Toward Live Virtual Constructive Simulations in Healthcare Learning

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Toward Live Virtual Constructive Simulations in Healthcare Learning

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Abstract: This article explores the combination of live, virtual, and constructive (LVC) simulations in healthcare. Live, virtual, and constructive simulations have long existed in the military, but their consideration (and deployment) in medical and healthcare domains is relatively new. We conducted a review on LVC its current application in the military domain and highlight an approach, challenges, and present suggestions for its implementation in healthcare learning. Furthermore, based on the state of the art in simulation in healthcare, we suggest that a combination of two simulation types (LV, VC, LC) at the time may be a simpler approach to the community at large.
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Key Words: Live simulation, virtual simulation, constructive simulation, LVC simulation, LVC in healthcare.

The US Department of Defense (DoD) for decades has leveraged modeling and simulation (M&S) to provide effective and realistic training to warfighters. Within this context, there are three major types of simulation typically used to deliver warfighter training: live, virtual, and constructive (LVC). A training simulation is considered *live* or a live simulation if all the roles are played by human beings in a real environment with real systems. A training simulation is considered *virtual* if some roles, systems, and/or the environment are represented via a computer program, mathematically and/or graphically. A training simulation event is considered *constructive* if all the roles, the systems, and the environment are represented via a computer program.

The decision to use a live, virtual, or constructive training event is driven by time, level of effort, available resources (trainers, computers, money, etc), and the desired learning outcomes. As the complexity of DoD training requirements increases and the need to use and reuse M&S assets grows, we are reaching the limits of a single paradigm, tool, or approach. Consequently, the idea of generating mixed LVC simulations to account for the increased complexity of training and education needs has begun to take hold.[1] Several LVC architectures and frameworks have been proposed by the DoD[2,3] and cyber domains.[4]

Typically, LVC solutions focus on simultaneously training a large group of individuals that would not be able to physically train together (geographically dispersed), playing distinct roles at different levels of responsibility, and at lower comparative costs (logistics, equipment, manpower) to develop coordination and communication skills in large-scale challenging scenarios. Technologically, to achieve these goals, LVC training systems have (1) large heterogeneous components at multiple levels of resolution and aggregation, (2) some components that execute in parallel (run simultaneously to save time) over a common network using a set of interoperability protocols such as the distributed interactive simulation standard or the high-level architecture standard, and (3) components that are distributed geographically connected via networks. These complex LVC training solutions are not without challenges, including the following: data engineering issues such as the administration, management, mapping, and transformation of data between simulations; technical issues such as network security, data latency, and data consistency; and conceptual issues such as the alignment of assumptions, the underlying models, and their implementations. Resolving these challenges is time-consuming, expensive, and error-prone, which is perhaps why LVC simulations are not the norm even in the DoD domain. Given the level of complexity and challenge faced by the well-resourced and centralized DoD when employing LVC training, should (or can) elements of the complex healthcare domain adopt LVC?

The answer is *potentially*. There are scenarios where using LVC to establish a parallel, distributed, interoperable set of simulations and simulators applies to the healthcare domain. One LVC use case includes creating a "digital human." In this case, LVC provides the framework and architecture to integrate different models of human physiological systems that, when combined, create a digital human. Another LVC use case involves training for a mass casualty response. In this case, an LVC training simulation can incorporate multiple types of training simulations that, together, can provide integrated training solutions for everyone from first responders, dispatchers, emergency department personnel, surgical teams, and hospital clinical staff. This type of LVC simulation can include the opportunity to manage a myriad of issues, such as disaster site management, transport, routing, triage, staging, and supply management. The LVC event might also include other local, state, and federal disaster management teams training from their own facilities.

