Medical readiness for operations other than war: Boyd's OODA loop and training using advanced distributed simulation technology

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To the memory of Col. John Boyd, USAF,
the most extraordinary of Tigers

Abstract: Synthetic Distributed Readiness Training Environment (SDRTE) combines Advanced Distributed Interactive Simulation (A-DIS) and Medical Application Service Provider (Med-ASP) concepts into a seamlessly integrated training platform for the development and maintenance of First Responder (1RP) operational medical readiness. A synthetic substitute for the traditional, restrictive methods of training, SDRTE is based on the already developed and tested fusion of Virtual Reality (VR), Auto Stereoscopy (AS), High Fidelity Human Patient Simulation (HFPS), videoconferencing (VCON) and visualisation of complex data with the existing high speed internet connectivity (ISDN, DSL, I2), that operates as a real time, distributed simulation network. Full scale implementation of SDRTE allows real time 'free play' training of multi-agency personnel in a near-real-life environment that permits incorporation of fluidity, stressors and unpredictable elements. Neither of these elements can be successfully implemented in the currently practised, predetermined and strictly scripted physical drills. While the proposed synthetic readiness-training environment will not substitute for physical drills, it will assist in the development of critical command- and decision-making skills required for the successful conduct of operations in dynamically changing disaster environments. Moreover, the synthetic nature of SDRTE permits collection of quantitative data necessary for the development of performance metrics, development of operational standards and doctrines and – ultimately – for the unbiased data-based assessment of the existing readiness levels.

Keywords: Application Software Provider (ASP); disaster management; distance learning; first responders; human patient simulation; OODA loop; simulation; simulation networks; training; virtual reality.

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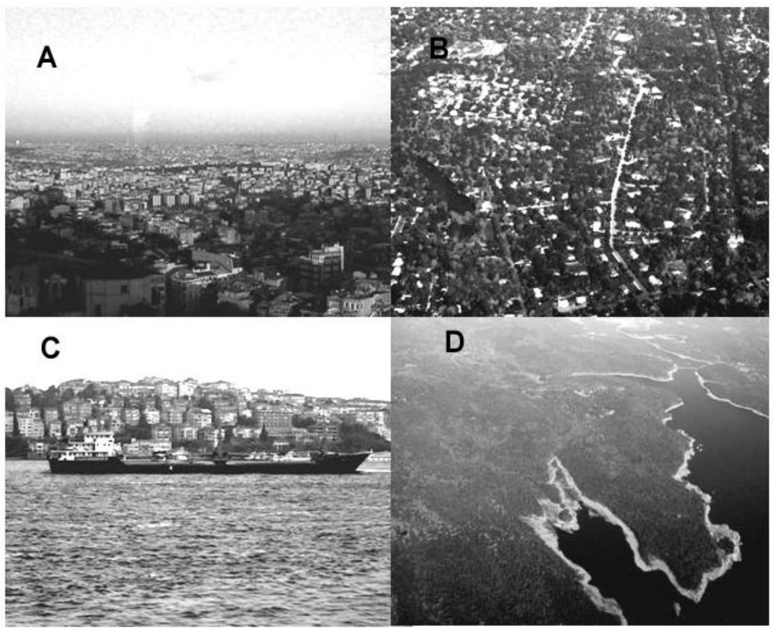
1 Introduction

Changing weather patterns, rapid urbanisation, expansion of industry whose operations are frequently dependent on a steady supply of highly dangerous materials, development of intricate ground and air transportation networks, population growth and migration frequently accompanied by unrest, political turmoil and recently – acts of terrorism, are associated with the ever-increasing frequency of major disasters involving multiple casualties (Figure 1). Hence, there is an increasing demand for the parallel growth of effective disaster management capability, i.e. pre-hospital and emergency/trauma in-hospital medical services, fire-fighting, disaster-related law enforcement operations, etc. Most of these services are governed by different local or national agencies, are subject to different rules and regulations and develop independent operational plans. Unsurprisingly, a multiplicity of sometimes conflicting training guidelines, manuals, books, or comprehensive response plans are published by individual operators, agencies, or even national governments (e.g. King County Sheriff Office (KCSO); FEMA; Bath and Berg, 2001). Printed (or electronic) documents outlining execution of disaster management notwithstanding, only practical training provides adequate test of theoretical solutions. Hence, in similarity to the armed forces, civilian agencies embark with an ever-increasing vigour on the execution of practical drills. However, as the history of military operations also shows, even most carefully prepared plans accompanied by extensive field training of the involved units failed in practical implementation (Baldwin, 1966; Wright, 2000; De Ségur, 2002). In many cases, the failure originated at the command level and related to inflexibility, application of rigid tactical or strategic rules to the dynamically evolving operational situation, inability to predict future consequences of present actions, and personal timidity of the commanders which, in turn, precluded effective deployment of the available resources (von Manstein, 1958; Alexander, 2002; Hough, 2001). Historical examples of military defeats indicate very clearly that the critical thinking of the commander under pressure, his ability to extract relevant information from multiple sources and formulate flexible response based on such information, and his ability to predict the course of action a few tempi ahead of the current situation, provide the essential operational advantage that is prerequisite to victory (e.g. Baldwin, 1966). While some commanders have an intuitive grasp of the principles involved in successful field operations, the majority need training. 'Free-play' exercises provide the best instrument for the development of the required skills.

Figure 1 Population growth leading to rapid expansion of cities (A – Istanbul), encroachment of urbanisation in the previously rural regions (B – New Jersey), increased activity in the commercial traffic 'choke points' (C – Bosphorus Strait), and industrial exploitation of remote regions (D – the coast of Canadian Maritimes) result in escalating potential for catastrophic events and acts of violence (terrorism) associated with large numbers of casualties. Each environment has its unique characteristics, each poses special challenges during disaster management operations, and each is capable of stressing 1RP resources to the maximum. Hence, the development of readiness must be context-specific, a goal virtually unobtainable in the prevalent atmosphere of either multipurpose drills or drills aimed at the currently perceived major threat – terrorism. Simulation exercises allow much greater flexibility both in the operational context and in the development of critical thinking needed in the fluid and unpredictable setting of OOTW



