LVC Simulation for Land Operations Training

Jo Erskine Hannay, Ole Martin Mevassvik, Arild Skjeltorp and Karsten Brathen,
Norwegian Defence Research Establishment (FFI),
P.O. Box 25, NO-2027 Kjeller
NORWAY

jo.hannay@ffi.no ole-martin.mevassvik@ffi.no
arild.skjeltorp@ffi.no karsten.brathen@ffi.no

ABSTRACT

Augmenting and extending military training by combining Live*,* Virtual *and* Constructive *(LVC) simulation is thought to yield a range of benefits. A Concept Development and Experimentation (CD&E) activity was initiated to investigate the feasibility of complementing the Live training range at The Norwegian Army Combat & Manoeuvre Training Centre (NACMTC) with Virtual and Constructive simulations of BLUEFOR and OPFOR vehicles, UAV and artillery. The focus was on leadership training, and the military situation was augmented by activating contextual forces from the scenario and introducing more resources to administrate. The LVC simulation system prototype was run as a trial during an actual military exercise over four days. We found that the prototype did enable enhanced training, and that it is feasible and desirable to establish the LVC capability in full. Further, it is desirable to extend the LVC capability with augmented reality for Live forces and Joint Terminal Attack Controller (JTAC)/Close Air Support (CAS) simulation. We found it premature to evaluate the* effect *of LVC simulation training; because this is a longer-term activity, and because of a lack of validated instruments for measuring skill acquisition; in particular for decision making and judgement tasks. We conclude that there is a clear desire among operational personnel to acquire the LVC capabilities, and that several aspects of the capabilities can be established quickly. However, the use of LVC simulation for training and education must be mandated at all levels and incorporated explicitly in training plans and curricula, with a sufficient business case, so that political decisions for acquiring LVC capabilities can be made.*

1.0 INTRODUCTION

Simulation holds the potential for increasing the benefit/cost ratio of military defence training [1], and it is well advertised that simulation is beneficial for increased learning and for risk reduction, as well as for saving cost in terms of human resources and material expenditure [2]. Even when simulations increase cost, it is rational to use simulations as long as the benefit of doing so is large enough.

To further increase the benefits of simulation, it has been a goal of recent activities within the simulation community to use *distributed* simulation techniques to combine all three modes of simulation currently denoted by *Live*, *Virtual* and *Constructive* (LVC) [3]. *Live* simulation involves real people operating real equipment but where the equipment is instrumented; e.g., when live munition is replaced by laser pulses. *Virtual* simulation involves real people operating simulated equipment; e.g., when a pilot is training in a flight simulator. In *Constructive* simulation, all entities are simulated; e.g., when vehicle and personnel movement and actions are simulated in war gaming with Computer-Generated Forces (CGF).

In 2012/2013, a Concept Development and Experimentation (CD&E) effort was conducted to support the development and evaluation of a LVC capability for training in the land domain. The CD&E activity was conducted in cooperation with The Norwegian Army Combat & Manoeuvre Training Centre (NACMTC), and the final demonstration of the LVC simulation system prototype was run at NACMTC's Combat Training Centre (CTC). The CTC organizes and conducts training for land forces on a *Live* instrumented training range with exercise control (ExCon) systems and training officers.

In line with guidelines for capability development, the LVC capability is split into a *LVC Technical*

New/Increased Technical Capability (TechCap) $\xrightarrow{\text{enables}}$ New/Increased Training Capability (TrainCap) $\xrightarrow{\text{enables}}$ Increased Training Efficiency (TrainEff)

Figure 1: Desired relationships between technical capability, training capability and training effect.

Capability enabling a *LVC Training Capability*, which enables a capability for *Training Effect*; see Figure 1. In Section 2, we elaborate on capability development according to this model.

In Section 3, we outline the desired three capabilities. What these should be is not fully understood at this stage; a common challenge in all systems development that involves various stake-holders in human-intensive processes. Therefore, the specification of these capabilities are on a high level, reflecting the present understanding. In line with guidelines, we present criteria for evaluating the degree to which a capability enables another capability. Again, criteria are rather unspecific, reflecting current understanding.

In Section 4, we describe the operationalization of the capabilities for this study. We also present the evaluations that we were able to conduct regarding the enabling power of capabilities.

Section 5 discusses the results of the study, and Section 6 concludes.

2.0 CAPABILITY DEVELOPMENT

To develop an LVC capability necessitates (A) the clever design and construction of a distributed and federated multi-system simulation as a technical installation, as well as (B) insight into what functionality that installation should provide and how to use it in an appropriate manner. The use of appropriate development frameworks can guide the former, while the use of appropriate evaluation frameworks can aid the latter. The Distributed Simulation Engineering and Execution Process (DSEEP) [4] is a recommended practice for developing and executing distributed simulation systems intended to facilitate (A). The CD&E Method Description [5] and Code of Best Practices for Experimentation (COBPEx) [6] give guidelines enabling (B) for empirical and analytical evaluation and development of military capabilities. The development and evaluation of the technical capability is covered in [7], where the actual development process was held up against the DSEEP. Here, we regard the fuller picture, relevant for the CD&E, of capabilities at three levels as shown in Figure 1.

To ensure both (A) and (B), the systems development process has to be integrated with capability development at large. Using NATO's C3 Taxonomy [8], one can depict this integrated effort as in Figure 2. The relationships in Figure 1 are rendered in Figure 2 as vertical relationships between capability requirement specifications (capability packages) on the technical level (grey area) and operational capabilities (red area). The LVC technical capability enables training and effectiveness capabilities in the operational context. Conversely, what the technical capability should be must be mandated by the operational training capability development; which in turn must be mandated by requirements for training effect capabilities in terms of Measures of Effectiveness (MoE) and Measures of Performance (MoP). Development at each level should follow appropriate development methods.

A CD&E is an initiative toward developing and validating a new capability by scientific methods which may consist of empirical and/or theoretical (analytical) studies. To yield results under practical constraints, an empirical study cannot test the full range of the propositions under investigation, but only more or less well-selected representations of parts of the propositions. In a specific study, such a snap-shot amounts to an *operationalization* [9] of the theoretical propositions. In our context, the proposed capabilities are operationalized in term of capability prototypes which are developed and executed; see Figure 2.

It is common in virtually all empirical studies that operationalizations are not optimal with regards to the theoretical concepts they are intended to represent. This is the case in our study as well, where operationalizations are constructed with what was available and under imperfect development conditions. This, and the fact that empirical studies are, in general, constrained by limited versions of objects under