These use cases demonstrate that LVC simulations have the potential to allow us to explore complex training scenarios

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TABLE 1. Shared Characteristics, Conducive to LVC Initiatives, Between Military and Civilian Organizations

Characteristics	Military Organization	Nonmilitary Organization
Size	Unit, company, brigade	Department, unit, division, subsidiaries
Leadership	Operational, strategic, tactical	Senior management, midlevel management, team leaders
Governance	Doctrine, tactics, techniques, procedures	Strategic plans, individual goals, manuals
Context	Joint, coalition, service	Multinational, divisions, branches
Aspect	Human, social, cultural, behavioral, kinetic	Leadership, management, organizational, technical, social

that involve healthcare situations alongside other factors, teams, systems, and roles. In this article, we explore the applicability of LVC simulation in the healthcare domain. The article is organized thusly: Section 1 briefly describes LVC in the context of DoD and consideration for transition out of DoD. Section 2 provides an approach and potential challenges to implement LVC simulations in healthcare domain. Sections 1 and 2 inform Section 3 looking at how LVC simulations are seeing in healthcare. Section 4 provides examples of LVC in the context of healthcare, and Section 5 provides a discussion on LVC in healthcare followed by the conclusion.

TRANSITIONING LVC SIMULATIONS OUT OF THE MILITARY DOMAIN

Regardless of the resources available, publicly funded organizations are often asked to deliver services more efficiently and cheaply, but without compromising quality and value. This exact problem existed in the US Army between 1991 and 2000. During that decade, live warfighter training budgets were dramatically cut. In response, the Army used virtual and constructive simulation as an effective and affordable means to keep the force trained. During this period, deployments increased 400 percent, yet the Army remained trained to a very high level.

More recently, a mix of LVC simulations have been successfully used reduce the cost to train senior warfighting staffs. Instead of using actual warfighting assets (ships, units, planes, tanks, etc.), DoD has employed constructive simulations. These simulations enable distributed training worldwide. Examples of this form of LVC simulations include the following: (1) the Ulchi-Freedom Guardian, an annual yearly US and South Korea event focused on defense of the Korean peninsula; (2) the NATO Pathfinder program, which integrates various NATO country simulations; and (3) the Swedish-initiated VIKING Computer-Assisted Exercise (CAX), which prepares civilians, police, and military for crisis management and disaster response.

The healthcare domain is ripe for adopting aspects of the LVC paradigm. This is due to several factors: (1) the need to foster collaboration and trust under stressful medical situations, (2) the need for repeatable training scenarios, which may be challenging in live conditions, and (3) the need to make training available to more people and at more locations, simultaneously. According to Paige and Chauvin,[5] operating rooms are highly dynamic environments in which effective teamwork is crucial for patient safety, yet it is common to find poor communication and disruptive behavior within these environments. A well-deployed LVC simulation can provide a realistic training event that helps complex and distributed teams to overcome significant performance challenges.

Although LVC is used mostly in support of training in the military, the concept can be extended to the nonmilitary world. Table 1 provides a parallel between the military world, where LVC simulations are currently used, and the nonmilitary world, where LVC solutions are lacking.

Table 1 summarizes some characteristics that military and medical and healthcare organizations share:

- *Size:* Both types of organization are divided into echelons overlaid with a leadership structure at each level;
- *Leadership:* Both types of organizations are often controlled with a top-down approach where orders/directives emanate from the top and are propagated and executed downward with built-in independent decision-making;
- *Governance:* Both types of organizations have a well-defined mission and vision and follow a unified set of codified procedures not only at the organizational level but also within each echelon;
- *Context:* Both types of organizations deal with other similar types organizations and often operate in more than one country. In addition, both types of organizations are made up of branches and divisions that play a specific and sometimes independent role in the organization;
- *Aspect:* Both types of organizations require multiple aspects of their activities to function in unison to be effective.

Based on these shared attributes, we can loosely state that LVC simulations are useful in the context of a System of Systems (SoS). In theory, SoS approaches such as soft-system methodology[6] are supposed to be considered better alternatives to the traditional system engineering approach to LVC because they provide a holistic view and therefore gives developers more opportunities to detect potential problems. However, these approaches are extremely difficult to implement in nontrivial cases, because they are usually more time-consuming and costlier. In addition, this approach is not always feasible because of its inherent complexity to build a model. We use M&S concepts to model and study the SoS. Modeling and simulation can be used to represent and study organizational challenges using live simulations such as focus groups, surveys, and role-playing. It is also possible to have live members of the organization interact with a virtual computer simulation of the technical components of the system. We focus on the M&S approach to building LVC simulations in the next section.

