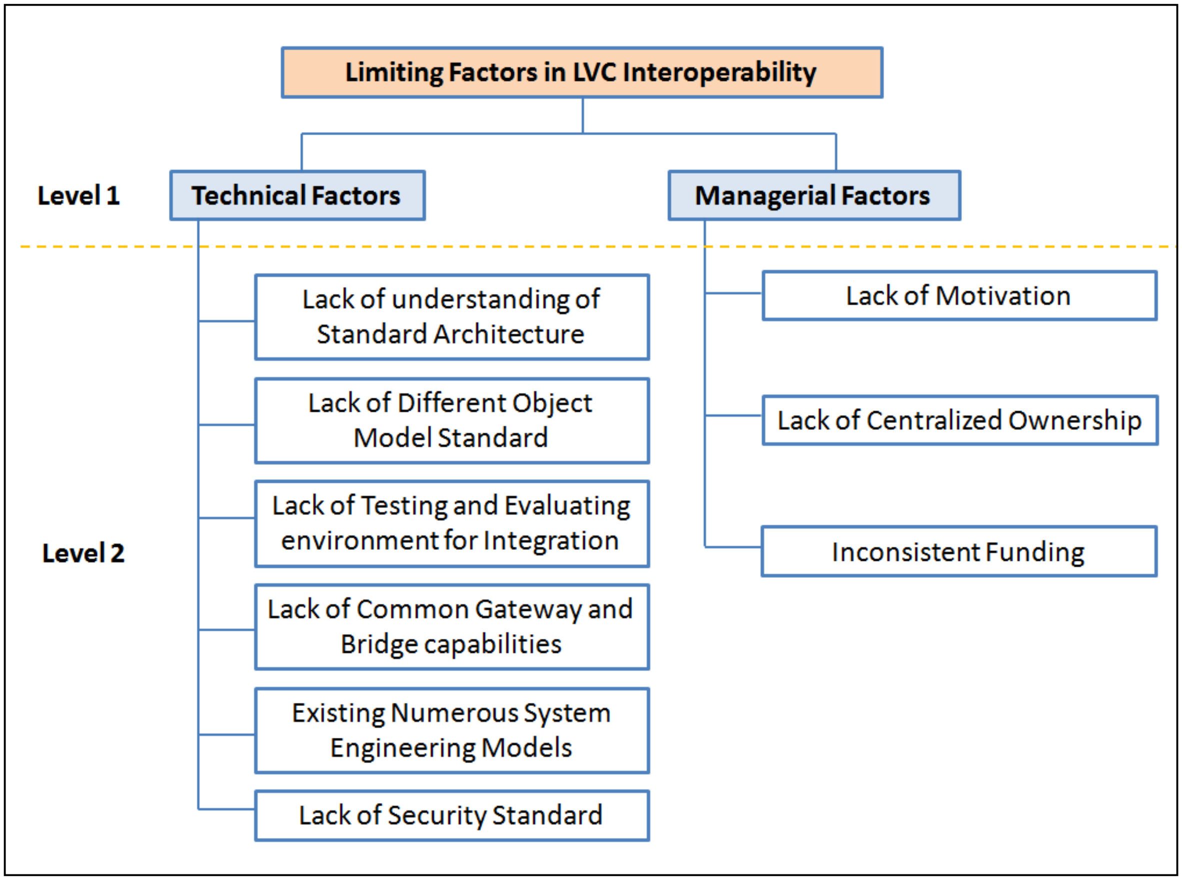


Figure 9 : Hierarchy of Limiting factors in LVC interoperability

3.2.1 LVC Interoperability Technical limiting Factors

A lack of understanding of the standard architecture means that each standard architecture was originally developed for different domains and intended uses. For example, HLA was created to focus on reusing of modeling and simulation assets and integrating virtual and constructive assets, while TENA focuses on the reuse of test sources and integrating live assets into training exercises (Cutts et al., 2006). People who are responsible for generating seamless LVC interoperability sometimes do not understand the features of each standard architecture, which may result in many problems.

Different architectures have different object model standards. An object is defined as a location in memory, including values, and referenced by the user. In other words, an object is a combination of data and related processes, such as variables and data structures. There is no concept of object models in the DIS standard architecture. Object model format of the TENA standard is the TENA Meta-Model, while HLA Object Model Template (OMT) specifies the elements of HLA Object model. Because of the different and unique approaches for object model standard, flexibility among LVC environments are restricted.

Lack of testing and evaluating environment for integration means that there is almost no external testing environment where each LVC simulation system can be tested before the entire system operates (Zalcman et al., 2011). Sometimes, each LVC simulation system can be developed at different periods, and only the technical functions need to be tested. However, current testing environments usually does not support real time testing for this situation. Another issue is that there is no general evaluating method for interoperability among LVC simulation systems (Ford, 2008). Most of the evaluating approaches for interoperability that have been developed are qualitative methods. Thus, users are having problems deciding the objective and exact interoperability criteria among systems.

Gateways and bridges are intelligent translators, and the difference between them is that a gateway is used in dissimilar simulation architectures, while a bridge is used in same simulation architecture. A lack of common gateway and bridge capabilities means that many LVC simulation programs that have been developed have built their own gateway or bridge without considering reuse of their respective capabilities. These issues have led to excessive amounts of gateways and bridges in LVC simulation environments, which is causing inefficiency.

Lack of security standard means databases or core technologies in certain programs can be accessed by people who have no responsibility for security, causing risks to entire systems. Because of a lack of security standard, temporary users or engineers can do harmful actions under the cooperating environment.

3.2.2 LVC Interoperability Managerial limiting Factors

Usually, there is very little incentive for interoperate different simulation architecture. Without proper incentive for interoperable tasks for LVC integration, engineers and developers are reluctant to do tasks that interoperate different systems.

Ownership means authority or control and responsibility over systems (Carney, Anderson, & Place, 2005). Though some sub-systems or components can be controlled by an individual person or organization, but it is very hard for an individual to control the entire LVC simulation system. Lack of centralized ownership could make the technical or organizational problems worse.

Inconsistent funding is another issue for LVC interoperability. Organizations have limited budgets for developing and managing the systems. Usually, this indicates that these kinds of organizations want immediate performance instead of potential performance over a longer period of time. They don’t want to put the time and resources into efforts to realize the effect of successful interoperability. This problem restricts consistent funding for interoperable tasks.

3.3. Step 2: AHP Survey Design

3.3.1 Setting the Hypotheses

A reasonable hypothesis guarantees reliability of the survey. Hypotheses of this survey are: 1) there will be priority differences among limiting factors in LVC simulation interoperability, 2) participants in this survey have specialized knowledge and experience for determining priority, 3) each of the participant is considered to be of equal importance, and 4) limiting factors are classified only as technical factors and managerial factors.

3.3.2 Selection of Participants

There are so many people who are using and developing Live, Virtual, and Constructive simulations over the world. These survey targets these users, researchers, etc., from the government agencies who are responsible for managing the LVC simulation program, industrial representative who develop and use the LVC simulation program, and academicians.

3.3.3 Organization of Questionnaire

Section 1 of questionnaire collects the information about the organizations and jobs of the participants, i.e., years of experience, profession organization membership, etc.

Section 2 consists of the technical and managerial part for the pair comparison of limiting factors. Before the pair comparison for each part, there is a brief definition of each factor before doing the pair comparison to accommodate participant’s understanding. The scale used for this survey range is from 1 to 9.

In addition to this, there are open ended questions for additional comments or opinions. Diverse opinions can be collected by this means.

Table 9 : Summary of Questionnaire Organization

Section	**Content**
1	• Number of experience years for LVC simulation • Organization of participant • Role of participant in organization
2	• Definition of each limiting factor in LVC interoperability • Level 1 pair comparison - Additional comment / opinion(open question) • Level 2 pair comparison - Additional comment / opinion(open question)

3.4. Step 3: Survey Implementation and Data analysis

The main procedure for implementing the survey was by using email link. The period of the survey was about 11 weeks. Most Consistency Ratio (CR) of each of the survey results was less than 0.1. However, five samples didn’t meet the criteria and were disregarded. After calculating the consistency value, 37 samples were proved as valid values and used for this research.

Usually, aggregation of individual judgements for each factor is done by using geometric mean or arithmetic mean. According to the previous research, the geometric mean is more valid than the arithmetic mean (Adamcsek, 2008). So, data aggregation method of this research used geometric mean.

When analyzing the priority of limiting factors in LVC, the first analysis was implemented by each hierarchy level. After finishing this step, results of level 1 and level 2 were combined to calculate the entire priority of each limiting factor.

Though this survey didn't collect personal information; however, differences of priority among organizations were identified through survey question.

CHAPTER FOUR: RESULT AND ANALYSES

4.1 Chapter Overview

This chapter describes the result and analyses of this research through the AHP survey. Identifying the characteristics of participants was performed before analyzing the limiting factors in LVC interoperability to obtain specified results. Following that, priority analysis of limiting factors for hierarchy level 1, and level 2 was implemented step by step. Based on the priority analysis for each level, the overall priority analysis was done by combining the result of each level.

4.2 Sample Analysis

Before analyzing the limiting factors in LVC simulation interoperability, the analyzing the characteristics of participants was completed because it seemed be a more logical process to obtain reliable results. Through this process, we can infer the differences of opinion among different organizations, roles, and people who have varying years of experience.

