Structured crisis training with mixed-reality simulations

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ABSTRACT

We argue that current technology for crisis training does not explicitly cater well enough for managing training objectives and skill building metrics throughout the lifespan of training. We suggest how successful crisis training may be enabled by interoperating next-generation exercise management tools with mixed-reality simulations. We propose an architecture consisting of (1) a front-end in which training objectives, essential skills, corresponding events and metrics can be declared, (2) a back-end consisting of simulations that implement the events and metrics and (3) a middleware which transfers information between the front-end and back-end to enable semi-automatic composition of the simulations and performance analysis. The purpose of this architecture is to facilitate learning through the principles of deliberate practice. We indicate where emerging technologies are necessary to achieve this.

Keywords

Exercise management, Mixed reality, Simulation, Deliberate practice, ADL, MSaaS, C2Sim, ExConSim, ExManSim

INTRODUCTION

Civilian and military crisis management organizations regularly conduct training and large-scale exercises. For example, over 50,000 participants, 250 aircraft and 65 vessels from more than 30 nations recently partook in NATO's Trident Juncture 18 exercise. More than 300,000 soldiers, 36,000 military vehicles, 1000 aircraft, helicopters and drones, and 80 warships from three nations joined the Vostok-2018 in Eastern Siberia. On the civilian side, most large cities regularly conduct city- or region-wide exercises that involve fire, law enforcement and healthcare organizations over the course of several days.

Although often deemed highly successful, such exercises are also extremely costly and often infringe on society in unacceptable ways. Moreover, although there is a lack of systematic observations as to the effects of exercises, discussions with subject matter experts, trainers and observers suggest clearly that exercises often do not have clear and structured training objectives, that lessons identified are recorded in an *ad hoc* manner, and that lessons identified are often not transformed into lessons learned. These are unfortunate shortcomings to the demands that heightened levels of readiness pose in today's global situation.

The use of simulations for training and exercises has been investigated over several decades by industry, academia and practitioners. Indeed, simulations are an integral part of many training and exercise regimes in both the civilian and military domains. Well-known examples are flight simulators and various vehicle and equipment simulators for safe operator training. Moreover, planning, coordination, collaboration and decision-making protocols are trained using various computer-aided simulations. This happens in dedicated training events, but is also done in conjunction with large-scale exercises such as those mentioned above. Trainers use exercise control (ExCon) systems to administer events and injects in a timely manner. Simulations are perceived to save time, cost and increase quality for training and enable training not possible otherwise (NATO Modelling and Simulation Group 2012; NATO Research and Technology Organization 2010; Hannay, Brathen, et al. 2015).

In all this extensive exercise and training activity, there is an explicit tool focus on *what* should happen in exercise and training scenarios. The explicit mention of *why* is not prevalent; that is, the skills underlying task performance – the actual target of training – are not addressed to the same extent in exercise management tools.

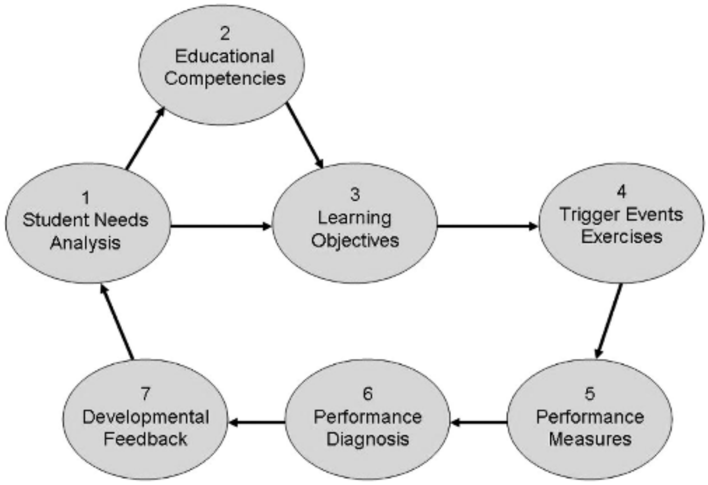

Figure 1. Simulation-based training loop (Salas et al. 2009)

THE INTENT IN SIMULATION-BASED TRAINING

The, by now, hackneyed simulation-based training loop diagram due to (Salas et al. 2009) proposes how simulation-based training should be an incremental and reflective process, rooted on learning objectives.