There are many obvious differences between military and civilian operations. Among the principal ones is the fact that disaster management is, by its very nature, *reactive.* Contrary to the military action that can be pre-emptive with respect to the perceived or emerging danger, the civilian or joint civilian/military response to a disaster is always the consequence of and the response to the event that has already taken place. In other words, it has many elements common with a purely military response to an ambush. The sudden emergence of the threat (i.e. the disaster) and the dynamic nature of its evolution need to be countered with the flexibility and fluidity based on the appropriate assessment of the principal danger(s) posed by the disaster, allocation of the available resources to contain the immediate threat(s), followed by the appropriate and relevant action based on threat evolution and suitable resource deployment. The outcomes of the immediate actions must be then re-evaluated, the next step reiterating assessment, disposition, counteraction, etc. Thus, in similarity to the military, intensive cognitive training is essential for 1RP and their development and instinctive mastery of operational skills. It is these skills, after all, that are the fundamental aspect of readiness, that is instantaneous ability to respond to sudden, unexpected threats (Lary, Pletcher and von Lubitz, 2003). To assure adequate level of such response, training must not be based on predetermined patterns and pre-scripted scenarios but on the development of situational awareness and assessment abilities, and on the decision-making and command capability of the trainees that is their ability to think and act clearly and rapidly in the environment saturated with stressors. Such training must also emphasise the ability to perform contiguous assessment of the evolution within the changing environmental envelope of the event. Finally, emphasis must be placed on flexibility that is necessary for the development and implementation of actions commensurate with the ongoing evolution of the threat. The theoretical reasoning for such approach can be, rather surprisingly, traced to the principles of physics demonstrated by Boyd in his seminal (albeit little known) paper on destruction and creation of cognitive constructs (Boyd, 1976). The concept of the OODA loop, also developed by Boyd (1987), provides a striking graphical interpretation of the ongoing nature of all subcomponents involved in cognition and response to the dynamically evolving environment, and the intricate interrelationships among all constituents of the process. Put more directly, in order to be truly effective, 1RP training (at least at the command level) must be based on the principles similar to those used in free play military exercises. For the most part, this is not the case.

2 Current training models: preparedness versus readiness

The present models of large scale 1RP training follow the classical pattern of either strictly didactic education or full scale drills ('foot-on-the-ground') approaches (Lary, Pletcher and von Lubitz, 2003; von Lubitz and Lary, 2005). The didactic approach utilises self-study of manuals and books, pamphlets, lectures and seminars, or web-based instructional materials (some of which may be interactive). Full scale drills may involve either single components of disaster response continuum (e.g. fire-fighters, police, healthcare) or multi-agency personnel (EMS, FEMA, FBI, etc.)

Didactic training is useful in the development of general *preparedness*, that is acquisition of the required subject knowledge and familiarity with the existing guidelines and procedures. It also enhances the *awareness* of the existing threats and potential threat scenarios. Drills play, essentially, the same role and test preparedness rather than *readiness*, as evidenced by the published rules describing the structure of the development and execution of such evolutions (e.g. Louisiana Office of Public Health and Hospitals). Currently, drill preparation is based on elaborate pre-planning, distribution of scenarios and event chronologies among all participants to allow mobilisation of personnel, determination of appropriate logistic support, materiel deployment and so on [*ibid*]. Hence, drills conducted today test preparedness defined as *the availability of all resources, both human and physical, necessary for the management of, or the consequences of, a specific disaster type.* Even in such carefully pre-planned setting, where surprises and operational stress are either eliminated or significantly reduced, major procedural and operational errors are common and frequently repeated. The persistent existence of such errors emphasises the fact that, while the level of national preparedness for OOTW increases, the level of *readiness* defined as *instantaneous ability to respond to a suddenly arising major crisis [e.g. terrorism attack]* *that is based on the locally available/unpre-positioned and un-mobilised countermeasure resources* is either unchanged or, possibly, decreased because of the inherent flaws built into the current philosophy of drills.

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The common error of using preparedness as a synonym for readiness is among the major sources of slowly developing complacency in the attitudes to training (Smith, 2004). Yet, simulation-based studies have clearly demonstrated that highly trained (i.e. *prepared*) personnel exposed to a sudden crisis whose nature falls outside the scope of prior preparation grave errors of judgment and procedure (Pizzi, Goldfarb and Nash, 2001; Smith, 2004; The 9/11 Commission Report). In other words, while the level of preparedness may be at maximum, the level of readiness remains minimal.

The operational doctrine behind the current drills fails to address the realities of crisis development, that is, its unpredicatbility, confusion, inadequacy of immediately available resources, involvement of unplanned factors (e.g. suddenly deteriorating weather, crisis-related political tensions, etc.) continuously changing patterns of temporal elements, or even the impact of sheer physical and mental stress of the participants (Beier et al., 2000; von Lubitz et al., 2000; Gawande et al., 2003; Baldwin and Daugherty, 2004; Papp et al., 2004; Bailey, Konstan and Carlis at http://interruptions.net/literature/Bailey-Interact01.pdf). In addition, interagency conflicts make even the simplest drills utterly unrealistic since operational consensus must be reached prior to the execution of the exercise (e.g. the criticism of TOPOFF2 – see Block, 2003) While the sheer cost [*ibid*] of large scale drills (that can reach millions of dollars/drill) imposes severe restrictions on the frequency of drills, the same cost impacts their official assessment leading to the misleading emphasis of the 'positive' rather than the objective (if not necessarily complimentary) aspects of the concluded exercise. Yet, it is the latter, negative, findings that have the greatest value. The enthusiastic 'Bravo Zulu' assessment of the majority of the conducted disaster management exercises that can be neither verified nor supported by the quantitative measures and performance metrics arrests even further the development and sustainment of true OOTW readiness.

3 Critical command thinking and OOTW training: the current status

Currently accepted definitions of the elements in 1RP training (Louisiana Department of Health and Hospitals, 2004) are a clear indicator that the essential element of *critical command thinking* is largely bypassed.

Tabletop exercise is defined as a "structured meeting...conducive to promoting discussion, addressing issues and evaluation procedures of emergency response abilities and roles wherein a chronological scenario is introduced by a facilitator with each participant verbally playing his/her role..." [*ibid*] Translated, the definition describes an evolution that promotes neither preparedness nor readiness, and whose 'structured' character eliminates all aspects of command decision-making in a dynamically changing environment. *'Full Scale Drill'* constitutes "A means of thoroughly instructing personnel, evaluating procedures and addressing issues of emergency response activities and roles wherein a scenario of chronological events is introduced by facilitators..." Accordingly to the definition, full scale drill is an instruction platform within a rigidly defined set of parameters. No elements of surprise are introduced, the scenario is predetermined and therefore static, and the drill, instead of testing response capability, tests the ability to follow a set of already familiar game rules. In other words, the drill is similar to a chess match played accordingly to the previously published master game pattern. Decline in practicing decision-making and command skills is implicit to the current practice of essentially strictly scripted drills in which all elements are carefully arranged in their temporal sequences that, in turn, dictate operational tempo of all executed actions. With predetermined events and prior preparation to their occurrence, the preponderance of equally pre-determined (or almost predetermined) action follows as a natural consequence. Ultimately, the outcomes become predetermined as well despite the inclusion into the drill of seemingly random and confounding elements (e.g. TOPOFF2). 'Randomness' – when planned and prepared for a priori, will result in an equally pre-planned outcome, 'surprise elements' notwithstanding. Finally, with the exception of light to moderate physical fatigue, the nature of the current drills (pre-scripted, short duration, minimum operational complexity) does not permit incorporation of the intense stressors that frequently affect real life operations (e.g. sleep deprivation, mental fatigue, information overload, emotional trauma, etc.) although numerous studies have documented that stress has an intensely adverse effect on the performance of mental and skills tasks (Pizzi, Goldfarb and Nash, 2001; Baldwin and Daugherty, 2004; Smith, 2004).