The Table 10 shows the analysis of the participants. According to the survey responses, experts who have from 11 years to 15 years of experience were in the majority with 37.84%. Also, according to the organization where participants belong, academic organizations were the major proportion with 40.54%. At last, for classification by participant's role, program developers and simulation users were main in the majority for this area.

Table 10 : Characteristic of Participants

Years	0 - 5	6 - 10	11 - 15	16 - 20	Over 20	Total
Number of Participants	6	5	14	8	4	37
Proportion	16.21%	13.51%	37.84%	21.62%	10.81%	100%

Organization	Academic	Industry	Government	Total
Number of Participants	15	10	12	37
Proportion	40.54%	27.03%	32.43%	100%

Role	Project Manager	Program Developer	Simulation user	Systems Engineer	Total
Number of Participants	5	12	14	6	37
Proportion	13.51%	32.43%	37.84%	16.22%	100%

4.3 Priority Analysis for Hierarchy Level 1

This chapter describes priority of LVC limiting factors for hierarchy level 1. Based on the AHP method, overall priority analysis and comparative priority analysis for each organization and the user's role are implemented.

4.3.1 Overall Priority Analysis for Hierarchy Level 1

From the diverse respondents who have expertise and experience, analysis of hierarchy level 1 indicates experts rank technical factors as the most significant with a weight of 0.7301 and rank managerial factors as the less significance with a weight of 0.2699. The following figure 10 shows the assigned weight to each factor.

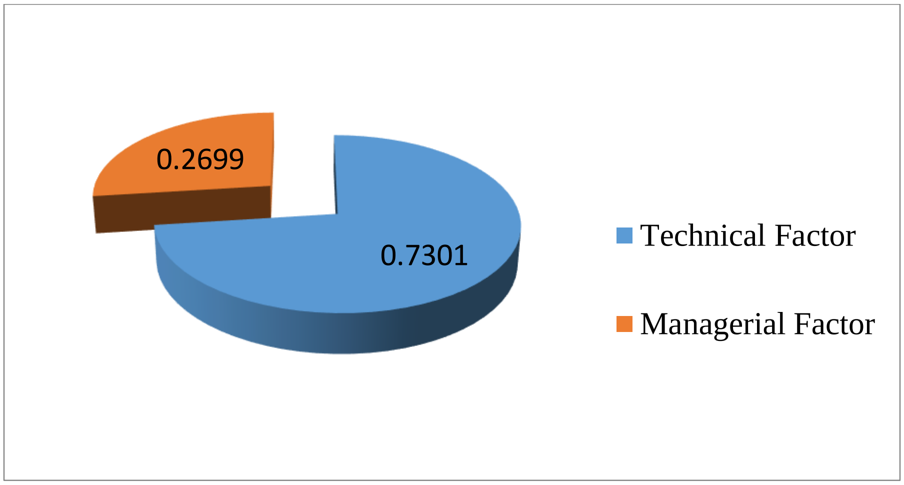


Figure 10 : Weight of Each factor in Hierarchy Level 1

This analysis can be interpreted to implicate that although there are many limiting factors in LVC simulation to be accounted for, experts perceive technical factors as being more important than managerial factors.

4.3.2 Priority Analysis for Respondents' Organization

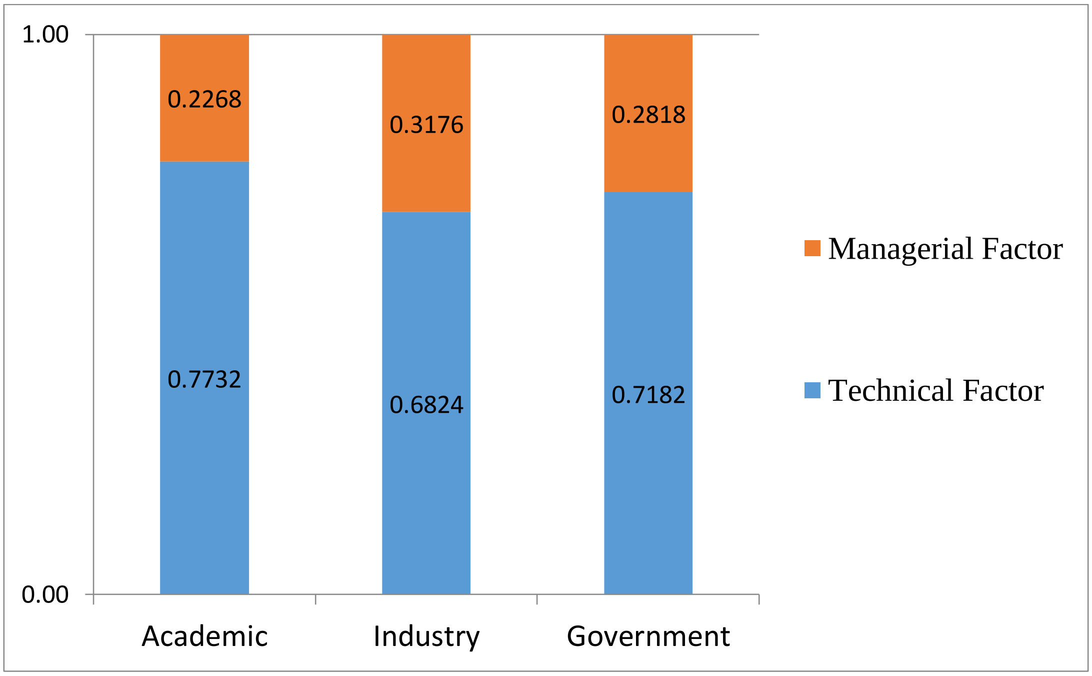


Figure 11 : Weight of Each factor for Respondents' Organization in Hierarchy Level 1

As shown in Figure 11, all organizations surveyed perceive technical factors as being more important than managerial factors. However, there are some opinion differences depending on the respondents' organization. Experts in academic organizations rank technical factors as a first priority with a weight of 0.7732, while the weight of technical factors in industry is 0.6824, and in government with a weight of 0.7182. This means that the experts in academic organizations are more inclined to consider technical factors than experts in other organizations and people in industry have more managerial issue compared to the people in other organizations.

4.3.3 Priority Analysis for Respondents' Role

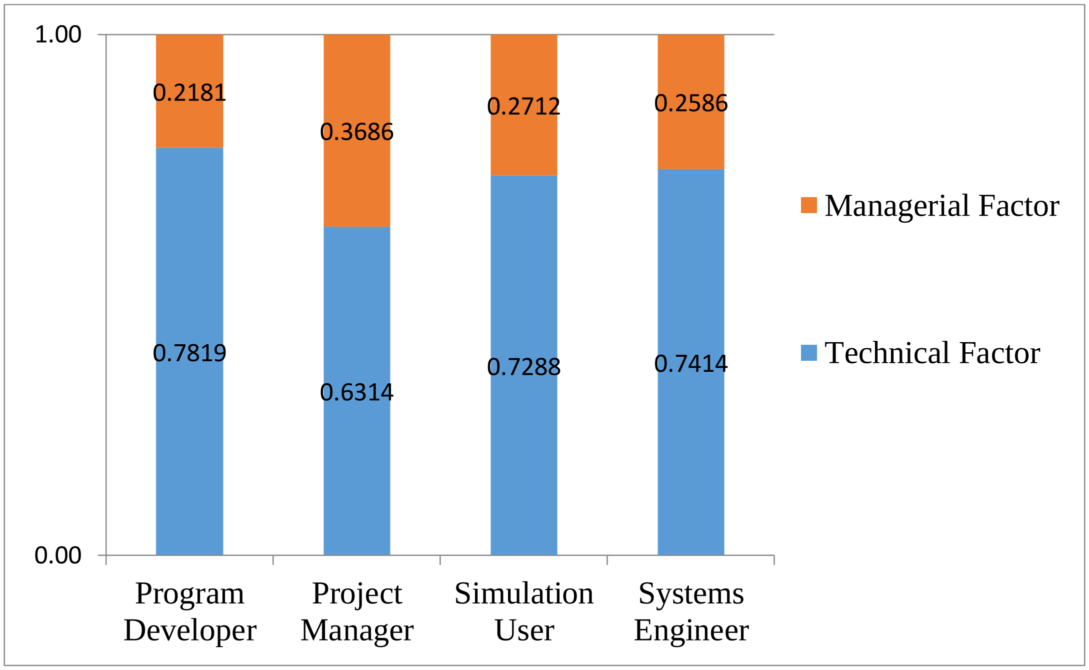


Figure 12 : Weight of Each factor for Respondents' Role in Hierarchy Level 1

Figure 12 also shows that there are some opinion differences among people's role in each organization. The weight of technical factors for the role of program developer is 0.7819 while the smallest weight of technical factors is 0.6314 for the role of project manager. This analysis indicates that project managers and system engineers are usually more affected by managerial factors.