Anecdotal evidence suggests that this loop in many cases is broken. A governmental Emergency Planning College recently summarized participants' perceptions of exercises (which are so-called *Live* simulations) as follows; see also (Pollestad and Steinnes 2012):

- Exercises have little effect
  - Continuity:
    - Exercises are conducted in isolation and without any connection to earlier exercises
    - Experiences from one person or group are not used by others
    - Lessons identified are not processed further to lessons learned
  - Objectives
    - Exercise objectives are not formulated clearly
    - Objectives are not differentiated on roles
- Exercises are scary
  - Exercises are given as tests or "exams", rather than as a means for improving performance
  - Challenges are given that participants do not have the means to master
- Exercises are time-consuming and demand excessive resources
  - Exercises are something one does not really have time, nor resources, to conduct
  - The benefit of conducting an exercise does not justify the cost.
- Exercises are difficult
  - Exercises are difficult to plan and organize
  - Exercise objectives, events and scenarios are difficult to define
  - Exercise results are hard to grasp

These anti-patterns for learning in large exercises are also found in day-to-day training. Most simulators and simulations are capable of recording a lot of relevant data. We are aware of a number of instances where such data are not used at all; seemingly because there are neither routines for collecting data, nor tools at hand to analyse data. Also, clear learning objectives are a prerequisite to determine what data to collect. Further, the notion of continuity with the possibility to compare training results over time is often not rooted in the organization. Lessons are identified, but there are insufficient mechanisms for transforming those into lessons learned and integrating them into the daily work (Skarpaas and Kristiansen 2010).

In the following, we argue by design that current technology in use does not give enough support for keeping the simulation-based training loop alive.