Obvious deficiencies of both tabletop exercising and full scale drills executed within the framework of the preceding definitions combine with their cost, which, particularly at the level of small communities, can pose a very significant burden that, in turn, plays the major role in determining the frequency of drills (GAO, 2003; Fischer, 2004; Concord Monitor). When similar training is performed either at a state/national or even international level, the cost is staggering and amounts to tens of millions of dollars (Block, 2003). Altogether, despite vastly increased funding for 1RP, solution to the inadequacy of financial and personnel resources needed to execute training and drills remains as elusive as ever. In the meantime, the combination of cost, very limited frequency (in part dictated by the cost), and the limited value of drills in the context of the development and maintenance of readiness and operational command skills serves as a poor prognosticator of the management outcomes consequent to real OOTW.

4 Development of critical command thinking skills: the OODA loop

Implementation of Boyd's OODA loop-based critical thinking and decision-making (Boyd, 1976, 1987; Coram, 2002; von Lubitz and Wickramasinghe, 2005) provides the ideal solution to the present dilemma of training these skills in a manner consistent with their practical use within a constantly changing environment of multiple situational inputs that are, in turn, characterised by their own temporal and physical instability (operational chaos or 'fog of war' – see von Clausewitz, 2004). Originally aimed at the war fighting community, OODA loop not only revolutionised many aspects of modern combat, but found its practical applications in disciplines as diverse as business, medicine, and even dispersion of internet viruses (Richards, 2004; Luzwick (2000) at http:// shockwavewriters.com/ Articles/PGL/4.htm**;** Executive Perspectives at http:// 72.14.203.104/search?q=cache: OFNAoSYD4aIJ: www.qinetiq.com/home_ep/ technology_watch/july_2005.html+Urban+planning+and+OODA+Loop&hl=en&gl= us&ct=clnk&cd=17). The loop is based on a cycle of four critical and interrelated elements: Observation -> Orientation -> Decision -> Action that revolves both in time and space. Observation and Orientation segments of the loop are its critical stages at

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which the plurality of implicit and explicit inputs determines the sequential Decision- and Action steps. The outcome of the latter affects, in turn, the character of the next initiation point (Observation) in the forward progression of the rolling loop (Figure 2). The Orientation stage specifies the characteristics and the nature of the 'centre of thrust' (Schwerpunkt) at which the most significant activity is to concentrate that, in turn, determines the specifics of the sequential stages (Determination/Decision – definition of action to be taken, and Action – its specific execution.) However, the progression of the Loop is not linear – a commonly made error in the interpretation of its progression. It does not merely roll along the time axis – the stages within the loop are simultaneous, delicately intertwined and balanced. Action does not interrupt Observation, or Decision does not halt Orientation. The domain of the loop is multi-dimensional and embraces all constituents of the environment. Time is only one of those.

Figure 2 The OODA loop by John Boyd. Two aspects of the loop are striking: its multidimensional complexity and its dynamic nature that encompasses both time and space. The deceptively simple loop represents arguably the best depiction of the complexity of interactions and interrelationships involved in critical thinking and decision-making processes., and how actions based on these processes together with other, external, inputs affect the environment, and hence – the next revolution of the loop. Importantly, all actions within the loop are simultaneous – action does not interrupt observation or decision does not relieve from the need to orient. Contrary to the commonly committed error, OODA loop does not represent a linear process developing along the time axis but a process that develops simultaneously within the operational sphere where time is but one of the constituent elements

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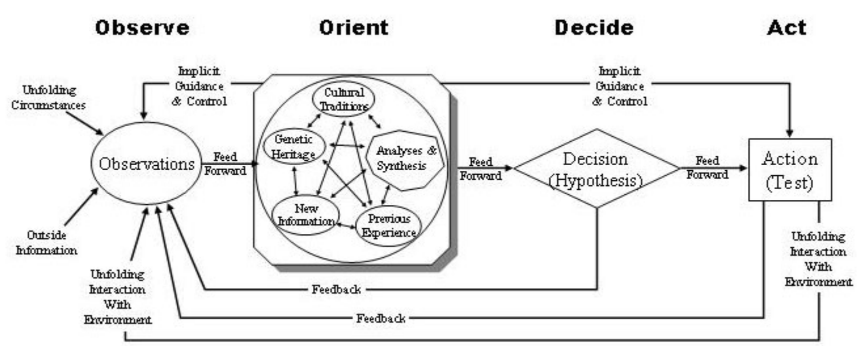


Outwardly, the OODA loop appears almost banal. In reality, it provides the essential framework for knowledge-based, multidimensional critical thinking and decision-making whose operational consequence – action – is executed in real time and determine the operational tempo and direction of the entire process. Unsurprisingly, practical implementation of the OODA loop as one of the pivotal elements in the current doctrine of network-centric operations led to significant changes in many aspects of modern warfare (Smith, 2001; Tan Chon Ming, 2002; von Lubitz, 2003).

Although the dynamic nature of the OODA paradigm makes it a pre-eminently suitable readiness development tool in the context of the fluid OOTW and 1RP operations, the currently employed pattern of training prevents such implementation. As shown above, today's exercises effectively eliminate the Observation and Orientation stages by predetermining their characteristics – in fact there is not much to observe or to orient. Both stages are entirely static since both have been presented and thoroughly explained to the drill participants prior to the commencement of the evolution (Louisiana Department of Health and Hospitals, 2004). Hence, the course of the sequential steps (Determination/Decision and Action) is enforced *a priori* and results in a rigid, algorhythmic structure. In other words, even with a rigorous implementation of loop-based training of 1RP within the framework of currently practiced drills, the resulting outcomes would be at best inconclusive and, at worst, entirely misleading. The latest advances in simulation technology and the rapid development of network-centric operations' philosophy provide not only a tool allowing implementation of effective OODA Loop-based training in command skills, but also a practical (and less costly) solution to the dilemmas of 1RP/OOTW (Operations Other Than War) readiness developing drills.

5 The significance of context

Disaster preparedness and readiness may mean very many things. The events of 9/11 shifted much of the current emphasis on terrorism countermeasures and on consequence management of terrorism-related events. The positive outcome of this shift is the sudden increase in funding of 1RP organisations that promoted modification of interagency communication systems assuring interoperability, acquisition of materiel that meets new demands, development of new surveillance systems, etc. Terrorist attacks in Bali, Spain or Turkey indicate not only the continuous, high probability of such events taking place in the future, but also their rapid global spread. The multiplicity of offensive means stretching from simple explosive devices to the potential use of nuclear/biological devices combines with multiplicity of potential targets and results in the continuous uncertainty with respect to time, place and mode of the next attack. With the exception of terrorism targeting the electronic infrastructure of the target country(-ies) where only indirect casualties may occur due to, for example, disruption of life supporting electronic devices at hospitals or interruption of medical dispatch systems, practically all other forms of terrorism will result in direct injuries and fatalities whose nature and number are almost impossible to predict. Moreover, depending on the nature of such events, the character of the accompanying morbidity and mortality, and thus the nature of the demand for specialised medical resources, will also vary. Explosives will increase the need for surgical facilities and surgery-capable personnel, while the use of biological agents will elevate the requirement for personnel specialising in infectious diseases, public health, epidemiology, etc.