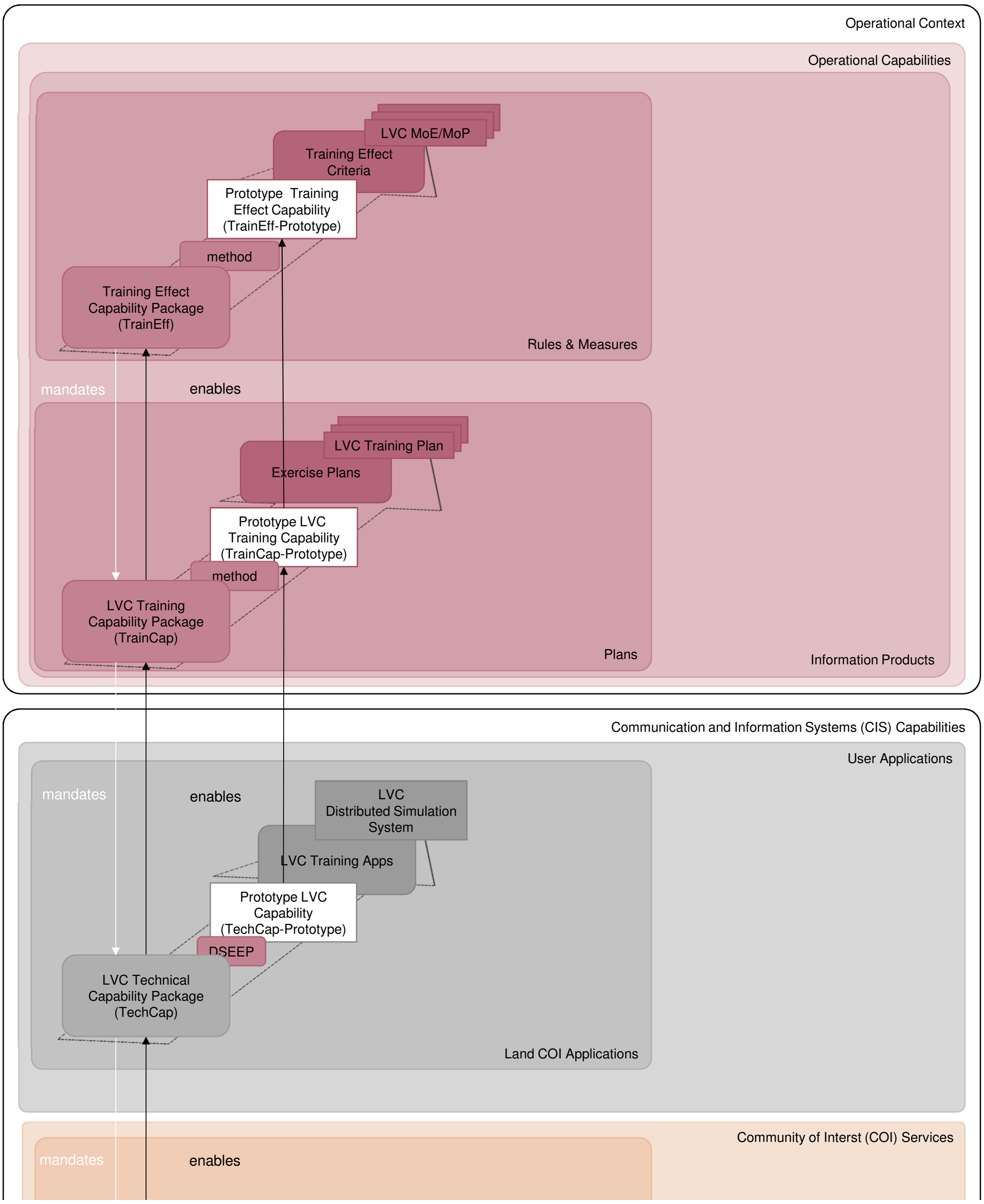

Figure 2: LVC capability roles and development: The technical capability enables a (new/improved) training capability, which enables the capability for (new/improved) training effect. Development of each capability follows an appropriate method (arrows inward). For scientific validation, prototype capabilities are designed on the way to actual capabilities.

investigation and are subject to errors and biases in observation, entails that one is generally haunted by *threats to validity* of the empirical study relative to its intended objectives [9], [10], [11], [12].

We will discuss three types of threats; see Figure 3. A *construct* is a (theoretical) concept together with its operationaliztion; e.g., a capability together with its operationalization in a study, or a personality factor together with its indicators as measured in a test. *Construct validity* pertains to the degree to which the operationalization reflects or expresses the concept; here, the degree to which the actual implementations, or prototypes, in the CD&E study reflect or express the intended capabilities. *External validity* pertains to

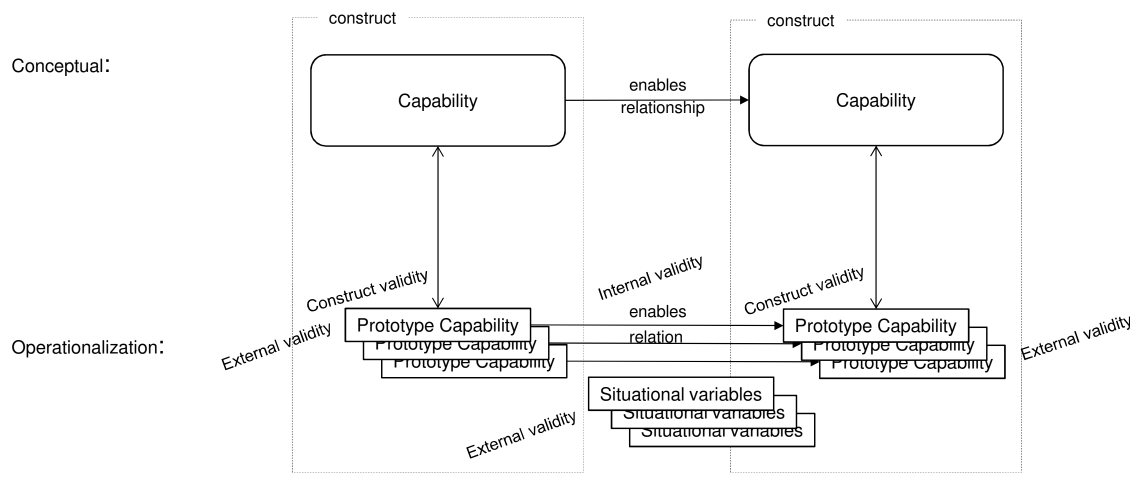

Figure 3: Constructs consisting of concept and operationalization. Threats to construct, external and internal validity.

the degree to which a study's results hold over relevant variations over operationalizations of the particular study. For example, if if the LVC simulation system prototype is shown to enable a training capability prototype for a certain training audience in our study, an external validity issue would be whether the enabling relation would also hold if the prototypes were implemented differently and used with a different training audience. Thus, construct validity and external validity are criteria for generalizing the results of a study. *Internal validity* deals with the degree to which the inferences within the empirical study are valid. For example, internal validity can be compromised if it is unclear whether it was the technical capability prototype that enabled better training, or whether, say, the ingenuity of Exercise Command during that trial led to improved training. If internal validity is sufficient, then inferences one makes at the prototype level can be lifted to the conceptual level; but only if construct validity is sufficient.

3.0 CAPABILITIES

We present the three capabilities, or capability packages, that are outlined in Figure 1 and Figure 2. There is a choice of the order in which to present the capabilities, both with regards to relations (enabling versus mandating) and development (early total planning versus incremental and combined top-down and bottom-up). We here choose to present the capabilities starting with the technical capability.

3.1 LVC technical capability

From the technical point of view, the main motivation was to connect various systems implementing *Live*, *Virtual* and *Constructive* simulation together in a simulation network using designated architecture standards. Further, we were interested in integrating operational systems into this network. The high-level description of the technical capability under development was as follows:

TechCap1. To simulate Unmanned Aerial Vehicle (UAV), including

- UAV flight for Vehicle Operator (VO)
- video feed over simulated terrain from simulated UAV camera for Mission Operator (MO)

TechCap2. To simulate artillery
TechCap3. To stimulate Battle Management System (BMS) from *Virtual* and *Constructive* simulations
TechCap4. To simulate adjacent units to *Live* units
TechCap5. To use distributed simulation based on the High-Level Architecture (HLA) standard
TechCap6. To enable personnel using any of *Live*, *Virtual* and *Constructive* simulations to see all relevant entities across the other domains
TechCap7. To establish correlated terrain representations among the LVC domains

3.2 LVC Training Capability

“Train as you fight” embodies the idea that training for a task should be undertaken on tasks as close to the actual task as possible in an environment as close to the actual environment as possible. LVC simulation training provides substitutes for actual tasks and environments, whenever it is benefit/cost-effective to do so. However, it is important that participants view and manipulate the simulated battle situation through their regular applications used in actual operations [13], [14]. Thus, this CD&E emphasizes the stimulation of operational systems, here BMS, and Exercise Control systems, by the simulation systems involved.