4.4 Priority Analysis for Hierarchy Level 2

4.4.1 Priority Analysis for Technical Limiting Factors

4.4.1.1 Overall Priority Analysis for Technical Limiting Factors

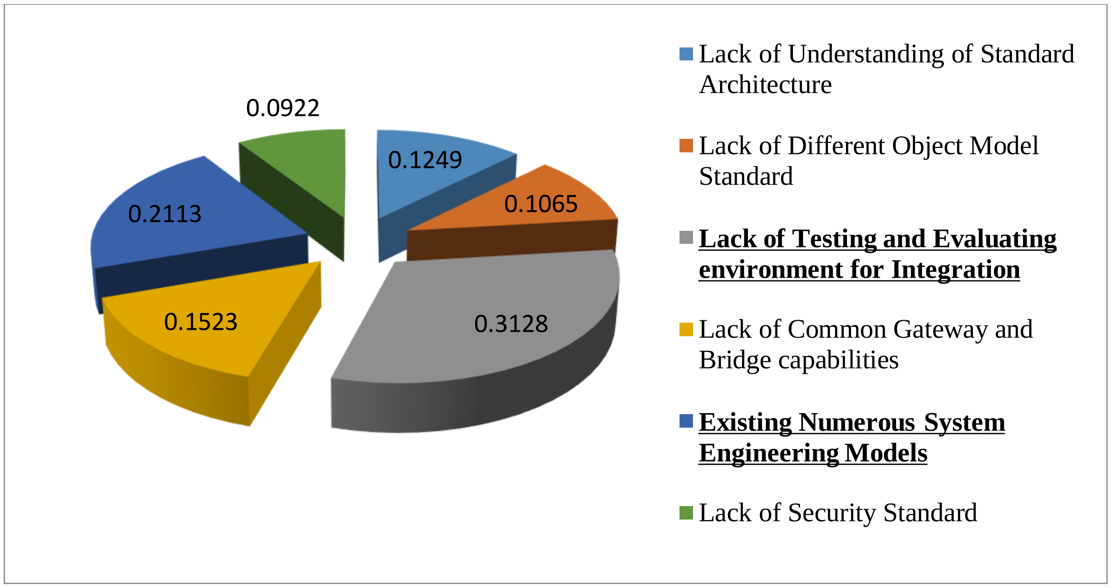


Figure 13 : Weight of Each Technical factor in Hierarchy Level 2

As shown in Figure 13, experts rank “Lack of Testing and Evaluating environment for Integration” as the first priority with a weight of 0.3128. The second positon with the weight of 0.2113 is “Existing Numerous System Engineering Models”. The weight of other technical factors are as follows: 0.1523 for “Lack of Common Gateway and Bridge Capabilities”, 0.1249 for “Lack of Understanding of Standard Architecture”, 0.1065 for “Lack of Different Object Model Standard”, and 0.0922 for “Lack of Security Standard”.

Considering the weight of each factor, “Lack of Testing and Evaluating Environment for Integration” and “Existing Numerous System Engineering Models” are significantly greater. This point can be interpreted as people who relate to LVC simulation have considerable restriction for testing simulation system before the event itself. Additionally, because of the large amounts of existing system engineering models, developers and users are prone to be confused when integrating certain steps and may end up spending more time and costs.

4.4.1.2 Priority Analysis for Respondents' Organization

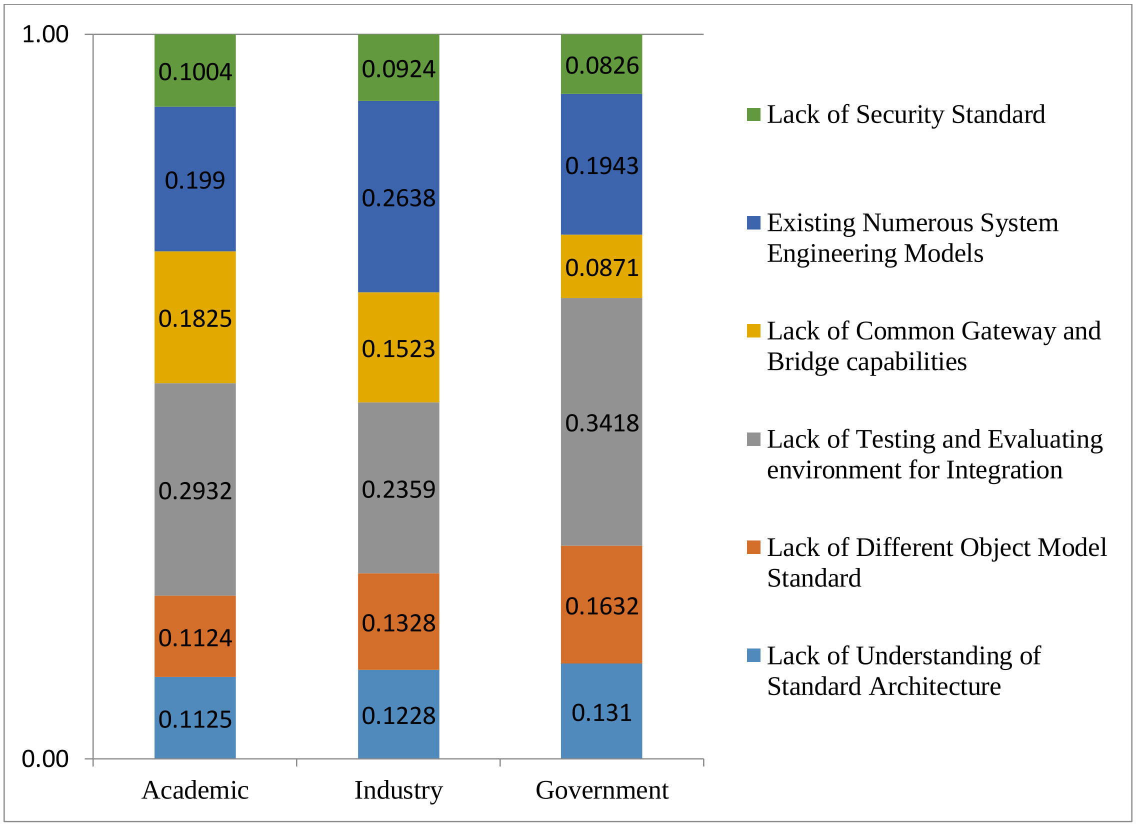


Figure 14 : Weight of Each factor for Respondents' Organization in Technical Factors

Common findings of this analysis is "Lack of Testing and Evaluating Environment for Integration" and "Existing Numerous System Engineering Models" generally have high percentages. Figure 14 describes the opinion differences among the expert's organization. The highlight of the analysis about academic organization is that experts consider "Lack of Common Gateway and Bridge capabilities" as important as "Existing Numerous System Engineering

Models”. The feature of the analysis on industry organization is that “Existing Numerous System Engineering Model” was the most significant with a weight of 0.2638. Also, another interesting feature of the analysis on government is that they consider “Lack of Testing and Evaluating Environment for Integration” more strongly than experts in organizations.

4.4.1.3 Priority Analysis for Respondents' Role

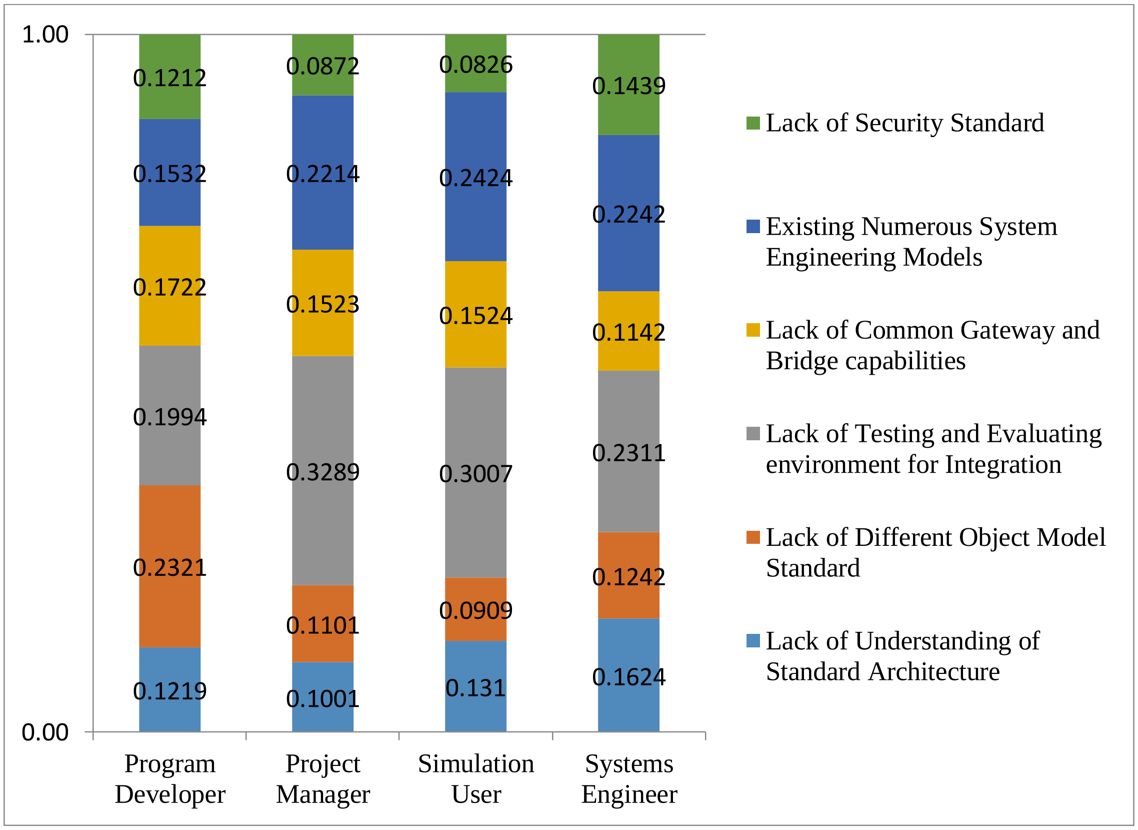


Figure 15 : Weight of Each factor for Respondents' Role in Technical Factors

As shown in Figure 15, there are some findings of the analysis for experts' role. First, in contradistinction to the general judgement from experts, program developers rank “Lack of Different Object Model” as more important with a weight of 0.2321. Second, systems engineers rank “Lack of Testing and Evaluating environment for Integration” as more important with a weight of 0.2311.

