NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

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STO TECHNICAL REPORT **TR-HFM-257**

Modelling and Simulation Technologies for Training Medical/Healthcare Professionals

(Technologies de modélisation et simulation destinées à la formation des professionnels médicaux/de santé)

Final Report of Task Group RTG-HFM-257.

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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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List of Acronyms

AI	Artificial Intelligence
ASC5	Advanced Systems Concepts #5
COE	Centre Of Excellence
DOD	U.S. Department Of Defense
HFM	Human Factors and Medicine
I/ITSEC	Interservice/Industry Training, Simulation and Education Conference
JETS	Joint Evacuation and Transport Simulation
M&S	Modelling and Simulation
MILMED	Military Medicine
NDIA	National Defense Industrial Association
NIAG	NATO Industrial Advisory Group
NTSA	National Training and Simulation Association (U.S.)
RTG	Research Technology Group
STEM	Science, Technology, Engineering, and Math
STO	Science and Technology Organization

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Modelling and Simulation Technologies for Training Medical/Healthcare Professionals

(STO-TR-HFM-257)

Executive Summary

Modern military medicine has extensive training requirements to prepare healthcare professionals at all levels for the unique demands of combat medicine and peacekeeping missions, especially in Joint, Multi-National, and Multi-Domain Environments. Advancements in Modelling and Simulation (M&S) technologies are accelerating and their applications to medical education and training are becoming more common. The main objective of RTG HFM-257 is to explore and assess the use of modelling, simulation, and related technologies to develop medical training and education applications for medical professionals.

HFM-257 focused on assessing ways to use M&S tools to prepare medical professionals prior to deployment to recognize and cope with combat casualty care issues, improve their abilities to perform under highly stressful conditions, and function effectively as teams.

This report describes three separate but related efforts, all contributing to knowledge and understanding of current M&S technologies and applications. The first is a comprehensive assessment for the Joint Evacuation and Transport Simulation (JETS) system, completed to support a future simulation program for patient-movement training. The second effort describes Models for Surgical Training and Tactical Combat Casualty Skills, which lays out options for utilizing a simulated scenario followed by effective feedback and debriefing. The third section is the HOSPEX Tabletop Exercise, which originated in the United Kingdom and focuses on important aspects of medical management of the sick and wounded as casualties pass through the medical chain of evacuation.

Modelling and Simulation are important components of training for all personnel within the current and future survival chain who provide medical care on the battlefield, through evacuation, or at hospitals. Validation studies need to be conducted on currently available simulation technologies, and metrics for accurate assessment of learning need to be developed. Collaboration within the medical community and across NATO is important to realize benefits from future advancements in training technologies. In order to achieve these goals, the NATO Modelling and Simulation COE should be leveraged to produce a strategic plan to support current and future medical simulation and training needs.

Given the international activities of the simulation industry, NATO is strategically placed to leverage national expertise and devise innovative strategies, validated for safety and efficacy, for using M&S tools to teach healthcare professionals about medical treatments and associated psychological health issues.

Technologies de modélisation et simulation destinées à la formation des professionnels médicaux/de santé

(STO-TR-HFM-257)

Synthèse

La médecine militaire moderne impose une formation complète des professionnels de santé à tous les niveaux, pour qu'ils répondent aux exigences uniques de la médecine de combat et des missions de maintien de la paix, en particulier dans les environnements interarmées, multinationaux et multidomaines. Les progrès des technologies de modélisation et simulation (M&S) s'accélèrent et leur application à l'éducation et la formation médicales devient plus courante. Le principal objectif du RTG HFM-257 était d'étudier et évaluer l'utilisation de la modélisation, la simulation et les technologies liées pour développer des applications de formation et d'éducation médicales destinées aux professionnels de la médecine.

Le HFM-257 s'est concentré sur l'évaluation d'utilisations des outils de M&S pour préparer les professionnels médicaux avant leur déploiement, de sorte qu'ils sachent reconnaître et faire face aux problématiques de soins des blessés en zone de combat et fonctionnent efficacement en équipe.

Le présent rapport décrit trois travaux distincts, mais liés, tous contribuant à la connaissance et la compréhension des technologies et applications actuelles de M&S. Le premier travail est une évaluation complète du système de simulation d'évacuation et de transport interarmées (JETS), qui a été réalisée à l'appui d'un futur programme de simulation pour la formation au déplacement des patients. Le deuxième travail décrit les modèles de formation chirurgicale et les compétences de premiers secours tactiques, ce qui établit les options d'utilisation d'un scénario simulé, suivi d'un retour d'expérience efficace et d'un debriefing. Le troisième travail est l'exercice sur table HOSPEX, qui provient du Royaume-Uni et se concentre sur les aspects importants de la gestion médicale des malades et des blessés lorsque les patients sont pris en charge dans la chaîne médicale d'évacuation.

La modélisation et la simulation sont des éléments importants de la formation de tout le personnel au sein de la chaîne de survie actuelle et future qui fournit des soins médicaux sur le champ de bataille, par le biais de l'évacuation ou dans les hôpitaux. Il faut mener des études de validation des technologies de simulation actuellement disponibles et mettre au point des indicateurs d'évaluation exacte de l'apprentissage. La collaboration au sein de la communauté médicale et dans l'OTAN est importante pour tirer les bénéfices des futurs progrès des technologies de formation. Afin d'atteindre ces objectifs, il convient d'utiliser le Centre d'excellence du Groupe OTAN sur la modélisation et la simulation pour produire un plan stratégique soutenant les besoins actuels et futurs de la simulation et la formation médicales.

Étant donné les activités internationales du secteur de la simulation, l'OTAN occupe une place stratégique qui lui permet d'utiliser l'expertise nationale et de concevoir des stratégies innovantes, dont la sécurité et l'efficacité sont validées, afin d'utiliser les outils de M&S pour former les professionnels de santé aux traitements médicaux et aux problèmes associés de santé psychologique.

Chapter 1 – INTRODUCTION

Jan Harris
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1.1 INTRODUCTION

Advances in Modelling and Simulation (M&S) technologies for education and training are accelerating and their applications to medical education and training are becoming more common. While the medical/healthcare community has been a recent entrant into the M&S world, they are pushing new capabilities into use at an accelerated pace at major M&S medical simulation centers. Portable devices that can be used for training as well as job performance aiding are also being developed.

Note: HFM-257 falls under 2016 NATO Science and Technology Priority ASC-5 Integrating Live and Simulation Systems: integration of operational, experimental, and simulated systems for purposes such as training and exercises, as well as concept development and experimentation (e.g., distributed simulation). Particular attention was given on interoperability of distributed systems (e.g., standards, architectures, and services) with multi-user/multi-echelon interactive capabilities.

1.1.1 Objective

The primary objective of this RTG was to explore the use of modelling, simulation, and related technologies to develop and assess medical training and education applications, with emphasis on the training of healthcare professionals. The optimal platform for delivering these capabilities depends on the needs of the user; portable, hand-held delivery systems and hospital-based systems can all provide some degree of capability. Collaboration across healthcare disciplines is needed to determine the current and future state-of-the-art and then to help users determine which delivery system and M&S technologies best support the capabilities required.

1.2 BACKGROUND

Both the NATO education and training communities and the Science and Technology Organization (STO) are emphasizing the broad-based use of M&S for training and education. Based on the establishment of the Medical Centre Of Excellence (COE) in Budapest, it became obvious that a broad-based, M&S-focused RTG was needed to assist with the varied uses of M&S for medical and healthcare education and training. The NATO COE is focusing on standards, interoperability, and performance measurement metrics, all of which are an integral part of this RTG.

NATO recognizes that the use of models and simulations are necessary across both civilian and military domains to refresh skills, test competencies, and provide training to austere and remote environments. The goal is to provide valid simulations of humans that can be used for just-in-time rehearsal and provide immediate information on high-fidelity mobile devices. Military medical M&S provides the unique opportunity to train combat casualty life-saving skills that are not usually relevant or available in the civilian healthcare system and are often provided as on-the-job training in combat zones or during humanitarian relief efforts. A collaborative effort among the NATO Alliance is needed to identify technology gaps and areas of collaboration for high-payoff research investments.

With the development of valid representations of the human patient, we now have the opportunity and responsibility to provide ethical, less expensive, more flexible, scalable training and education capabilities,

including eliminating the use of animals for medical education and training. Rapid advances in M&S have created the ability to develop medical outreach tools using the latest computer graphics, natural language processing, web content, and artificial intelligence technologies. Using these methods, M&S provides the means to educate military personnel about the impact of physical and psychological injury. Although M&S can significantly influence the next generation of healthcare training, education, outreach, and advocacy, extensive attention to educational design principles, human factors issues, and rigorous validation is needed to assure that platforms are both safe and efficacious. Evaluation of performance outcomes is a critical focus.

The main objective of this RTG was to explore and encourage the use of modelling, simulation, gaming, and related technologies to develop medical training and education applications, with emphasis on training healthcare professionals, educating the warfighter in the field, and educating their families at home. A secondary objective is to explore the challenges of using this approach to tackle traditional training issues for healthcare providers.

The optimal platform for delivering these capabilities depends on the needs of the users; portable, hand-held delivery systems as well as hospital-based systems provide some degree of capability. Collaboration across disciplines is needed to determine the current and future state-of-the-art and help users determine which delivery system and M&S best meet the capabilities required.

HFM-257 focused on the first task in its Terms of Reference, Military Unique Training for Medical Professionals. Modern military medicine has extensive training requirements that prepare healthcare professionals at all levels for the unique demands of combat medicine and peacekeeping missions, especially in Joint, multi-national, and multi-domain environments. These include different patterns of injury and combinations of injury, and adaptation to care in tactical and austere environments. Advancing beyond the use of animals through the use of more suitable simulation technologies will potentially improve outcomes and eliminate an ethical quandary. Additionally, healthcare professionals need to be adequately trained in pre- and post-deployment issues related to psychological health. Medical professionals also face unique stresses in both traditional warfare and peacekeeping missions. They need to be prepared prior to deployment to recognize and cope with combat casualty care issues, improve their abilities to perform under highly stressful conditions, and function effectively as teams.

1.3 REVIEW OF OTHER EFFORTS

There is an increasing emphasis on M&S for healthcare within the US Department Of Defense (DOD) and across NATO. Part of HFM-257's task was to identify who was working on M&S projects, including the NATO Training Group and the NATO Modelling and Simulation COE. The RTG worked with the M&S COE in Budapest and Rome, Bundeswehr Medical Academy and Centre of Excellence for Military Medicine (MILMED), the Lithuanian University of Health Sciences Extreme Medicine Department, and the NATO Industrial Advisory Group (NIAG). Additionally, RTG members evaluated the activities of related RTGs (see Section 1.5).

1.4 HFM-257 ACTIVITIES

In 2014 the NATO HFM RTG decided to merge two previous Science and Technology efforts. One effort, HFM-215, focused on the use of M&S for medical training and the second focused on the mobile aspects of the same topic. It was believed that by merging them into one integrated Research Technology Group (RTG), NATO could provide NATO Human Factors and Medicine (HFM) with an RTG that meets many of the needs for medical and healthcare education and training, while reducing the number of meetings and trips needed for meaningful coordination and collaboration within the NATO Alliance.

The new RTG, HFM-257, was approved in 2014 and held its first meeting in Nov 2015. It held seven meetings, with the last in April 2018, and participated in three site visits.

1.4.1 RTG HFM-257 Meetings

3 – 5 November 2015: Inaugural Meeting, Paris France

Inaugural meeting of the RTG endorsed by NATO HFM in 2014, to outline current national and NATO initiatives in military medical training using simulated environments, define future requirements, and develop an action plan, networking and linkages. The participants from each country discussed their country's priories as related to the RTG objectives. Several RTG members felt that many of the smaller NATO countries are unable to afford expensive high-tech training and that the RTG needed to look for applicable low-tech and low-cost medical training technologies.

9 – 11 May 2016: NATO Centre of Excellence for Military Medicine, Budapest, Hungary

Meeting in Budapest with representatives from the MILMED COE to discuss Modelling and Simulation in medical collective training and to hear presentations about the MILMED COE. Topics included discussion of HFM-257 objectives and potential interactions between the MILMED COE and HFM-257, use of M&S already available for medical training, existing simulation centers, interoperability issues, need for standardized instructional approach and assessment, development of an accepted and comparable system of indicators of performance and best practices for deployed medical systems, parallel and complimentary efforts, and lessons learned from MILMED COE exercises.

A few months after the MILMED COE meeting, the MILMED COE received a new commander and the representative from the MILMED COE to HFM-257returned to his home country. The Chair of HFM-257 was unable to secure another representative from the MILMED COE.

11 – 12 May 2016: NATO Modelling & Simulation Centre of Excellence, Rome, Italy

Meeting included a site visit to the NATO M&S COE. COE members provided an overview of the COE's capabilities and activities. The RTG discussed NATO Community of Interest for M&S, NATO responsibilities vs the responsibilities of each Nation, and best practices in medical education. The NATO M&S COE does not currently support any medical activities but their 2015 GAP Analysis Report on Modelling and Simulation in support of Military Training did identify both individual and collective medical support gaps which could potentially be addressed in the future.

28 Nov – 3 Dec 2016: Interservice/Industry Training, Simulation and Education Conference, Orlando, Florida

The Interservice/Industry Training, Simulation and Education Conference (I/ITSEC) is the world's largest modelling, simulation, and training conference. The conference consists of peer-reviewed paper presentations, tutorials, special events, professional workshops, a commercial exhibit hall, a serious games competition, and STEM events for teachers and secondary students. I/ITSEC is organized by the US National Training and Simulation Association (NTSA), which promotes international and interdisciplinary cooperation within the fields of M&S, training, education, analysis, and related disciplines. The NTSA is an affiliate subsidiary of the National Defense Industrial Association (NDIA). Hence, I/ITSEC also emphasizes themes related to defence and security.

Attendance at the conference by RTG members provided an opportunity to learn about cutting-edge technologies that could be leveraged for military medical training. The Chair of HFM-257 attended the exploratory meeting for 268, Cross-RTG Activity on Synthetic Environments for Mission Effectiveness Assessment. The central idea behind this multi-disciplinary Technology Team is to establish an inter-RTG activity on synthetic environments for assessment of mission effectiveness. As the RTG progresses, they will discuss the addition of application areas/cases as well as other RTGs. Following the conference, the HFM-257 members met to discuss lessons learned from the conference and the applicability to the HFM-257 report.

28 – 30 Mar 2017: Bundeswehr Medical Academy, Munich, Germany

The HFM-257 meeting discussed:

1) Design and delivery of effective simulation-based medical education to an inter-professional audience in garrison and in the field;
2) Learning objective theory, matching of simulation modality to learning objective, facilitator training, debriefing training, and information management during exercises;
3) Augmented, mixed and virtual reality simulation; and
4) Capability gaps identified during the International Medical Modelling and Simulation workshop.

The RTG meeting was held in conjunction with the NATO MILMED COE: Centre International Medical Modelling and Simulation workshop, which included presentations by subject matter experts from NATO nations on Military Medical Modelling and Simulation capabilities and capability gaps. Participation with this workshop allowed the HFM-257 members to further define simulation and training needs from NATO countries. The need to evaluate less expensive training modalities was also discussed.

18 – 20 Apr 2018: Lithuanian University of Health Science Extreme Medicine Department, Kaunas, Lithuania

A site visit to the Lithuanian University of Health Sciences Extreme Medicine Department to gain an understanding of how the HybridLab System is being used to support trauma education and training. Participants also discussed sharing emergency medicine training algorithms developed by Lithuanian emergency physicians. The goal was to determine the feasibility of utilizing the algorithms with or without the HybridLab for trauma training within NATO countries.

Participants also attended the Lithuanian Conference for Emergency Medicine 18 – 20 April. The conference topics include Future of Emergency Medicine in the World, Europe, and Lithuania; tactical emergency medicine; ketamine for analgesia and sedation; lidocaine for pain management; and emergency care in trauma.

17 – 19 May 2018: Bundeswehr Medical Academy and Centre of Excellence for Military Medicine, Stuttgart, Germany

A NATO Medical Simulation Symposium in conjunction with the US Program Executive Office for Simulation, Training, and Instrumentation, Bundeswehr MILMED COE multi-national military medical symposium on the topic “International Military Medical Simulation Requirements and Solutions: Building Alliances and Interoperability”. The keynote speaker was from Germany, Commandant of the Bundeswehr Medical Academy, Major General (MC) Dr. Gesine Krueger. Dr. Harris also provided a presentation on advances in medical simulation science and technology research. Participation provided HFM-257 members an understanding of simulation and training needs from a representative sample of NATO countries.

Multiple Video Conference Meetings

Dr. Janet Harris, Chair of HFM-257, held multiple telephone/video conference meetings with RTG members to plan future meetings and discuss the report contents. The final video conference was held on 2 April 2020 to finalize edits on the HFM-257 report, discuss required Form 13 clearances, and obtain concurrence on the report.

1.5 SCOPE CHANGE

Several other NATO RTGs are working on topics related to the objectives of HFM-257. A concurrent NATO effort, RTG HFM-258: Impact of Military Life on Children from Military Families, chaired by Alla Skomorovsky (CAN), addressed families. In order to reduce duplication between efforts, senior leadership directed HFM-257 to eliminate Medical Education and Training M&S Tools for Military Personnel and Families as an objective.

The main objective of another concurrent NATO RTG, HFM-279: Leveraging Technology in Military Mental Health, is to identify and validate technologies that will advance psychological health and mental healthcare provision within military populations.