Research in various domains has shown that training that simply reflects actual circumstances is not sufficient. For the defence domain, Shadrick and Lussier remark: “The maxim ’Train as you fight’ has risen to such a level of familiarity in the U.S. Army that the value of the notion goes almost unquestioned. Yet studies of the development of expertise clearly indicate that ‘as you fight’, [...], is neither the most effective nor efficient method of developing expertise” [15, p. 294]. In general, repetition frequency in task exposure should be designed from an understanding of risk, where *risk* = *likelihood* x *consequence*, rather than on likelihood alone [15]. Modelling and simulation enables risk-based task repetition.

It may also be necessary to engage in artificially enhanced tasks. In this CD&E, there is an emphasis on leadership training and on collaboration and coordination training; which all involve judgement and decision making. In combat decision making (for which Shadrick and Lussier’s remark above was made), it is not sufficient to engage in normal training, even if it involves both realism and repetitions, since this does not in itself focus on developing decision-making skills [15], [16], [17]. Decision makers must engage also in training that triggers the explicit development of thinking skills. In line with this, the notion of *adaptive thinking* [18] has been adopted in the defence domain for decision making [19], [15]. All of this can be included in a *deliberate practice* framework [20] which takes on the short-comings of “learning on the job” by a strong focus on difficult aspects and immediate and tailored feedback (by a coach or computer-adaptive system) followed by immediate tailored re-trials. LVC simulation is essential in both enabling the use of artificial tasks and enabling deliberate practice regimes.

The high-level description of the training capability under development was as follows:

TrainCap1. *Virtual* UAV flight and communication/collaboration training for VO, MO, Information, Surveillance, Reconnaissance (ISR) personnel and platoon/squadron/battalion commanders.
(A) The training capability must enable the VO to train the operation of UAV and sensors realistically. This demands a UAV and sensor simulation which accurately mirrors the real UAV (with its actual limitations) used in operations. Real flight and sensor controls should be used. The training capability must also enable targeted training and deliberate practice to focus on risk-based training and difficult tasks. This requires that one can run and stop/restart UAV simulations *ad lib* as long as this does not disrupt training.
(B) The training capability must enable the VO and MO to train collaboration and coordination on navigation and force detection/tracking. For this, (A) is a prerequisite. Realism in actual procedures must be followed. In addition, training for adaptivity should be employed to enhance decision-making skills.
(C) The training capability must enable the MO and ISR personnel and commanders to train collaboration and coordination on force detection/tracking requests and reporting. Realism in actual procedures must be followed. In addition, training for adaptivity should be employed to enhance decision-making skills.

TrainCap2. *Live* and *Constructive* artillery fire support chain training for Forward Observer (FO), Fire Coordination Officer (FCO) and Fire Direction Center (FDC).
The training capability must enable the FO, FCO and FDC to train fire support chain collaboration and coordination. The FO, FCO and FDC equipment should be actual devices. In addition to this level of realism, realism in terms of actual procedures must be followed and trained repeatedly. Learning by feedback on target finding and impact accuracy performance is important, and artillery must be simulated realistically in terms of flight times, ballistics and effects. Prioritization, decision and judgement skills should be trained by adaptive principles.

TrainCap3. Train collaboration and coordination skills for platoon/squadron/battalion commanders. This capability aspect should be treated in detail for each type of commander, but we leave this for a more thorough analysis elsewhere. Here we outline common issues relevant in the context of LVC simulation. Leadership skills are notoriously hard to train quickly, and this is where adaptive principles are especially relevant. For LVC simulation, the following enablers are relevant:

- Train against larger enemy than *Live* forces can deliver. To train against a more realistic enemy in terms of size and complexity, the training capability must enable the training audience to conduct operations against an enemy which is augmented by *Virtual* and *Constructive* forces. This demands that the technical capability can stimulate operational systems with simulated units. It is important that simulated forces are visible when in line-of-sight. This demands augmented reality (AR) technology.
- Increase number of underlying units to platoon/squadron/battalion commanders by *Virtual* and/or *Constructive* simulated units. To train collaboration and coordination at the level of Commander, it is important that the Commander has a full platoon/squadron/battalion at his disposal. Therefore, the training capability must enable the training audience to conduct operations with a large number of own forces. The same remarks as for training against a large enemy apply.
- Train over a larger geographical area than the physical training range provides for. Training scenarios are often realistic in that they provide a wide political and military context in which the particular exercise is set. Due to resources, only a tiny part of the full scenario is applied in the exercise. To train tactical skills, a fuller picture can be included by using the above training capabilities together with the capability of using simulation to enlarge the geographical area for training.

TrainCap4. More flexibility in designing and implementing exercises. The Exercise Command staff must be able to rapidly and readily design and implement exercises consisting of LVC elements according to the training objectives at hand. This demands stable user friendly systems presented in a service-oriented manner so that the overall training system can be (re)configured on the fly.

3.3 Training Effect Capability

The training effect capability embodies the return on investing in the LVC training capability. It must have definitions of returns; i.e., of what the notion of training effect is. This should be based on theories of expertise and learning; including skill building for collaboration and coordination. It must have criteria to evaluate the degree to which the LVC training capability delivers this effect to greater benefit/cost. These criteria should be anchored in strategic plans for developing human skills for operational capabilities.

Training effect should manifest itself in expertise. Expertise is one of the classic concepts of social and behavioural science. It is related to specific tasks within a given domain and does not in general transfer across domains or tasks [21], [22], [23]. Expertise has several aspects which are related, Figure 4. For example, in descriptions of skill acquisition [24], [25], [26], a person starts by acquiring declarative knowledge which for experts is qualitatively *superior in representation and organization* compared to novices [21], [27]. Further, through practice, declarative knowledge is transformed into procedural skill, which at first is slow and error prone [26]. However, though *extended experience*, performance improves and experts should converge on their understanding of the domain for which they are an expert as well [28] (i.e., *consensual agreement*). Experts should also regard themselves as being experts, for example, through the use of *self-assessments*. Overall, the desired effect of expertise is superior *performance on the job tasks* on which one is an expert. In our context, this is performance on real-world warfare tasks. It is, however, unreliable and inefficient to predict future job performance by observing actual job performance [29]. This is why it is desirable to design quick tests based on how well an individual reliably performs on *representative tasks* [21] for which there are well-defined measures of performance (MoP) and measures of effectiveness (MoE), and for which there is strong theory that allows generalizing from performance on small representative tasks to performance on the job [9], [30], Figure 4.

Performance in military exercises is often evaluated by battle judges. The exercise itself can be seen as

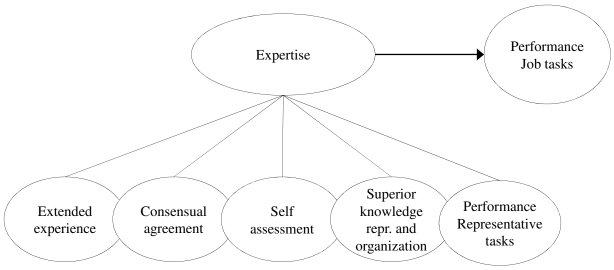

Figure 4: Aspects of Expertise. The desired effect of expertise is superior job performance.

consisting of representative tasks; but devised with a variable degree of scientific rigour. A full training effect capability with MoP and MoE relevant for LVC training has to be detailed out in collaboration with various stakeholders and harmonized with strategic guidelines. As far as we know, this does not exist explicitly at present. However, in time, each **TrainCapX** should have an associated **TrainEffX** which defines what it is to build the intended skills (operating skill for vehicles, communication/collaboration skills, etc.), must justify how it is benefit/cost effective to use **TrainCapX** to achieve **TrainEffX**, and must give criteria for evaluating the effectiveness of **TrainCapX** to these ends.