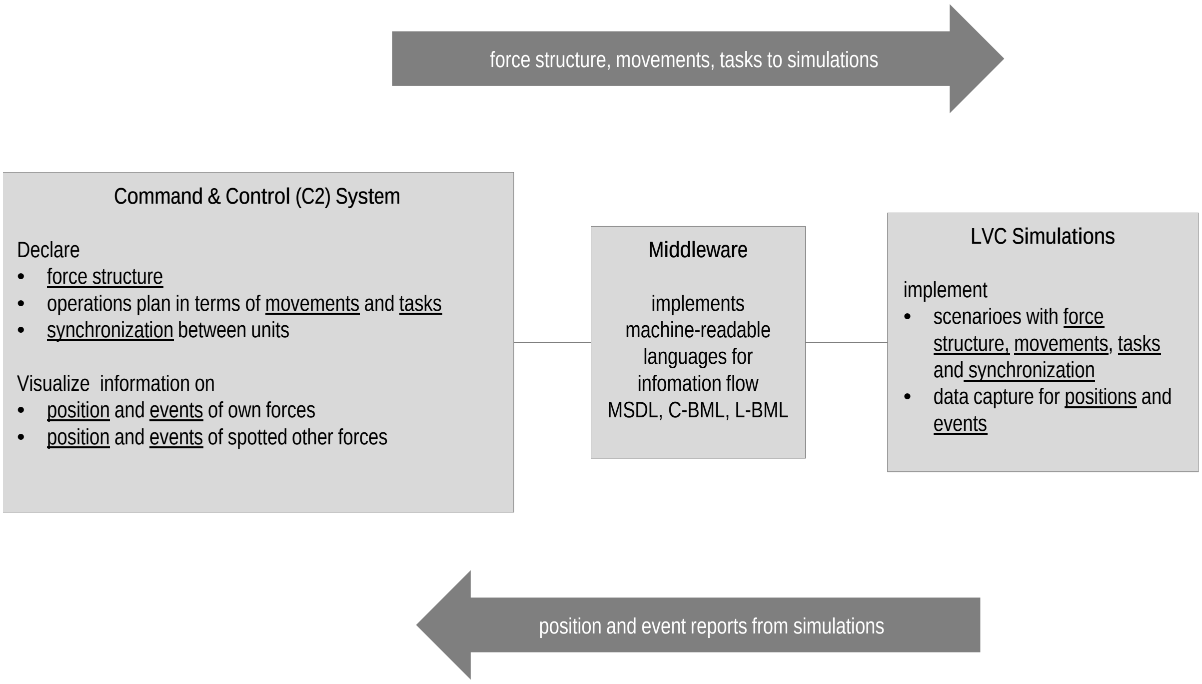

Figure 2. C2Sim configuration

COMMAND & CONTROL WITH SIMULATIONS

Command and control (C2) information systems (C2IS) are used for planning, commanding and monitoring military operations, usually in a geographical map-based user interface. There are similar systems for the civilian sector. In the defence domain, substantial effort is being laid down to enable C2IS to interoperate with simulations (Simulation Interoperability Standards Organization 2014b; Tolk 2012a; Tolk 2012b). The purpose of this is that personnel can use their normal working tools when participating in simulation-based training. Thus, machine-readable languages have been developed, so that force structures, unit movements and task that are specified in the C2IS can be automatically sent via these languages to a simulation, where the planned operation can be simulated. C2IS also receive position and event updates from the simulation, and can render these to users on the C2IS map; see Figure 2. In particular, the Military Scenario Definition Language (MSDL) (Simulation Interoperability Standards Organization 2008) is a standard for describing force structures and their initial positions, the Coalition Battle Management Language (C-BML) (Simulation Interoperability Standards Organization 2014a) is a formalized language for expressing a commander's plans, orders and reports across C2IS, simulation systems and autonomous systems, and Low-level BML (L-BML) (Alstad and Mevassvik 2013) is a language to specify more detailed movements and tasks to simulation entities from a break-down of C-BML orders (Løvlid et al. 2018). A number of system demonstrators have been developed to explore the concept; e.g., (Pullen et al. 2012; Allen and Schroeder 2011; Coolahan and Allen 2011; Bruvoll et al. 2015).

Efforts toward further interoperability between C2IS and simulation systems are consolidated in a C2Sim initiative (Simulation Interoperability Standards Organization 2014b; Heffner et al. 2014), now also involving ontologies for enhanced conceptual expressiveness at the machine level (Singapogu et al. 2016). These efforts build on earlier work based on large data models such as the Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM) (NATO standard STANAG 5525) and its successor, the Multilateral Interoperability Program Information Model (MIM) (Gerz and Bau 2016) that specify the minimum set of data that needs to be exchanged in coalition or multinational operations.

All this makes it possible to achieve interoperability between C2IS and simulation systems. As is evident from the above, there is a substantial focus on being able to represent entities and tasks accurately in the military domains. However, even though the initial motivation for all this was training, there is no explicit mention of training objectives, what skills to be trained or skill performance metrics. Indeed, besides interoperability between C2IS and simulations, C2Sim languages are now also designed for connecting C2IS themselves and for controlling and monitoring unmanned vehicles from C2IS.