APPROACH AND CHALLENGES of LVC

To the authors' knowledge, there is not an approach for developing LVC solutions. As such, because LVC is at its core a federated approach to M&S, we depart from the Distributed Simulation Engineering and Execution Process[7] to identify overarching steps to obtain a generic LVC. Figure 1 shows the suggested approach. It is noted that the development of

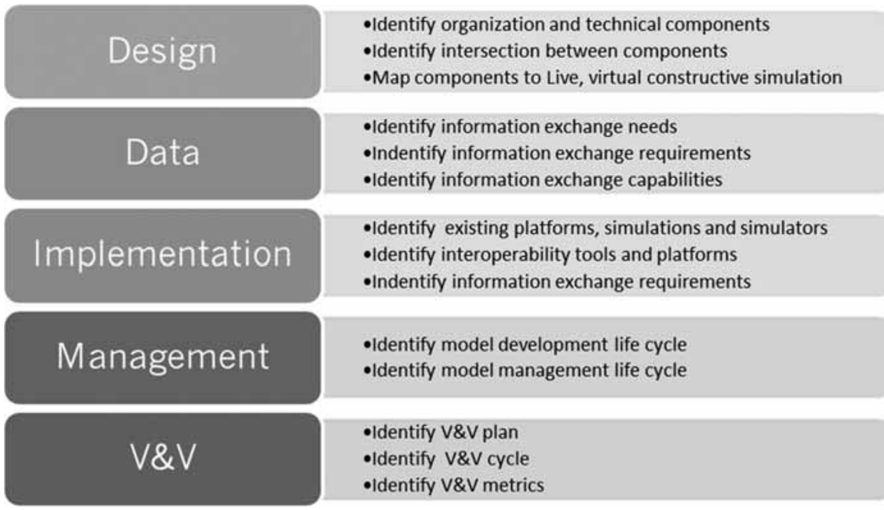

FIGURE 1. Adapted DSEEP into an LVC Methodology.

this approach was informed by a low-cost in-house prototype developed by the researchers.

Healthcare domain experts need to be at the center of an LVC effort for these steps to take place. They are the ones that provide the training scenarios and generate the requirements for those scenarios to be successful. Domain experts will cut across the different areas that require training. For instance, if training for a disaster, individuals with expertise on procedures conducted by paramedics, emergency department personnel, and hospital administrators must be present to design scenarios and means for evaluating whether training of such procedures is taking place.

The design phase is centered on the identification and specification of a reference model[8] that captures the problem or situation that we intend to study. This model includes all relevant actors, activities, behaviors, and interactions. At a high level, we associate activities that involve only human actors, behaviors, and interactions with the live component. Similarly, we associate activities that involve only machine actors, behaviors, and interactions with the constructive component and activities that involve a mix of both with the virtual component.

During the data phase, we apply model-based data engineering.[9] This data phase extends the reference model specified in the design phase by adding relationships between activities and actors, further specifying attributes, data types, and value domains. At the end of this phase, we have a well-defined data model specification that encapsulates the data exchange needs and capabilities, with the appropriate resolution and scope. The implementation phase focuses on establishing simulation development and/or integration of LVC simulations across computers in separate locations. The management phase ensures that the LVC project accomplishes its goals and meets its requirements. The verification and validation (V&V) phase consist of developing a V&V plan for the LVC simulation. Rather than being isolated, the V&V phase is done in close connection with all other phases from design to implementation.

It is important to note that this process requires a team of experts, namely domain knowledge expert (healthcare), systems engineers, M&S professionals, data engineers, distributed simulation professionals, federation managers, and V&V professionals. Such variation in expertise and activities required generate a myriad of challenges.