HFM-297, RTG: Assessment of Augmentation Technologies for Improving Human Performance is assessing new and emerging augmentation technologies from state-of-art to state-of-practice for training and operations within the NATO Alliance nations. The main objective is to assess the effect of new and emerging system interaction capabilities for individuals and units on learning, retention, performance and transfer, and their ability to manage cognitive load and the time/cost to reach a required level of competency.

A cross-RTG activity, RTG-268: Synthetic Environments for Mission Effectiveness Assessment, is a multi-disciplinary Technology Team to establish inter-RTG activity on synthetic environments for mission effectiveness assessment.

As HFM-257 members worked through the scope of research laid out in the Terms of Reference, it became clear that it was too broad for one RTG. Additionally, ongoing activities of other NATO RTGs are focusing on some of the objectives within HFM- 257. Therefore, the members decided to focus on Military Unique Training for Medical Professionals as the highest priority for NATO countries, and the Chair notified the RTG Coordinator.

1.6 TG OBJECTIVE RESULTS

Within the scope of the priority objective (to explore the use of modelling, simulation, and related technologies to develop medical training and education applications, with emphasis on the training of healthcare professionals), the RTG addressed the subsidiary frames of reference shown in the RTG HFM-257 Terms of Reference [1].

Identify performance metrics related to assessing effectiveness of medical simulation platforms (e.g., rehabilitation, e-Health, education).

Metrics depend on the material and context of the training, and the RTG decided not to address Education and Training Performance Metrics separately. Additionally, RTG-268 is evaluating synthetic environments for assessment of mission effectiveness.

Determine philosophy of and appropriateness of Serious Games for medical M&S for education and training.

The RTG was unable to study this field in depth. Gaming technologies to support medical training are in their infancy. The successful development of medical simulations on gaming platforms will require advances in artificial intelligence, emotive computing, animation, voice recognition, human factors, and a variety of other areas. This area should be revisited in the future when the technology is more fully developed.

Assess state-of-the-art and international scope of medical M&S development.

See Chapter 2: Assessment Report for the JETS Areas of Research.

Explore civilian simulations and games for health which might be leveraged for military medical applications.

See Chapter 3: Models for Surgical Training and Tactical Combat Casualty Skills and Chapter 4: HOSPEX Tabletop Support Package.

An additional chapter, Simulation to Support Damage-Control Surgery, was developed by Colonel Dominique Mayer and Lt Col Axel Ziegler (Germany). The report is currently being translated into English but was unavailable at the time this report was finalized.

Identify short and midterm technology gaps related to medical simulation and training effectiveness such as artificial intelligence, facial animation, emotive computing, voice recognition, and other critical applications.

See Chapter 2: Assessment Report for the JETS Areas of Research.

Summarize Human Factors and Medical challenges and standards to support the effective design and objective evaluation of traditional and simulation technologies in defence and civilian medicine.

Maj Kathleen Doyle and Lt Col Bethann D. Meunier (Canada) agreed to address this. The HFM-257 Chair was unable to contact them to get their chapter.

Identify technology gaps and areas for collaboration and additional investment and develop strategic roadmap.

See Chapter 2: Assessment Report for the JETS Areas of Research.

1.7 SYNOPSIS OF CHAPTERS

Chapter 2: The Assessment Report for the Joint Evacuation and Transport Simulation (JETS) Areas of Research covers the current and projected technologies that offer integrated training at permanent and deployable training centers. The report covers M&S areas such as patient surrogates, moulage/simulated tissue, holography and augmented reality, haptics/tactility, and artificial intelligence and machine learning. The technologies supporting the enabling capabilities covered under JETS are also applicable to other areas of medical training.

The use of patient surrogates is explored further in Chapter 3.

Chapter 3: Models for Surgical Training and Tactical Combat Casualty Skills focuses on the need for and the development of more realistic synthetic models to generate improvements in future medical surgical training. The chapter aims to review the current state-of-the-art, future directions, and innovations to:

- Train surgical skills;
- Refresh or maintain skills;
- Exercise triage; and
- Rehearse medical evacuation processes.

Chapter 4: The HOSPEX Tabletop Exercise was developed by Colonel David Vassallo, United Kingdom Defence Medical Services, for internal unit training prior to full-scale exercises or deployment. Michaël Leenhouwers and Huub Curvers (Netherlands) developed a training package to facilitate use of HOSPEX Tabletop Exercise as a low-tech training technique for small countries and austere environments.

Chapter 5: Chapter 5 presents conclusions and recommendations for future study.

Chapter 2 – ASSESSMENT REPORT FOR THE JETS AREAS OF RESEARCH

Dr. Beau Freund, Edie Wiarda, Brian Tell, and Todd Daniels
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UNITED STATES

SURVEY OF CURRENT AND EVOLVING ENABLING CAPABILITIES TO SUPPORT JOINT EVACUATION AND TRANSPORT SIMULATION (JETS) REQUIREMENTS

Original Report Date: 31 October 2018
Version 1.1 Date: 28 February 2020
Excerpts from Version 1.1

This report covers seven key Enabling Capability Areas that will drive the JETS program work across four technology infusion Increments over the next 20 years. The assessment was conducted for JPC-1 by MilTech, a Partnership Intermediary located at Montana State University. Assessment Methodology, findings from Subject Matter Experts, and Analysis are presented.

2.1 INTRODUCTION

The U.S. Army Medical Research and Materiel Command's (USAMRMC) Joint Program Committee-1 (JPC-1) is developing the Joint Evacuation and Transport Simulation (JETS) system. The competing missions of war, beneficiary care, homeland security, natural disaster response, and medical response training have put huge demands on the military medical service, with training opportunities falling short in offering adequate preparation for the duties required to support the Joint evacuation and transport mission. The effect of these shortfalls is a lack of a compatible, interoperable, standardized, and cohesive mission approach to sustain and protect the health of the American Warfighter [1].

The Joint community (Navy, Army, Air Force, Marine Corps, Special Operations, Coast Guard, and others) must bridge this gap with new capabilities and technologies that offer integrated training modalities at permanent, mobile, and deployable training centers with distributed training in virtual environments, providing collaborative and individual learning. In 2007, the Joint Training Functional Concept (JTFC) was developed to allow "any individual, unit, or staff to train anywhere, anytime, on any skill, system, or mission" to meet DOD needs [3].

JETS will be the key enabler of the JTFC. JETS is a System of Systems (SoS) whose sole purpose is to provide a standardized, integrated, scalable, state-of-the-art Global Patient Movement (GPM) and Joint Patient Movement (JPM) training platform, incorporating formal education, training, exercises, and other teaching methods[2]. JETS will deliver modular training sites that enable individual, team, and unit training

[1] For more information on the gap analysis, see Initial Capabilities Document for Joint Force Health Protection, 24 February 2010 [2].

[2] The Key Performance Parameters (KPPs), Key System Attributes (KSAs), and Additional Performance Attributes of the JETS system are set out in the Capabilities Development Document for Joint Evacuation and Transport Simulation (JETS) System, 21 June 2018 (JETS CDD) [4].

of patient movement tasks covering the complete chain of evacuation, throughout the full Continuum of Care. It will provide distributed, global, Point of Demand (PoD) training, linking training centers and Warfighters around the globe, available 24 hours a day, 7 days a week, and 365 days a year.

The JETS Final Objective Capabilities (FOCs) are highly advanced and may be beyond the capabilities of technology that is currently available in academia and industry. Achievement of FOCs will require multiple technology insertions and capability upgrades (Increments) over an anticipated period of 20 years.

2.1.1 The JETS Taxonomy

The JETS taxonomy, as laid out in the JETS Capabilities Development Document (CDD), names the constituent parts that together make up the JETS whole. The Taxonomy makes use of a standard set of terms for referring to the hierarchy of those constituent parts:

- Systems: Operations and Support:
  - Subsystem – 6 subsystems:
    - Component – 34 distinct components:
      - Capability – 94 distinct capabilities.

2.1.1.1 JETS' Constituent Systems and Subsystems

The JETS CDD includes overviews of the Operations and Support systems that provide helpful orientation for this report. Quotes in the paragraphs below are directly from the JETS CDD, which also gives further detail at the subsystem and component levels[3]:

- Operations System. This system consists of a Component defined and operated subsystem for each Component (e.g., Navy, Army, Air Force, Marine Corps, SOCOM, and others) that has a bi-directional communication capability (through the Support system) across each Component subsystem. Each Component subsystem will support and enable the cross cutting functions of Global/Joint Patient Movement, such as: en route care; communications; patient evacuation, hand off, movement control; global patient management, teamwork; logistics; Command and Control (C2); mission planning and rehearsal; and inter-Component qualifications across all DOD Components, inter-Governmental and Coalition Partners. The Operations System is further integrated with, and supported by, the Support System and made up of the unique capability subsystem and common capability subsystem.

The Operations System has two subsystems, the Common capability subsystem, and the Unique capability subsystem. The distinction recognizes that many of the activities and training content associated with the Components is essentially identical (e.g., training on how to insert an airway tube). Such shared content is held within the Common subsystem. Many activities and training content remain specific to the needs of particular Components (e.g., Navy needs for ship-ship/ship-shore/shore-ship transfers); these fall under the Unique subsystem:

- Support System. This system is standardized across the JETS platform … [and] provides necessary support required to operate the JETS [System of Systems]. It is an integrated system that provides support to the Operations System by obtaining the data to enhance training transfer and outcomes. This Support System utilizes the data obtained from the Operations System to inform users, trainers, and leaders with future decision and planning.

[3] Note that the JETS CDD distinguishes between two uses of the word "component." When capitalized, "Component" refers to DOD services branches (Army, Navy, etc.); lower-case "component" refers to one level of the JETS taxonomy as described above.

Four subsystems make up the Support System: The Virtual Patient subsystem (VPS), the Instruction Support Subsystem (ISS), the Medical Training – Command and Control (MT-C2) subsystem, and the Medical Training Evaluation and Review (MeTER) subsystem.

2.1.1.2 JETS Increments

As noted above, JETS is envisioned as a long-term development effort spanning at least 20 years. Four distinct stages of implementation and modernization, or Increments, are anticipated. Important development milestones that distinguish the Increments as described in the JETS CDD are as follows:

- **Increment 1:** "leverages existing DOD Component capabilities. [It] fields new training capabilities to existing training sites and integrates them" through a Point of Demand (PoD) portal for distributed users.
- **Increment 2:** "attains Initial Operational Capability (IOC) by standardizing existing training sites, fielding the PoD training management site, and standardized Operations and Support systems. Delivers fully automated components."
- **Increment 3:** "fields … new training sites and full global PoD capability to the user where, when and on the device of choice the User needs…. [Incorporates] force feedback haptics, semi-autonomous, remotely morphing, smart components."
- **Increment 4:** "attains Full Operational Capability (FOC)… [and] provides seamless and fully immersive PoD and training center integration, fully autonomous, auto-morphing, 360-degree force feedback haptics, embedded [Artificial Intelligence], … [and] intelligent components, … [Delivers human-like surrogate patients,] fully replacing live tissue training."

The JETS CDD contains further detail on required capabilities sought at each Increment and how these relate to particular JETS subsystems and components.

2.1.2 Assessment Objectives

This research was conducted to support JPC-1's Materiel Development Decision (MDD) brief and entry into the Acquisition Framework. Assessment is a statutory requirement during the Material Solution Analysis phase, prior to Milestone A. This assessment is a step that sets the stage for a continuing life-cycle process of seeking information on relevant solutions available in academia and industry.

The objectives of the assessment are to:

- Assess the current/near term ability of academia and industry to deliver capabilities necessary for achievement of JETS program objectives.
- Assess the likely development timelines for capabilities that are necessary to JETS objectives, but not yet available.
- Compare these capability timeline projections against the needs of planned JETS technology infusions/Increments.
- Identify capabilities at risk in the timeframe needed to meet JETS objectives and identify the JETS components most likely to be affected.
- Map SME findings about the risks associated with capabilities to particular JETS system components.
- Develop recommendations for continuing assessment and technology analysis.

This report is also intended to be used as input to Science and Technology (S&T) strategy development and future life-cycle planning for the JETS program.

2.2 METHODOLOGY

This section outlines the considerations that went into the selection of appropriate methods for meeting the assessment objectives and provides an overview of the selected approach. Details are provided in the Research Activities sections that follow.

2.2.1 Considerations in Methodology Design

Four considerations drove the selected methods and approach:

1) Most critical was the need to assess industry's *future* ability to deliver *future* capabilities, capabilities that in some cases will not be needed by JETS until Increment 4. The research required data sources and analysis that would yield credible, long-range forecasts.

2) Also important was the recognition of the sheer scale and ambition of the JETS effort, and the consequent huge number of potential contributing technologies. The desired approach would yield rapid and effective synthesis of vast amounts of information across many technology domains. These include several technical areas mentioned explicitly in the JETS CDD: robotic manikins; controlled material "morphing" (shape and appearance change); artificial intelligence and machine learning; and the full spectrum of Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), potentially combined with holography and haptics, to create realistic training environments and optimal learning effectiveness.

3) Another factor was the recognition that technical solutions to JETS objectives might well come from industries that are outside the usual medical simulation and DOD "orbits." An accurate assessment of the likely availability timelines for key capabilities must include a scan of developments in sectors such as automotive (where autonomous vehicles are making massive strides in highly-sensored networks combined with Artificial Intelligence), aerospace (traditionally an early adopter of simulation for pilot training and now an early user of AR for training assembly technicians), and manufacturing automation (the driver behind developments in "soft" robots that interact directly with humans, and in the "Internet of Things" (IoT) for factory control.)

4) A final consideration was the need to draw conclusions at the level of JETS system components. JETS contains 34 distinct components, with widely-varying technical and organizational content. A separate study for each of the 34 was infeasible. The desired methodology would allow JPC-1 to draw conclusions at the component level but reach those conclusions by means of a broader framework.

An early conclusion was that a successful methodology would incorporate substantial input from Subject Matter Experts (SMEs). It was recognized that the ability to develop accurate capability availability timelines and how those relate to the JETS system and vision would necessarily involve the application of judgment. Most valuable would be judgment based on deep knowledge of developments in relevant technical domains and on thoughtful consideration of long-term implications across multiple applications and industry sectors.

2.3 RESEARCH ACTIVITIES, TASK 1

2.3.1 Select and Define Key Enabling Capability Areas

This task focused on making the research effort manageable and coherent by careful delineation of topics and scope. It also sought to ensure that SME Findings could be used to help JPC-1 draw conclusions at the level of JETS components as described in the JETS CDD, per the assessment objectives.

This task is predicated on the notion that the JETS system, despite its complexity and sophistication, relies most critically on only a few major sets of capabilities. Put another way, achievement of JETS objectives requires incorporation of a huge number of discrete technical solutions, but the capabilities required to deliver those solutions fall into a limited set of broad categories. It is those broad categories, the "Enabling Capability Areas", that define the research effort.

2.3.2 Task 1 Activities

Enabling Capability Areas were defined according to the following criteria:

1) **Necessary** to achievement of JETS Final Objective Capabilities (FOCs).
2) **Critically Important** to achievement of the most fundamental aspects of the JETS vision.
3) **Related to a Coherent and Recognized Field of Research and Industry Activity.** The Enabling Capability Areas are defined in ways that are recognizable to industry and academia, with overlapping and interrelated research activities and development timelines.

Careful perusal of the JETS CDD led to a list of seven Enabling Capability Areas. While other capabilities may be needed to fully implement the JETS program, these seven are critical to the success of the program.

This list, along with descriptions of JETS final state objectives associated with each, was submitted to JPC-1 for review. After acceptance, JPC-1 provided a matrix that maps the seven Enabling Capability Areas to the full list of 34 JETS components. This exercise confirmed that statements and conclusions reached about the Enabling Capability Areas can be translated into statements about the components.

2.3.3 Task 1 Output – Enabling Capability Areas

The Enabling Capability Areas are as follows:

- **Patient Surrogates** – development of virtual or physical (robotic or manikin) patient substitutes, for purposes of training and simulation.
- **Moulage/Simulated Tissue** – techniques for conveying realistic trauma or disease conditions, in conjunction with the Patient Surrogates.
- **Holography** – techniques for creating digital images that the brain perceives as 3-dimensional.
- **Haptics/Tactility** – techniques for creating touch sensations and sensations of force and "pushback" within a Virtual Reality (VR) or Mixed Reality (MR) simulated environment.
- **Artificial Intelligence/Machine Learning (AI/ML)** – advanced computing methods that mimic or improve upon human cognition, allowing machines and systems to make complex decisions autonomously.
- **Distributed Connectivity** – the ability to share digital content with users over large geographic areas via wireless networks.
- **System of Systems** – the ability to link all of the elements of the JETS taxonomy into a functional whole.

2.4 RESEARCH ACTIVITIES, TASK 2

2.4.1 Investigate Development Timelines Via Primary and Secondary Research

This task constitutes the main data collection work. The goal was to complete interviews with 10 – 15 SMEs with expertise spanning the seven Enabling Capability Areas, and with industry backgrounds including automotive, aerospace, manufacturing automation (or "Industry 4.0"), and medical simulation. This task also

included a scan of secondary sources, particularly for Capability Areas that were underrepresented among participating SMEs.

2.4.2 Task 2 Activities

The primary Task 2 activities included gathering the list of 33 SME candidates, inviting them, creating the interview guide, completing interviews with 11 SMEs, organizing the research, and performing secondary research.

2.4.3 Task 2 Output: SME Selection

The 16 participating SMEs met this effort's goals for total number of participants.[4] Coverage across the Enabling Capability Areas was excellent for all areas (Table 2-1).

Table 2-1: SMEs by Enabling Capability Area.