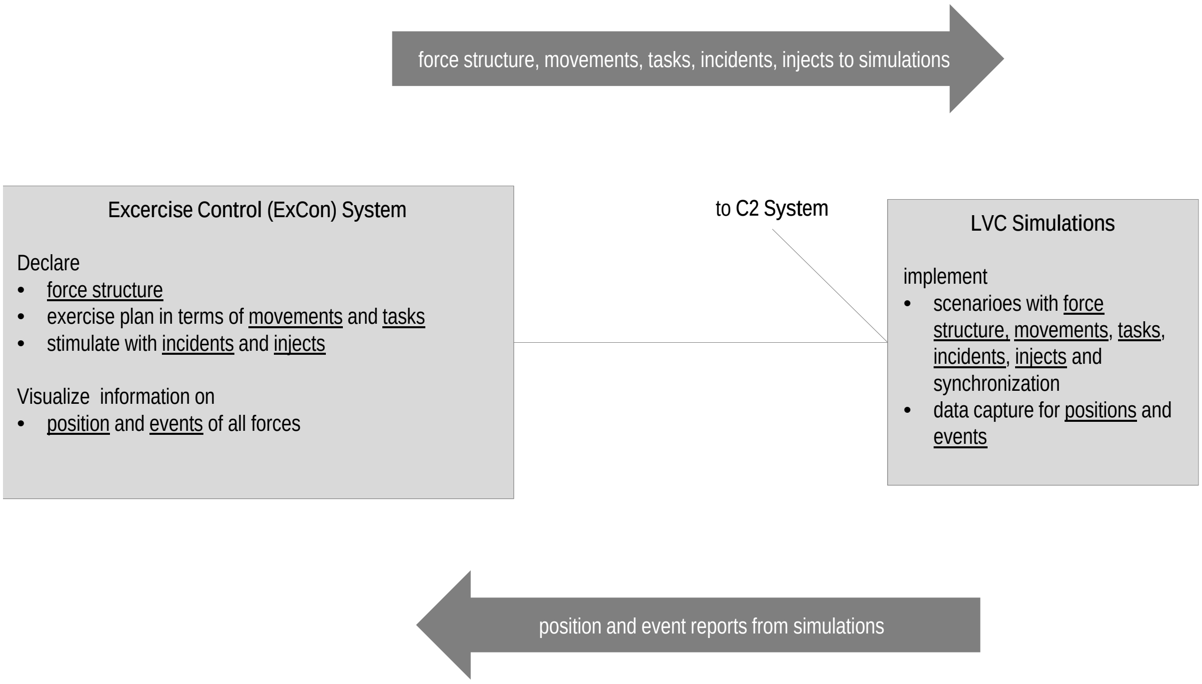

Figure 3. ExConSim configuration

EXERCISE CONTROL WITH SIMULATIONS

Of course, the C2Sim initiatives above are extremely important. Simulations have to be sufficiently detailed and accurate to be of any value to training. Usually, trainer staff have their own consoles in which they control and monitor exercises and training using an exercise control (ExCon) system integrated with simulations (ExConSim); see Figure 3. These are often direct front-ends to simulations, but can also be third-party products designed to administrate training simulations. Thus, while trainees in the C2Sim configuration above participate in a simulation via their C2IS, trainers monitor and control the simulation via the ExCon system.Trainers can stimulate training with incidents and injects, but ExCon systems usually do not have functionality to define training objectives or any higher-level functionality to support, say, learning principles. They usually have functionality to record entity positions and events and can thus present reviews based on this data.

EXERCISE MANAGEMENT WITH SIMULATIONS

Beyond C2Sim and ExConSim, there is a need for a more explicit approach to support the simulation-based training loop and to alleviate the problems that seem to be integral to crisis training. We now outline an architecture which, by design, addresses the shortcomings in the preceding architectures. Figure 4 presents this architecture; where an exercise management tool interoperates with mixed-reality simulations. The architecture consists of three main components: A front-end, a back-end and a middleware component.

Front-end

The front-end consists of a user-facing system (a web application for easy access on portable devices) that allows exercise management staff

- to declare training objectives,
- to select which essential skills to be trained to reach those objectives,
- to select events to stimulate development of those essential skills,
- to select corresponding metrics for measuring essential skill performance in the events and
- to compose vignettes and scenarios from the selected events.