4.0 OPERATIONALIZATION

In this section, we describe how the capabilities outlined above were operationalized as prototypes in this particular CD&E study. This is where threats to *construct validity* arise.

4.1 LVC Technical Capability Prototype

Figure 5 shows the architecture of the prototype LVC simulation system. The *Live* simulation system at NACMTC is the Tactical Engagement System (TES) which is an instrumented training range which relays sensor data over a data Acquisition Network (DAN) to its ExCon system (WinExcon/ExPERT).

TechCap1-Prototype. Virtual Battle Space 2 (VBS2) version 1.6 was used to simulate a UAV. The VO and MO sat at respective VBS2 terminals on which the VO could operate the UAV and the video feed could be displayed. The VBS2 instances were connected to the HLA network over a LVC Game gateway.

Modifications to the VBS2 Raven B UAV model were committed to harmonize camera rotation (day and night thermic) and zoom levels with what is available on actual Raven aircraft.

Main threats to construct validity are the lack of fidelity of the UAV Raven model in VBS2 in terms of flight and sensor characteristics. Especially flight characteristics are far from reality. During the trial, a Predator model was used interchangeably, since it was easier (possible) to fly, but the Predator is a much larger aircraft, and introduces other threats to construct validity. Moreover, the VO and MO did not use actual Raven controls, but operated the craft via PC joystick controls.

TechCap2-Prototype. The Norwegian Army has a digitally linked fire command support system: a Fire Support Terminal (FST) connected to a LP10TL laser target locator, a Fire Coordination Officer (FCO) terminal, and a Fire Direction Center (FDC) terminal which computes fire missions data (range, trajectory, fuse and shell information). In the study, the FDC was linked, via a Tactical Training System (TTS) infrastructure to a Weapon Simulator, which receives the data from the FDC and simulates gun readiness status, time delay, flight time, impact and detonation. The Weapon Simulator can also simulate smoke screens. The output from the Weapons Simulator is sent to the simulation network as Distributed Interactive Simulation (DIS) standard IEEE 1278 [31], [32] Protocol Data Units (PDUs), which are converted to HLA RPR FOM (see below) interactions by a DIS/HLA gateway.

Main threats to construct validity are that the FDC operator is seated inside the exercise control room, rather than on site in field, and that artillery effect is simulated by audio and smoke markers only.

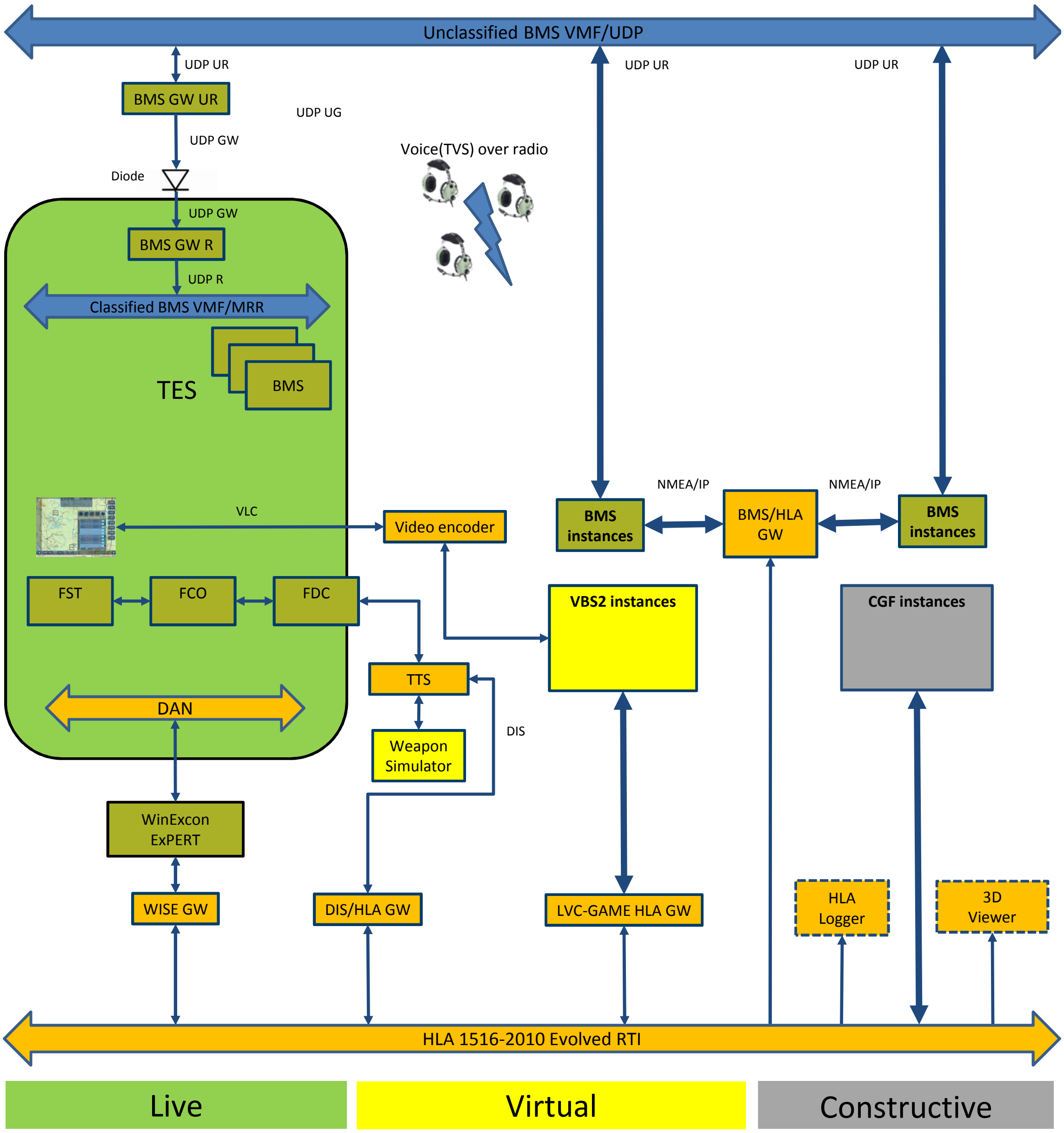

Figure 5: LVC technical capability prototype. *Live* in green, *Virtual* in yellow and *Constructive* in grey. Operational systems in olive, BMS network in blue and middleware and simulation networks in orange.

TechCap3-Prototype. *Virtual* and *Constructive* BLUFOR entities (at platoon level) were associated with virtualized BMS instances on a separate simulated BMS network (blue arrow bar in upper part of Figure 5). The BMS instances were associated to simulated BLUFOR by receiving pertinent BLUFOR entity position data from the simulation network via a BMS/HLA gateway.

The data on the simulated BMS network was pushed to the in-field BMS network through a diode (upper left part of Figure 5) due to the classification of live platforms. BMS data was sent over the User Datagram Protocol (UDP) protocol which does not require two-way communication for acknowledgement. In a real-time simulation, where position data is continuously transmitted, packet loss is acceptable.

A threat to construct validity was that using one virtualized BMS per BLUEFOR entity limits the number of units possible to display on the BMS due to the number of required virtual instances.