An LVC federation, a combination of simulation systems exchanging data via a platform, common language or template, presents challenges not found in live, virtual, or constructive federations individually. In general, the challenges are related to the design and specification phase and in the execution phase. In the design phase, it is often very difficult to identify and represent entities and their interactions along with their existential dependencies and their transformational dependencies. In the implementation phase, synchronization, data distribution management, multiresolution, and multiscope issues are sources of increase in time, number of errors, and cost. Although these challenges need to be addressed separately and holistically, they only cover the technical aspects of the problem. On the other hand, and considering Table 1, there needs to be healthcare professionals with knowledge of procedures that require training across the mentioned characteristics. For instance, deciding what, and how, to train large groups of individuals across departments and organizations that requires the simultaneous involvement of different levels of leadership is a complex task.

LIVE, VIRTUAL, AND CONSTRUCTIVE IN HEALTHCARE LEARNING

The healthcare domain uses virtual and live training simulations extensively. According to Scerbo,[10] "many in our healthcare simulation community are familiar with live and virtual forms of simulations that incorporate mannequins, part-task trainers, virtual reality (VR) systems, and standardized patients." However, and based on the same article, Scerbo[10] highlights the following: (1) the scarce presence of constructive simulations, (2) the consideration of adopting LVC simulations from the military, and (3) the embracement of simulation beyond training. On activities beyond training, Scerbo[10] posits that simulation for testing in healthcare is gaining acceptance as "simulation centers work with medical device manufacturers to provide context-based user evaluations of equipment before seeking US Food and Drug Administration approval." This is consistent with the military M&S literature as LVC is applied to activities such as testing[11,12] and analysis.[12] On constructive simulations, Scerbo[10] presents that "there is a great potential for these types of systems. They can be used for modeling the delivery of healthcare services, inform providers and administrators about potential impact of policies, and incorporated into live and virtual scenarios to enhance the environmental and operational context." While works by Diaz et al[13] provide insight into how constructive simulation can be applied to healthcare, more cases can indeed be found in traditional M&S outlets, such as Society For Simulation International and Association for Computing Machinery conferences and journals such as *Simulation: Transactions of the Society for Modeling and Simulation International* and *Journal of Simulation*, among others. Works by Brailsford et al,[14] Gunal and Pidd,[15] and Duguay and Chetouane[16] to mention a few showcase the positive application of constructive simulations in healthcare.

However, LVC does not seem to be on the radar of healthcare researchers or educators. Searching in the *Simulation in Healthcare* journal (as the main simulation in healthcare outlet), there is only one return referring to the live virtual constructive entry: Scerbo.[10] The work of Phrampus et al[17] provides a description of a detailed setting that could implement LVC for training (Ebola readiness) and there seems to be a simulation implementation, but the authors could not assess whether the implementation was LVC.

Looking at the Society for Simulation in Healthcare (SSH) Simulation Dictionary,[18] the authors assessed keywords in the context of M&S (as in the M&S community at large) and simulation in healthcare (as in the M&S community that specializes in healthcare or the healthcare community that relies on simulation products and services) as it relates to LVC. The assessment seeks to identify the most likely use of the keyword on both communities. It is noted that the assessment was conducted by the authors lending potential bias to the result. Table 2 shows a sample of the keywords assessed.

Table 2 shows the assessment of terms, live (L), virtual (V), constructive (C), LVC (live virtual constructive), lv (live or virtual), and lvc (live or virtual or constructive). Lower case "lv," "vc," and "lvc" are used to convey that terms are used in either domain but not necessarily combined. Terms such as immersion, modality, and realism are used in M&S as either live or virtual or constructive and in LVC but are not unique terms to LVC like distributed simulations or system integration.