SME Counts by Enabling Capability Area	
Patient Surrogates	11
Moulage/Simulated Tissue	7
Holography	10
Haptics/Tactility	10
Artificial Intelligence/Machine Learning	10
Distributed Connectivity	8
System of Systems	7

Coverage by industry experience was skewed toward those with a background in medical applications (Table 2-2). SMEs with orientation toward other industries were fewer in number but provided high-quality and detailed interviews that reflected developing capabilities in those sectors.

Table 2-2: SMEs by Industry Experience.

SME Counts by Industry Experience	
Aerospace/Aviation	3
Automotive	3
Manufacturing Automation/Industry 4.0	3
Medical	12

[4] Counts sum to more than 16, reflecting SME expertise in multiple areas.

2.5 RESEARCH ACTIVITIES, TASK 3

2.5.1 Analyze Data, Hone SME Findings with Input from Expert Reviewers

This task focused on repeated synthesis and refinement of findings drawn from SME interviews. Interviews proved to be wide-ranging, with SMEs often emphasizing differing issues. While there were broad areas of consensus, there were also areas of disagreement which made initial synthesis challenging. Five SMEs consented to provide detailed reviews of initial drafts. Their inputs were detailed, careful, and generous, allowing significant clarification and convergence of results. "Last say" and final arbitration rights were assigned to Dr. Thomas Talbot, Technical Advisor to this project.

2.5.2 Task 3 Activities

The primary Task 3 activities included examining the data; using SME responses to estimate timelines for capability readiness/availability by Capability Area and Increment; preparing the initial draft Findings and distributing it to reviewers with targeted requests for feedback; incorporating reviewer comments and insights into the Findings; and final review by the Technical Advisor.

2.5.3 Task 3 Output: Analysis

- Reviewer responses to the initial Findings draft were compiled into a single document.
- Final output is the Analysis of Data section, below. This includes projected capability readiness timelines, by Increment, for each Enabling Capability Area.

2.6 ANALYSIS OF DATA

2.6.1 Projected Availability Timelines, by Increment, for JETS Enabling Capability Areas

Table 2-3 summarizes the analysis of data based on input from SMEs. Colors in the chart signify readiness or progress toward commercial availability. The scale is based on Technology Readiness Levels (TRLs), as described below, which SMEs used to evaluate available technology. See Section 2.8 Technology Readiness Levels.

Table 2-3: Summary SME Findings by Enabling Capability Area.

Enabling Capability Area: Patient Surrogates					
	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 1					
Increment 2					
Increment 3					
Increment 4					
Enabling Capability Area: Moulage/Simulated Tissue					
	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 1					
Increment 2					
Increment 3					
Increment 4					

Enabling Capability Area: Holography					
	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 3					
Increment 4					
Enabling Capability Area: Haptics/Tactility					
	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 3					
Increment 4					
Enabling Capability Area: Artificial Intelligence/Machine Learning					
	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 3					
Increment 4					
Enabling Capability Area: Distributed Connectivity					
	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 1					
Increment 2					
Increment 3					
Increment 4					

2.6.2 Availability Scale

Each Increment for the first six Areas was rated red, yellow, or green based on the TRL (Table 2-4). The ratings are:

Table 2-4: Readiness Scale.

Rating	TRL	Description
Red	1 – 3	Basic research, basic principles and characteristics.
Yellow	4 – 7	Capability to produce results in a lab environment through operational environment, proof-of-concept/working prototype.
Green	8 – 9	Advanced prototype successfully tested in operational environment, or commercially-available products/technologies in use.

2.6.3 Analysis Summary

Some Increments are not shown in Table 2-3 because the technology is not mentioned in the JETS CDD until Increment 3.

Analysis for each Enabling Capability Area are below the summary.

Note: Descriptions of each Enabling Capability Area are based on the JETS CDD. All quotations are from the JETS CDD.

2.6.4 Patient Surrogates

Patient Surrogates are substitutes for real patients used for training. There is a long history of using scripted actors, known as Human Standardized Patients, as patient surrogates. For purposes of this discussion, Patient Surrogates will refer to artificial substitutes aiming for a high degree of anatomical and/or behavioral and emotional realism, including fully virtual avatars, full-sized physical models ("manikins"), and task trainers which focus on a specific type or category of clinical procedure.

2.6.4.1 State of Development[5]

Patient Surrogates available or under development today can be grouped as follows:

- Virtual Standardized Patients (VSPs) – completely virtual and focused on conversational interactions; VSPs with highly sophisticated natural conversation capabilities exist today. Example: USC Standard Patient.
- Virtual Physiological Patients (VPPs) – somewhat analogous to VSPs, but with a focus on trauma- and treatment-related scenarios, not on patient behavior or conversation, and with physiological modelling. Airway and Task Trainers are good candidates for VPPs. Product examples include HumSim and Combat Medic by the Virtual Heroes division of Applied Research Associates.
- Multimedia Virtual Patients (commonly referred to as simply "Virtual Patients") – typically a web-based multimedia interactive experience that carries the trainee through a patient assessment and care scenario. Examples: Virtual Heroes Medic, T3Sim, ArchieMD, Decision Sim.
- High-Fidelity Manikins – life-sized and life-like physical models, sometimes with robotic platforms. Many have software-based systems to represent physiology and they may be controllable via input from an instructor or through pre-defined software scenarios. Vascular, Airway, and CPR procedures may be performed on these systems using real-world equipment. Examples: Caesar, Noelle, CAE's iSTAN, and Laerdal's SimMan 3G.
- Task Trainers (or part task trainers) – these make up the bulk of the Commercial Off-The-Shelf (COTS) market and typically focus on a specific type or category of clinical procedure. They can range from very realistic, such as those available from companies like 3D Systems [5], to very simplistic and basic products, such as Blue Phantom's Ultrasound Training Block [6] or typical IV placement and female exam trainers.

The JETS Core Manikin project, currently in development, aims to create an open-source platform that will allow manikins and task trainers to integrate with devices and to incorporate elements of virtual patients.

Based on input from SMEs interviewed for this report, the current state of development for patient surrogates can be further characterized as follows:

- There is modest realism available in manikins today, such as with the Multiple Amputation Trauma Trainer (MATT) system by TraumaFx, but current technologies do not allow for natural user interfaces, do not evoke empathy, and are unable to realistically characterize human tissues, facial expressions and patient verbal interactions.
- There is no universally accepted standard for a physiology engine as applied to a full patient manikin. Some are in development, such as the open-source BioGears engine and the Pulse engine by Kitware, as well as some task-level and virtual patient engine integration with limited Artificial Intelligence (AI) capabilities.

[5] This State of Development relies heavily on scientific assessments provided by Dr. Brett Talbot, Technical Advisor to this project, of the JETS Virtual Patient Subsystem (VPS) and Instructional Support Subsystem (ISS).

- Although some task trainers address gender physiology differences, full-body trauma manikins, simulated physiology, and physiology engines do not. This may be putting female soldiers at risk if combat medics and surgeons are not being trained to address the differences in how combat wounds manifest in female anatomy and physiology.
- Specific stasis or state-of-wound-based physiology is often preferred for scenarios; physiology engines are applicable for some simulations but are not optimal for other types of scenarios.

2.6.4.2 Possible Developments

SMEs saw a variety of possible upcoming developments in Patient Surrogates:

- Ability to run physiologically robust scenarios, via improved physiology engines and development of state machine software libraries to facilitate physiology engine integration and pre-built response scenarios to yield appropriate physiological responses to unique trauma scenarios.
- Surrogates able to naturally communicate with trainees, and to express themselves differently depending on physiological or injury status, which could include such variables as skin pallor, temperature, dehydration and other ways to determine "feel" of the skin.
- Ability to incorporate such capabilities into a range of display forms, including on-screen displays and mixed reality.
- Eventual evolution of today's most-capable manikins into fully-robotic systems.
- Development of AI engines capable of broad knowledge representation, and development of knowledge bases to drive these engines.
- Improved realism of synthetic tissues and organ systems built from smaller, faster sensors and actuators, and distributed tissues that can generate or utilize data.
- Content development – there is a lot of content work needed to develop complex training scenarios within which patient surrogates will operate.

The full scope of training requirements needs to be clearly articulated to ensure successful development and deployment of technology solutions. A performance and instructional analysis should define, in detail, the tasks that need to be trained, to what standard, and under what conditions. It is likely that a family of simulators will be required – not just a single trainer – which would incorporate some subset of the potential capability areas. A family of simulators which can train to a range of scenarios would require, as a foundation, a patient Federation Object Model (FOM) which allows a virtual patent to be transferred over a network; a common scenario/lesson plan creation system; and a common system for exporting captured LMS/AAR data.

2.6.4.3 Development Timeline Relative to JETS Capability Increments

Increment 1

Objective Capabilities

Increment 1 calls for collection and integration of existing capabilities; no new Patient Surrogate capabilities are required.

Availability Timeline

Existing Patient Surrogates technologies are sufficient for Increment 1 (Table 2-5).

Table 2-5: Patient Surrogates, Increment 1.

Patient Surrogates	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 1					

Increment 2

Objective Capabilities

Increment 2 calls for Patient Surrogates that are "fully automated". For physical manikins, this means that a scenario can be pre-programmed, and once initiated, does not require intervention by an instructor or operator to fully carry out its full range of responses within that scenario.

Availability Timeline

SMEs view Increment 2 capabilities as at TRL 4 – 7 today, and at TRL 8 – 9 within 6 – 10 years (Table 2-6). Some SMEs caution that focusing on fully automated part task trainers is a more practical and less expensive strategy for building a broad set of capabilities and experiences that can be applied to real world use.

Table 2-6: Patient Surrogates, Increment 2.

Patient Surrogates	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 2					

Increment 3

Objective Capabilities

Patient Surrogates at Increment 3 include fully-holographic virtual patients, Mixed Reality (MR) patients, and MR patients that overlay manikins and robotic task trainers to provide a clinically realistic appearance and dynamic visual changes in response to trainee actions. Patient Surrogates incorporate AI at Increment 3, both for intelligent response within scenarios and for partly autonomous system self-diagnosis and self-maintenance. They are able to be integrated with Simulated Tissues (discussed in the Simulated Tissues section below). Increment 3 does not require extreme realism; complete suspension of disbelief and full substitution away from live tissue training are objectives at Increment 4.

Availability Timeline

SMEs view Increment 3 capabilities today as TRL 1 – 3 (but clearly closer to 3 than to 1), at TRL 4 – 7 in 1 – 5 years, and at TRL 8 – 9 thereafter (Table 2-7). Several SMEs noted that an important aspect of realism is that Patient Surrogates be able to convey meaningful differences and diversity in the real patient population. This certainly includes adequate attention to Surrogates that can convey gender differences. It also includes work on simulated physiology and physiology models that incorporate still-to-be-uncovered patterns of variation across patient subgroups. SMEs do not believe patient surrogates will integrate holography or simulated tissue in any functionally useful way for at least 10 years.

Table 2-7: Patient Surrogates, Increment 3.

Patient Surrogates	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 3					

Increment 4 – JETS Final State

Objective Capabilities

Increment 4 delivers Patient Surrogates that are highly realistic, fully autonomous, allowing complete suspension of disbelief and complete substitution away from live tissue training.

Availability Timeline

SMEs view the JETS final state for Patient Surrogates as at TRL 1 – 3 today (closer to 3 than to 1), at TRL 4 – 7 through 6 – 10 years, and reaching TRL 8–9 by 11 – 15 years (Table 2-8). Extreme realism was seen by SMEs as the most difficult and furthest out of the Increment 4 requirements. The objective of maximum realism, or fidelity, for robotic manikins was challenged by some SMEs, who noted both the significant cost to develop it without a clear objective and necessity, as well as the challenge of the "uncanny valley" effect (referring to the known tendency of humans to feel "creeped out" by highly realistic yet slightly-off simulated humans), and questioned whether extreme realism would achieve the desired sense of empathy among trainees.

Table 2-8: Patient Surrogates, Increment 4.

Patient Surrogates	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 4					

2.6.5 Moulage/Simulated Tissue

Traditionally, "Moulage" is the making of realistic molded models of injured or diseased tissues and applying them to actors or manikins; recently, virtual options have been developed that accomplish the same task. "Simulated Tissues" refers to physical materials that mimic human tissues. It includes those parts of a physical manikin or Part Task Trainer that represent skin and organs.

This Enabling Capability Area refers to technologies that stand alone or are integrated within all capabilities. Moulage/Simulated Tissue concerns primarily physical materials; strictly virtual mimicry of tissues is addressed under Holography and/or Haptics.

2.6.5.1 State of Development

In recent years there has been substantial investment made to improve the realism of simulated skin and tissues. Notable progress has been made, for example, with regard to visual realism and skin color using heat, light, cold, and electricity as stimuli, but other types of tissue changes have not been demonstrated at any usable level. A 2016 article by Oliver et al. [7] discusses synthetic shape-changing materials such as medical devices that unpack inside the body, and reviews "examples of natural shape-changing materials–skeletal muscle, tendons and plant tissues–and compare with synthetic examples with similar methods of operation."

Realism of individual tissues is improving but significant development and integration are still required to apply these technologies in ways that can effectively replace the use of live animals. In particular, the heterogeneous nature of tissue (i.e., the various tissue planes, fascia surrounding muscles, embedded blood vessels, nerves, lymphatic pathways, etc.) is not well addressed at present.

2.6.5.2 Possible Developments

SMEs saw a variety of possible upcoming developments in Moulage/Simulated Tissues:

- Realism, both visual and haptic, to allow elimination of live tissue training and to achieve complete suspension of disbelief.
- Progression and Programmability to improve simulation realism via tissues that change over time to convey progression of trauma and disease conditions, in a controlled and programmable way.
- Full and automatic reset back to starting conditions. This may be extremely difficult to achieve due to the small subset of materials that can be activated at the micro level and achieve full return to initial state.

SMEs and published sources indicate that the JETS vision for Moulage/Simulated Tissues involves the need for highly-engineered, multi-material composites. Such composites would include bio-like structures or webs made of one type of material, interlaced with other types of soft materials. "Tissues" would be made of complex inter-layering of multiple variations of such composites. Good biomimicry of processes and changes at the macro level (i.e., at the scale observable to the trainee) would derive from material behavior and control exerted at the less-than-macro level. The materials would be activated at the milli-, micro- or nano-levels (hereafter referred to as "nano" for simplicity), with actuators, controls, and instructions that cause small regions within the Tissues to move, swell, or otherwise "morph" in response. A system architecture for that Tissue (or "Kit") would control the nano-responses so that their combined effect is a tissue or organ with the desired look, feel, and progression called for in a simulation.

Also relevant is potential for an "Internet of Nano Things (IoNT)"[6], enabling the needed control at micro and nano scales. JETS objectives require IoNT for local or limited networks (i.e., within the vicinity of physical manikins and Tissues). IoNT is seen as reliant on dramatic increases in the numbers of network-connected devices, and thus on dramatic increases in usable spectrum and bandwidth (see Distributed Connectivity, below). The as-yet-untapped terahertz spectrum is viewed as a promising source for usable spectrum. Early work is underway mainly in academic research centers to develop transmission and reception devices.

2.6.5.3 Development Timeline Relative to JETS Capability Increments

Increment 1

Objective Capabilities

Increment 1 seeks to "enable integration of JETS training capabilities across the DOD." This will include identification of Moulage/Simulated Tissues best practices/best technologies across DOD Components, and their standardization and incorporation into trainings and exercises.

Availability Timeline

Increment 1 Moulage/Simulated Tissue requirements can be met with today's commercially-available technology (Table 2-9).

Table 2-9: Moulage/Simulated Tissue, Increment 1.

Moulage/Simulated Tissue	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 1					

[6] The use of the word "nano" in this context is meant to represent any scale not observable with the naked eye.

Increment 2

Objective Capabilities

JETS documents are silent regarding increased capabilities for Moulage/Simulated Tissues at Increment 2.

Availability Timeline

SMEs presume that Increment 2 will incorporate those products under development today, as well as those which will be commercially-available within 1 – 5 years (Table 2-10). However, some SMEs noted that advances in this capability area could be unpredictable and could take either less or more time to develop. There is also some skepticism about whether viable commercial technology for this capability area exists, and some suggestion that the technical capabilities may not progress without significant DOD funding commitments.

Table 2-10: Moulage/Simulated Tissue, Increment 2.

Moulage/Simulated Tissues	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 2					

Increment 3

Objective Capabilities

Increment 3 envisions "initial [incorporation into JETS of] morphing nanotechnologies" used in Moulage/Simulated Tissues.

Availability Timeline

Exploration of soft materials that can be made to activate and morph in response to controlled stimulation are at TRL 1 – 3 today; what is being developed and tested are very small samples, with simplistic response capabilities, on a limited number of materials. SMEs expect that the delivery of a composite, tissue-like macro structure with limited morphing is achievable in 16 – 20 years (Table 2-11). They view such capabilities as being TRL 1 – 3 today and in 1 – 5 years, and at TRL 4 – 7 in 6 – 10 and 11 – 15 years. Some SMEs suggested that tracking and leveraging the progress technical developments already underway, such as soft robotics, may be a more cost-effective way to accelerate the advancement of this Increment.

Table 2-11: Moulage/Simulated Tissue, Increment 3.

Moulage/Simulated Tissues	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 3					

Increment 4 – JETS Final State

Objective Capabilities

Increment 4 involves the delivery of trauma and diseased tissue sets that "will function on a nano-technology level enabling fully autonomous morphing, that provides accurate disease and wound initiation, presentation, progression, culmination and reset (for repetition of training)."

Availability Timeline

Current research is finding examples of fully-reversible shape-shifting materials. Demonstrations are at TRL 1 – 3. SMEs place the delivery of the JETS final state for Moulage/Simulated Tissues, including controllability via local IoNT, as being 16 – 20 years out (Table 2-12).

Table 2-12: Moulage/Simulated Tissue, Increment 4.