This design promotes the idea of composing exercise and training scenarios and vignettes (sub-scenarios) from a selection of predefined events that are designed to stimulate given essential skills. The events have associated skill metrics. Scenario composition can range from manual (Simulation Interoperability Standards Organization 2018) through semi-automatic to automatic; e.g., (Martin et al. 2009) or (Zook et al. 2012) who describe a method for

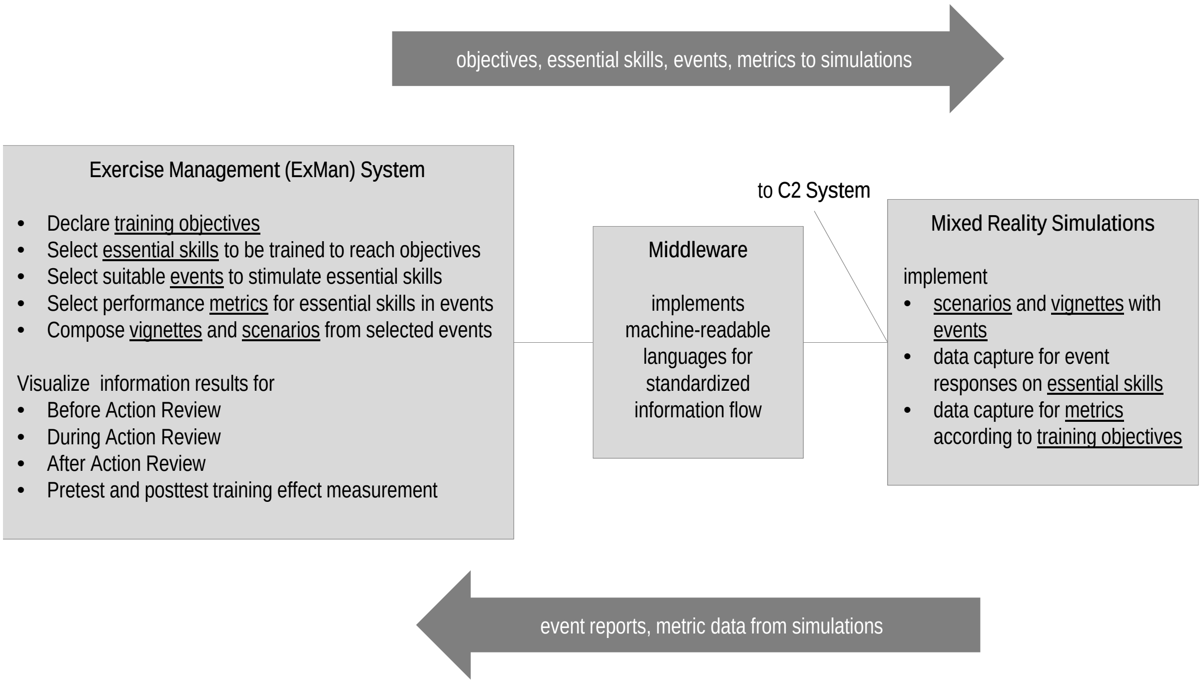

Figure 4. ExManSim configuration

generating scenarios using combinatorial optimization: An algorithm constructs a scenario by choosing events and determines the appropriateness of the scenario using a fit function over training objectives. Events may be designated as *mandatory* or *preferred*, giving degrees of variety in the generated scenarios.

When events and their associated skill metrics are combined, a new combined event and combined metric is generated. Also a skill may have varying metrics according to roles and combination of roles. How this should be done in the face of combinatorial explosion and validity is a topic currently under investigation. Another topic under investigation is how an essential skill as a generic construct; e.g., acquiring shared situation awareness, should be instantiated in a range of domain-specific events, with some sort of reuse of the concept and associated metrics in the various domains.