Unfortunately, terrorism is only one of the sources with the potential for causing mass casualties and major environmental damage. Death and injury accompanying hurricanes or earthquakes (e.g. Hurricane Katrina, the Kashmir earthquake) are unavoidable. Major shipping disasters take place with an ever-increasing frequency, and commercial aircraft continue to crash, while large-scale industrial catastrophes are becoming almost a commonplace. Even more worrisome is the fact that the rapidly increasing size of the metropolitan centres, rapid population growth in the previously rural areas, and vast increase in the commercial sea/air/land traffic, combine with the industrial expansion and leave practically no territory that is, at least potentially, 'disaster-safe' (Figure 1).

The broad range of the likely disaster threats indicates the need for an equally broad range of the appropriate countermeasure resources. While such resources become increasingly more and more available, their distribution, both nationally and internationally, is still uneven and concentrates in the regions assumed to be the most likely terrorism targets.

The continuously elevating potential for a major catastrophic event occurring at almost any place characterised by enhanced human activity, and the uneven distribution of disaster-management resources (both personnel and materiel) underline the critical need for training that emphasises and sustains readiness rather than the currently conducted preparedness drills. However, in order for readiness training to be meaningful, it has to be conducted in the specific context of the conceivable threat. Training against the consequences of bio-terrorism will not prepare adequately for dealing with the aftermath of a hurricane or an earthquake. Simply stated, despite the commonality of some forms of the involved response (e.g. solutions to the patient surge or a suddenly increased need for medical supplies), the differences are too significant to be reasonably dealt with, and prepared for, through an all-encompassing drill. On the other hand, even simple drills are, as pointed out previously, associated with very significant expenditure, disruption of the daily functions of the participating personnel and their home agencies, and – very significantly – with often quite uncertain outcomes. There is no doubt that most, if not all, participants in such drills clearly realise the need for their execution at frequent intervals. Yet, the current and (most likely) future fiscal and operational realities make practical implementation of such training difficult. Execution of frequent, context-relevant readiness developing drills is, for the very same reasons, practically impossible. It is here that the intensive use of simulation technology, particularly in a distributed environment, may provides the only meaningful solution to the rapidly growing dilemma of training and the development of critical thinking skills demanded by the present environment of multiple disaster threats

6 Simulation: the current status

Today, simulation is one of the essential tools in military training and a wide variety of flight, naval and land combat simulators are in routine use (AMSO at http://amso.army.mil/aboutBCSE/msn/; Society for Modeling and Simulation Europe at http://www.ecs-europe.org/**;** NAVMSMO at http://navmsmo.hq.navy.mil/ ND_Contents.cfm). Civilian aviation is using them with equal benefits in cockpit crew training, aircraft maintenance, etc. In medicine, simulators developed from a fairly modest (even if, in its day, revolutionary) Harvey Simulator to the ultra-complex and realistic High Fidelity Human Patient Simulators (HFPS), semi- and full VR partial and complete task simulators, integrated 'medical flight simulators' that combine HFPS and VR technologies [40] and, finally, fully immersive VR surgical training system (von Lubitz et al., 2000, 2001). Quantitative data indicate that medical simulation training results in improved performance and reduction of medical and procedural errors (Graschew et al., 2002; von Lubitz, 2003; Richir et al., 2004).

The major disadvantage of simulators is their cost and stationary nature (Beijer et al., 2000; Lary, Pletcher and von Lubitz, 2003; von Lubitz and Levine, 2005). Particularly in medicine and its related branches, the number of comprehensive simulation centres is small, and only a small percentage of the potential users have the advantage of simulator-based training (unpublished data.) Furthermore, the average rotation period among those who have access to such training varies between 2 and 3 years. Hence, 'hands on' training continues to predominate.

While training deficiencies pose a continuous potential for causing casualties in all walks of life, in no other discipline is this potential as real and as imminent as in medicine. The annul rate of 100.000 deaths due to medical error (caused largely either by the lack or deficient training – see Richir et al., 2004) vastly exceeds the combined number of combat- and peace operations-related casualties incurred by *all services of all Armed Forces of NATO.*

Although no institution is immune to medical error, the prevalence of grave incidents occurs at smaller hospitals and at the pre-hospital level (Kohn, Corrigan and Donaldson, 2000; Lary, Pletcher and von Lubitz, 2003), and it is paradoxical that healthcare workers with seemingly highest need for simulation-based training have the least possibility of benefiting from it. To counteract infrequent exposure and difficult access of 1RP to medical simulation, and to provide frequent training in the complex environment of large-scale disasters the principles of remote, interactive access to HFPS and of Med-ASP have been introduced (von Lubitz et al., 2003b; 2004a,b). The training center acts as a Med-ASP containing and/or controlling all distributed resources, that is simulation software and hardware, visualisation and communication resources, intellectual resources (training and supporting technology experts), and also retains operational control of training itself. Remote trainees gain interactive, real time access to the centre and its simulation resources via the Internet (Web-based portal.) Real-time remote interaction with HFPS is based on OODA concepts with the trainees exposed to sudden, unpredictable medical crises that require medically appropriate management involving diagnosis, administration of drugs and procedures, patient disposition, etc. Logistic issues such as the need for evacuation, availability of drugs/transport/receiving facility space and so on constitute the integral part of medical management. Failure at any of the involved steps may result in status deterioration, complications or even death of the 'patient' (HFPS is programmed to respond to treatment just as a real patient would. Depending on their nature, management mistakes may adversely affect chances of survival.)

Long term testing of the Med-ASP training approach has been conducted over distances of up to 7 km separating the training center from the trainees, with the latter typically located in technology-deficient regions. The most direct practical advantage of Med-ASP concept is the routine exposure of 1RP to simulation-based training in the regions where such training was previously entirely unknown. More importantly, the data accumulated over two years show that the implementation of Med-ASP approach resulted in a rapid quantitative improvement of medical readiness, and in the reduction of medical management errors (as measured against pre-simulation performance, see von Lubitz et al., 2003a,b) Finally, once the performance plateau has been reached, a brief (30 min) monthly session sufficed to sustain the high level of operational readiness. Small scale MedASP network operations involving four remote sites and 3-D interaction has been tested as well (von Lubitz et al., 2003b, 2004b).

7 The physical structure of a large scale synthetic training network

All technologies required for the creation of the physical structure of Synthetic Distributed Readiness Training Environment (SDRTE) already exist. Their ability to integrate and operate as a federated system has been also tested in operational setting (von Lubitz et al., 2003b, 2004a,b; von Lubitz and Levine, 2005). Hence, the following general outline of S-DRTE is based on prior experience rather than purely theoretical considerations.