Moulage/Simulated Tissues	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 4					

2.6.6 Holography

Holography, as used in this assessment, includes both holography and mixed reality. "Holography" has come to mean dynamic images or video projections that appear 3-dimensional to the viewer. Most achieve this effect by means of 2D displays (often in "wearables") that manipulate light in ways that trick the brain into interpreting the visual input as 3D. In this document, Holography should be understood to cover the full range of multi-dimensional immersive display capabilities, including volumetric displays for which light sources or "voxels" (3D pixels) are truly distributed in 3-dimensional space. It also covers various applications of Virtual, Augmented, or Mixed Reality (VR, AR, MR) capabilities. Multi-dimensional is sometimes used to refer to integrating additional senses, such as smell.

Within JETS, holography is critical to achieving realism in simulated environments, in Patient Surrogates, and in delivery of training content to users in the field.

2.6.6.1 Holographic Systems

Holographic systems are defined as real-world visual projection volumetric displays which support multiple simultaneous users in a space, support shared experiences seamlessly, and do not require wearable devices.

2.6.6.2 State of Development

Based on secondary research and input from SMEs interviewed for this report, the current state of development for holographic systems can be characterized as follows:

- Holographic systems are increasingly reliable for displaying accuracy and precision of detail; however, there are still limitations with the aspects that achieve extreme realism, including:
  - Resolution – involving optimal voxel size.
  - Parallax – the ability to be viewed at various angles with consistent realism, including ability of multiple users at different locations to simultaneously view the experience from multiple angles.
  - Registration – persistence of a virtual object in the real-world space (position and orientation) despite human user translational and rotational movements (change of location and head movements).
  - Haptic integration – involving kinetic sensory capabilities.
  - Illumination (within AR overlays) – the ability to accurately illuminate virtual objects.
- True holographic system prototypes are in a very primitive, experimental state (TRL 1 – 2).

- Displays that do not require wearables are getting close to being available for procurement, including The Looking Glass and DeepFrame (Voxon Photonics), which use a "sweeping display" technique to show volumetric displays of different sections of an object. However, these still utilize multiple display surfaces to emulate a volumetric display and interaction with them is not possible.
- Zebra Imaging holographic volumetric display was funded by Army Research Laboratory and JPC-1 for more than $4 million. The resultant prototypes were impressive, but impractical due to cost, low-light environment requirements, and extreme computational power requirements. This display was still embedded within a flat surface and did not volumetrically inhabit the real-world space; thus, it was potentially useful for three-dimensional exploration, but not the mixed reality interactivity that JETS medical simulations require.
- The JETS final state vision of a fully immersive holodeck simulation environment does not yet exist. Several military and university simulation labs have developed MR wall and floor back-projected holo-image environments to create simulated environments and scenarios. However, these typically require shutter glasses and other wearables to obtain realistic senses of depth, so they are not holographic.

2.6.6.3 Possible Developments

SMEs saw a variety of possible upcoming developments in holographic systems:

- Vastly increased laser power, data volume, and computational power to move beyond wearables and achieve human visual resolution. The challenge is creating systems which can sense every detail needed in a given procedure or scenario, capture and store that information, and then reflect all of it back out in a realistic, real-time manner with true resolution and registration, and in which trainees have the full ability to interact with the display in various patient treatment use cases, utilizing advanced gesture tracking and recognition.
- Improved optics, light modulators, ultra-haptics (ultrasound enabled surfaces), and latency (distance of an object in space) to achieve better resolution, illumination, and registration of objects.

2.6.7 Mixed Reality Systems

Mixed reality systems are defined as technologies which support Mixed Reality (MR), Augmented Reality (AR), and Virtual Reality (VR) by use of wearable devices. These devices permit visualization of three-dimensional virtual objects in the real-world space, register the real-world environment and map virtual objects into the real world, and maintain stable location and orientation of virtual objects despite user changes of location or head movements.

2.6.7.1 State of Development

Based on secondary research and input from SMEs interviewed for this report, the current state of development for mixed reality systems can be characterized as follows:

- Mixed reality systems are increasingly reliable for displaying accuracy and precision of detail; however, there are still limitations with the aspects that achieve extreme realism, including:
  - Resolution – involving optimal pixel size.
  - Parallax – the ability to be viewed at various angles with consistent realism, including ability of multiple users at different locations to simultaneously view the experience from multiple angles.
  - Registration – persistence of a virtual object in the real-world space (position and orientation) despite human user translational and rotational movements (change of location and head movements).

    - Haptic integration – involving kinetic sensory capabilities.
    - Illumination (within AR overlays) – the ability to accurately illuminate virtual objects. With regard to illumination there is optimism that future off-the-shelf wearable products, such as Microsoft HoloLens and Magic Leap, and virtual reality displays with camera image passthrough, such as HTC Vive and Oculus Go, will be able to achieve the desired state within 5 years.
- CT or MRI scans are presently being utilized to render 3D models of a patient's internal organs. These models can then be developed into software and can be placed in a mixed media VR simulator with incorporated haptics. Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) is one example where this is this technology is already commercialized and could be used as a building block to create a library of different anatomies.
- In the automotive industry, heads-up planar displays which utilize projector reflections are the only relevant holographic application that is being developed in any serious way; the industry as a whole is at a TRL of about 4. Although there is a lot of buzz about this technology, it will be another 5 – 10 years until it is integrated into vehicles in ways that are safe and functional.

2.6.7.2 Possible Developments

SMEs saw a variety of possible upcoming developments in mixed reality systems:

- Processors need to be faster and displays must run at a minimum of 120 – 240 Hz to ensure they can refresh fast enough to avoid viewers becoming nauseous from looking at the display. Currently the industry standard is 60 – 90 Hz.
- Improved optics, light modulators, ultra-haptics (ultrasound enabled surfaces), and latency (distance of an object in space) to achieve better resolution, illumination, and registration of objects.

2.6.8 Immersive Mixed Reality Simulations: Non-Display Considerations

Immersive mixed reality simulations, whether via MR wearables or true holographic volumetry, share common requirements for interactivity and content expression.

2.6.8.1 State of Development

Based on secondary research and input from SMEs interviewed for this report, the current state of development for immersive mixed reality simulations can be characterized as follows:

- Immersive mixed reality simulations are increasingly reliable for displaying accuracy and precision of detail; however, there are still limitations with the aspects that achieve extreme realism, including:
    - Haptic integration – involving kinetic sensory capabilities.
    - Active Acoustics:
        - Manipulation of perceived sound so that objects or character sounds appear to come from their virtual environment locations.
        - Speaker arrays that manipulate sound fields to allow private auditory messages to be heard by a particular user and ability to localize and isolate speech sounds from individual users.

2.6.8.2 Possible Developments

SMEs saw a variety of possible upcoming developments:

- Gesture and Speech Interface – ability to work with mixed reality environment without use of hand controllers. This includes ability to use real-world medical instruments within the mixed reality space. Speech interfaces will benefit from advances in natural language processing.
- Advanced Non-Player Characters – virtualized environments will require advanced virtual humans to interact with, requiring AI-driven dialogue capability.
- Content development – there is a lot of content work needed to develop complex interactive training scenarios involving holographic capabilities. Advanced technical capabilities are ineffective without relevant content, a delivery platform, and useful interface practices.

2.6.8.3 Development Timeline Relative to JETS Capability Increments

Holographic capability is not explicitly called for in the JETS CDD until Increment 3.

Increment 3

Objective Capabilities

At Increment 3, holography is critical to conveying situational realism in Patient Surrogates, in simulated environments, and in delivery of 3D training content to users in the field. What is envisioned are Patient Surrogates that make use of "mixed reality", e.g., using Head-Mounted Displays (HMDs) and wearables to impose augmented or virtual content on or within a physical manikin, with the volumetric display being fully and seamless integrated with the manikin even as the wearer moves around. Also envisioned are highly realistic, life-sized, holographic visual environments at training facilities (e.g., conveying the sense of being in a transport vehicle or in a trauma care suite). Increment 3 does not call for holography to be "fully immersive." There is an allowable gap between the holographic content and full suspension of disbelief.

At Increment 3, the JETS vision calls for "holographic capabilities that are seamless between the training site and PoD user." That is, distributed users in the field are able to connect 24x7x365, via the PoD portal with content or live sessions, using their device of choice, and experience the same holographic "views" as participants at the facility.

Availability Timeline

Most of the interviewed SMEs place life-sized, highly realistic holography at TRL 4 – 7 today, with TRL 8 – 9 achievable within 11 – 15 years or sooner, but primarily through the use of HMDs (Table 2-13). They are less clear about the delivery of a seamless experience for PoD users, citing concerns about outdoor lighting conditions and needs for much higher computing power if holograms are to be projected into the field to create the same (perhaps wearable-free) experience as users at the facility. For Increment 3 as a whole, including delivery of an identical experience to PoD users, SMEs rate the capability at TRL 1 – 3 today, at 4 – 6 through years 6 – 10, and at TRL 8 – 9 thereafter.

Table 2-13: Holography, Increment 3.

Holography	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 3					

Increment 4 – JETS Final State

Objective Capabilities

Increment 4 envisions "fully immersive holographics" applied to patient surrogates (including mixed reality), within facilities (360-degree, fully-believable environments) and available to distributed PoD users.

Availability Timeline

SMEs mostly view the delivery of the fully immersive, end state JETS holography capabilities as at TRL 1 – 3 today and through 1 – 5 years, at TRL 4 – 7 through 11 – 15 years, and reaching TRL 8 – 9 by 16 – 20 years (Table 2-14). There was a minority view that delivery of a fully immersive holographic experience to the PoD user would not achieve TRL 8 – 9 until more than 20 years out.

Table 2-14: Holography, Increment 4.

Holography	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 4					

2.6.9 Haptics/Tactility

Haptics refers to the forces on our joints that are perceived by the sensing organs, including the force needed to create movement. The concept of "force feedback haptics", haptic stimulation that goes beyond skin sensations to convey a realistic sense of pressure or "pushback" when the user interacts with an object in the virtual world, is important to the JETS vision. Tactility in its most general sense means having to do with the sense of touch and the pressure and shear felt on the skin surface; it does not include the accumulation of forces felt at or in the joints. It can also include an individual's sense of his/her own body position. With regard to virtual and augmented reality, tactility refers to the ability to integrate "touch and feel" sensations into a virtual experience.

Haptics and tactility contribute to achievement of the JETS final state in two main sets of applications:

1) As a requirement in the context of "crew, team, environment and equipment interactions" for joint/common training exercises, and for trainings held at Facilities. That is, JETS envisions developing simulations in which participants experience the feel and "pushback" of encountering equipment, people and things, even when the equipment, people and things exist only virtually.
2) As a critical contributor to realism of mixed reality Patient Surrogates. The perceived realism of a manikin whose abdomen is being palpated by a trainee, for example, might be improved via a complex sensory-and-activation feedback loop between the trainee and the manikin.

2.6.9.1 State of Development

Based on secondary research and input from SMEs interviewed for this report, the current state of development for Haptics/Tactility can be characterized as follows:

- The aviation, autonomous vehicle, cell phone, gaming, and entertainment industries are deploying a range of tactile sensation capabilities in flight simulators, autonomous vehicle simulators, cell phones, gaming consoles, and movie theatres. These include vibration, temperature, moisture, and the pressure and feeling sensations of wind.
- The automotive industry is exploring the use of ultra-haptic gestures using subsonic feedback which responds to physical gestures. However, this is a very long-term development effort and will be difficult to achieve in any functional way due to the infinite variations in how people express themselves using gestures.

- Companies such as Syntouch, Soft Robotics Inc., and academic research labs such as the Harvard Biodesign Lab, Cornell University Organic Robotics Lab, and the Bristol Robotics Laboratory have made significant advances in soft or tactile robotics. Bristol has developed an open-source 3D-printed tactile fingertip that can "feel" similarly to how humans feel touch. Cornell has developed a robotic "hand" technology linked with sensors integrated within the robot's body so that the robot can detect forces transmitted through it, similar to how humans feel pain. Harvard's Biodesign Lab is working on a range of textiles that transmit assistive torques to the wearer's joints without the use of rigid exoskeletal structures**.**
- Medical and surgical task trainers have made significant advances in limited haptic capabilities. Several commercially-available systems, such as OSSimTech, Simbionix, U/S Mentor, LapSim, and VirtaMed, integrate force feedback haptics with either VR-based scenarios, physical task trainers, or both. However, a fully immersive VR/MR environment which integrates haptics at the level that JETS envisions is still a long way off.
- Computer Haptics and Active Interface 3D (CHAI 3D) is an open source, freely available set of C++ libraries for computer haptics, visualization, and interactive real-time simulation specifically geared for research purposes. CHAI 3D can support commercially-available three- and six-degree-of-freedom haptic devices and can accommodate customized and remote site haptic applications utilizing different hardware configurations.

2.6.9.2 Possible Developments

SMEs saw a variety of possible upcoming developments in Haptics:

- Wearables and exoskeletons with vast improvements in sensing capability, power, and functionality, lighter weight, lower power requirements, and improved human factors design.
- Quantifiable mapping (i.e., algorithm development) of the entire range of "feel" of human tissues, injuries, and related elements such as temperature, blood, and other fluids. This also should include mapping what sensory inputs are really required to perform a given clinical task.
- Development of actuators that sense the interaction between humans and virtual haptics with respect to objects rendered by the user. Actuation technology must be very small, flexible, stretchable, low power, using nanowires or magnetic.
- Distributed skins that can generate data or use data to recreate skin shape and surface features.
- Adaptation of CHAI 3D or creation of new "middleware" computer language and architecture that enables various haptic devices in the JETS context to connect to each other and to other devices.

2.6.9.3 Development Timeline Relative to JETS Capability Increments

Haptics capability is not explicitly called for in the JETS CDD until Increment 3.

Increment 3

Objective Capabilities

At Increment 3, the JETS vision calls for delivery of "force feedback haptics." This capability will play out in such areas as: increased realism of simulated evacuation and transport equipment and environments, realistic sensations of hand-held medical instruments encountering virtual patients and tissues, supplementation of the "feel" of a patient surrogate with sensations that are delivered via haptic devices, and creation of realistic palpations of patient surrogate by means of force-activated responses in the surrogate that deliver the "right" pushback to trainees. Increment 3 does not call for "360-degree" realism or ability to completely suspend user disbelief.

Availability Timeline

Based on known achievements in haptics applied to surgical simulation, industrial training environments, and entertainment/museum applications, SMEs place Increment 3 capabilities as TRL 4 – 7 today through 1 – 5 years. They view Increment 3 capabilities as achieving TRL 8 – 9 in 6 – 10 years (Table 2-15). SMEs would substantially lengthen that timeframe if JETS were to call for similar haptic content be delivered to distributed users via PoD.

Table 2-15: Haptics, Increment 3.

Haptics	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 3					

Increment 4 – JETS Final State

Objective Capabilities

At Increment 4, JETS calls for "360-degree force feedback haptics," i.e., complete realism, creating complete suspension of disbelief among participants. Facilities achieve a full "holodeck" experience.

Availability Timeline

SMEs place Increment 4 capabilities at TRL 1 – 3 today and in 1 – 5 years, at TRL 4 – 7 through 11 – 15 years, and reaching TRL 8 – 9 in 16 – 20 years (Table 2-16). SMEs do not interpret the JETS vision as calling for full haptic realism delivered via devices with fully virtual patient surrogates. That is, they anticipate that the best approach to creating full realism within a simulation will be via mixed reality, with many sensations being generated by a physical robotic patient surrogate. Completely realistic haptics in a virtual-only context or delivered to PoD users is not viewed as attainable within 20 years.

Table 2-16: Haptics, Increment 4.

Haptics	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 4					

2.6.10 Artificial Intelligence/Machine Learning (AI/ML)

Artificial Intelligence or AI refers to computers able to carry out cognition-like tasks, such as learning, reasoning, and problem-solving. AI is a powerful tool for creating nimble, self-programmed, and continuously-improving responses to complex situations. Particularly relevant to the JETS program is the branch of AI called Machine Learning (ML). In ML, the computer applies pattern recognition heuristics to large quantities of data, building its own decision-making algorithm. Also included under this heading, though perhaps not properly AI/ML as it is usually thought of, are new developments in assisting and augmenting human cognition.

2.6.10.1 State of Development

There is general agreement among SMEs and published sources that AI/ML has recently passed a threshold for practical use across a wide variety of applications. In the Large Scale Visual Recognition Challenge, image labeling error rates achieved by AI have fallen from 28.5% to 2.5% since 2010; in 2015, the best AI competitor performed better than humans for the first time. One forecast of global AI enterprise applications

puts projected spending growth at 50% per year over the next seven years, moving from $1.6B in 2018 to $31B in 2025. DARPA has introduced AI Next, a multi-year campaign to address limitations of first- and second-generation AI technologies.

Examples of current efforts mentioned by SMEs, with relevance to the JETS system include:

- Honeywell is developing an application which allows an aerospace engine technician to speak his or her engine inspection observations into a voice-assisted device which records and stores the comments and answers into a database along with photos; it becomes part of an AI/ML environment to build a virtual or self-maintaining system**.** In the future, it may be integrated with haptic features such as the touch and feel of specific engine parts and components.
- 3D Systems is digitizing a range of surgery-related data and developing an AI program which helps surgeon training by performing remote simulated surgery in a VR setting with robotic assist devices.
- GE and Caterpillar have had self-maintenance predictive analytic systems (also called "condition-based maintenance") in place for several years. GE monitors their engines on a 24/7 basis and the engines communicate back to GE when they need servicing. Caterpillar places sensors all over their tractors to predict wear and tear; although they have not yet automated repairs, they are using the data to proactively service their equipment.
- Amazon and other companies such as British supermarket Ocado have developed automated warehousing systems using robots for picking, lifting, sorting, and packing. Google spin-off Waymo has autonomous truck fleets deployed in limited pilot uses delivering parts and products in Phoenix and Arizona. The use of drones in automated warehousing and logistics is not too far away.
- On an enterprise scale analogous to JETS, Schneider Electric has employed AI-based predictive analytics in its distribution system; this tool was developed by Llamasoft [8].