Table 2 shows red, yellow, and green rows highlighting the level of matching or overlapping of terms on both contexts. Red rows show where the term does not reconcile or does not exist in either context. For instance, the terms incognito standard patient or distributed simulation seem specific to each domain (healthcare and M&S respectively). However, terms such as advocacy and inquiry may be conducted under a different name in M&S. A term close in meaning is that of accreditation, which is not found in the dictionary. Yellow rows show terms that are overlapping. Terms such as computer-based simulation and simulator overlap on both M&S and simulation in healthcare because they both refer to virtual simulations. However, computer-based simulation and simulator are also used in the M&S community as a form of constructive simulation. Lastly, green rows show where the terms on both context match. Terms such as virtual reality, discrete-event simulation,

TABLE 2. Context Comparison Using Sample Keywords From SSH Simulation Dictionary

	Context	
Keyword	M&S	Healthcare
Avatar	V	V
Advocacy and inquiry*	Not used	LV
Briefing	lvc	lv
Computer-based simulation	vc	V
Discrete-event simulation	C	C
Distributed simulation	LVC	Not used
Embedded participant	L	L
Fidelity	lvc	lv
Guided reflection	lvc	lv
Haptic	V	V
Immersion	lvc	lv
Incognito standardized patient	Not used	L
Just-in-time simulation	C	lv
Low fidelity	C	lv
Modality	lv	lv
Multiple modality**	lvc	lv
Nontechnical skills*	lvc	lv
Objective Structure Clinical Examination*	Not used	lv
Prebrief	lvc	lv
Process-oriented simulation	lvc	lv
Realism	lvc	lv
Scenario	lvc	lv
Serious games	vc	lv
Simulated person	lvc	lv
Simulator	vc	v
Systems integration	LVC	lvc
Task trainer	lvc	lv
Virtual reality	V	V

and embedded participant are used consistently on both communities to refer to virtual, constructive, and live simulations respectively.

Finally, Table 2 provides two insights as we move LVC to the medical/healthcare domain: (1) reliance on combination of two forms of simulation (LV, LC, VC) to implement more complex training/testing scenarios. Table 2 shows that the lv combination is already widely used in the simulation in healthcare community and (2) moving toward LVC simulations may rely on considering the inclusion to these lv cases of constructive solutions. For instance, discrete-event simulations could provide the consideration of a large number of patients to an emergency department, while training using haptic and embedded patient is taking place. This provides training to different individuals at different levels within an organization ranging from higher-level management to people in emergency departments.

LIVE, VIRTUAL, AND CONSTRUCTIVE HEALTHCARE-RELATED TRAINING EXAMPLES

Documented cases of LVC exercises that include healthcare training are scarce. As mentioned, perhaps the best-known case is the Viking CAX.[19,20] The Viking CAX series are distributed computer-assisted exercises that provides joint training to military, police and civilian units from different countries. Training focuses on cooperation in peace operations and crisis situations. According to the Swedish Armed Forces Web site,[21] Viking CAX 18 will take place in April 2018 with 2500 participants from 50 countries and 35 organizations participating from sites in Sweden, Brazil, Bulgaria, Finland, Ireland, and Serbia. The exercise is coordinated by the Swedish Armed Forces and the Folke Bernadotte Academy (Swedish government agency for peace, security, and development). The Viking CAX exercise has taken place seven times since 1999.

Bolcar and Collins[20] highlight other exercises that involve LVC. The SEESIM (South Eastern Simulation Network) CAX in 2002 worked out of an earthquake scenario with damages through the Southeastern Europe forcing nations "to determine what outside assistance is required, make the request for assistance, and coordinate external support." The Joint Theater Level Simulation, a multisided simulation system focusing on operational level of war, was distributed from Athens, Greece, to nine sites in Southeast Europe (Greece, Turkey, Bulgaria, Romania, Former Yugoslav Republic of Macedonia, Croatia, Slovenia, Albania, and Italy). The lessons learned from this exercise identified the following needs[20]: "standardization of message formats and response procedures, development of a regional training program on standard procedures, establishment of a reliable means of national communications, and a relevant, challenging, and realistic scenario to meet training objectives."