The front-end also allows exercise management to visualize information for use in

- Before-action review (BAR); in which a training session or an exercise can be pre-run in a simulation for validation of the consistency and coherency between objectives, skills, events and metrics.
- During-action review (DAR); in which identified learning and performance issues can be addressed immediately during training and exercise in simulations, thereby giving trainees direct feedback.
- After-action review (AAR); in which learning and performance issues can be analyzed and addressed in after action simulations; thereby turning identified lessons identified into lessons learned immediately after training or an exercise.
- Pretest and posttest effect measurement; in which essential skill performance can be measured in controlled simulations before and after training and exercises for measuring the effect of training and exercise.

The purpose of these functions is to support *deliberate practice* (Ericsson 2006); a framework that addresses the short-comings of "learning on the job", by a strong focus on difficult aspects, immediate and tailored feedback (by a coach or computer-adaptive system), followed by tailored re-trials integrated into the larger sequence of tasks.

Further, it is common to emphasise the importance of training on realistic tasks in a realistic environment. However, research has shown that training that simply reflects actual circumstances is not sufficient (Shadrick and Lussier 2009). Using artificial, rather than realistic, elements in training is common in other domains. For example, an athlete will not spend all her training time practising the exact sequence of actions she will perform during competition, but will spend considerable time on specific training of muscle groups, on mental preparation, and even on other sport disciplines. A musician will repeatedly focus on difficult passages, thus engaging in artificial behaviour compared to an actual performance, while still using his actual instrument.

For tactical decision making, normal realistic training is, in general, insufficient, because it does not target the development of decision-making skills (Shadrick and Lussier 2009). Judgement and decision tasks are often so-called inconsistent (different people develop differing successful strategies) (Campbell et al. 1993; Campbell 1990) or ill-defined (hard even to define successful strategies) (Johnson 1988; Simon 1973; Reitman 1965; Voss and Post 1988). Research shows that practitioners on inconsistent and ill-defined tasks may spend half their careers apparently *not* learning and *not* improving performance beyond, perhaps, a very narrow subset of (consistent) tasks. Instead, the idea is to train adaptability; i.e., how to adapt to unknown and surprising situations. In line with this, the notion of *adaptive thinking* has been adopted in the defence domain for tactical decision making (Shadrick, Lussier, and Hinkle 2005; Shadrick and Lussier 2009) based on a concept of adaptive job performance (Pulakos et al. 2000).

Thus, it may be necessary to engage in artificially enhanced tasks to heighten performance. Such tasks are the result of *task analyses* and depend on the actual task at hand. Particularly relevant for judgement and decision-making tasks, *cognitive task analysis* uncovers a range of unconscious processes as well as how decision-makers of varying degrees of proficiency think (Mussweiler 2003; Gigerenzer and Todd 1999; Klein 1997; Kahneman and Frederick 2004). The ExManSim architecture has a focus on events targeted at essential skills, and the idea is that training and exercises can be explicitly planned with events containing such artificially enhanced tasks when appropriate.

Back-end

The back-end consists of mixed-reality simulations. Simulations are often divided into *Live*, *Virtual* and *Constructive*. *Live* simulation has live personnel using real equipment, but where, e.g., live ammunition is replaced by laser pulses and detectors; all networked to combine event and positional data for a comprehensive digitized view of events. *Virtual* simulation has live personnel in a virtual environment (e.g., flight simulators and vehicle manoeuvre in gaming), and *Constructive* simulation has totally computer-simulated entities. Combining the three modes in so-called LVC simulation in a distributed system is assumed to increase training capabilities and training effect. Using appropriate standards such as the High Level Architecture (HLA) (IEEE Standards Association 2010) or the Distributed Interactive Simulation (DIS) standard (IEEE Standards Association 2015), all entities and movements in the combined simulation can be seen in the various *Virtual* and *Constructive* simulations (Hannay, Mevassvik, et al. 2014). *Live* players can see simulated entities in their C2IS (using C2Sim) (Hannay, Mevassvik, et al. 2014), and when equipped with augmented reality technology, may also see and interact with simulated entities in their field of view. This combination of LVC simulation modes with player interaction in all three modes constitutes *mixed reality* simulation.