The JETS vision calls for deep infusion of AI and/or ML into every subsystem and component. It is useful to recognize three primary AI/ML applications within JETS:

1) AI/ML will drive autonomous responses within training sessions and within Live Virtual Constructive Gaming (LVCG) simulations, allowing content and scenarios to be highly responsive to the actions of trainees and players.
2) AI/ML will enable autonomous self-sustainment of all JETS components, allowing all JETS components to be self-monitoring and to autonomously carry out replacement and repair of supplies and equipment.
3) AI/ML will enable enhanced human cognitive performance. One way is via training and cognitive aids, i.e., the creation of learning experiences that are profoundly customized and optimized to the individual and of tools which enhance human decision-making in the context of work. Such cognitive aids might be tested in JETS simulations to determine their potential value for real-world application. Another way is through instructional analysis based on a systems approach. There is 100 years' worth of scientific work to draw upon to develop a systems approach which can be achieved in the near term to improve the effectiveness and efficiency of current training technologies, while the envisioned AI/ML capabilities are being developed in parallel.

The third application, related to AI/ML enhanced human cognitive performance, is an emerging field and substantially behind the other two. Importantly, the National Science Foundation (NSF) has announced a new program area under its "10 Big Ideas" initiative: Future of Work at the Human-Technology Frontier. NSF is currently funding projects in two major theme areas that have significant potential to contribute to JETS final state objectives: 1) Foundations for Augmenting Human Cognition, and 2) Embodied Intelligent Cognitive Assistants.[7]

[7] See Appendix I of the original report for more detail on this NSF program area.

2.6.10.2 Possible Developments

SMEs saw a variety of possible upcoming developments in AI/ML:

- One challenge in the JETS vision for AI, even in the first two areas listed, is the simultaneous application of AI to a huge number of discrete decisions or problem areas. Patient responses require almost exclusively human-built logic.
- The sheer volume of ML training, coupled with the need to integrate the models into a coherent whole, requires development work. For example, within simulated scenarios, the capability for AI responses from Opposing Forces (OPFOR) is available now but is expensive and requires a lot of human-built logic.
- In Patient Surrogates, a wide range of sensing capabilities would be required to identify and catalogue all of the relevant conditions and issues that would need to be addressed in any of the envisioned JETS applications.

2.6.10.3 Development Timeline Relative to JETS Capability Increments

AI/ML capability is not called for explicitly until Increment 3.

Increment 3

Objective Capabilities

The distinction between JETS-required AI capabilities at Increment 3 vs. Increment 4 is consistently described as "partly autonomous" for Increment 3 vs. "fully autonomous" for Increment 4. This implies application of AI to an ever-increasing set of decisions and problems in the interim between Increments 3 and 4; the number of man-machine interfaces will be larger at Increment 3 with AI/ML folding an increasing number of scenario responses into a seamless experience at Increment 4.

Availability Timeline

The SMEs interpreted the difference between Increments 3 and 4 as a distinction of quantity, more than of kind. SMEs see attainment of Increment 3 capabilities as at TRL 4 – 7 today and achieving TRL 8 – 9 by 6 – 10 years out (Table 2-17).

Table 2-17: AI/ML, Increment 3.

AI/ML	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 3					

Increment 4 – JETS Final State

Objective Capabilities

With regard to simulation and training, the JETS final state vision is for "robotic mannequins operating with on-board AI, … [Facilities with] imbedded AI, … fully automated data mining [for] scenario generation, … [and skills training that] will autonomously capture and record, predict and individualize [content]." AI-driven robotic instructors will replace at least some human instructors. With regard to self-sustainment, AI/ML will allow system-wide "supply and logistics replications, … on-board predictive management [and] self-diagnosis…"

Availability Timeline

SMEs see attainment of Increment 4 capabilities as at TRL 4 – 7 through 6 – 10 years and achieving TRL 8 – 9 by 11 – 15 years (Table 2-18). However, a minority of SMEs caution that the goal of Increment 4 is not realistic and may ultimately be unachievable without huge, long-term levels of funding, a commitment to develop a range of content, and an overall sharper definition of what is trying to be achieved.

Table 2-18: AI/ML, Increment 4.

AI/ML	Today	1 – 5 Years	6 – 10 Years	11 – 15 Years	16 – 20 Years
Increment 4					

2.7 ANALYSIS OVERVIEW

This section presents information that fulfills the Assessment Objectives.

As noted throughout, all analysis is drawn primarily from structured interviews with SMEs, followed by several rounds of further clarification and reviews. SME data was supplemented with secondary sources, including academic articles, government reports, and trade and business publications.

2.7.1 SME Finding

Analysis indicates the following SME findings:

- Based on research covering seven Enabling Capability Areas, JETS final state objectives are technically achievable within 20 years.
- However, none of the Enabling Capability Areas is able to deliver JETS final state objectives *in the near term*. All require substantial development work that is likely to last into at least the 6 – 10 year period.
- Patient Surrogates and Artificial Intelligence/Machine Learning are the Enabling Capability Areas with the shortest likely development timelines for achieving JETS final state objectives. For both, end state (Increment 4) capabilities are expected to be at TRL 4 – 7 within 10 years, and at TRL 8 – 9 during 11 – 15 years.
- The other five Enabling Capability Areas – Moulage/Simulated Tissue, Holography, Haptics/Tactility, Distributed Connectivity and System of Systems – will require a longer development period. Final state (Increment 4) capabilities for these are viewed as reaching TRL 8 – 9 during 16 – 20 years.
- At Increments 1 and 2, risks to JETS objectives derive primarily from the System of Systems area. There is unavoidably large effort required to achieve necessary cross-Component integration. SMEs noted that the JETS Architecture initiative is the necessary first step and is unlikely to begin before the latter half of 2020. Thus, SMEs viewed Increment 1 integration goals as medium risk out to 5 years, and low risk by 6 – 10 years. Large, fully-integrated, joint medical exercises at Increment 2 were viewed as medium risk at 1 – 5 and 6 – 10 years, but low risk by 11 – 15 years.
- Increment 3 involves very significant levels of technology infusion, including the first introductions (per the JETS CDD) of Holography, Haptics/Tactility, AI/ML and fully-global, always-on Distributed Connectivity. All involve major development challenges. Increment 3 capabilities are viewed as achievable in 6 – 10 years in the areas of Patient Surrogates, Haptics/Tactility and AI/ML. For Holography and Distributed Connectivity, Increment 3 capabilities are expected to reach TRL 8-9 in years 11 – 15. Moulage/ Simulated Tissues and System of Systems yield the highest risk at Increment 3; those capabilities are not viewed as reaching TRL 8 – 9 until years 16 – 20.

- Industry can be relied on to deliver the preponderance of needed developments in Holography, Artificial Intelligence/Machine Learning, and Distributed Connectivity. Haptics/Tactility will also benefit from large commercial investments but not to the full extent required by JETS. Substantial government investment is viewed as necessary to Patient Surrogates, Moulage/Simulated Tissues, and System of Systems.

2.7.2 Recommendations for Continuing Assessment and Analysis

JPC-1 staff is immersed in the Medical Simulation community. The organization's ability to carry out continued assessment and analysis on new developments from within that community is a given.

This effort identified and confirmed likely sources of relevant technical advancements that are outside of the usual medical simulation orbit. Non-medical industries and applications recommended for continued analysis and technology scouting include the following:

- **Industrial Automation** – Extensive work is being done on "collaborative robots" or "cobots," meant to work together with humans in a shared workspace. Such robots need to be smart and highly-sensored in order to maintain safety. Leading companies (or those worth watching) include ABB, Fanuc, Epson, Festo, Locus Robotics, Rethink Robotics, and Vecna.
- **Soft Robotics** – This is a developing subfield within robotics and involves building robots of flexible and compliant materials for highly-varied applications. Often the designs seek to exploit biomimicry to achieve desired results. Potential applications include agriculture and food preparation/service. Soft robotics could benefit JETS in the areas of Patient Surrogates and Moulage/Simulated Tissue. Its research agenda also overlaps with Haptics/Tactility. In 2018, IEEE held its first International Conference on Soft Robotics. Companies to watch include robotics leaders ABB, Fanuc, and KUKA AG as well as specialists Cyberdyne, Soft Robotics, Inc., Ekso Bionics Holdings, and Bionik Laboratories Corp.
- **Human-like Robots in Adult Entertainment** – The adult entertainment industry is perhaps the industry sector with the greatest incentive to produce pseudo-humans that look and behave like the real thing. Several companies have made product announcements in 2017 – 2018 concerning AI-assisted "dolls" or robots. According to a report by Foundation for Responsible Robotics [9], these include: RealDoll, Sinthetics, Abyss Creations, Android Love Dolls, TrueCompanion, and Sex Bot Company.
- **Aircraft/Engines, Mining Equipment, and Agricultural Equipment Manufacturing** – These makers of large, complex capital equipment are at the forefront of AI-based self-monitoring and self-maintenance capabilities. They are also at the forefront of providing AR/MR assists and training to their assembly and maintenance workers. Companies include Boeing, Airbus, Caterpillar, Deere, General Electric, Komatsu, Volvo, and many others.
- **Warehousing and Fulfillment** – Amazon is the known leader in all aspects of smart warehousing and automated delivery.
- **Gaming/Entertainment Industry** – Entertainment gaming is the big source of commercial industry demand for VR/AR/MR devices and capabilities. Current leaders in VR device sales are Sony (PS4 VR), Facebook (owners of Oculus Rift), and HTC (Vives). Experiential entertainment developers (including for amusement parks and museums) are expected sources of 3D immersive holography and haptics. Disney and Google Expeditions are among the leaders here.

2.7.3 Additional Considerations

Discussions with SMEs were sometimes far-ranging, going well beyond technical issues encompassed by the seven Enabling Capability Areas. Two themes in particular were raised in multiple interviews.

First, SMEs recognized that full optimization of the JETS system, achieving maximum training outcomes subject to cost and other constraints, will most likely *not* involve maximal technology use. This point was made most often with respect to simulated realism and use of AI/ML. Regarding realism (of patient surrogates and simulated tissues), SMEs questioned whether "full" or "extreme" realism will prove to be best practice. Some made this point strictly in terms of a cost-benefit tradeoff ("fidelity equals cost."). Others argued that extreme realism is only one possible means to evoke empathy. Complex and "emotionally impactful scenarios" can also evoke empathetic responses even in the absence of hyper-realism. Whether JETS should choose to invest in realism vs. complex scenario development is an open question.

Put another way, some SMEs felt that JETS objectives seem technocentric as currently stated. With regard to AI/ML, several SMEs commented that "full" use of AI might not be better than "partial" use. Why use AI to predict replacement of an inexpensive, easy-to-replace part? As one SME put it, sometimes "software and automated regulation" may be a good-enough solution and more cost-effective than AI/ML.

Second, SMEs emphasized the need for robust and early investment in instructional analysis regarding who needs training and on what content. One expressed that "the most difficult issue is training-value research." Another emphasized what he sees as a pervasive difference in approach between industry and government in this regard. "The military seems unwilling to invest money or resources in field research to determine what the real [training] needs are. [In contrast,] industry spends a lot of money to do that, as they don't want to waste their investments."

Both of these themes point to the notion that refinement of JETS objectives and strategies requires complex, multi-factor decision-making. Decisions about system objectives and technologies are ideally made simultaneously with decisions about training content, training outcomes, and cost/benefit trade-offs.

2.8 TECHNOLOGY READINESS LEVELS

The Availability Scale is based not just the TRL level of individual technologies and equipment, but on the availability of the full capabilities JETS requires (Table 2-19).

Table 2-19: Technology Readiness Level Definitions.

TRL	Definition	Description
1	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied Research and Development (R&D). Examples might include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof-of-concept.	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in a laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.

TRL	Definition	Description
5	Component and/or breadboard validation in a relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include “high-fidelity” laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology’s demonstrated readiness. Examples include testing a prototype in a high-fidelity.
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include Developmental Test and Evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in Operational Test and Evaluation (OT&E). Examples include using the system under operational mission conditions.

Chapter 3 – MODELS FOR SURGICAL TRAINING AND TACTICAL COMBAT CASUALTY SKILLS

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3.1 REQUIREMENT (BACKGROUND AND PURPOSE)

Teaching methodologies and tools used to impart skills in medicine and surgery have remained almost unchanged for many years, relying on the use of rigid models, live animals or the dissection of cadavers. Blended training scenarios, involving actors or mannequins, have been used to prepare trainees, not only in clinical skills, but in the emotional and logistical challenges they also face, however, there is clearly a stage in the process when the simulation is interrupted and progression between models becomes necessary.

From the point-of-wounding through to damage control resuscitation and surgery, simulation offers the potential to expose personnel to the stresses of real-time decision-making in a safe but highly realistic simulated environment. In this context, the models used in simulation must allow the procedures required actually to be performed and their success or failure determined by relevant clinical observation. If not, the simulation breaks down and the ability to transfer the lessons learned into real life may well be impaired.

There is a growing need to explore the potential of simulated training environments in military medicine, particularly in areas currently covered by the use of physical models, balancing the costs of training, ethical and political imperatives, effectiveness, standards and opportunities to enhance and maintain skill sets. This may include the use of simulated environments, enhanced live training, immersive environments or fidelic models; employment of enhanced haptic technologies and high fidelity will be crucial to success, particularly in combat casualty care and damage control surgery (where simulated surgical procedures should also include potential complications).

Maintaining the knowledge, skills and performance attained by the defence medical services in recent conflicts is essential to protecting our Armed Forces' most important assets, its personnel. The chain of care, which begins with Tactical Combat Casualty Care (TCCC) and was continued by the Medical Emergency Response Team (MERT) may be redefined in future conflicts [10], [11]. However, the key TCCC and MERT interventions are likely to remain the cornerstones of mission rehearsal.

There are multiple elements to consider for a simulation programme, and technology is only one of the many dimensions. The ultimate goal is to engage learners to experience the simulated scenario followed by effective feedback and debriefing. Simulation is a useful modality to supplement training in real clinical situations because it enables control over the sequence of tasks offered to learners, provides opportunities to offer support and guidance to learners, prevents unsafe and dangerous situations, and creates tasks that rarely occur in the real world. It is also an effective method for inter-professional education [12].

This chapter is focused on the development of fidelic, synthetic physical models to benefit future medical surgical training. The chapter aims to review the current state-of-the-art, future directions and highlight innovations to:

- Train surgical skills;
- Refresh or maintain skills;
- Exercise triage;
- Rehearse medical evacuation processes.

3.2 STATE-OF-THE-ART

3.2.1 Introduction

Developments in the use of immersive environments and advanced computing power has enabled a wide range of activities to be opened up to individual (e.g., surgeons and specialists), joint (mission planning, e.g., HOSPEX type scenarios – see Chapter 4 and Ref. [13]) and collective (e.g., mass casualty triage rehearsal) training.

The utilisation of advanced synthetic materials, combined with 3D scanning and rapid prototyping, has enabled the development of high fidelity, cost effective surrogates, which can be employed in teaching or training of a range of medical tasks specific to military scenarios.

Existing simulation mannequins are largely developments of models intended for anaesthetic and medical emergency training. As a consequence, they retain doll-like characteristics which hinder the immersion of participants in the learning environment. Mannequins designed with large electronic elements are inherently vulnerable to damage or complete failure in all but the most controlled environments. These models include the "Caesar™ Trauma Patient Simulator" (CAE Healthcare Sarasota USA) and the "Ultimate Hurt" and "SimMan 3G Manikins" (Laerdel UK). which are all limited in terms of their capabilities and ruggedness.

These innovations stand apart from existing capabilities which rely upon live animal models (Surgical Training Denmark [13]), human cadavers (UK Military Operational Surgical Training – MOST) and existing simulation mannequins. The ethical considerations of using tissue (whether animal or human cadaver) are substantial. In addition, animal simulations are significantly limited by the drastic anatomical differences, which mean that many procedures cannot be executed in a true-to-life manner, exemplified by those relating to the airway.

Although those anatomical differences do not apply to human tissue, the source material means that the tissues are generally those of frail elderly people, many of whom have undergone invasive medical or operative procedures before their deaths. This often restricts the scope of what can be undertaken. Although techniques to re-perfuse cadavers have been described, the potential contamination issues, if massive haemorrhage is simulated, are considerable, and compound the restrictions on location for such exercises determined by Anatomy Law licensing (in the UK governed by the "Anatomy Act 1984" and "Human Tissue Act 2004").

Consideration needs to be given to how models (immersive environments, mannequins and synthetic models) are employed. Several studies have demonstrated that there is no significant difference in skill acquisition, aptitude and use, in surgeons trained using live tissue, compared to those trained on high fidelity patient simulators in battlefield trauma training. However, user feedback demonstrates a clear preference to live tissue, citing immediate response, temperature, enhanced confidence and better preparation for the field.

3.2.2 Examples of Commercial Solutions

This is a rapidly expanding market, with degrees of fidelity, realism and functionality growing year-on-year, however, unit cost of the models remains high. Whilst many commercial players may enter the market bringing novelty and innovation, these become integrated and consolidated within larger, more established organisations' products and services [14].