TechCap4-Prototype. MÄK VR-Forces was used to operate BLUEFOR and OPFOR computer-generated forces (CGF). Also Ground BLUFOR and OPFOR were simulated in VBS2.

Operation of the CGF was controlled by the Exercise Commander. Since personnel controlling and using these forces was not part of the training audience, both BLUEFOR and OPFOR units were operated in a single VR-Forces instance. No aggregated units were used, because full control over all units was important. Simulated squadrons were initially set up so that the squadron members were set to follow the squadron commander in predefined relative positions. This made it possible to move the whole squadron only by setting a new plan for the squadron commander.

Threats to construct validity were the lack of physical and operational fidelity of entities in both VBS2 and VR-Forces, and the artificial classroom environment and PC joystick controls.

TechCap5-Prototype. In our system, the *Live*, *Virtual* and *Constructive* simulation systems joined as federates to the overall High Level Architecture (HLA) IEEE 1516-2010 Evolved federation administered by an Runtime Infrastructure (RTI) running on the simulation network (orange arrow bar in lower part of Figure 5). The Realtime Platform Reference Federation Object Model (RPR FOM) SISO-STD-001.1-1999 [33] was used; although in a newer draft version commonly used at present (version 2, draft 17) [34]. The TES, TTS, VBS2 and virtualized BMS had to be linked to the HLA network over gateways.

A threat to construct validity was that the federation agreement and entity mappings were not sufficiently detailed. This resulted in problems in terms of interoperability and connectivity [7].

TechCap6-Prototype. To enable personnel using any of *Live*, *Virtual* and *Constructive* simulators to see all relevant entities across simulations. This was achieved by linking all relevant systems to the HLA federation. The threats to construct validity for **TechCap5-Prototype** are inherited here. Visualizations and behaviour of entities suffered from unclear agreements and mappings of entity data on the network to entity representations in the various systems.

TechCap7-Prototype. The three simulation systems must relate to the same terrain and render that terrain equally. The *Live* entities relate to the physical terrain in the TES training range, and their presence and actions are reflected in WinExcon/ExPERT according to its terrain model and rendering methods. The *Virtual* and *Constructive* simulations must relate to terrain models which enable their simulated entities to act and to be rendered in ExPERT as intended, and vice versa.

Existing TES terrain models for the VBS2 installation at NACMTC were improved to cater better for UAV simulation. Previous experiences with simulated UAV at NACMTC uncovered that it was too easy to detect entities on ground because vegetation was too sparse in the terrain model used in VBS2.

The terrain database for VR-Forces was created from the same source data covering the TES exercise area used for generating VBS2 terrain. The Terra Vista (Presagis) terrain modelling software was used to create the terrain database for VR-Forces.

4.2 LVC Training Capability Prototype

A training scenario sketch for a battalion-level exercise was developed based on input from officers at NACMTC; see Figure 6. *Virtual* and *Constructive* players, mainly at the company/squadron level, were to be played non-invasively (east and west) out of line-of-sight from *Live* forces. UAV operators should detect OPFOR and report sightings on BMS or over voice. Personnel using the *Virtual* and *Constructive* simulations should be able to see all entities, and personnel training live should be able to see simulated entities in their BMS. However, the actual scenario that was played during the trial could not be determined until the training forces finalized their Orders of Battle (ORBAT) and Concept of Operations (CONOPS).

TrainCap1-Prototype. The UAV team's task was to loiter over the battle field to detect OPFOR and to report to ISR personnel on ground over radio.

Threats to construct validity for the training capability prototype are the lack of realism in operating the UAV and its sensors due to the lack of fidelity in the technical capability and that the VO and MO were seated inside the exercise control room rather than on site in field. The VO and MO were placed

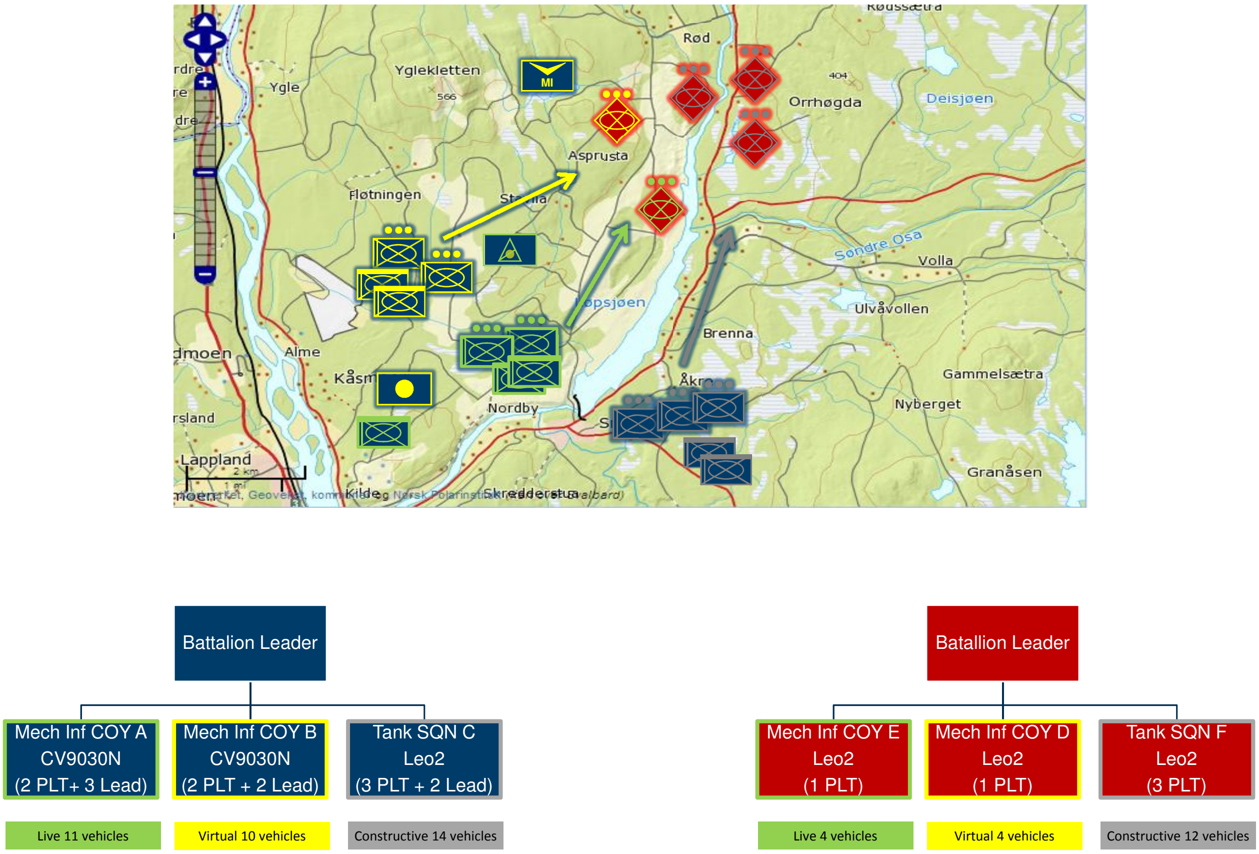

Figure 6: Scenario sketch. *Live* forces in green, *Virtual* forces in yellow and *Constructive* forces in grey. Forces movements (top), ORBAT for BLUEFOR vehicles (left) and OPFOR vehicles (right).

facing away from the exercise control system screens and inside a cubicle to reduce the risk of exercise control information short-circuiting the intended flow of information. No targeted training for developing prioritization, decision making and judgement skills was implemented.