In addition to the the general benefit/cost arguments in favour of simulation-based training, simulation is essential for conducting artificial tasks and deliberate practice regimes. Moreover, mixed reality simulations are necessary when crisis response personnel need to train in simulations with their regular working equipment. Personnel training for road tunnel fires would not enter a burning tunnel in real life but would train in a virtual simulation. Virtual reality headsets may be used for better immersion, but to enable trainees to use their normal equipment such as radios, firefighting equipment, first aid equipment, etc., they would rather use augmented reality headsets, so that they can see and interact with their real surroundings and tools and interact with the virtual simulation at the same time.

Once a scenario has been composed in the front-end, the simulations for running the scenario must be composed quickly and accurately. Today, it typically takes months or even years to develop simulations; see e.g., (Edgren 2012). This is a serious disabler for generating simulations that match differing training objectives and skills to be stimulated though appropriate events in a flexible manner. Initiatives on *Modelling and Simulation as a Service* (MSaaS) work toward setting up simulations for operations and training readily and rapidly (Hannay and van den Berg 2017; van den Berg et al. 2017; Asprusten and Hannay 2018) from simulation services. The *service* concept embodies reusability by standardization of common functionality, and composability through loose coupling and standardized service descriptions. Thus, events can be reflected by simulation services at the back-end. Then, composing events to vignettes and scenarios on the operational level in the front-end map to composing simulation services to composed simulations at the back-end.

Metrics selected in the front-end must also be implemented as data collectors and/or measurements in simulations. For example, (Cornell et al. 2007) describe an automated process for measuring human performance. A performance measurement pipeline is developed to assess human performance in virtual training, so that raw simulation output data is transformed to give meaningful event assessments. Using this, C2Sim data, say, may be transformed to event metric information in the ExManSim setup.

Middleware

The middleware component handles information flow between the exercise management system (front-end) and the simulations (back-end). As for the C2Sim configuration, machine readable languages must handle this.

ExManSim requires a language that can express not only what to do, as MSDL and C-BML do, but also for what objectives and for what training effect one is doing those things. This requires additional language structures. An immediate thought is to combine C-BML with Experience API (xAPI); a language from the Advanced Distributed Learning (ADL) initiative (Fletcher et al. 2007) that is used to collect experiences online and offline in a structured and standardized way. This combination might be used to track a trainee's learning when using a simulation system to reach certain training objectives, since xAPI has structures to store information and results about an activity. This means one can define criteria on when performance in an event is considered successful, and one can define more advanced scoring algorithms based on that. For further pointers, see (Durlach 2018).

Example

To illustrate how the ExManSim architecture is intended to function, consider the domain of *fire crisis management*. Recent fire incidents in road tunnels give rise to a training objective "Improve communication and collaboration between first responders at the scene of road tunnel fires". One essential skill (among several others) in crisis management is *acquiring shared situation awareness* (SSA), which is the overlap in situation awareness (SA) between members of a team (Nofi 2000).

Situational awareness is defined in (Endsley 2000) as "...the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Hence, this definition can be split out in three levels (Valaker et al. 2018):

1. the position of all entities in an area of interest, regardless of their identity
2. in addition to the above, the relationships between the entities
3. in addition to the above, the possible future configurations of the entities and relationships

To stimulate the development of this essential skill in this particular domain, one conceivable event would be a collision in a road tunnel and subsequent fire with human casualties. This event requires personnel in different roles collaborating to respond to the event: Firefighters must extinguish the fire, health personnel must treat the injured and police must secure the scene. SA, and especially SSA, is crucial to execute the required tasks successfully and to create a safe working environment for all personnel. To acquire SSA, the trainees must first be aware of the relevant entities and their relevant relationships (car fire close to flammable tunnel lining) and what resources can be drawn from the other roles (SA Levels 1 and 2). Then, the trainees must understand how the situation might evolve; for example, if there is a danger of a second fire and if further civilians may become at risk (SA Level 3).