These findings can be interpreted as program developers having considerable issues with different object model standards when they develop new simulation programs. In addition to this, systems engineers need robust and a well-defined testing and evaluation environment as well as systems engineering model.

4.4.2 Priority Analysis for Managerial Limiting Factors

4.4.2.1 Overall Priority Analysis for Managerial Limiting Factors

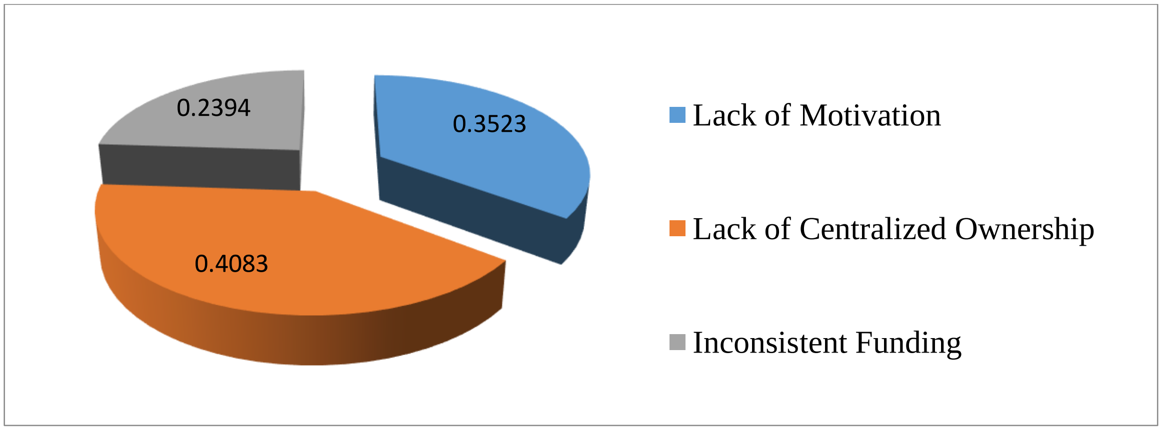


Figure 16 : Weight of Each Managerial factor in Hierarchy Level 2

Experts rank “Lack of Centralized Ownership” as more important with a weight of 0.4083. Second in importance is “Lack of Motivation” with a weight of 0.3523. Through this analysis, it has been identified that LVC simulation communities need stronger people or organizations which can lead the interoperability task to success.

4.4.2.2 Priority Analysis for Respondents' Organization

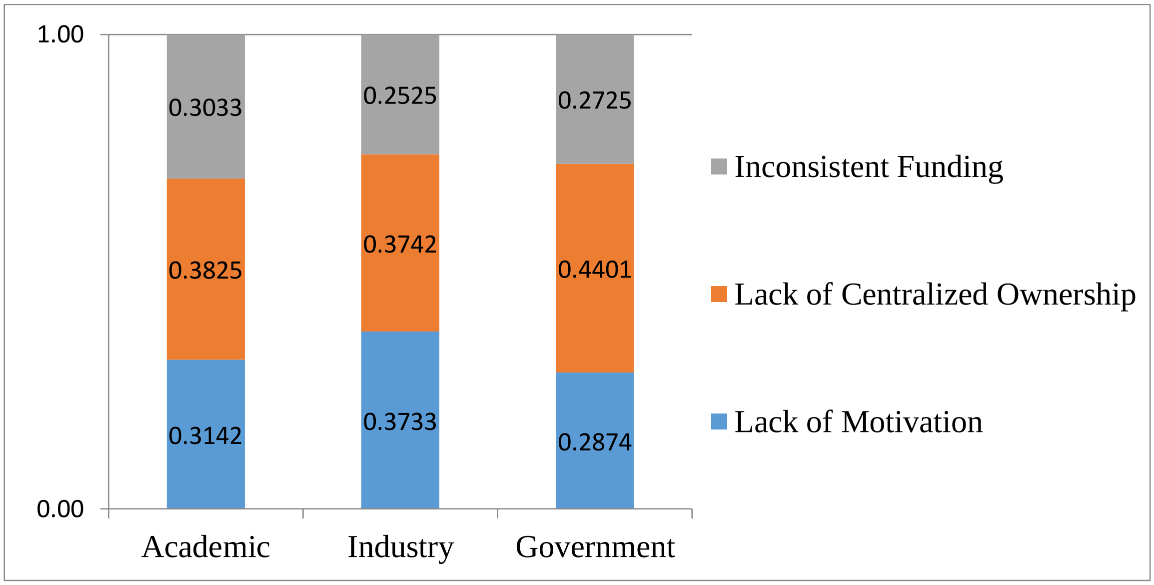


Figure 17 : Weight of Each factor for Respondents' Organization in Managerial Factors

As shown in Figure 17, there are subtle opinion differences among the experts in industry, government, and academic organizations. A common finding in this analysis is that "Lack of Centralized Ownership" is generally the most selected with every organization. The finding in industry shows that experts consider "Lack of Motivation" as important as "Lack of Centralized Ownership". Also, another interesting finding on government is that they consider "Lack of Centralized Ownership" more strongly than other organizations.

4.4.2.3 Priority Analysis for Respondents' Role

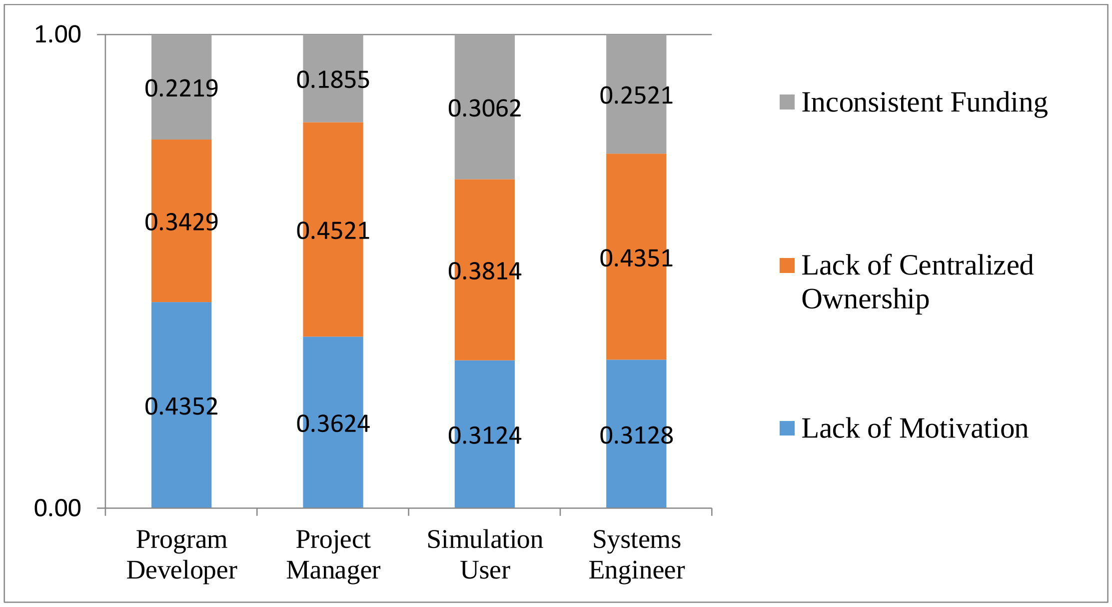


Figure 18 : Weight of Each factor for Respondents' Role in Managerial Factors

Figure 18 represents the weight of each factor for respondents regarding managerial factors. In contradistinction to the overall analysis, the program developers rank "Lack of Motivation" as the most important with a weight of 0.4352. This can be interpreted as the LVC simulation program developers needing more incentives for the interoperability tasks. Furthermore, project managers and systems engineers consider "Lack of Centralized Ownership" more important than other managerial factors.

4.5 Priority Analysis for Integrated Hierarchy Level

This chapter describes the overall ranking of global weights. As mentioned above, each weight of LVC simulation limiting factors is rated in a hierarchy level 1 and level 2. The next step is calculating the overall priority among all limiting factors. In order to calculate the overall priority, the weight of each factor in hierarchy level 1 should be multiplied by the weight of each factor in hierarchy level 2. For example, the weight of the “technical factor” (0.6274) should be multiplied by the weight of the “Lack of Understanding of Standard Architecture” (0.1249).

4.5.1 Overall Priority Analysis for Integrated Hierarchy Level

The following Table 11 represents the overall priority of the limiting factors in the LVC simulation interoperability. This analysis shows that the “Lack of Testing and Evaluating Environment for Integration” (0.2284) is the most influential factor, followed by the “Existing Numerous System Engineering Models” (0.1543) and “Lack of Common Gateway and Bridge Capabilities” (0.1112). Moreover, experts rank “Inconsistent Funding” as the lowest position with a weight of 0.0646.