A selection of solutions on offer worldwide include (but are not limited to):

- **TOMManikin**: An all-in-one system that provides the ability to enhance Tactical Combat Casualty Care (TCCC) from point-of-injury to transfer of higher care. Created in collaboration with **Techline Technologies, Inc**., this system allows users to build multiple PR Scenarios and create realistic Full Mission Profiles (FMP) with reactive patients. TOMManikin is a trauma mannequin

simulator designed for classroom settings, Trauma Lanes and field training scenarios. Multiple appendages present a variety of wounds including Gunshot Wound (GSW), blast and burns to provide full mission profiles in combat scenarios. The vendors claim that *"durability and realism make TOMManikin a cost effective, educational trauma training tool capable of surviving the rigours of TCCC, APT and Tactical Medicine"*.

- **SIMBODIES:** Developed by **Trauma FX Limited**, these are extremely life-like bodies and body parts, designed and hand produced for use in medical training and incident scenarios. The team work in partnership with Prometheus Medical, who develop and supplies state-of-the-art medical equipment for the pre-hospital care environment, and provide medical training for a wide audience, including UK emergency services and other organisations. The training is delivered by currently practicing, highly-experienced doctors, paramedics and nurses, in realistic training environments and scenarios.
- **SimMan 3G (Laerdal):** An advanced patient simulator that can display neurological symptoms as well as physiological. It is relatively simple to operate and features innovative technology such as automatic drug recognition. The system is used globally by emergency services and military organisations, as it is *"specially adapted for training rapid assessment of trauma emergencies"*.
- **Caesar™ Trauma Patient Simulator** (CAE Healthcare, Sarasota USA): CAE Healthcare delivers specialized educational tools that help healthcare professionals provide safe, high quality patient care. Their end-to-end spectrum of simulation-based solutions includes patient, surgical and ultrasound simulators with virtual and augmented reality, centre management systems and turnkey solutions.
- The **"Surgical Cut Suit"** has received much attention in recent years and been trialled and reviewed by a number of military medical organisations worldwide. The system is a partial task surgical simulator for practicing, for instance, haemorrhage control, organ incisions suture techniques, laparotomy and abdominal exploration. Skin and organs are user-repairable, allowing for multiple uses per unit. The system has interchangeable organs with variable wound patterns or pathologies (internal and external haemorrhaging), and users can create and customise wounds.
- **Ultimate Hurt:** Developed by Laerdal, "Ultimate Hurt" is described as a cost-efficient, multi-functional and realistic training mannequin; airway management, trauma assessment and extrication skills can all be taught. It is designed to be durable, rugged and portable for field training exercises; the manufacturers claim that quality of construction and materials allow the mannequin to be used in extrication and triage exercises. To add additional realism to training, modules such as "Nuclear, Biological, Chemical Simulation" and "Bleeding Control" can be used with the Ultimate Hurt.
  - The mannequin comes with a wide range of trauma wound modules and three interchangeable heads to enhance scenarios, with multiple facial and cranial fracture modules permitting assessment of traumatic head injuries and realistic articulation for application of cervical collars, splints and traction or for use of a spine-board.
  - The three interchangeable heads are described as: "Standard intubation head", which allows for airway management by manual manoeuvres and various airway devices; "Trauma intubation head", which has an impaled object in the cheek, avulsed ear, unequal pupils, broken teeth and multiple lacerations; "Mr. Hurt Head", which facilitates facial and cranial trauma assessment including an open depressed skull fracture, deviated trachea, bilateral mandible fractures, and fracture of the C6 vertebrae.
  - The trauma wound modules allow trainers to adapt training to a variety of situations. Modules included are: "sucking chest wound"; "burn arm", with first, second and third degree burns; "compound fracture radius"; "industrial hand" (including, severe laceration to the dorsum of

the hand with exposed bone and soft tissue and open and closed fracture of index finger and severe tear of the fingernail with contusion); “exposed viscera”; “large and small calibre entry and exit wounds”; “impaled object”; “compound fracture femur”; “closed fracture tibia and fibula”; “contused ankle and foot”; “crushed foot”.

- Note: Ultimate Hurt has been discontinued as of May 2017. Some parts and accessories are still available.

3.2.3 Example Scenarios and Systems in Development

3.2.3.1 Introduction

Using mannequins in clinical simulations allows future and current physicians to “practice on plastic” first. The reality of mannequin-based simulations allows for virtual feedback using computers that can regulate the mannequin’s compressors, mimicking pulses and chest raising. These life-like mannequins simulate heart tones and other vital cues that when connected to monitors, provides real-time information to students. By practicing true clinical skills in a safe and regulated environment, future physicians can learn permanent evaluation and treatment techniques [15].

This section provides details on a selection of systems in development.

3.2.3.2 TraumaSim Limited (Leg/Pelvis Blast Model)

In the UK, Trauma Simulation Limited (a partnership between industry and academia) was funded by MoD (through the Centre for Defence Enterprise, now Defence & Security Accelerator) to develop a realistic trauma simulation model for massive lower limb and pelvic injury (modelled on a volunteer amputee’s MRI data) (Figure 3-1). The model has the look and feel of a realistic patient and is suitable for the training of a number of minor surgical procedures. The model is used to help military medical personnel, from first responders to surgeons, train for how to respond to major battlefield injuries. The model reproduces patterns of injury and bleeding encountered by surgical teams in combat zones and uses advanced materials to simulate the properties of different human tissue. The model was created using a silicone ‘copy’ of a 3D printed master and based on CT scans of a former patient.

Developed in 2014 it has already been used at July 2015’s MOST (Military Operational Surgical Training) course at the UK Royal College of Surgeons and demonstrated at the NATO Wales Summit (September 2014) and DSEI (September 2015).

The original model development was targeted towards reproducing the signature injury of the Afghan conflict. At the DSEI event the research team demonstrated that repairs to a pelvic packing incision could be achieved and the model was used a total of six times.

The research team have now acquired all of the MRI data for their original volunteer which will enable the reproduction of the entire body, providing the capability to simulate any injury pattern in any part of the body (or combination thereof) – see Section 2.3.4. Given the change in focus to contingency operations and planning, this may be an option for future consideration.

In parallel, the team have continued to work on other elements of the simulation and have developed a very good proximal humerus intraosseous infusion model ready for mass production (January 2016). A groin junctional haemorrhage/shunt model was completed in March 2016 (Figure 3-2).

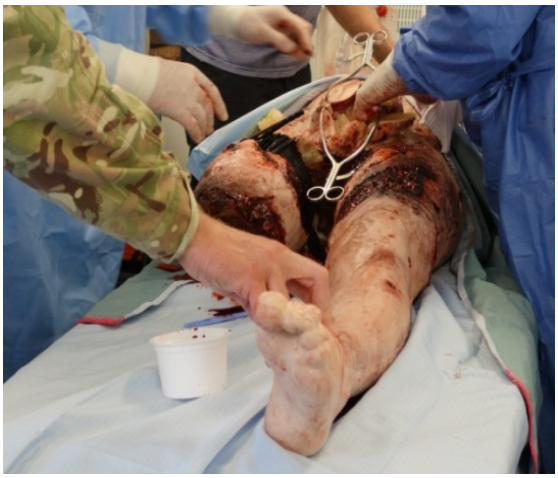

Figure 3-1: Trauma Simulation Blast Injury Patient.

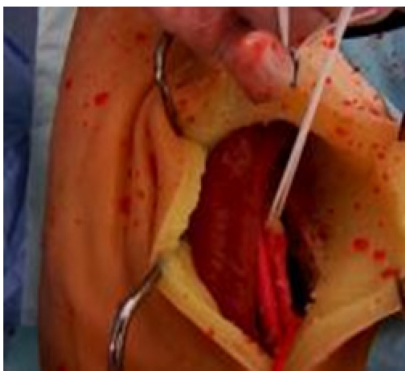

Figure 3-2: Trauma Simulation Model – Groin Injury Simulation.

Trauma Simulation Ltd, as awarded the prize for Innovation at the Sun Military Awards in 2016 (Gov.uk, December 2016). Following on from this, additional single procedure models have been created for training in intraosseous needle insertion in the proximal humerus, an essential step in resuscitation in the critically injured. In the presence of severe blood loss, the peripheral and indeed central veins collapse making their cannulation impossible. However, the vessels within the honey-comb structure of the bone of the upper arm cannot collapse and so once a needle is inserted, it can be used to provide transfusion, pain relief and anaesthetics. Novel features of this model have enabled a patent to be filed (UK Patent Application No: 1608979.9).

3.2.3.3 Nottingham Trent University (Thoracic Trauma Trainer)

A realistic simulated thoracic cavity would reduce or obviate the need for trials on cadavers and animals when training surgical personnel. The aim of this project has been to provide a simulated thoracic cavity, where the internal organs are not only visually accurate, but also have the required surface texture and mechanical characteristics under deformation and manipulation. Nottingham Trent University (NTU) has already developed simulated body tissue and organs. For example, a simulated human heart and human adipose tissue have been created (Figure 3-3). These were made from polymeric elastomers (e.g., silicones). However, they were created for applications in the health service whereas, in military applications, different criteria will be required. For example, arterial damage is likely to be a major focus of the military surgeon and significant disruption to the position and morphology of organs can occur after blast or shrapnel impact.

Phase 1 of this project (funded by UK Royal Centre for Defence Medicine) has completed. The study focused on identifying end-user requirements, physiological data capture, materials identification and property matching and development of 3D printed moulds [16]. Subsequent iterations of the model have been incorporated into commercial development (such as Trauma FX's "Simbodies").

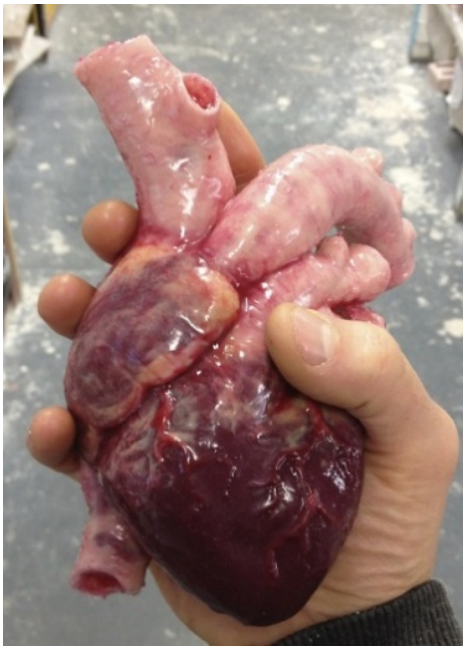

Figure 3-3: NTU: Synthetic Heart.

3.2.3.4 TraumaSim Limited (Rugged Whole-Body Trauma Simulation Model for Pre-Hospital and MERT En-Route Care)

Two whole-body models have been developed, building upon the Trauma Simulation Ltd complex blast injury model, the development of which was previously supported by UK MoD [17]. The custom silicone elastomers used in the production of that model enabled the feel, weight and flexibility of living human tissue to be faithfully reproduced. The further development of a unique cast-and-construct method has enabled the team to streamline the production of the models, while retaining the anatomical detail created in the 3D printed master models derived from a former patient's scans.

Each of the two models developed has been prepared with specific injury patterns (blast, ballistic, blunt or combined) appropriate to the training scenario in question. Both are rugged in construction and visually striking representations of the relevant injury patterns.

The "simpler" procedure training model is "inanimate" but will enable the participants to execute all of the above interventions, with continuous bleeding simulated from carefully prepared complex wounds using special effects techniques for the greatest visual impact. The more complex animated version contains all of these features, plus a mechanism to produce pulsatile bleeding and simulated spontaneous breathing. These features would be under remote control and could be manipulated by a simulation controller.

For both models the materials previously developed have been refined to ensure they retain life-like handling properties (including physical weight) whilst being rugged enough to withstand the physical demands of the simulation environment. Importantly the model is capable of being ventilated, with the option of a replaceable section for performance of cricothyroidotomy (see Figure 3-4).

The realism of the upper parts of the airway is crucial to the impact of the breathing mechanism on those executing procedures on the model; the original design of the plug over the cricothyroid membrane tended to collapse when landmarks were palpated and extruded when the neck was moved. Modifications to the geometry of the plug were made and re-tested along with the use of gel silicone material for the tongue and gum silicone for the airways which is extremely strong (Figure 3-4). By covering the new design of plug in a layer of "skin" which overlaps its margins, gapping at the edges of the plug during manoeuvres is prevented.

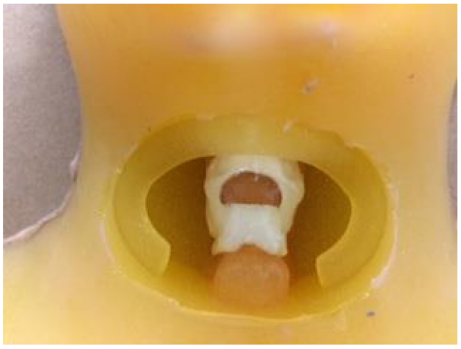

Figure 3-4: Trauma Simulation Model – Cricothyroidotomy Element.

Completed models contain replications of all major bones, muscles, blood vessels and organs including a complete airway, appropriately positioned and then covered in silicone "skin" (see Figure 3-5). Additionally, incorporated is a blood reservoir and the mechanisms to animate the "complex" model, including a customised, compact peristaltic pump and a servo driven breathing mechanism.

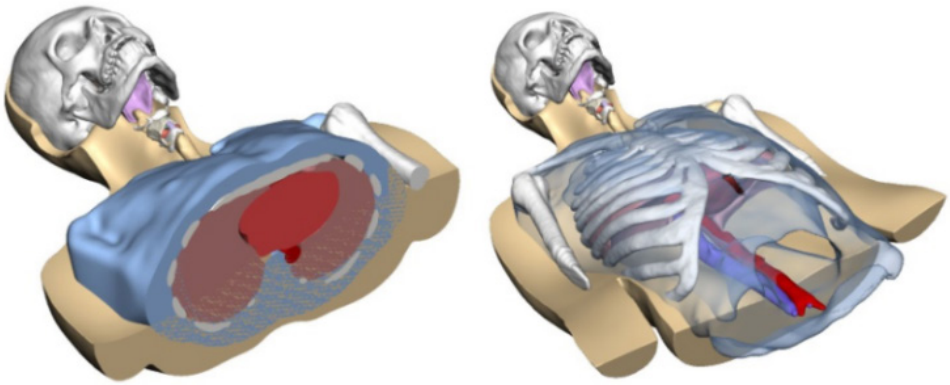

Figure 3-5: Representation of the Trauma Simulation Upper Torso (Prior to Skin Application).

Trialling of the models took place at RAF Brize Norton within a series of operational scenarios (27 April 2018). The animated model was tailored towards a multiple gunshot casualty and the simpler model to massive blast injury, including traumatic amputation and cavitating pelvic injury with catastrophic bleeding and resulting traumatic cardiac arrest.

With support from the UK MoD Defence & Security Accelerator "Open Call for Innovation" TraumaSim have begun the development of a rugged, waterproof, harness-lift capable human model, aligned with the existing Medical Emergency Response Team MERT Training Programme requirements, along with those of Field Hospital Units and Special Forces. Maintaining the knowledge, skills and performance attained by the Defence Medical Services in the Afghan Conflict, however, the model will also be relevant to civilian services such as HART and paramedic teams.

Two versions of the whole-body model have been created, each of which can be prepared with specific injury patterns (blast, ballistic, blunt or combined) appropriate to the scenario in question. Both will be rugged in construction and visually striking representations of the relevant injury patterns.

The simpler procedure training model is “inanimate” but will enable the participants to execute all of the above interventions, with continuous bleeding simulated from carefully prepared complex wounds using special effects techniques for the greatest visual impact. The materials previously developed will be refined to assure they retain life-like handling properties (including physical weight, skin and tissue texture) while being rugged enough to withstand the physical demands of the simulation environment. Importantly the model will be capable of being ventilated, with the option of a replaceable section for performance of cricothyroidotomy.

The more complex animated version contains all of these features, plus a mechanism to produce pulsatile bleeding and simulated spontaneous breathing. These features will be under the control of a simulation controller (Figure 3-6).

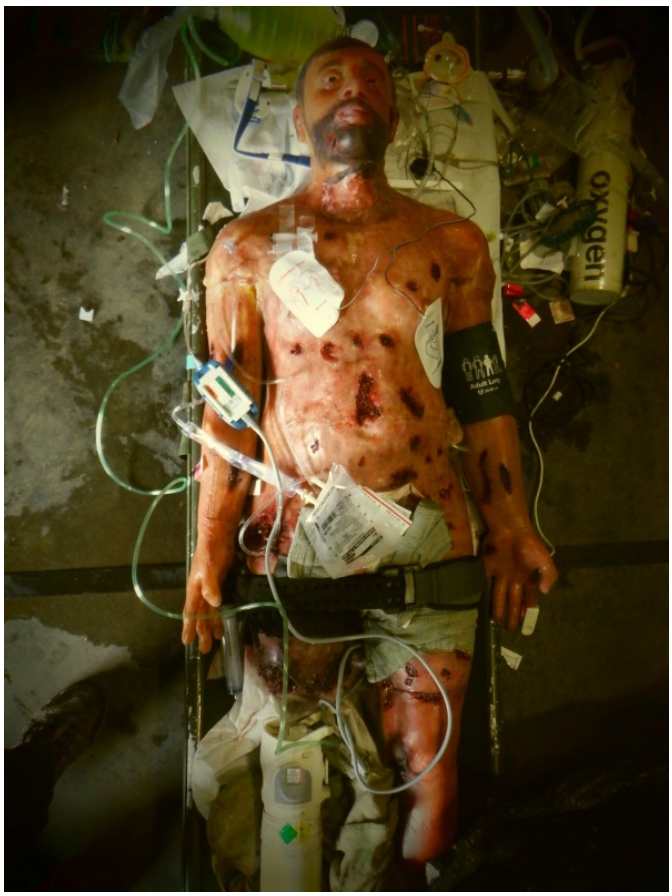

Figure 3-6: Instrumented Whole Body Patient.