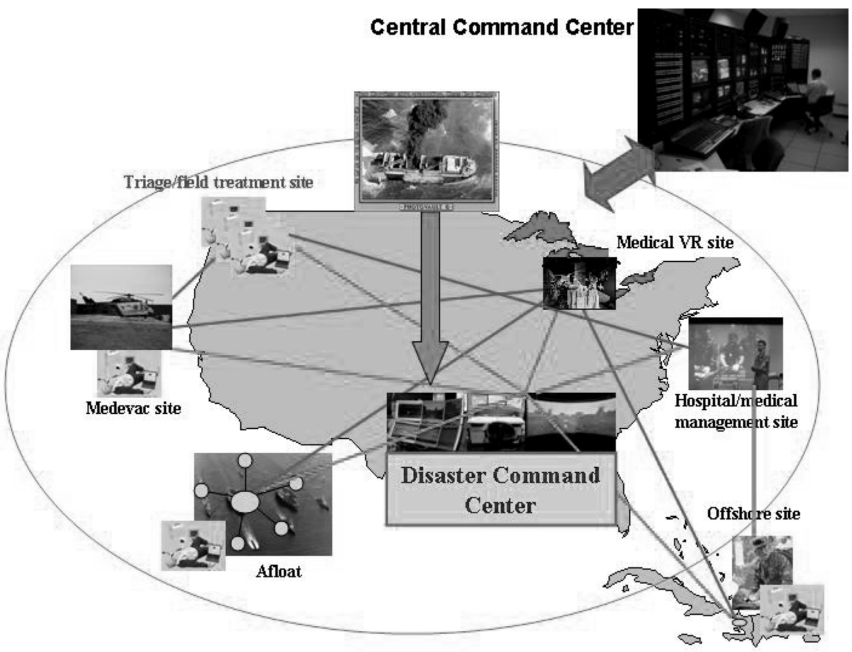
The major attribute of SDRTE is the layered nature of technologies whose integration produces a flexible system with multiple access points, and allows 'role switching' among the peripheral training sites. SDRTE network consists of a number of distributed advanced medical simulation (HFPS) sites, immersive VR/autostereoscopic sites providing the network with non-medical inputs, remote interaction sites utilising advanced VCON technologies, the principal control centre with its associated training/technical support experts and supporting/didactic/data gathering and computational resources, and (if needed) a number of distant, lower technology VCON-based control centres with the capacity of remote interaction with all subordinate elements of the network (Figure 3).

The principal control centre functions as the principal Med-ASP node that, in addition to coordinating standard training activities of a large number of distributed learners, provides simulation-centred content and software, supplies supporting electronic training elements, such as access to more traditional didactic tools, archives of previous simulation-based courses, testing materials, etc. Prior experience (von Lubitz et al., 2003b, 2004a,b; von Lubitz and Levine, 2005) indicates that transmission speeds of 128 Kbs are adequate to fulfill all of these tasks without any deterioration in the quality of image/voice/data elements.

7.1 Telecommunications structure of the network

It is essential that all operations of the network take place in real time (Beijer et al., 2000; von Lubitz et al., 2000, 2004a,b). Hence, due to the large number of data generated by the VR sites, the remote VR simulation centres link to the primary control centre using Internet. Whenever visual VR inputs are required by other than VR sites, data compression and visualisation algorhythms (D'Auriol, 2004; Patson, 2004) are available at the primary command centre for the conversion of 3-D imagery into 2-D [48], and its subsequent distribution among the sites requiring such information. WinVicos [51] or similar wavelet transmission platform needs to be implemented for this purpose. Finally, HFPS simulation sites will be connected to the control centres via high speed internet (DSL) or, if need be, ISDN-based connections (Figures 3 and 4 and von Lubitz and Levine, 2005) for a schematic outline of the telecommunications structure).

Figure 3 Distributed nature of the training environment – a simplified diagram of a sea rescue drill involving coast guard, naval, national/territorial guard elements in addition to the civilian components (EMS, hospitals). Some peripheral sites are synthetically generated in VR (e.g., SAR Medevac site or a shipboard site), others (e.g. triage site) are 'hands-on' participants. Global range of SDRTE is indicated by the offshore location of one of the participating component (e.g., forward deployed military unit) whose network access site is located at its forward deployed station (von Lubitz et al., 2003a). Information flows both among the training sites, and to and from the Disaster Command Center. The Principal Control Center (designated in the figure as Central Command Center) has overall control of the exercise, determines the nature of all events, introduces confounding elements, and also records all incoming data. CCC is also in charge of post-exercise debriefing, data analysis and report generation (see details in the text)



Access from the periphery to the central facility and vice versa can be obtained either by using either point-to-point connectivity with each remote site having its own IP address and an allocated fast internet connection, dedicated ISDN lines, or through a web-based portal hosted at the central training facility (von Lubitz and Levine, 2005). The internet-based access without Quality of Service (QOS), although the simplest one, may become unreliable during extended (more than 1 hr) continuous transmission due to frequent connection interruptions and slow-downs, or up- and down-load loss of transmission speed. These problems are particularly annoying during long- or very long distance operations (e.g. transcontinental or global) Work in which ISDN-lines are routinely used is also the most expensive. For these reasons, password-mediated web portal is considered the most reliable access pathway. Located at the servers of the primary control facility (principal control centre), and with the significant part of the operational software necessary for the efficient training (HFPS control/translation software; remote camera control software, training scenario programs, etc.) accessible through such portal, multi-site activities become greatly facilitated. The peripheral control sites are be provided with a simple, intuitively understood simulator control interfaces displayed at the remote computer monitor and/or wall mounted screens to allow the operation of simulators either via a point-and-click mouse interaction or, at a more sophisticated level, by touching appropriate controls on the touch-sensitive screen (von Lubitz et al., 2004a). Also in this case, our previous experiments showed that transmission at $\geq$128 Kbps is adequate to fulfill the requirements of remote HFPS control from any peripheral site.

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7.2 Operational structure

7.2.1 Participants and participant interactions

Drills can be conducted either as mono- (e.g. training in medical response to natural disasters, bio-terrorism) or multi-disciplinary (e.g. multi-agency management of major disasters demanding multi-layered disaster consequence management.)

During the exercise, all participants have access to the network based on password identification. The exercise-specific password is be generated by the command centre and, as a security precaution, electronically distributed immediately prior to the beginning of the drill. This precaution prevents accidental dissemination of the scenario that would allow prior preparation. Thus, until the very moment of its execution, full details of the forthcoming drill are available only to the personnel at the principal control centre.