To capture the extent to which **TechCap1-Prototype** enabled **TrainCap1-Prototype**, we arranged a post-trial meeting for UAV personnel and ISR personnel/commanders based on the following questions:

- To what degree did you experience that the simulated UAV solution enabled you to train collaboration between VO and MO [MO and ISR personnel/commanders]?
- List three negative aspects of the simulated UAV solution for training collaboration between VO and MO [MO and ISR personnel/commanders] ranking the most negative as number 1.
- List three positive aspects of the simulated UAV solution for training collaboration between VO and MO [MO and ISR personnel/commanders] ranking the most positive as number 1.
- Open discussion.

Threats to internal validity are that these questions might not adequately capture the true enabling relation between the prototypes, since they are at once explicit and subjective; possibly not correcting for biases. Also, unreliability is not reduced by using complementary measures to capture the relation.

TrainCap2-Prototype. Only the FDC part of the fire command chain was staffed during the trial. Thus artillery requests from the field were relayed over radio to exercise command, who then requested fire from the FDC who sat inside the exercise control room. Further, the FDC was not part of the training audience in the trial and no measurement variables were set up to record the degree to which**TechCap2-Prototype** enabled **TrainCap2-Prototype**. The training output from the prototype was therefore limited to weapons effect for forces in the field.

With the understanding that only a small part of **TrainCap2** is operationalized, remaining threats to construct validity are that artillery requests were issued to Exercise Control rather than through the fire command chain, and no targeted training for developing prioritization, decision making and judgement skills was implemented.

TrainCap3-Prototype. No targeted training for developing prioritization, decision making and judgement skills for platoon/squadron/battalion commanders was implemented. However, the the overall scenario was played to a fuller extent by operationalizing the following enablers:

- Train against larger enemy than *Live* forces can deliver. The OPFOR was enlarged by a group of two *Virtual* enemy tanks and a *Constructive* tank squadron during the first part of the exercise (when only one mechanised infantry company was training), and by a tank squadron during the second part of the exercise (when the entire battalion was training). It was decided that *Virtual* and *Constructive* units were to be operated and moved according to decisions made by Exercise Command on the fly to complement the battalions training. The *Virtual* enemy tank group was designated to resist, as best it could, a *Virtual* BLUEFOR squadron. The *Constructive* OPFOR tank squadron was designated to resist a *Constructive* BLUEFOR armoured battalion. The *Virtual* and *Constructive* forces were not to interact with *Live* forces, because simulated entities were not visible to *Live* forces.

  Augmented reality was not implemented, and a substantial threat to construct validity is that *Live* forces cannot see *Constructive* and *Virtual* units that are in line of sight. Other threats to construct validity pertain to the scalability of simulated OPFOR.
- Increase number of underlying units to platoon/squadron/battalion commanders by *Virtual* and/or *Constructive* simulated units. The training forces were augmented by a *Virtual* BLUEFOR tank squadron and a *Constructive* BLUEFOR armoured battalion during the first part of the exercise, and by a *Virtual* cavalry squadron followed by the rest of simulated *Constructive* battalion. As with simulated OPFOR, *Virtual* and *Constructive* units were to be operated and moved according to decisions made by Exercise Command on the fly to complement the battalion under training.

  Thus, the augmentation of BLUEFOR was done at squadron/battalion level. This increased the situational complexity of the exercise by activating notional forces. However, because training forces could not interact directly with simulated entities, there is a substantial part of the training capability which was not operationalized with regards to leadership training. Nevertheless, simulated entities constituted contextual forces, which does have bearings on tactical and combat-technical decisions.

  As for OPFOR, threats to construct validity are that *Live* forces cannot see *Constructive* and *Virtual* units that are in line of sight and the scalability of simulated BLUEFOR.
- Train over a larger geographical area than the *Live* training range provides for. The simulations activated notional forces from the total scenario. This enlarged the geographical area over which the training forces should build situational awareness, beyond the instrumented *Live* range.

To measure the degree to which **TechCap-Prototype** enabled **TrainCap3-Prototype**, we prepared a post-trial meeting for platoon and squadron commanders [and Exercise Control staff] with the following questions for discussion:

- To which degree did you experience that the simulated entities (BLUEFOR, OPFOR, artillery, UAV) enabled you to train [to administer training and feedback in] situational awareness better than if they had not been present?
- To which degree did you experience that the simulated entities enabled you to train [to administer training and feedback in] resource management and coordination better than if they had not been present?
- To which degree did you experience that the simulated entities enabled you to train [to administer training and feedback in] collaboration better than if they had not been present?
- List three negative aspects of the simulated entities with regards to training leadership, ranking the most negative as number 1.
- List three positive aspects of the simulated entities with regards to training leadership, ranking the

most positive as number 1.
- Open discussion.

Threats to internal validity are that these questions might not adequately capture the true enabling relation between the prototypes, since they are at once explicit and subjective; possibly not correcting for biases. Also, unreliability is not reduced by using complementary measures to capture the relation.

TrainCap4-Prototype. More flexibility in designing and implementing exercises. Exercise Command could decide on the fly where and how many *Virtual* and *Constructive* entities should join the exercise, as long as the entities were already defined and mapped in the various systems. Beyond this, this capability aspect was not operationalized.

4.3 Training Effect Capability Prototype

The CD&E did not operationalize the training effect capability beyond what the training forces themselves have as their evaluation criteria (which are classified). The CD&E operationalized the enabling relation by simple post-trial questions. If properly validated, such questions operationalize parts of the Self-assessment aspect of expertise. It is possible to devise much better instruments than was done here, for assessing training effect, given the amount of theoretical and empirical knowledge on the subject.

TrainEff1-Prototype. To capture whether **TrainCap1-Prototype** enabled **TrainEff1-Prototype**, we arranged a post-trial meeting for the UAV personnel with the following questions for discussion:
- To which degree did you experience that you were able to build skills in collaboration between VO and MO [MO and ISR personnel/commanders].

Threats to internal validity are similar as for the other questionnaire items.

TrainEff2-Prototype. Not operationalized.

TrainEff3-Prototype. To capture whether **TrainCap3-Prototype** enabled **TrainEff3-Prototype**, we prepared a post-trial meeting for the commanders with the following questions for discussion:
- To which degree did you experience that you were able to build skills in situational awareness?
- To which degree did you experience that you were able to build skills in resource management and an coordination?
- To which degree did you experience that you were able to build skills in collaboration?

We also prepared similar post-trial questions for Exercise Control:
- To which degree do you think the training/feedback you administered built skills in situational awareness better than if the simulated entities (BLUEFOR, OPFOR, artillery, UAV) had not been present?
- To which degree do you think the training/feedback you administered built skills in resource management and coordination better than if the simulated entities had not been present?
- To which degree do you think the training/feedback you administered built skills in collaboration better than if the simulated entities had not been present?

Threats to internal validity are similar as for the other questionnaire items.

TrainEff4-Prototype. Not operationalized.

5.0 EVALUATION OF CAPABILITIES

The trial of the system took place over 4 days during a battalion training operation in the TES at CTC/NACMTC. During these first two days, only one mechanised squadron from the battalion was training. The *Live* simulation thus consisted of one instrumented squadron in the TES. During Days 3 and 4, the entire battalion was in the TES. Once running, entities from all three simulation modes (LVC) and Weapon Simulator effects were visible in all three simulation systems (*Live* ExCon system, *Virtual/Constructive* VBS2, *Constructive* VR-Forces), and *Virtual* and *Constructive* BLUEFOR and detected simulated OPFOR were visible in the BMS alongside *Live* units. Approximately 550 LVC entities were on line during the trial during the first two days and even more where on line during the next two days.

5.1 Technical Capability

The LVC technical capability prototype functioned well enough to illustrate the main ideas for the LVC technical capability, but was unstable with regards to dependability and connectivity; thus introducing threats to internal validity.