The key interventions simulated will be:

- Securing control of catastrophic haemorrhage;
- Advanced Airway Intervention: rapid sequence induction intubation or cricothyroidotomy;
- Chest decompression: thoracotomy, tube or open or needle decompression;

- Intraosseous access: humeral access sites;
- Intravenous access: peripheral or central venous;
- Pre-hospital Blood: administration of red cell concentrate and plasma.

The whole-body simulation models are robust, customised to requirements and capable of being re-used to contain costs. The visual impact of the models is striking and their physical properties will assure that the anatomical landmarks used and the feel of the simulated tissues during each procedure faithfully prepare the participants for the real event.

3.3 LIMITATIONS (TO MODELS) AND EFFECTIVENESS

Consideration needs to be given to how models (immersive environments, mannequins and synthetic models) are employed. Several studies have demonstrated that there is no significant difference in skill acquisition, aptitude and use, in surgeons trained using live tissue, compared to those trained on high fidelity patient simulators in battlefield trauma training. However, user feedback demonstrates a clear preference to live tissue, citing immediate response, temperature, enhanced confidence and better preparation for the field.

Reported at the NATO Symposium HFM-254 (Paris, October 2015) and MHSRS (Fort Lauderdale – August 2015) was a study conducted by DRDC on the use of live tissue versus high fidelity patient simulators in battlefield trauma training. 20 trainees on the 7 day TACMED (casualty care skills training course) were split into two equal groups, who trained on live tissue or simulator, and then tested under field conditions on either of the modalities (live or simulated, thus giving four groups of n = 5). Outcome measures, included aptitude, plus stress, cognitive function and user interviews. The study concluded that there were no significant differences in training, regardless of modality (both were successful), however, there was a dip in performance for those who switch modalities (e.g., trained on simulator, but tested on live tissue). In user feedback there is a clear preference to live tissue (immediate response, warm, enhanced confidence, better preparation for field), but some positive elements for the simulation ("human" rather than animal model) [18]. A further study of n = 60 is planned.

Although the use of high fidelity mannequins in a number of training regime worldwide, as yet there is no conclusive evidence to suggest that simulation or live tissue training offers a superior modality [14].

3.4 SYSTEMS IN DEVELOPMENT (AND HORIZON SCANNING)

3.4.1 Introduction

Although many organisations, either with commercial, charitable or government funding are continuing to develop simulators and models, much of the current focus is on refinement, either to modality, durability or use case scenarios (see examples below). There is a significant recent drive to using the models in field based scenarios and wider, blended training regimes [19].

3.4.2 Specific Examples

TraumaSim: Major Trauma Damage Control Resuscitation and Surgery: Simulation Modularity and Flexibility

Haemorrhage is the leading preventable cause of death in combat. Training in surgical haemorrhage control on unfamiliar junctional zones (groin and shoulder) is constrained to using cadaveric/animal material. Redesign of existing TraumaSim models will enable the creation of task trainers with exchangeable modules for rapid reuse, specific to UK Defence Medical Services requirements. Once task analysis and trialling are

completed, these elements will be integrated into the whole-body model allowing immersive simulation. In response to feedback from the MERT and MOST teams, improved materials and construction will ensure the models withstand the rigours of course use and retain their fidelity and impact.

In both the TCCC and DCR/S models, the use of highly realistic customised silicones and composite cast/construction methods allows models to be created with great visual impact and realism in terms of handling properties when invasive procedures are carried out.

TraumaSim's work has demonstrated that appropriate models can be created which offer excellent simulation of common trauma pathology and necessary interventions. The point-of-wounding models were designed specifically to enable the recognition and management of immediately life-threatening problems in keeping with TCCC plus key Advanced Medical Retrieval (AMR) interventions. Embracing the <C>ABC paradigm, control of catastrophic haemorrhage can be secured with the use of proximal manual pressure, pelvic binders, limb tourniquets and wound packing. Intravenous and intraosseous cannulation can be performed along with chest decompression with the option of enhanced realism of chest wall movement with simulated respiratory effort. Advanced airway interventions include simulated rapid sequence induction and intubation or cricothyroidotomy.

All of the above procedures can also be executed on the DCR/S models with the added dimension of pulsatile blood flow, a measurable "blood pressure" within the simulated circulation, along with concealed internal or obvious external haemorrhage. Junctional control at the groin, extra-peritoneal pelvic packing, arterial shunting, lower limb compartment decompression and external fixation of the pelvic and lower limbs can all be executed.

While enabling these interventions to be executed real-time was the focus, the method of producing the models was refined applying the cast/construction approach previously described. The initial cradle was cast from an extremely tough silicone elastomer to ensure the maximum resistance to wear and tear on the model's base. New simplified bone models were developed for the upper limbs to allow realistic passive movement especially in the elbow, wrist and hand.

The use of specific toughened gum silicone elastomers in the upper thigh and pelvic region mean the tourniquets can be applied multiple times securing control of simulated bleeding without any visible damage to the model's "skin". The same approach has enabled the mouth and oral airway to be reinforced, successfully resisting the tendency for tears to occur in the corners of the mouth.

The research team has recently completed a series of experiments using this model simulating catastrophic bleeding from a traumatic above knee amputation to compare a standard "hospital" pneumatic tourniquet with point-of-wounding tourniquets (commercial and improvised). This has confirmed realistic occlusion pressures are needed when these devices are applied to the model, when "blood pressure" in the model blood vessel is at a clinically relevant level (Unpublished data).

Specific goals of the next steps in development are:

1) Develop task training models tailored to UK Defence Medical Services requirements for junctional haemorrhage control at the groin and shoulder with exchangeable modules to assure swift reset but retention of visual integrity.
2) Trial and re-trial of these models in parallel to the established activity at the MOST Course to refine their design, fidelity and utility with incremental improvements.
3) Review and redesign the task training elements included in the MERT models, prototyping these as specific task training models to assure their utility in a whole-body model.

4) Modify the design and production of the whole-body model to allow the incorporation of these elements towards the conclusion of this project, along with the use of a flexible metal core armature to allow the model to be more freely poseable (especially relevant in the point-of-wounding scenarios) along with changes in the cradle material to afford flexibility with toughness.

3.5 CONSIDERATIONS FOR FUTURE DEVELOPMENT AND ADOPTION

Training surgical skills using traditional aids carries a number of moral, ethical and financial implications and may additionally teach techniques that do not translate to living patients. Although advances have been made in recent years in both simulation and immersive technologies, a single environment, linking realism, haptics and emotional connection remains elusive.

No matter how realistic, adaptable and durable existing mannequin systems (or those in development) are, to be incorporated into training curricula consideration needs to be given to the following:

- Development of guidelines, practicalities and standards.
- Establishing measures and metrics of competencies.
- "Training the trainer" options.
- Options to optimise adaptive distributive learning.
- Options to blend usage into team and collective training scenarios (including interoperability between partner nations).
- Examination of costs, procurement and acquisition strategies.

3.6 RECOMMENDATIONS

Prototype versions of a number of simulation models suitable for training of military medical skills have been developed.

All models have the potential to enhance future training regimes but need to be evaluated and tested under appropriate conditions and compared to existing training practice.

Further consideration is required, namely:

- What training needs could be provided through simulation?
- Where should future investments be made e.g., in virtual reality environments, synthetic models or a blended approach and should it focus on specific injures, body regions or a modular "whole-body"?
- How could models be used and integrated into training courses?
- How models would be benchmarked and accepted (including measures, metrics and competencies).
- What procurement/acquisition strategies would be appropriate?

Chapter 4 – HOSPEX TABLETOP SUPPORT PACKAGE

HOSPEX Tabletop Exercise created David Vassallo
Defence Medical Services
UNITED KINGDOM

Support Package created by Michaël Leenhouwers and Huub Curvers
Military Health Educpation & Training Centre
NETHERLANDS

4.1 HOSPEX TABLETOP EXERCISE

The HOSPEX Tabletop Exercise, drawing on many years' experience of field hospital deployments and major incidents, as well as on current UK/NATO doctrine, comes in two versions for internal unit training prior to full scale exercises or deployment: The Tabletop and the Expanded Tabletop.

The HOSPEX Tabletop is a scenario-based tabletop training exercise undertaken as a morning or an afternoon Workshop (Figure 4-1). It uses two to five tabletop areas representing deployed NATO Role 1 (and point of injury), Role 2 Basic and Enhanced, and Role 3 Medical Treatment Facilities / Hospitals during a contingency operation in a wide range of environments.

Each Tabletop play board has cards representing each member of the medical staff. Casualties are represented by sets of cards in plastic wallets, replicating scenarios from single disease or trauma cases up to a variety of major incidents. There are other visual aids and documents. Participants learn and practice important aspects of the principles of command and Control, Safety, Communication, Assessment, Triage, Treatment and Transport (CSCATTT), testing their decision skills, in an enjoyable and interactive learning environment during a Workshop lasting 2 – 3 hours.

Figure 4-1: Typical HOSPEX Tabletop Setup, Classroom Setting.

The HOSPEX Expanded Tabletop uses some 16 or more tables to represent the layout of a tented Medical Treatment Facility or Field Hospital (Figure 4-2). It can be set up in a large classroom but is ideally set up in a large hall (such as an Army Reserves Centre drill hall). It is run over a half-day or preferably a whole day, or even longer. The HOSPEX TableTent variant of this uses both tables and tents in a large drill hall, enabling a greater degree of simulation training to occur at the unit's discretion. It can also be used in an actual tented field hospital under exercise conditions.

Aim: The aim of this exercise is to familiarise field hospital staff with the processes, standard operating procedures, and casualty management protocols of a deployed field hospital, within a drill hall setting or very large classroom, before the unit conducts full scale simulation or field exercises.

Method: The drill hall is set up to represent the layout of a deployed field hospital. Casualty and event card inserts simulate trauma, DNBI, and major incident scenarios. The departments are represented by tables, or by a combination of tables and tents, the 'TableTent' variant, in which case unit training staff should provide relevant equipment for greater simulation value. The photos show this exercise in different settings: classrooms, drill hall, and TableTent within a Reserves drill hall.

Figure 4-2: Different Exercise Settings.

The HOSPEX Tabletop and Expanded Tabletop were developed by Colonel David Vassallo of the United Kingdom's Defence Medical Services (DMS), with design work by the British Army's Graphics Studio. The DMS point of contact for HOSPEX enquiries is:

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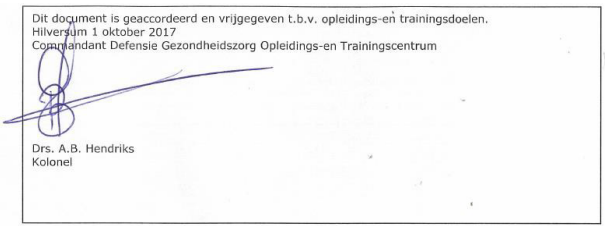
Level 3 Zone I,
Main Building, Whitehall,
London, SW1 A 2 HB.
Email: SG-DMed-MedOpCap-MedNATO-SO1@mod.uk.

4.2 TABLETOP SUPPORT PACKAGE

Tabletop HOSPEX
(English version)
Short name: TTHSPX
Version: 1.0

Michaël Leenhouwers
Huub Curvers

Date: 01 Sept 2017
TC/Unit: DGOTC



Contact:

OTC: DGOTC
Section: OTK
Bureau: H-BOTO
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1213 PW
Hilversum
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Tel: 0355774529

Evaluation and Revision

One year after release of this TSP the document will be evaluated with the units involved with the practical implementation of the content. After that the TSP will be evaluated on a yearly basis by OTK in terms of content, doctrine and user feedback.

4.2.1 General Information

4.2.1.1 Introduction

4.2.1.1.1 About the TSP

The TSP consists of four parts:

- General: This part is meant for all users of the TSP. It contains information about the purpose of the training, the target audience and general provisions.
- Training audience: This part contains the description of events for the participants of the Tabletop and states what is expected from the training audience.
- TT Organisation: This part contains the instructions for the organising authorities. It indicates what is expected and what conditions have to be created for optimal training. The organising authority could be the organic unit, the medical training centre or a third party.
- Planning and organisation: This part contains information about planning and (secondary) conditions.

4.2.1.1.2 Characterisation and Purpose of Tabletop

A Tabletop (TT) exercise is a way to describe, train, test, improve and review (existing) processes, procedures and the internal modus operandi by means of simulation using paper casualties. “HOSPEX TT” is a Tabletop which originated in the United Kingdom. It focuses on important aspects of medical management of the sick and wounded as casualties pass through the medical chain of evacuation: command and Control, Safety, Communication, Assessment, Triage, Treatment and Transport (CSCATTT). Its emphasis throughout is on decision making and situational awareness.

This TSP describes two variants of the HOSPEX Tabletop: the eponymous “HOSPEX TT” and the “Expanded TT”, the latter being specifically designed to use the Role 2 Medical Treatment Facility. The great advantage of a tabletop is that it is easily portable and quick to apply at almost any location without putting a great strain on logistics or personnel.

For the application within the Dutch defence system we have chosen the two British TT variants of “HOSPEX”. This gives us the opportunity to apply the TT within a multinational course, exercise or mission. Another advantage is that we can resort to the original developers for supplements or expansions.

The TT can be used for all medical services of the armed forces. It contains scenarios, cases, roles and maps that can be applied in various work environments: on a ship, on a base or elsewhere. The duration of a tabletop can vary, depending on the objectives to be obtained. The recommended duration is half a day (either a morning or an afternoon session) for a TT, and a whole day for ETT.

The HOSPEX Tabletop is principally intended for the following audiences:

- Primary, for personnel working within a Medical Treatment Facility (MTF) and personnel attached to dedicated medical means of transport.
- Secondary, for medical staff officials.
- Tertiary, to provide insight for non-medical personnel into the processes and procedures that are relevant to them.

4.2.1.1.3 Practical Utilisation

HOSPEX is suited to numerous uses. It can be used in an educational setting as well as in a training environment, but also during real life support or a mission.

Below you will find a summary of possible uses of a tabletop exercise:

- Teaching material for (medical) education, such as the medical officer course, the military nurse course and the military doctor course;
- Tool to introduce new personnel to their function and work environment and to provide insight into their role and relation to other officials and capabilities;
- Tool to train, test and review SOPs/SOIs and internal modus operandi;
- Staff training for MEDCELL, SSM med staff, Role 2MTF staff;
- Staff training in medical chain of evacuation by MEDCELL;
- Wargaming a specific scenario;
- Tool to be used in an after action review;
- Tool to support issuing of orders; and
- Tool for commanders or staff officials to visualise processes or chains within the medical system.

4.2.1.2 HOSPEX Variants

There are two HOSPEX Tabletop variants:

1) **The HOSPEX Tabletop Role 1 – 3**

   This Tabletop is mainly designed for training and improving processes and procedures within the medical system of evacuation, treatment and transport.

   The participants will usually be the commanders and key players in the various capabilities within the medical chain of evacuation, treatment and transport.

2) **The Expanded Tabletop Role 2 MTF**

   This Tabletop focuses particularly on the Role 2 MTF. The ETT is particularly suitable for training the coherence between the various modules of the Role 2, but it also enables a module-commander the opportunity to train the processes and procedures within his modules.

4.2.1.3 Management of HOSPEX

The TC/DGOTC will manage all matters concerning HOSPEX.

The HOSPEX sets will be provided on loan to the operational units by the Training Centre DGOTC. The DGOTC Bureau for Education and Training will manage accompanying documentation, such as this TSP and will embed it in DGOTC courses where possible. Specific wishes and modifications can be filed by users with the TC. The TC will take care of the printing and distribution of these new options.

On the HOSPEX SharePoint page you will find all versions and variants of the TT products, as well as all relevant supporting information concerning TT:

4.2.2 Participants' Tabletop

This section contains a description of training.

4.2.2.1 Event 1 HOSPEX Tabletop

Situation

You are taking part in HOSPEX TT (ideally you will do so in your organic role!).

Your role will be part of the medical chain of evacuation and treatment that is being trained. There can be various reasons for organising a tabletop exercise (see Section 4.2.1.1.2).

In this event we are using a scenario in which our unit is preparing for a level 5+ exercise in which the entire medical system of evacuation and treatment will be trained and evaluated. All sick and wounded have to be treated and managed by the relevant capabilities and/or medical staff members in accordance with valid SOPs/SOIs.

Perception

The TT will take place in an area that is large enough to accommodate all participating capabilities and key players. Each capability has its own "table" (Figure 4-3).

If available, use can be made of maps of mission areas and the camps or bases situated there It is highly recommended that training will be conducted using realistic timings!

The scenario will be started by the TT organisation.

Figure 4-3: Example Capability.

At a location in Area X one or more persons are wounded. These wounded personnel will need to be evacuated, treated and transported by the various capabilities within the medical chain of care. Within their own area of expertise, each capability and key player has to perform the medical, logistic and communication procedures in order to allow the patient to pass through the system as efficiently andeffectively as possible.

Points of Interest

- Make sure that each person within your facility knows what is expected of him.
- Make sure that each person within your facility knows what the tasks and responsibilities of his colleagues within the facility are.
- Make sure that you know what the right procedures are for requesting various methods of medical evacuation.
- Have insight into the links before and after you in the medical chain, so you know what to expect and what is expected of you.
- Be pro-active and help the links after you in the medical chain; make sure you give a full and complete patient transfer.
- Make sure you have a complete set of all of the relevant documents and forms.
- Be aware that the TT may also be (partially) in English!