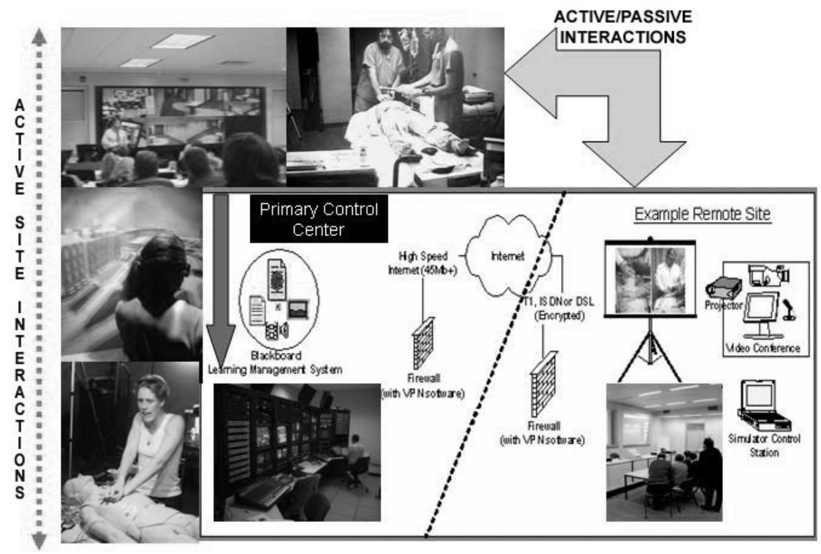
The structure of the network permits participation of three classes of trainees (Lary, Pletcher and von Lubitz, 2003; von Lubitz et al., 2004a,b):

- hands-on
- remote control access
- passive

As in the previously conducted training (see above), the *hands-on group* is physically present at the HFPS and VR locations and performs either hands-on medical interventions or extracts the relevant information (e.g. traffic patterns, weather conditions, resource allocation, etc.) from the VR-based sources, determines the relevance of such information in the context of the ongoing activities, and passes information deemed relevant to appropriate recipients. The 'hands on group' has voice/video access to all other participating sites allowing them to communicate either at a network-wide level or with the selected sites (Figure 4).

The *remote control* group has the remote voice/video/control access to all sites. Trainees at remote control sites may either participate as 'on the ground personnel' (e.g. in charge of remote management of an HFPS(s) or as supervisory personnel in charge of specific tasks (e.g. resource management, emergency dispatch and law enforcement operations). The schematic pattern of interactions between hands-on and remote control groups is shown in Figure 4. Both hands-on and remote control groups are allowed to pass and request information and imagery to or from the entire network or its specific constituents. Whenever such requests are made, the principal control centre serves as the automatic transmitting station that retains the record of the request, its type, and the information passed or received.

Figure 4 Simplified depiction of interactions and communication principles among individual components of SDRTE. The primary exercise control centre (lower left side of the white box) receives internet-transmitted input from all distributed, interactive 'hands-on' participants (indicated by the downward arrow). Hands-on participants (sites 1–4) can communicate among themselves (indicated by the stippled arrow to the left side of the figure) but all exchanges are automatically relayed and recorded (black, arching arrow on the left side of the white box) at the primary control site (e.g., the Blackboard system). The primary control passes video outputs to either passive (upper panel on the right side of the box) or active (the group of participants on the lower panel.) Using a video output and simple, computer-based controls, the latter group can actively participate in several activities taking place at the 'hands-on' sites (e.g. remote management of HFPS in at site 2 and 4). Modification of the depicted environment has been used during the transatlantic trauma- and emergency medicine training described in von Lubitz et al. (2004c,d.) Large-scale telecommunications platforms serving wide-area, distributed medical activities such as the Euro-Mediterranean Virtual Hospital have been already successfully deployed



The passive observer group follows the exercise using passive VCON links (Surgical research Unit at http://www.rrk-berlin.de/op2000) connected to a web-based portal. Once inside the portal, passive participants have real time access to the scenario and can observe its management either as a comprehensive picture (link to the disaster control site) or at any of the selected sites (e.g. the hospital site, the disaster scene site, etc.). However, the passive participants have no control inputs and no voice communication with any other site. At the debriefing stage, the passive group will be allowed to post questions and comments using the designated web portal.

Particularly important group of passive observers that must be included in exercises are the representatives of the media. Typically, media relations are handled by public relations officers attached to the drills. The disbursed information is, therefore, indirect (prepared press releases) or based on post-drill interviews with its participants. Consequently, the subsequent reports are frequently either 'glossy', representing the idealised views of the drill, or incomplete and even misleading (see also ECRI at http://www.ecri.org/Patient_Information/Patient_Safety/RMREP603.pdf.) Yet, accurate reporting is critical during and following real events Press and TV play a major role in the dissemination of essential information among the affected population, and the news may serve either as an invaluable tool in reducing uncertainty and psychological stress, or fuel unrest and tensions beyond controllable levels. In the world where ill-founded 'conspiracy theories' are an exceedingly common phenomenon, and any governmental action curtailing common liberties (e.g. quarantine or movement restrictions) may be the potential source of unrest, appropriate training of the journalist corps should be viewed as a necessary constituent of all preparedness plans and journalist participation as an inherent and important part of readiness development rather than an evil avoided at any cost. Significantly, inclusion of journalists both in the synthetic exercises and in the physical drills may assure their appropriate behaviours during real events (Figure 5) where the professional need 'to get a story' or 'the best shot' often conflicts with the operational needs of the involved units, and introduces yet another distracting element during the already tense and complex event. The 'embedded' concept developed by the Coalition Forces during Operation Iraqi Freedom that assured unprecedented level of excellent and truthful reporting should be seriously considered also in the context of readiness training in preparation for domestic and overseas OOTW.

7.2.2 Curriculum and scenarios

The limits imposed upon the presently conducted physical drills convert them into agenda-driven evolutions. In reality, however, drills are nothing but practical education/training operations. As discussed by Lary, Pletcher and von Lubitz (2003), drills particularly in the context of readiness training, need a more elaborate foundation than a 'what, how, when and where' structure. In the context of SDRTE, the curriculum must contain the essential element of multi-agency, multidisciplinary constructs centered on realistic threat scenarios that extensively use dynamic multidimensional inputs and thus support OODA Loop-centred activities. Consequently, in order to offer complete flexibility and serve as tools in the OODA-based development of critical thinking and command skills, all scenarios must be open-ended and have no rigid internal structure other than the general outline of the initial event provided at the start of the drill. The fundamental operational paradigm of SDRTE-based training is the 'mission', that is management of disaster consequences by any means available at hand at the time disaster happens, rather than 'plan execution' since the 'plan' (e.g. King County Sheriff Office) is (typically) based on theoretical assumptions that may not be true at the time of implementation (see, for example Smith, 2004). Thus, while plans are critical for the development of preparedness, they may be less suitable for the development of readiness whose essence is the instantaneous (and correct) counteraction rather than more deliberate (and thus less dynamic) response evolution. For this reason, SDRTE scenarios need to contain a number of critical but hidden inputs that must be uncovered and their significance determined by the participants. In real situations, it is the hidden factors that exist within the operational environment that may, unless addressed, assume full control of the event evolution, and convert interventions into either entirely futile effort or even into a completely passive observation. Thus, a meticulously conceived action that has all apparent chances of success unravels instead; the plan fails to match the reality whose true nature hides from the participants and, unless discovered, moves event evolution in

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the direction that is not unanticipated and poses another layer of potentially demoralising threats.