For this example, an exercise manager would use the front-end to select the domain of "fire crisis management" and declare the objective "improve communication and collaboration between first responders at the scene of road tunnel fires". The front-end then allows the exercise manager to select "acquire SSA" (and other skills that the ExManSim system supports) from a list of essential skills to be trained in that domain. For each selected essential skill, the front-end then presents a list of events (for example the "car collision event") supported by the ExManSim system. Each event has associated metrics for measuring skill performance. For "acquiring SSA", appropriate metrics would be sorted under the three categories above. To make an evolving scenario, subsequent events may be selected as well; e.g., "secondary fire in flammable material on tunnel wall".

Acquiring SSA involves several roles acting on the same events. For an impression of some of the complexity in composing metrics when combining roles even in a single event, consider again SSA: To acquire SSA, the team members must share and enquire each others individual situation awareness (ISA).

Figure 5 shows this schematically, suggesting that there are different SSA configurations depending on the number of personnel and roles involved. For example, *X123* in this example consists of the information that is available to

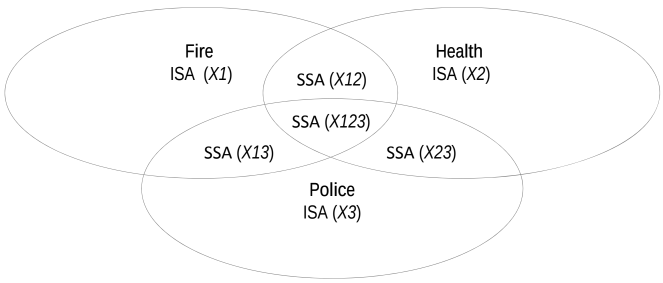

Figure 5. Schematic visualization of individual situation awareness (ISA) and shared situation awareness (SSA)

all personnel. One might think that the more information that is shared, the better. However, interviews with subject matter experts suggests otherwise: It is often the case that personnel receive too much information, resulting in lower performance. Hence, trainees should train to achieve *effective* SSA; that is, the amount and type of SSA that results in higher task performance.

Effective SSA depends on the role of a person. A task force leader may need a more extensive SSA than personnel with a more individual role. When composing SA-dedicated events into vignettes and scenarios in the front-end, effective SSA must be expressed in the combined skill metrics that result when composing those events.

At the back-end, a virtual simulation might be composed by a simulation service implementing the car collision event and a simulation service implementing the tunnel wall fire. Separate metrics services composed to measure effective SSA for each intended trainee role may be composed into the simulation. Trainees may use virtual or augmented reality equipment, or other media, depending on the need to interact with real equipment.

For information flow between the exercise management tool and the simulation, the scenario composed of the events and metrics would be transmitted in a machine-readable language to the back-end, where a simulation composer may semi-automatically compose the simulation from simulation services and metrics services. SSA skill metric information would flow back to the front-end for presentation in the various action reviews.

CONCLUSION

There is a strong focus on accurate representation of entities and events, and a paradoxical lack of focus on structures and standards that explicitly address training and learning, in architectures for simulation-based training. We propose the need for an architecture for exercise management and simulations (ExManSim). This architecture is designed to take on the challenges faced in simulation-supported exercises and training, so that the intents of simulation-based training may be realized. The architecture relies on emerging technologies within machine-readable semantic representations of events at the model level, and associated simulation services at the implementation level.

The architecture is proposed based on arguments of design. Current research is refining this architecture in collaboration with stakeholders from a range of crisis management organizations and industry. A working prototype for some of the functionality in the architecture is planned to be released in increments in the near future.

Acknowledgements

This research is funded by the Research Council of Norway under project no. 282081 “MixStrEx”. The authors are grateful to the anonymous reviewers and Ole Martin Mevassvik at FFI for helpful comments.

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