Table 11 : Overall Priority of Limiting Factors in LVC Simulation

Level 1		Level 2		Global Weight	Rank
Factor	Local Weight	Factor	Local Weight		
Technical	0.7301	Lack of Understanding of Standard Architecture	0.1249	0.0912	6
		Lack of Different Object Model Standard	0.1065	0.0778	7
		Lack of Testing and Evaluating environment for Integration	0.3128	0.2284	1
		Lack of Common Gateway and Bridge capabilities	0.1523	0.1112	3
		Existing Numerous System Engineering Models	0.2113	0.1543	2
		Lack of Security Standard	0.0922	0.0673	8
Managerial	0.2699	Lack of Motivation	0.3523	0.0951	5

Level 1		Level 2		Global Weight	Rank
Factor	Local Weight	Factor	Local Weight		
		Lack of Centralized Ownership	0.4083	0.1102	4
		Inconsistent Funding	0.2394	0.0646	9

4.5.2 Priority Analysis for Respondents' Organization

The following Table 12 shows the overall priority of limiting factors in LVC simulation based on the different organizations. "Lack of Testing and Evaluating Environment for Integration" is the most influential factor in academic and government organizations, while "Existing Numerous System Engineering Models" is the most influential factor in industry organizations.

In academia, the "Lack of Testing and Evaluating Environment for Integration" (0.2267), is followed by "Existing Numerous System Engineering Models" (0.1539) and "Lack of Common Gateway and Bridge Capabilities" (0.1411).

In industry, the "Existing Numerous System Engineering Models" (0.1800) is followed by the "Lack of Testing and Evaluating environment for Integration" (0.1610) and "Lack of Centralized Ownership" (0.1188).

In the government organizations, "Lack of Testing and Evaluating Environment for Integration" (0.2455) is followed by the "Existing Numerous System Engineering Models" (0.1395) and "Lack of Centralized Ownership" (0.1240).

Table 12 : Overall Priority of Limiting Factors in LVC Simulation based on organization

Factor		Academic		Industry		Government	
Level 1	Level 2	Global Weight	Rank	Global Weight	Rank	Global Weight	Rank
Technical	Lack of Understanding of Standard Architecture	0.0870	4	0.0838	7	0.0941	5
	Lack of Different Object Model Standard	0.0869	5	0.0906	6	0.1172	4
	Lack of Testing and Evaluating Environment for Integration	0.2267	1	0.1610	2	0.2455	1
	Lack of Common Gateway and Bridge Capabilities	0.1411	3	0.1039	5	0.0626	8
	Existing Numerous System Engineering Models	0.1539	2	0.1800	1	0.1395	2
	Lack of Security Standard	0.0776	7	0.0631	9	0.0593	9
Managerial	Lack of Motivation	0.0713	8	0.1186	4	0.0810	6
	Lack of Centralized Ownership	0.0868	6	0.1188	3	0.1240	3
	Inconsistent Funding	0.0688	9	0.0802	8	0.0768	7

4.5.3 Priority Analysis for Respondents' Role

Table 13 represents the overall priority of the limiting factors in LVC simulation based on the respondents' roles in the different organizations. The "Lack of Different Object Model Standard" is the most influential factor within program developers. On the other hand, "Lack of Testing and Evaluating Environment for Integration" is the most critical factor within the other three roles.

Table 13 : Overall Priority of Limiting Factors in LVC Simulation based on Role

Factor		Program Developer		Project Manager		Simulation User		Systems Engineer	
Level 1	Level 2	Global Weight	Rank	Global Weight	Rank	Global Weight	Rank	Global Weight	Rank
Technical	Lack of Understanding of Standard Architecture	0.0953	5	0.0632	8	0.0955	5	0.1204	3
	Lack of Different Object Model Standard	0.1815	1	0.0695	6	0.0662	8	0.0921	6
	Lack of Testing and Evaluating environment for Integration	0.1559	2	0.2077	1	0.2192	1	0.1713	1
	Lack of Common Gateway and Bridge capabilities	0.1346	3	0.0962	5	0.1111	3	0.0847	7
	Existing Numerous System Engineering Models	0.1198	4	0.1398	3	0.1767	2	0.1662	2
	Lack of Security Standard	0.0948	7	0.0551	9	0.0602	9	0.1067	5
Managerial	Lack of Motivation	0.0949	6	0.1336	4	0.0847	6	0.0809	8
	Lack of Centralized Ownership	0.0748	8	0.1666	2	0.1034	4	0.1125	4
	Inconsistent Funding	0.0484	9	0.0684	7	0.0830	7	0.0652	9

4.6 Summary

In this chapter the analysis of priority of limiting factors in LVC simulation were implemented using the AHP method, specifically the calculating of local and global weights. In addition to the overall analysis of priority, analysis for respondent’s organization and role was conducted to identify the opinion differences among specified groups.

As a result, the “Technical Factor” was more important than the “Managerial Factor”. Also, the “Lack of Testing and Evaluating Environment for Integration” was the most significant limiting factor among the sub-criteria. Conversely, the “Lack of Security Standard” was the lowest weight. The next chapter explains the conclusion and recommendations of this research.

CHAPTER FIVE: CONCLUSIONS

5.1 Chapter Overview

This chapter consists of three parts. The first part describes the summary of the results and analyses of the research. The second part of this chapter provides recommendations for LVC interoperability based on results from AHP analyses. Finally, the last section of this chapter provides recommendations for future research.

5.2 Research Summary

LVC Simulation is a broadly used taxonomy describing a mixture of live, virtual, and constructive simulations (Joint Staff, 2001). Also, the LVC simulation is one of the System of Systems, which means there are a lot of factors that need to be considered. The LVC simulation is a relevant issue in many organizations as well as the military. Simulation users and developers have been hoping for more effective and integrated simulation environments with the new technological developments. However, the presence of limiting factors in technical and managerial fields obstructs the accomplishments of interoperability.

The primary objective of this research is to analyze the priority of limiting factors in the LVC simulation interoperability. By analyzing the priority of limiting factors in the LVC simulation interoperability, future research directions and focus could be suggested with using the research.

After identifying the need for this research, the nine limiting factors in LVC simulation interoperability have been identified through a literature review. Six of the nine limiting factors were technical factors that are classified into Lack of Understanding of Standard Architecture, Lack of Different Object Models, Lack of Testing and Evaluating Environment, Lack of Common Gateway and Bridge Capabilities, Existing Numerous Systems Engineering Models, and Lack of Security Standard. Three of the nine limiting factors were managerial factors such as Lack of Motivation, Lack of Centralized Ownership, and Inconsistent Funding.

Based on the identified technical and managerial limiting factors in LVC simulation, this research used the AHP method in order to analyze the priority among these factors. When designing the AHP survey, the focus of selecting participants was their experience and knowledge in this area. So, participants were chosen from these three areas: academia, industry, and government organizations. The survey was implemented for 11 weeks; 37 out of 42 responses were valid and used for analysis.

Not only overall priority analysis which calculated the weights was performed, but also, diverse analysis was conducted. This analysis uses the information about the organizations and the roles of the respondents. The result of survey identified some points. First, experts in the LVC community think technical limiting factors are more important than managerial limiting factors to achieve interoperability. Secondly, “Lack of Testing and Evaluating Environment for Integration” is the most critical limiting factors among all limiting factors. The second position of importance was “Existing Numerous Systems Engineering Models” followed by “Lack of Different Object Model Standard”. On the other hand, the highest rank of managerial factors was “Lack of Centralized Leadership”, ranking 4th among all factors.

An interesting point in the result was that there are some differences of opinions among respondents regarding their organizations and roles within that specific organization. By identified which factor is more critical than others in certain group, this analysis could be helpful for each other when people do collaboration task.

5.3 Recommendation for LVC simulation interoperability

5.3.1 Proactive Testing and Evaluating Environment for Integration

As described in Chapter 3 the Lack of Testing and Evaluating Environment is classified into two sub sections. The first one is that there is almost no external testing environment prior to the event itself. The other one is that there is no general evaluating method for interoperability.

The integration of several simulation systems is not easy process. Some kinds of barriers such as synchronizing time mechanism, finding errors could delay the process. In order to prevent this problem, earlier integration effort is needed. This earlier integration allows systems to come to earlier verification prior to the entire integration. The sooner interoperability issue is identified, the more flexibility there will be to deal with the problem. Conducting earlier and more frequent integration exercises are recommended to resolve this issue. In addition to this, the capability such as establishing reusable simulation exercises covering multiple systems should be developed with a standard based methodology (Zalcman et al., 2011).

The way of evaluating interoperability has been mostly by qualitative rather than quantitative. Objective and precise measurement of interoperability will facilitate a wellorganized and smooth LVC system process. Many different interoperability measurement models have been developed: Spectrum of Interoperability Measurement (SoIM), Levels of Information Systems Interoperability (LISI), and Systems-of-Systems Interoperability Model (SOSI). However, none of these models are perfect. Taken together, the interoperability measurement models that can evaluate quantitatively have to be developed.