Figure 5 ‘Tabloid-style’ TV reporting at the disaster scene. Note the intrusive behaviour of the cameraman whose presence compounds the already existing tension. Media constitute an integral part of disaster response and management, and training of journalists in appropriate behaviour and reporting is critical for accurate (as opposed to sensational) reporting of the event itself and its long-term management. Press, radio, and TV are the essential tools for rapid dissemination of information critical for the safety of the population, maintenance of law and order, panic reduction, and reduction of event-induced psychological stress. In order to assure accurate reporting during OOTW, the journalist corps must be included in training exercises as an integral part of the readiness continuum instead of operating as an outside, and not always welcome, force. Understanding of mutual requirements and close cooperation between the media and disaster containment authorities is particularly vital during often protracted consequence management stages, and can be attained only through joint training

The ‘mission’ approach to synthetic training has been successfully tested (von Lubitz et al., 2004b, von Lubitz and Levine, 2005). During the course on surgical decision-making, the trainees received a garbled (telephone call) notice of a possible skiing accident allegedly involving, two casualties. From the moment the notice was given, the participants had to determine the site of the accident, the probable nature of the injuries, response needs, the nature of on-site medical management, medically stabilise the patients, require appropriate means of evacuation, perform initial treatment and determine surgical needs of both casualties. Importantly, the scenario started without any warning, in the middle of distance training (lecture) on the management of peri-operative crises. The situational envelope of the described event is highly realistic but, more importantly, offers essentially unlimited richness of the environment that permits surreptitious introduction by Med-ASP centre of subtle alterations (confounding elements). Such alterations force the participants to shift from the algorhythmic (typical of medical training) to OODA loop-based thinking. The participants must modify their response strategy with sufficient flexibility to accommodate new developmental inputs, continue refining the ‘point of thrust’ (Schwerpunkt) accordingly, or fail. Boyd’s OODA loop (Boyd, 1987; von Lubitz and Wickramasinghe, 2005) governs the entire process and its chances of success.

Another important element of the described exercise is the very significant room for procedure and medical mismanagement sustained by the pre-programmed behaviour of the High Fidelity Human Patient Simulator (in the quoted example one machine represented a skier with multiple internal injuries and an open lower leg fracture; the other HFPS simulated a patient in the beginning stages of shock but with minimal injuries) that also introduced a ‘slow’ but very intense stressor – time. In addition to the technical aspects of managing severe trauma, the existence of time limits imposed by the nature of trauma itself imposes subliminal pressure: survival time of the severely injured patient is limited. Hence, every committed error diminishes the chance of successful rescue. In inexperienced personnel fear of making such error introduces timidity. Yet, it is such timidity that may, ultimately, the fundamental source of failure (Alexander, 2002; Smith, 2004; see also ECRI at http://www.ecri.org/Patient_Information/ Patient_Safety/ RMREP603.pdf). SDRTE-based training helps to eliminate this obstacle: it is ‘medically safe’, that is it does not endanger the life of the patient, and allows error-based learning (Richir et al., 2004). It also habituates the student to intense stress (von Lubitz et al., 2003a; Richir et al., 2004).

Vastly more complex scenarios than the one describe above and involving multiple inputs, providing a variety of stressors, and demanding complex, multi-dimensional decision-making patterns can be easily created by SDRTE. Synthetic environment opens the unique possibility for the development of open-ended settings that the typical drills cannot reproduce due to their (by necessity) highly regimented structure and the vast planning and coordination effort that take place prior to the exercise, and that (also by necessity) reveals everything. With the element of surprise lost, the only aspect of disaster management training available is that of preparedness. The surprise-based element of readiness cannot be tested.

7.2.3 General pattern of synthetic drills

Unless total surprise is required, each training exercise should be announced at least a month prior to its commencement. The announcement allows the participants to familiarise with the ‘local’ resources since, in real life, the local responders would be also fully aware of the available resources such as the available personnel, average availability of transport, traffic patterns, etc. During the pre-drill stage, the trainees must have free access to the general data such as the synthetically generated location of the event (e.g. maps or 3-D renditions of the site such as an imaginary city, size and distribution of its population, typical weather patterns), resource availability (materiel, the total number and type of the available personnel, type and number of the available facilities such as hospitals, ambulance companies, fire-fighting and police stations, railroad access, etc.) The existence of such information does not mean that all such resources are available at the time the drill takes place. For example, the availability of personnel may change, the number of hospital beds may be reduced due to recent closure, etc. It is, therefore, imperative that the synthetically generated trainee-available information is presented in a manner that either entirely precludes any possibility of guessing the nature of the forthcoming drill or promotes wrong guesses. As already indicated, the specifics of the scenario must be known, up to the very last moment, only to the personnel at the principal command centre (Med-ASP node) that handles all technical aspects of the drill.

As already described, the drill scenario should be introduced not as full-scale briefings but in the most general form (as it typically happens – a call to the EMS dispatcher or a report from a police patrol). From that point on, the trainees have to determine the nature of the event, allocate resources, deal with the casualties, and face unpredictable events. The evolution of the scenario itself is fully automatic and subject only to the input from the trainees. Consequently, the outcomes depend entirely on the executed actions (or their absence) and on the correctness of the employed measures. The result of the drill is unknown to all participants, including the observers at the Med-ASP centre, and the 'pre-determination' factor completely eliminated.

The important aspect of the synthetic drills is the ease with which 'No Prior Warning' and 'Just-in-Time' exercises can be conducted (Figure 6) The only requirement is the presence of all relevant participants which can be accomplished by gathering them in the electronic space for a relevant but completely drill-unrelated activity such as debriefing, lecture and so on. 'No Prior Warning' drills increase the need for improvisation – typically present experts may be unavailable, the level of uncertainty increases significantly, and the magnified element of 'fog of war' enhances the stress level (a 'no warning' readiness test has been used at a major international conference (von Lubitz et al., 2004b, von Lubitz and Levine, 2005). Its results indicated profound lack of readiness in response to a bio-terrorism event).

It must be stressed that during the entire exercise the principal command (Med-ASP) centre is entirely 'mute', and serves only as a relay station and observation site. The centre has no influence on the conduct of the operational management of the 'disaster.' However, it is the only site that can generate and introduce without warning all stressors and unpredictable events (e.g. logistic problems, infrastructure collapses, adverse medical events, etc.) In parallel to the military operations, Med-ASP acts as the 'opposing force' (OPFOR) whose specific actions, while subject to anticipation and prediction, remain unknown until the moment they take place. Med-ASP may choose to remain entirely silent. It may also choose to interact stealthily and unpredictably, confuse, and attempt to mislead. It is the site that generates 'fog of war'. The other major task of the principal command centre is administration of the exercise: the centre tasked with monitoring, recording, and quantitative data collection. Following the exercise, the personnel at the principal control centre is also in charge of debriefings, data analysis and dissemination, and generation of all pertinent reports.