Smaller-scale exercises occur across municipalities in the United States. However, we found no evidence that the few documented cases are LVC. They are either live or virtual with few combining live and virtual. Figure 2 shows a small demonstration of an LV exercise taking place at MODSIM World 2010 in the City of Hampton, Virginia. The exercise focused on police forces (live) neutralizing a shooter (live), securing the site and aiding a victim (virtual) until paramedics (live) arrived. Paramedics then proceeded to stabilize the victim and wheeling out in their ambulance. The exercise provided training to first responders across organizations (police and paramedics).

Lai et al[22] provide an LV simulation-based training scenario for emergency medical first responders. Training focuses on communication, decision-making, allocation of resources, adaptation, and hazard protection. Scenarios are built around a mannequin and people: the mannequin (virtual) acts as victim 1, motionless after being exposed to a chemical agent, and a person (live) acts as victim 2, tending to the motionless individual. Trainees need to assess the danger while protecting themselves and complete a protocol that may include other individuals (live).

Cases that consist of a combination of two simulation types require role coordination without necessarily encumbering into interoperation efforts.

The crisis response community, police, paramedics, nurses, etc do have options for conducting realistic training without LVC. Disaster City (Texas A&M), for instance, provides a large site where emergency responders can train for rescuing and tending individuals among rubble of metal and glass. However, this training takes place in one location leaving out parties that could benefit from such a training at different levels of decision-making that are not field personnel.

DISCUSSION AND CONCLUSION

Purpose drives all simulation efforts. The challenge is identifying whether live or virtual or constructive or a combination thereof is required to satisfy the training objectives under cost and other constraints. In terms of LVC simulations training frequency, training at different levels of leadership across departments/organizations and training for different skills among others drive implementation decisions.

The following are some guiding questions when considering the implementation of an LVC initiative:

- What is the purpose of the training exercise?
- Would live, virtual or constructive simulations serve the exercise purpose?
- Would combination of LV or LC or VC serve the exercise purpose?
- Does the LVC exercise event provide multilevel (from coordinators to operators) training/planning capability?
- What is the number of personnel and equipment?
- Does the event support inter-department/interorganization training/planning capability?
- Do the personnel need to train simultaneously?
- How do we assess that the LVC exercise was successful?
- What is the frequency of these exercises?
- Would we rely on existing simulations that require interoperation support?

It is important to note that the healthcare domain has a comparative disadvantage to DoD to implement LVC initiatives: DoD is a large customer with a large budget. While spending in healthcare is increasing as an aggregate, advancement is driven by industry products to satisfy training but not at large scales. This is where agencies such as FEMA (Federal Emergency Management Agency) could play a leading role into developing not only LVC initiatives for crisis response but also low-cost LVC initiatives that can be used frequently across the country. Ultimately, these exercises provide lessons learned that advances not only the development of new and relevant scenarios and the readiness of organizations/agencies but also

FIGURE 2. Live Virtual Demonstration at MODSIM World 2010.

the technical infrastructure required to conduct those exercises, as was the case in SEESIM CAX 02.

In the meantime and considering that virtual simulations are widely used in the medical/healthcare domain, we must consider how to combine it with live and/or constructive options. A combination of two forms of simulation may be easier to implement and more cost-effective for a domain that still needs to decide whether LVC is a viable option. Considering LV, VC, or LC combinations may result in advances in training/education at lower costs with readily accessible technology. For instance, the simplest one to consider is the LV combination. Live simulations could involve role-play to develop communication and coordination skills, whereas mannequins provide the virtual simulations support for varied training objectives. Both exercises are available without technological or interoperation limitations. The requirement is then to develop the use case/scenario where such exercise provides the desired learning objectives. Similarly, the LC combination has low technological and interoperation challenges. This combination could be used for emergency response at a hospital. Hospital decision-makers could use the concept of a digital table top exercise where they train for an emergency with the input from a constructive simulation. Live simulation would support communication and coordination training. The constructive simulation would support analysis and experimentation.

On the other hand, the VC combination runs into all the challenges mentioned previously. Ultimately, the M&S community needs from the medical and healthcare communities use cases where these combinations can be tested, and their effectiveness evaluated. As such, collaboration of these communities and the M&S community is key.

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