5.3.2 Unified Systems Engineering Model

Different kind of systems engineering models for its own purpose have been developed. For example, the FEDEP systems engineering model was developed for the HLA federation. However, the FEDEP process needed to be re-examined to handle any specific requirements related to TENA(Cutts et al., 2006). A similar systems engineering process was outlined for TENA in the TENA Architecture Reference Document.

With the need for a single and unifying systems engineering process, DSEEP was developed based on the existing distributed simulation process. Nevertheless, because of the assumption that only one simulation architecture will be used, DSEEP is not complete solution for systems engineering model.

Differences of terms and procedures in systems engineering model cannot lead to effective collaboration work. So, every existing systems engineering process should be analyzed to find similarities and differences for generating a common process.

5.3.3 Common Gateway and Bridge Concepts

Both gateway and bridge are represented as an “intelligent translator” (RR Lutz & Drake, 2011). Like the initial phase of development for a systems engineering model, many programs have developed their own gateway and bridge based on immediate purposes. This trend has caused a lot of kinds of gateway and bridge without considering potential reusing. Sometimes, the same basic functionality has been developed with wasting time and budget. It is clear that there are many necessary steps are needed to provide a common gateway and bridge. Above all things, building a set of requirements for gateway and bridge and a developing common language are priorities.

Adequate and specific requirements lead to the right product. Many of the gateways and bridges that were already developed have little documentation regarding details(Henninger et al., 2008). So, identifying requirements could be valuable for the future development effort.

On the other hand, a common language for gateway and bridge has to support the reuse of data and machine-readable format with reducing the number of mappings (RR Lutz & Drake, 2011).

5.3.4 Consolidation of Ownership

According to survey results, managerial factors are not being considered lightly. It is true that technical factors are the major part of interoperability problems. However, with the System of Systems concept, managerial factors have to be considered throughout the entire cycle. One of the critical managerial factors was identified as “Lack of Centralized Ownership” in this research.

Cooperation and decision making among related people could be insufficient, especially in LVC simulation interoperability. Because of this point, strong and robust “control tower” is needed. Usually, most of the single simulation developments have a specified person and organization to deal with problem. However, consistent responsibility and control ability cannot be implemented for integration of LVC simulation.

In order to resolve this kind of problems, people or organizations that are exclusively responsible for interoperability tasks are essential. From the start to end of interoperability tasks, these dedicated people or organization can monitor the entire status and manage the problems effectively. In addition to this, ability for sharing the update of progress could be enhanced.

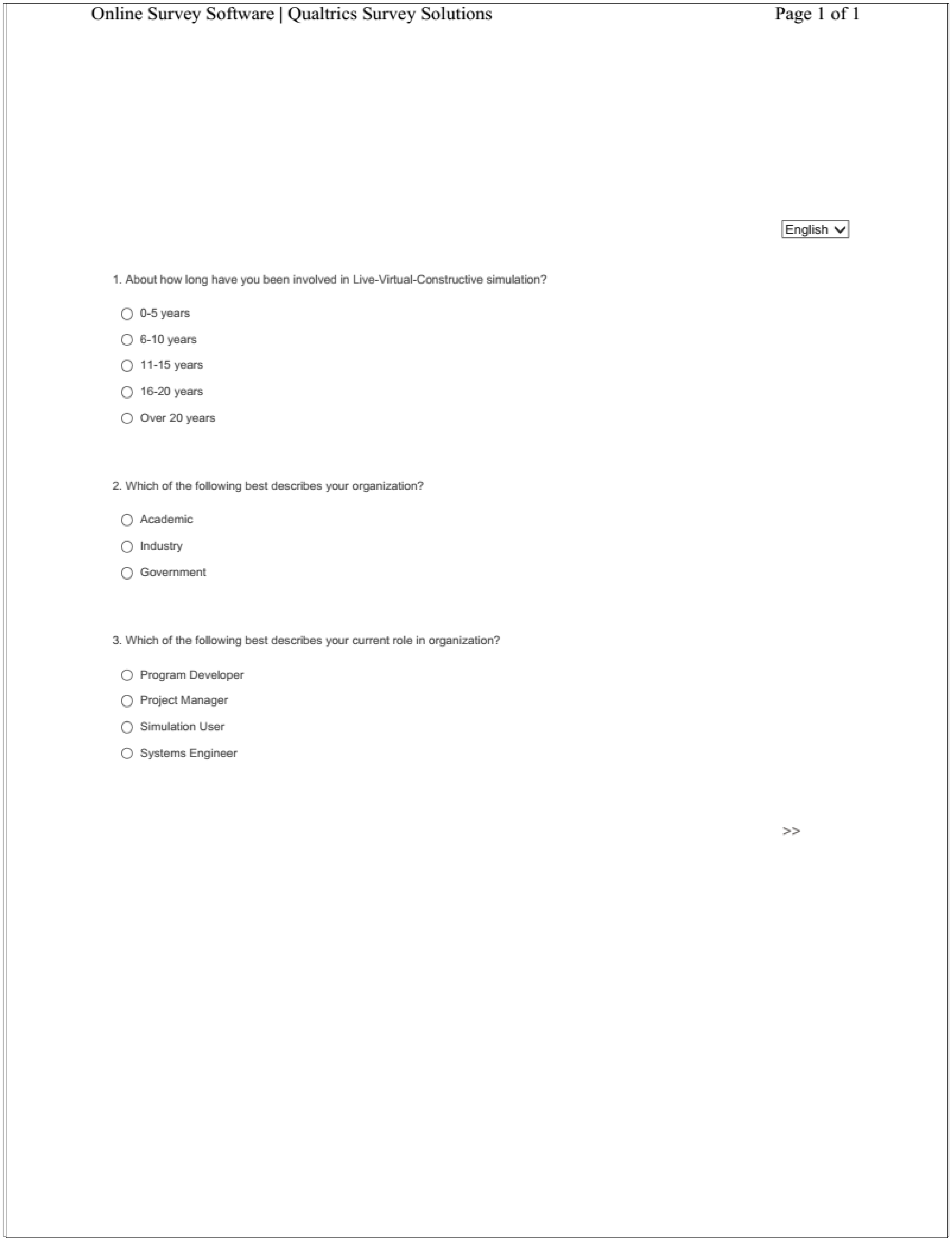
5.4 Recommendation for Future Research

This research might be the catalyst for future research about the limiting factors in the LVC simulation interoperability. However, regarding the methods that are used in this research to identify priority of limiting factors, there might be explicit limitations.

First, it is not sure that the AHP hierarchy and the vital factors are defined correctly. This issue is a fundamental limitation with the AHP method. So, future research must recognize the newest trend and specify the limiting factors.

Second, the result of this research came from the quantitative approach. This kind of approach is only useful for getting the general tendency in certain areas. In order to consider features of individual factors, qualitative approaches should be done with such things as interviews, case studies, etc. Doing both the quantitative and qualitative research methods for this topic can definitely make more valuable data.

APPENDIX A: QUESTIONAIRE OF AHP SURVEY



1. About how long have you been involved in Live-Virtual-Constructive simulation?

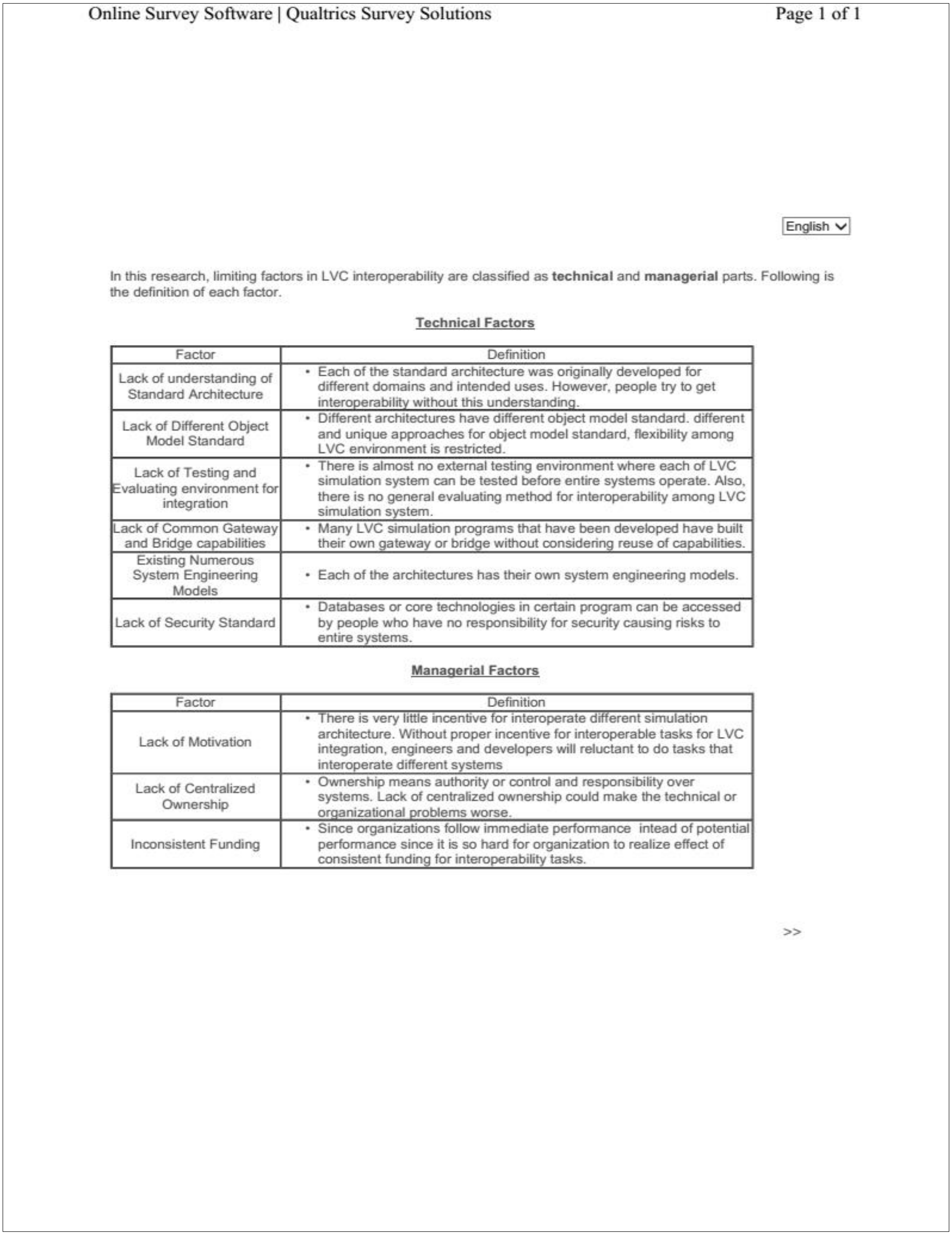
- ○ 0-5 years
- ○ 6-10 years
- ○ 11-15 years
- ○ 16-20 years
- ○ Over 20 years