The threats to construct and internal validity for the technical capability are solvable by further development of the technical solution. Main issues are:

- to develop a sufficiently complete federation agreement
- to validate the models used in the various systems
- to upgrade systems and middleware which do not comply to HLA Evolved IEEE std 1516-2010.
- to implement lacking technology such as AR systems.

5.2 Training Capability

The LVC training capability prototype was partly hampered by the instability of the technical prototype. This introduces additional threats to internal validity to the enabling relation between the two. Lack of construct validity was also perceived as a limiting for the prototype.

The UAV personnel completed their group discussion using our questionnaire. Main issues from that meeting are the following:

- The UAV simulation was too unrealistic for meaningful collaboration training between VO and MO to take place. Had manoeuvrability been realistic, VO-MO communication would have taken place naturally.
- The most negative issue with the UAV simulation for training VO-MO collaboration was the lack of fidelity between simulated UAV and the real aircraft. As a result, collaboration training for VO and MO did not really take place.
- The three most positive issues with the UAV simulation for training VO-MO collaboration was that it enabled training on the plan process, observation technique, and that those who had not yet had VO training got an impression of what the VO task is.
- The UAV simulation enabled MO and ISR personnel/commanders to train collaboration satisfactory. Here, the technical limitations were not as inhibiting.
- The three most negative issues with the UAV simulation for training MO-ISR/commander collaboration was that the commander is relieved form the task of positioning the UAV, the lack of air space control and manoeuvrability, and that training forces do not hear the UAV over head.
- The two most positive issues with the UAV simulation for training MO-ISR/commander collaboration was that it enabled training of situational awareness, and that offered ease and flexibility to launch a UAV capability regardless of weather and other airspace activities.

Other issues pertained to the radio voice communications between MO and the *Live* players falling out repeatedly, the distraction of sitting inside CTC and the lack of technicians (IT personnel).

The platoon/squadron/battalion commanders did not conduct their after-trial review meeting. However, in the regular daily after-action reviews, the Exercise Commander used the simulated forces in discussions and feed back to commanders. Both situational awareness and resource management were learning points, since the simulated forces were in active engagement and not merely notional forces. In particular, an incident where activated, formerly notional, BLUEFOR were fired upon by simulated OPFOR created a situation where the attacked BLUEFOR could no longer perform their planned support functions. This created an unexpected situation for training forces, which provided good learning.

Main feed back from the point of view of Exercise Command were as follows:

- For UAV personell: The LVC prototype enabled UAV personnel to mass train collaboration with the field (ISR and commanders). The capability will enable UAV training in peace time when real aircraft are deployed in battle. There was, however, next to no training capability for VO-MO collaboration due to lack of fidelity in the UAV simulation.
- For artillery: Although not tested in operation, the artillery simulation will enable training for the complete fire command chain without having to deploy artillery in the field.
- For tactical commanders: The LVC prototype contributed in building a more complete situation around the squadron and the battalion. The integration of BMS was instrumental to this. Training situational awareness was thus augmented, which in turn triggers the necessity for coordinating and prioritizing.
- For platoon/squadron commanders: The LVC prototype contributed in building a more complete situation around the commanders within the squadrons/companies, which in turn triggers the necessity for coordinating, prioritizing and tempo changes.

A JTAC/CAS training capability was expressed by exercise command as an important extension. Further, AR technology for *Live* forces to see *Virtual* and *Constructive* forces was seen as crucial for enabling realistic interaction and fully delivering the training capabilities outlined.

Judging by initial feedback, the enabling relation between the technical and training prototypes seems to be present for some of the aspects, and is clearly not present for others (e.g., UAV VO-MO collaboration training). External validity then pertains to the degree to which the enabling relation holds between relevant variations of the prototypes and circumstances in this study. It is reasonable to expect that the relation would hold for various prototype exercises at NACMTC. Construct validity is variable in this study and is low for some aspects of the technical capability in particular. It is, nevertheless, fair to say that it is possible to establish the LVC technical and training capabilities beyond prototypes. It is also fair to claim that the enabling relation between the prototypes is transferable to an enabling relationship between the capabilities at the conceptual level. This demands a persistent environment for supporting these capabilities.

It is relevant to establish LVC capabilities to other military domains as well, and also to joint operations training. This demands an extension of the constructs involved; i.e., of both capabilities and prototypes of capabilities for test. For external validity, variations of prototypes and situations must include trials in other domains. However, the LVC technical capability must be more loosely coupled for the total LVC capability to be useful in multiple contexts.

5.3 Training Effect Capability

The questions we posed for the after-trial reviews on training effect were not understood in the way we intended. We anticipated this, since the participants in this trial did likely not experience a system which was sufficiently mature to experience training effect in a way that could be measured by our questions.

When discussing the LVC trial with military personnel, it became clear that although the use of simulation for training and exercise is established at the strategic level nationally and in NATO, there is a lack of executable plans in use which incorporate simulation in training and curricula. This entails that, in practice, there are no tangible training objectives which pertain to LVC simulation, and therefore no link to expertise, skill building and learning metrics which involve LVC simulation. In fact, it has been remarked that the military discipline as such lacks proper definitions of skills and evidence-based methods to build them [35]. Until this is in place, at least for a selection of key skills, we can only address training effect in a superficial manner. This also goes for benefit/cost-analyses for introducing LVC technical capability and LVC training capability. This, then, is a substantial barrier for developing and acquiring the LVC capabilities, since any logistics organization (military or civilian) will need a business case to act upon.

At this stage, it is too early to say anything about the enabling relation between the LVC training capability prototype and training effect.

6.0 CONCLUSION

The LVC capabilities that were demonstrated by the prototypes of the CD&E trial are perceived by participants and observers as important and instrumental for effective training and exercise. There are challenges regarding generalizing the results from the prototype to the intended capabilities, but several of these issues can be sorted out by improving the technical capability. Indeed, parts of the technical and training capability prototypes can already be established as capabilities proper with little additional effort.

More challenging is the development of an evidence-based LVC training capability which is founded upon state-of-knowledge on collaboration and leadership training. It is important to acknowledge the, by now, well-documented difficulties in training for the shifting and unpredictable conditions in which judgements and decision making takes place in war efforts, and utilize viable principles for dealing with uncertainty. LVC simulation is no doubt instrumental to achieving this. The question is rather how to use LVC simulation in the most effective manner.

How to measure effectiveness is what should be done in the training effect capability. Concrete steps must be taken to align training and exercise plans and educational curricula with strategic goals regarding simulation in training and exercise. In other words, LVC simulation must be explicitly expressed in exercise plans and curricula. Although there is a clear operational desire to implement and established demonstrated technical and training capabilities (including extensions), and LVC simulation for training and exercise is mandated strategically, it is not incorporated explicitly in training plans and curricula to an extent that enables action to acquire LVC capabilities.

Onlookers to CD&E trial also expressed interest in LVC simulation capabilities for other, and across, domains. To cater for this, systems should be built loosely coupled and interoperable. The technical prototype in this study can be implemented in a service-oriented manner and also extended with services (map, terrain, weather, damage models), and plans are in progress for a next LVC trial with this in place.

7.0 ACKNOWLEDGEMENTS

The authors are grateful to Jan Erik Blix, Maj. Ken Tore Eriksen, Morten Kure Gåsvik, Jan Erik Holen, Capt. Atle Smestu at The Norwegian Army Combat & Manoeuvre Training Centre (NACMTC) and Erik Torp, Fredrik Åsgård at Kongsberg Defence for collaboration in the CD&E trial; the officers in command responsible for organizing the exercise for sharing their plans with us; and Lt. Col. Geir Karlsen, Håkon Kløvstad Olafsen, Morten Urdahl at FFI for guidance, comments and feedback.