8 Conclusions

The data collected during the operation of a small scale, experimental network indicate that the development of synthetic, distributed, remotely accessible, and fully interactive readiness training platform (SDRTE) is entirely feasible. The same data also indicate that the practical use of such network provides an ideal environment for highly realistic readiness training of 1RP. Importantly, drills conducted in the synthetic space are less disruptive of the normal activities of the participants who join on-line rather than by travelling to the drill site. In summary, the wide-area, distributed nature of S-DRTE and its remote interactive access and operability permit unprecedented flexibility in training at the community/state/interstate/national and, if needed, international levels. Other significant benefits of SDRTE are:

∉ Operational scaleability enabling multi-agency participation.

∉ Creation of remote SDRTE access sites at a small community level requires minimal establishment and operational funds.

∉ Significant decrease of inter-training intervals, increase frequency of individual team rotation, and facilitation of the operational integration of multi-agency teams.

∉ Easy and rapid creation of multiple synthetic inputs necessary for the realism and dynamism of training, and for the effective development of the OODA loop-based operational skills.

∉ Ease and speed of scenario creation and testing that enables mid-action modifications.

∉ Easy introduction of fast and slow-acting confounding elements necessary for the enhancement of drill reality.

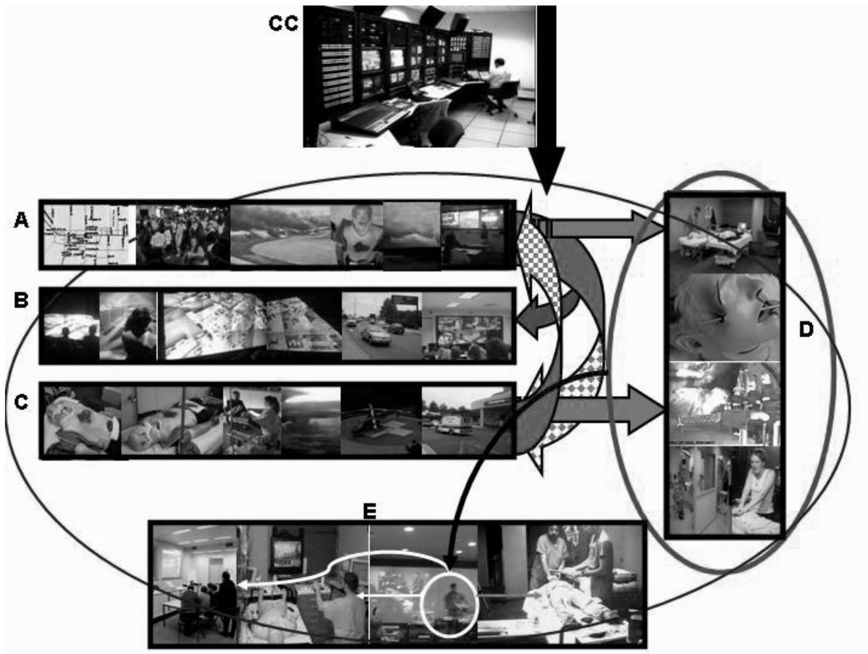
∉ Rapid and easy generation and conduct of 'just-in-time training' that is not possible in the classical drill setting.

Cost is an important factor in setting up physical drills, and is among the major factors contributing to the relatively sporadic nature of even moderately complex drills. Shifting the emphasis of training from physical to synthetic environments such as the one provided by SDRTE can lead to a substantial reduction of the fiscal burden. At present, any attempt to increase the frequency of physical drills needed to sustain adequate preparedness/readiness level causes concomitant elevation of the resource demand. On the other hand, the expenditure related to the frequent, routine operations of SDRTE will remain essentially stable. Once created, the network requires periodic upgrades in order to benefit from the latest available technologies. However, due to its inherent scaleability and distributed nature, the expansion of the network will be vastly cheaper than any other attempt at making realistic, high quality training available to the continuously increasing number of the First Responder personnel. After all, the price of telecommunications and technology decreases steadily.

The advantages of the SDRTE network are evident, particularly in the context of ultra-complex, multi-agency training. Still, there is no doubt that SDRTE and the synthetic drills it supports will not substitute for the physical ones – nothing, most likely, ever will. SDRTE-based training will, however, play a critical role in the preparation for the 'foot-on-the-ground' activities that are critically needed in the context of all preparedness-related issues. VR will not substitute for the experience-based ability to operate a water canon in the heat of the burning oil well. On the other hand, the readiness aspect of 1RP and their OOTW training – the instantaneous ability to assume control of sudden, fluid, and complex situations, the 'OODA Loop thinking' – can be best developed and practiced in the synthetic environment.

Figure 6 Practical SDRTE drill of responses following a collision between a passenger and freight trains close to a small (population 6.000) town. Initial assessment of the derailment site indicates both the presence of a large number of casualties and major spill of toxic load carried aboard the freight train ('A'). Management of the derailment site requires multi-agency cooperation (EMS, law enforcement, NTSB, etc., depicted in row 'B'). Several casualties require immediate air evacuation that may become impossible due to the approaching adverse weather (slow confounding element). Hence, alternative methods of either transport or on-site medical assistance need to be rapidly implemented ('C'). The small local hospital begin to receive casualties ('D') but their surge capacity is very limited (fast confounding element) Hospital management and physicians must either decide on ground transport to alternative locations that has the potential for further loss of lives. or restructure the typical patient flow and resource disposition. The latter may result in less than optimal patient care and endanger the patients. In an effort to avert legal possible consequences, hospital management attempts to force physicians to agree to transfer less severely injured to distant, alternative facilities (fast confounder). That decision puts major stress on the already strained local EMS and necessitating either mobilisation of distant resources (patient transfer delays or local improvisation (fast and slow confounders and decision-making conflicts). In addition to the urgent medical issues, the variable winds associated with the approaching weather front begin to blow the toxic fumes over parts of the city (fast confounder) requiring possible evacuation of the inhabitants. If the evacuation decision is made, due to the local traffic patterns the movement in and out of the city may become chaotic. This may, in turn, affect movement of casualties to other facilities, slow down arrival of support units from the outside (decision-making conflict affecting several agencies). Etc.

A physical drill of such scenario (it must be remembered that almost identical events have taken place) and its management would be not only very expensive, but also entirely predetermined due to the substantial lead time needed to prepare all participating components. Such preparation eliminates every surprise element, converts the evolution into a rehearsal of a 'stage show', and its results are spurious in the context of readiness. Yet, they may result in a false perception of safety. The use of SDRTE eliminates most of these drawbacks, and allows introduction of several critical elements (unpredictability, confusion, adverse events and interactions either as fast occurring or slow, creeping events). The result is a realistic rendition of real life interactions and their almost chaotic complexity (indicated by arrows among the individual components of the drill). The drill, conducted in virtual space, is managed by the central command centre ('CC') whose 'surreptitious' involvement and control of that space (indicated by the large oval surrounding the drill space) permits introduction of the confounding elements in a manner as they always occur – suddenly, without warning, and in a way that alters most of the solutions devised under more benign operational conditions of the traditional drills. The example shows the ideal suitability of the synthetic environment for training based on the OODA Loop rather than the typical algorhythm-based thinking



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