2. Which of the following best describes your organization?

- ○ Academic
- ○ Industry
- ○ Government

3. Which of the following best describes your current role in organization?

- ○ Program Developer
- ○ Project Manager
- ○ Simulation User
- ○ Systems Engineer



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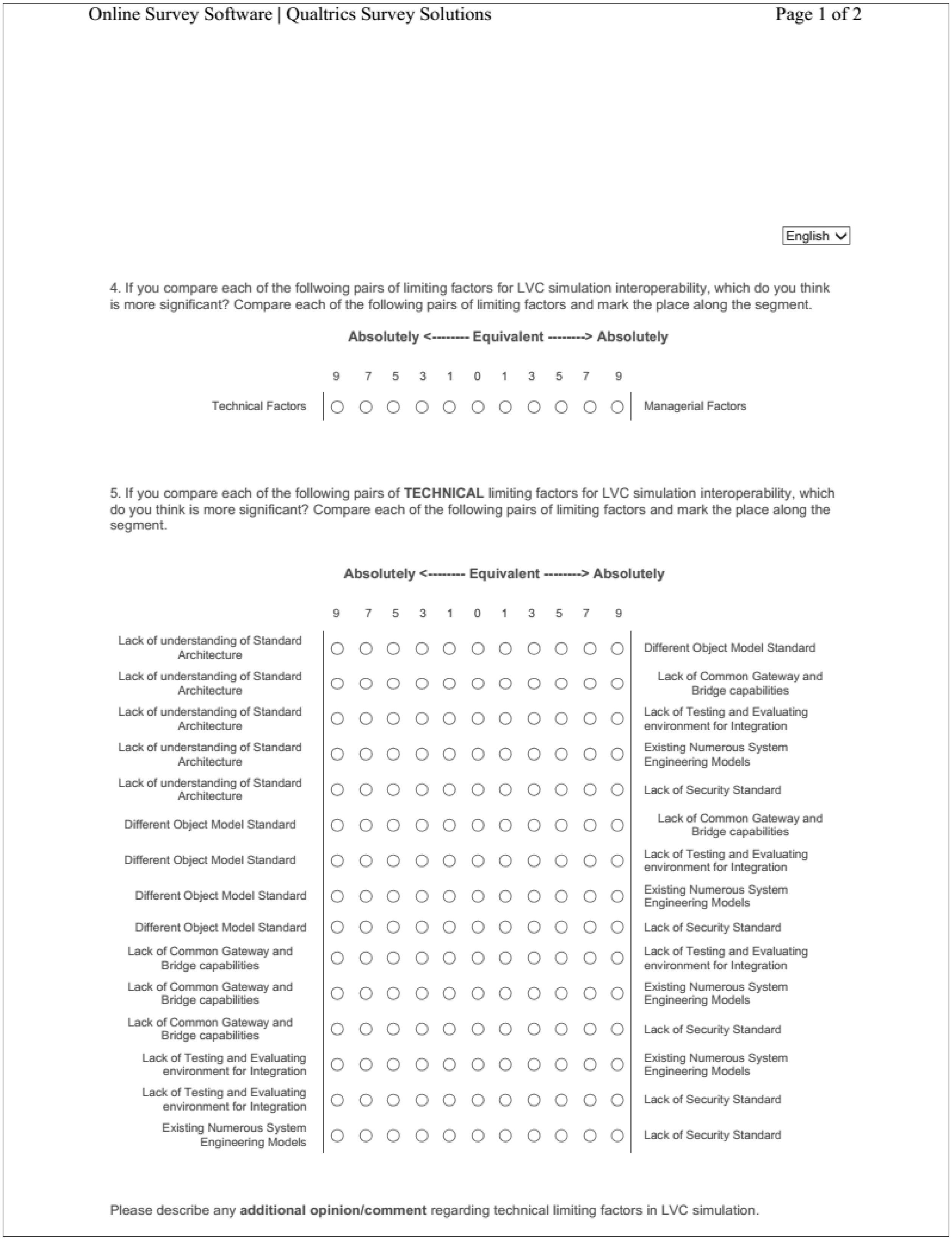
In this research, limiting factors in LVC interoperability are classified as **technical** and **managerial** parts. Following is the definition of each factor.

Technical Factors

Factor	Definition
Lack of understanding of Standard Architecture	• Each of the standard architecture was originally developed for different domains and intended uses. However, people try to get interoperability without this understanding.
Lack of Different Object Model Standard	• Different architectures have different object model standard. different and unique approaches for object model standard, flexibility among LVC environment is restricted.
Lack of Testing and Evaluating environment for integration	• There is almost no external testing environment where each of LVC simulation system can be tested before entire systems operate. Also, there is no general evaluating method for interoperability among LVC simulation system.
Lack of Common Gateway and Bridge capabilities	• Many LVC simulation programs that have been developed have built their own gateway or bridge without considering reuse of capabilities.
Existing Numerous System Engineering Models	• Each of the architectures has their own system engineering models.
Lack of Security Standard	• Databases or core technologies in certain program can be accessed by people who have no responsibility for security causing risks to entire systems.

Managerial Factors

Factor	Definition
Lack of Motivation	• There is very little incentive for interoperate different simulation architecture. Without proper incentive for interoperable tasks for LVC integration, engineers and developers will reluctant to do tasks that interoperate different systems
Lack of Centralized Ownership	• Ownership means authority or control and responsibility over systems. Lack of centralized ownership could make the technical or organizational problems worse.
Inconsistent Funding	• Since organizations follow immediate performance intead of potential performance since it is so hard for organization to realize effect of consistent funding for interoperability tasks.



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English ✓

4. If you compare each of the follwoing pairs of limiting factors for LVC simulation interoperability, which do you think is more significant? Compare each of the following pairs of limiting factors and mark the place along the segment.

Absolutely <-------- Equivalent --------> Absolutely

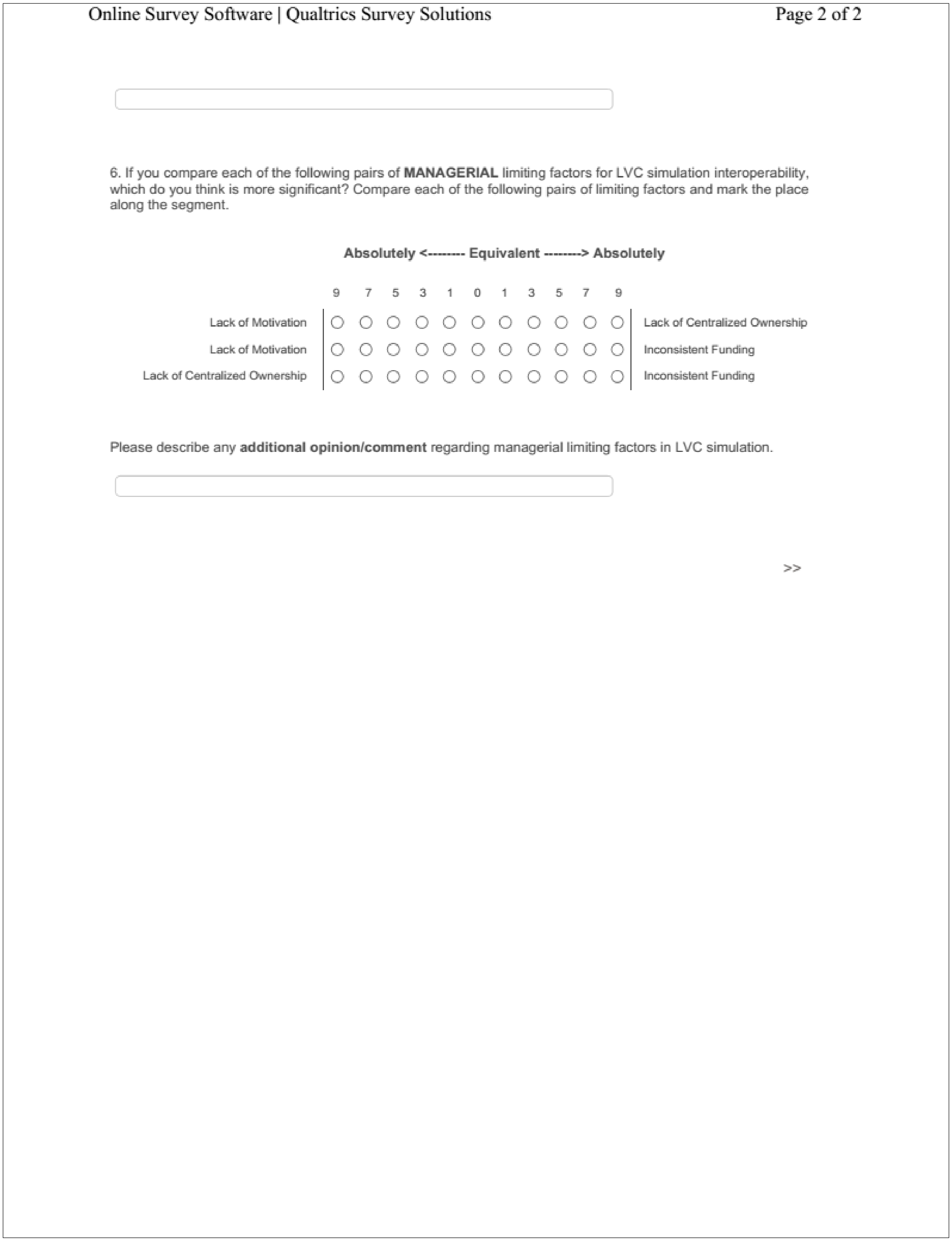
	9	7	5	3	1	0	1	3	5	7	9	
Technical Factors	○	○	○	○	○	○	○	○	○	○	○	Managerial Factors