8.0 REFERENCES

[1] NATO Research and Technology Organisation, The cost effectiveness of modelling and simulation (M&S), Technical Report RTO-TR-MSG-031 (2010).

[2] NATO Modelling and Simulation Group, NATO Modelling and Simulation Master Plan (version 2.0), `http://ftp.rta.nato.int/Public/Documents/MSG/NATO_MS_Master_Plan_Web.pdf`, accessed January 2013 (2012).

[3] M. L. Loper, C. Turnitsa, History of combat modelling and distributed simulation, in: A. Tolk (Ed.), Engineering Principles of Combat Modeling and Distributed Simulation, Wiley, 2012, Ch. 16, pp. 331–355.

[4] IEEE Standards Association, 1730-2010 – IEEE recommended practice for Distributed Simulation Engineering and Execution Process (DSEEP), `http://standards.ieee.org/findstds/standard/1730-2010.html`, accessed February 2013 (2010).

[5] Nordic Defence Cooperation (NORDEFCO), CD&E method description version 2.0 (2012).

[6] D. S. Alberts, R. E. Hayes, Code of Best Practice for Experimentation, CCRP Publication Series, DoD Command and Control Research Program, 2002.

[7] J. E. Hannay, J. E. Blix, J. E. Holen, O. M. Mevassvik, A. Skjeltorp, Live, Virtual, Constructive (LVC) simulation for land training: System description and technical evaluation, Tech. Rep. FFI-rapport 2014/01597 (in press), Norwegian Defence Research Establishment (FFI) (2014).

[8] NATO Communications and Information Agency (NCIA), The C3 Classification Taxonomy, `http://www.ncia.nato.int/ourwork/Pages/Coherence/C3-Classification-Taxonomy.aspx`, accessed August 2012 (2011).

[9] W. R. Shadish, T. D. Cook, D. T. Campbell, Experimental and Quasi-Experimental Designs for Generalized Causal Inference, Houghton Mifflin, 2002.

[10] T. D. Cook, D. T. Campbell, Quasi-Experimentation. Design & Analysis Issues for Field Settings, Houghton Mifflin, 1979.

[11] D. T. Campbell, J. C. Stanley, Experimental and Quasi-Experimental Designs for Research, Houghton Mifflin, 1979.

[12] R. K. Yin, Case Study Research: Design and Methods, 3rd Edition, Vol. 5 of Applied Social Research Methods Series, Sage Publications, 2003.

[13] A. Tolk, Integration of M&S solutions into the operational environment, in: A. Tolk (Ed.), Engineering Principles of Combat Modeling and Distributed Simulation, Wiley, 2012, Ch. 15, pp. 295–327.

[14] A. Tolk, Terms and application domains, in: A. Tolk (Ed.), Engineering Principles of Combat Modeling and Distributed Simulation, Wiley, 2012, Ch. 4, pp. 55–78.

[15] S. B. Shadrick, J. W. Lussier, Training complex cognitive skills: A theme-based approach to the development of battlefield skills, in: K. A. Ericsson (Ed.), Development of Professional Expertise, Cambridge University Press, 2009, Ch. 13, pp. 286–311.

[16] K. J. Holyoak, Symbolic connectionism: Toward third-generation theories of expertise, in: K. A. Ericsson, J. Smith (Eds.), Toward a General Theory of Expertise: Prospects and Limits, Cambridge University Press, 1991, pp. 301–335.

[17] E. M. Smith, J. K. Ford, S. W. J. Kozlowski, Building adaptive expertise: Implications for training design, in: M. A. Quinones, A. Dudda (Eds.), Training for 21st Century Technology: Applications of Psychological Research, APA Books, 1997, pp. 89–118.

[18] E. D. Pulakos, S. Arad, M. A. Donovan, K. E. Plamondon, Adaptibility in the work place: Development of a taxonomy of adaptive performance, J. Applied Psychology 85 (4) (2000) 612–624.

[19] S. B. Shadrick, J. W. Lussier, R. Hinkle, Concept development for future domains: A new method for knowledge elicitation, Tech. Rep. 1167, U.S. Army Research Institute for the Behavioral and Social Sciences (2005).

[20] K. A. Ericsson, The influence of experience and deliberate practice on the development of superior expert performance, in: K. A. Ericsson, N. Charness, P. J. Feltovich, R. R. Hoffman (Eds.), The Cambridge Handbook of Expertise and Expert Performance, Cambridge Univ. Press, 2006, Ch. 38, pp. 683–703.

[21] K. A. Ericsson, An introduction to Cambridge Handbook of Expertise and Expert Performance: Its development, organization, and content, in: K. A. Ericsson, N. Charness, P. J. Feltovich, R. R. Hoffman (Eds.), The Cambridge Handbook of Expertise and Expert Performance, Cambridge Univ. Press, 2006, Ch. 1, pp. 3–20.

[22] J. Shanteau, Competence in experts: The role of task characteristics, Organizational Behavior and Human Decision Processes 53 (1992) 252–266.

[23] M. T. H. Chi, Two approaches to the study of experts' characteristics, in: K. A. Ericsson, N. Charness, P. J. Feltovich, R. R. Hoffman (Eds.), The Cambridge Handbook of Expertise and Expert Performance, Cambridge Univ. Press, 2006, Ch. 2, pp. 21–30.

[24] J. R. Anderson, Acquisition of cognitive skill, Psychological Review 89 (4) (1982) 369–406.

[25] H. L. Dreyfus, S. E. Dreyfus, Mind over Machine, The Free Press, 1988.

[26] P. M. Fitts, M. I. Posner, Human Performance, Brooks/Cole Publishing Co., 1967.

[27] S. Wiedenbeck, V. Fix, J. Scholz, Characteristics of the mental representations of novice and expert programmers: An empirical study, Int'l Journal of Man-Machine Studies 39 (4) (1993) 793–812.

[28] J. Shanteau, D. J. Weiss, R. P. Thomas, J. C. Pounds, Performance-based assessment of expertise: How to decide if someone is an expert or not, Eur. J. Oper. Res 136 (2002) 253–263.

[29] J. P. Campbell, Modeling the performance prediction problem in industrial and organizational psychology, in: M. D. Dunnette, L. M. Hough (Eds.), Handbook of Industrial and Organizational Psychology, 2nd Edition, Vol. 1, Consulting Psychologists Press, Inc., 1990, pp. 687–732.

[30] E. A. Locke (Ed.), Generalizing from Laboratory to Field Settings, Lexington Books, 1986.

[31] IEEE Standards Association, Standard for Distributed Interactive Simulation (DIS), `http://standards.ieee.org/develop/project/1278.2.html`, accessed September 2012 (2012).

[32] A. Tolk, Standards for distributed simulation, in: A. Tolk (Ed.), Engineering Principles of Combat Modeling and Distributed Simulation, Wiley, 2012, Ch. 12, pp. 209–241.

[33] Simulation Interoperability Standards Organization (SISO), Real-time Platform Reference Federation Object Model (RPR FOM 1.0), `http://www.sisostds.org/DigitalLibrary.aspx?Command=Core_Download&EntryId=30823`, accessed January 2013 (1999).

[34] Simulation Interoperability Standards Organization (SISO), Real-time Platform Reference Federation Object Model (RPR FOM) version 2.0d17, `ftp://ftp.uni-duisburg.de/FlightGear/HLA/docs/RPR2-D17.pdf`, accessed January 2014 (2003).

[35] J. Storr, The Human Face of War, Birmingham War Studies, Bloomsbury Academic, 2009.