5. If you compare each of the following pairs of **TECHNICAL** limiting factors for LVC simulation interoperability, which do you think is more significant? Compare each of the following pairs of limiting factors and mark the place along the segment.

Absolutely <-------- Equivalent --------> Absolutely

	9	7	5	3	1	0	1	3	5	7	9	
Lack of understanding of Standard Architecture	○	○	○	○	○	○	○	○	○	○	○	Different Object Model Standard
Lack of understanding of Standard Architecture	○	○	○	○	○	○	○	○	○	○	○	Lack of Common Gateway and Bridge capabilities
Lack of understanding of Standard Architecture	○	○	○	○	○	○	○	○	○	○	○	Lack of Testing and Evaluating environment for Integration
Lack of understanding of Standard Architecture	○	○	○	○	○	○	○	○	○	○	○	Existing Numerous System Engineering Models
Lack of understanding of Standard Architecture	○	○	○	○	○	○	○	○	○	○	○	Lack of Security Standard
Different Object Model Standard	○	○	○	○	○	○	○	○	○	○	○	Lack of Common Gateway and Bridge capabilities
Different Object Model Standard	○	○	○	○	○	○	○	○	○	○	○	Lack of Testing and Evaluating environment for Integration
Different Object Model Standard	○	○	○	○	○	○	○	○	○	○	○	Existing Numerous System Engineering Models
Different Object Model Standard	○	○	○	○	○	○	○	○	○	○	○	Lack of Security Standard
Lack of Common Gateway and Bridge capabilities	○	○	○	○	○	○	○	○	○	○	○	Lack of Testing and Evaluating environment for Integration
Lack of Common Gateway and Bridge capabilities	○	○	○	○	○	○	○	○	○	○	○	Existing Numerous System Engineering Models
Lack of Common Gateway and Bridge capabilities	○	○	○	○	○	○	○	○	○	○	○	Lack of Security Standard
Lack of Testing and Evaluating environment for Integration	○	○	○	○	○	○	○	○	○	○	○	Existing Numerous System Engineering Models
Lack of Testing and Evaluating environment for Integration	○	○	○	○	○	○	○	○	○	○	○	Lack of Security Standard
Existing Numerous System Engineering Models	○	○	○	○	○	○	○	○	○	○	○	Lack of Security Standard

Please describe any **additional opinion/comment** regarding technical limiting factors in LVC simulation.



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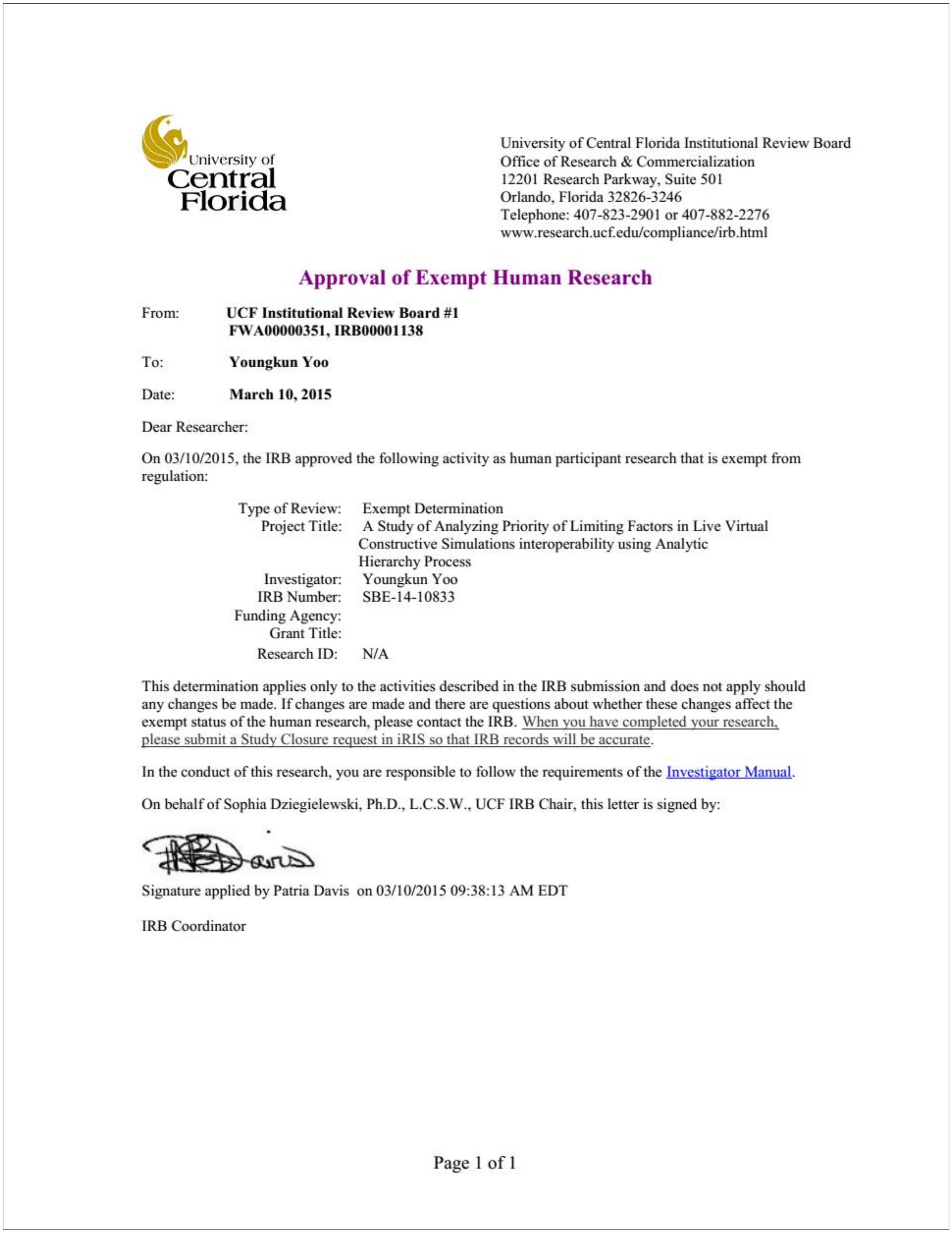
6. If you compare each of the following pairs of **MANAGERIAL** limiting factors for LVC simulation interoperability, which do you think is more significant? Compare each of the following pairs of limiting factors and mark the place along the segment.

Absolutely <-------- Equivalent --------> Absolutely

	9	7	5	3	1	0	1	3	5	7	9	
Lack of Motivation	○	○	○	○	○	○	○	○	○	○	○	Lack of Centralized Ownership
Lack of Motivation	○	○	○	○	○	○	○	○	○	○	○	Inconsistent Funding
Lack of Centralized Ownership	○	○	○	○	○	○	○	○	○	○	○	Inconsistent Funding

Please describe any **additional opinion/comment** regarding managerial limiting factors in LVC simulation.

APPENDIX B: INSTITUTIONAL REVIEW BOARD APPROVAL



University of Central Florida

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: **Youngkun Yoo**

Date: **March 10, 2015**

Dear Researcher:

On 03/10/2015, the IRB approved the following activity as human participant research that is exempt from regulation:

Type of Review: Exempt Determination
Project Title: A Study of Analyzing Priority of Limiting Factors in Live Virtual Constructive Simulations interoperability using Analytic Hierarchy Process
Investigator: Youngkun Yoo
IRB Number: SBE-14-10833
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 03/10/2015 09:38:13 AM EDT

IRB Coordinator

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