Desired Results

After the TT exercise the personnel of the participating facilities and all key players will know how to apply SOPs/SOIs in evacuation, the treatment and management of wounded personnel at their location and/or within their responsibility.

Every official will know his tasks and responsibilities within his own facility and those of the other facilities within the medical chain of evacuation.

Because of the realistic timings used within the exercise every participant will have an accurate insight into the various time spans that are involved in the procedures, management and treatment of wounded personnel in the various locations in the medical chain of care.

Participating Capabilities in the TT

Depending on the setting and the training audience there are several capabilities may be taking part in the HOSPEX TT:

- PECC;
- Medical evacuation/transport units;
- Flight nurse(s);
- One or more Role 1 MTFs;
- Role 2 MTF (only key players and module commanders); and
- Role 3 MTF (only key players and module commanders).

Documents Required

- Relevant medical bulletins and other doctrine publications.
- Current SOPs/SOIs.
- Internal methods of operating.

- The right forms and formats.
- Protocol booksand schedules.
- English dictionary (optional).

Supplementary Information (Figure 4-4**)**

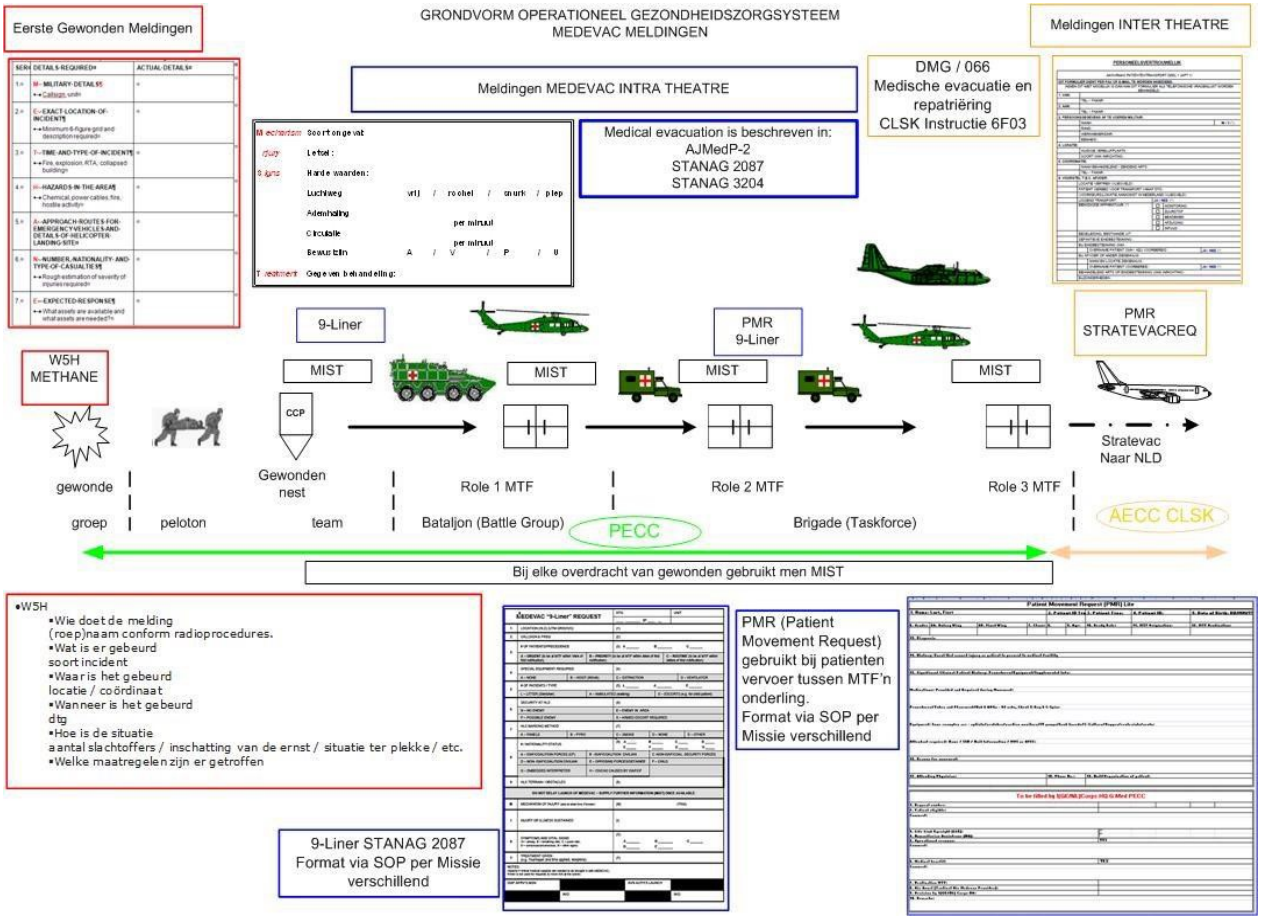

Figure 4-4: Basic Form of Operational Healthcare System Including MEDEVAC Reports.

4.2.2.2 Event 2 Expanded Tabletop

Situation

You are taking part in Expanded Tabletop (ideally, you will do so in your organic role!).

Your role will be part of the Role 2 MTF that is being trained.

There can be various reasons for organising an Expanded Tabletop exercise (see Section 4.2.1.1.2).

In this event we are using a scenario in which the Role 2, within the scope of operational readiness, is preparing for a level 5+ exercise in which the entire Role 2 will be trained, and the medical system of evacuation and treatment will be trained, assessed and evaluated.

All patient cases provided need to be treated and managed by the relevant modules and/or medical staff members within the Role 2 in accordance with valid SOPs/SOIs.

Perception

The ETT will take place in an area that is large enough to accommodate all participating modules and other key players.

Every capability/module within the MTF has its own table(s).

It is highly recommended that training be conducted in real time!

The scenario will be started by the TT organisation (Figure 4-5).

At the Role 2, paper casualties representing ill and wounded personnel will be presented for treatment and management by the various modules in accordance with the SOP/SOI Role 2. Each capability will decide upon and simulate the required medical interventions within their area of expertise and responsibility.

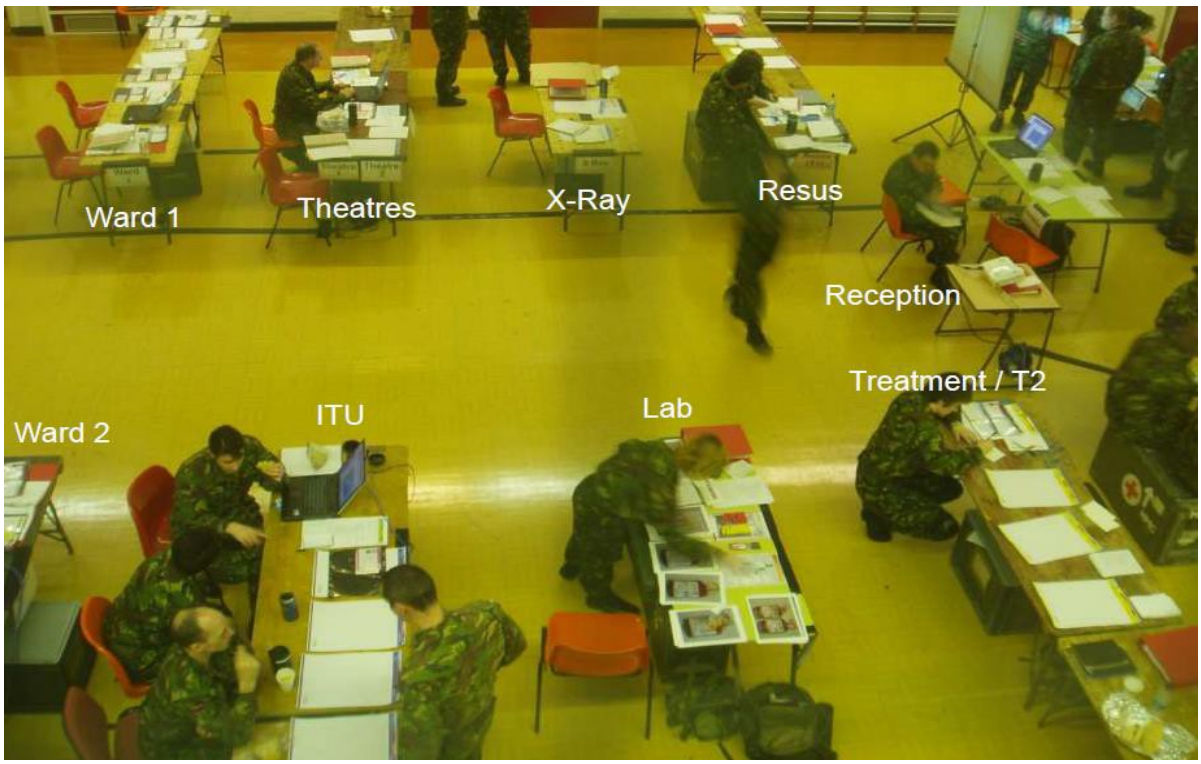

Figure 4-5: TableTop Organisation.

Points of Interest

- Make sure that each person within your capability knows what is expected from him.
- Make sure that each person within your capability knows the tasks and responsibilities of his colleagues within the capability.
- Have insight into the links before and after you in the patient route in the Role 2, so you know what to expect and what is expected from you.

- Be pro-active and help the links after you in the medical chain and make sure you give a full and complete patient transfer.
- Make sure you know the right procedures for requesting the various diagnostic services within the Role 2, such as laboratory and radiology.
- Make sure you know how the logistic lines within the Role 2 are arranged and which procedures and guidelines apply in areas such as requesting means and resources or removal of (contaminated) waste.
- Make sure you know which returns and reports have to be made at what stage and what information is to be given.
- Ensure the efficient and effective use of personnel and other assets.
- Make sure you have all relevant and current forms and documentation.
- Be aware that the ETT can also be (partially) in English!

Desired Results

On completion of the Expanded Tabletop, each capability or key player knows how to apply SOPs/SOIs and internal modus operandi in the treatment and management of a patient in his module or within his responsibility:

- Each participant knows the tasks of his capability/module within the Role 2.
- Each participant knows his own tasks and responsibilities within the capability/module. Each participant knows the tasks and responsibilities of his colleagues within the capability/module.
- All module commanders and other key players know each other's areas of responsibility within the Role 2.

Because of the real-time exercise every participant will have an accurate understanding of the various time spans that are involved in the procedures, management and treatment of sick and wounded personnel within the Role 2.

If necessary, the internal modus operandi of the Role 2 can be modified or fine-tuned.

Capabilities in the ETT

To meet the requirements of a Role 2, the following core-modules have to be present within the Role 2 configuration:

- Emergency area;
- Initial surgery response capability;
- Specified diagnostic capabilities;
- Patient holding area;
- Post-OP (high/medium dependency);
- C4I; and
- Medical supply.

These core-modules can be qualitatively extended with capabilities such as a primary care, sterilisation units, dental care, physiotherapy or a morgue.

Quantitatively, core-modules can be extended with extra operation rooms or ER bays, extra wards or more medical logistic services.

Besides the various modules of the Role 2, a PECC will also be created to take care of the insertion and extraction of sick and wounded patients within the Role 2.

Documents Required

- Relevant medical bulletins and other doctrine publications;
- Current SOPs/SOIs;
- Internal methods of operating;
- The right forms and formats;
- Protocol books and schedules; and
- English dictionary (optional).

4.2.3 Tabletop Organisation

4.2.3.1 Event 1 HOSPEX Tabletop

Roles and Perception of TT Organisation

Prior to a tabletop the organising unit or bureau needs to determine the objectives to be achieved. These objectives will help to determine the training or learning objectives which will serve as a reference for the scenario to be used and the cases to be inserted.

In this event we use a scenario in which all participants of an upcoming level 5+ exercise can test, adjust and improve their SOPs/SOIs as well as their internal modus operandi. Furthermore, it is an opportunity to examine and evaluate our entire medical system of evacuation and treatment and a way to give all participants involved the opportunity to gain a better insight into the medical playing field and all the capabilities and key players involved.

All sick and wounded personnel have to be treated and managed by the relevant capabilities and/or medical staff members by means of valid SOPs/SOIs. For you as the organising authority, it is important that you provide a programme that fits the level of the participants, complements their objectives and creates a real image of the expected practical execution of the upcoming level 5+ exercise.

Every TT is obviously a unique event that will be tailor-made for the participating capabilities and key players in order to gain optimal effectiveness and output.

In this TSP we have taken the “Two-day HOSPEX pilot”, which took place on the DGOTC in April 2017, as a basic format which can be modified according to your own insights, the relevant context and the objectives to be achieved. The pilot consisted of one day with two tabletop sessions, and one day of Expanded Tabletop.

There is no standard duration for a tabletop, this depends among other things on your objectives and the size of the playing field and participants.

Lessons learned from the "Two-day HOSPEX pilot" indicate that a whole day of TT is quite long, often at the expense of focus and output at the end of the day. In their feedback, the participants stated that half a day would be an ideal duration for this TT.

Envisaged Course of the TT

You start the TT with an introduction in which you indicate the purpose and desired objectives of the training, which capabilities and key players are present and what the TT will look like in terms of content and time frame. You briefly outline the scenario that will serve as the context for the TT and you introduce the members of the TT organisation and indicate their tasks and responsibilities over the course of the exercise. You also clearly state that it is essential for the participants to give their feedback at the end of the TT on the process and the results obtained; it is therefore advisable for them to keep a record of things they encounter in relation to the SOPs/SOIs during the TT, such as aspects that are not described in SOPs/SOIs, are described incorrectly or that just don't work in real life.

You direct the participants to the table assigned to their capability and give them some time to get installed and prepare for the start of the scenario.

When everything and everybody is ready, you start the scenario with the insertion of the first case.

During the first phase of the TT it is important that the TT organisation makes certain that the participants (especially if this is the first time they have participated in a TT) know what is expected from them during the exercise. Note should also be taken of whether all participants are on the same wavelength in terms of SOPs/SOIs. If everything is going smoothly you can increase the supply of casualties.

If things are not going well according to plan, you could consider a short interruption of the TT in order to explain things or to get everybody back on the "tabletop track".

On completion of the TT, you evaluate the event with the participants and state your observations and conclusions. You also ask them how they experienced the TT and what their conclusions and recommendations are in relation to SOPs/SOIs, as well as the organisation and execution of this TT. You ask what they could be improved/adjusted in order to increase the effectiveness and efficiency of the various processes within the medical chain of care.

The lessons learned from this TT will be recorded by the designated staff member(s).

Desired Results

After the Tabletop, all participating capabilities and key players know how to apply the SOPs/SOIs in the treatment and management of wounded personnel at their location or within their responsibility.

Every participant knows his tasks and responsibilities within the capability and those of the capability within the chain of medical evacuation.

Because of the real-time exercise every participant will have an accurate insight into the various time spans that are involved in the procedures, management and treatment of wounded personnel in the various locations in the medical chain of evacuation.

All participants take a critical look at the SOPs/SOIs from within their own fields of expertise and their location in the medical chain of treatment and evacuation. They indicate which elements of the SOPs/SOIs need to be changed or improved in order to work efficiently and effectively.

All capabilities will take a critical look at their own internal modus operandi and adjust this if necessary.

Feedback and Evaluation

- Does everybody understand the principle of a tabletop exercise and what is to be expected of them in this event?
- Does every official within the capability knows his tasks and responsibilities within the capability?
- Does every official know the role of his capability within the medical chain of treatment and evacuation?
- Is everybody aware of the current SOPs/SOIs and are these applied in the right way?
- Is every member of the capability aware of the internal modus operandi of the capability ?

Required Resources and Personnel

As stated in Section 4.2.4.

4.2.3.2 Event 2 Expanded Tabletop

Roles and Perception of TT Organisation

There can be various reasons for organising an Expanded Tabletop (ETT) exercise (see Section 4.2.1.1.2). Prior to an ETT, the organising unit or bureau needs to determine the objectives to be achieved. These objectives will help determine the training or learning objectives which will serve as reference for the scenario to be used and the cases to be inserted.

In this event we use a scenario in which the Role 2, within the scope of operational readiness, is preparing for a level 5+ exercise in which the entire Role 2 will be trained and in which the medical system of evacuation and treatment will be trained, assessed and evaluated.

All patient cases provided have to be treated and managed by the relevant modules and/or medical staff members within the Role 2 in accordance with valid SOPs/SOIs.

Every ETT is a unique event that will be tailor-made for the participating capabilities and key players in order to gain optimal effectiveness and output.

In this TSP, we have taken the “Two-day HOSPEX pilot”, which took place on the DGOTC in April 2017, as a basic format which can be modified according to your own insights, the relevant context and the objectives to be achieved. The pilot consisted of one day with two tabletop sessions, and one day of Expanded Tabletop.

There is no standard duration for a Tabletop; this depends among other things on your objectives and the size of the playing field and participants.

Experience in the UK indicates that an ETT should last a day or so and should replicate normal battle rhythm.

Envisaged Course of the TT

You start the ETT with an introduction in which you indicate the purpose and desired objectives of the training, which capabilities and key players are present and what ETT will look like in terms of content and timeframe. You briefly outline the scenario that will serve as the context for the ETT and you introduce the members of the ETT organisation and indicate their tasks and responsibilities during the course

of the ETT. You also clearly state that it is essential for the participants to give their feedback at the end of the ETT on the process and the results obtained; it is therefore advisable for them to keep a record of things they encounter in relation to SOPs/SOIs during the ETT, such as aspects that are not described in SOPs/SOIs, that are described incorrectly or that just don't work in real life.

You direct the participants to the table assigned to their capability and give them some time to get installed and prepare for the start of the scenario.

When everything and everybody is ready, you start the scenario with the insertion of the first case. The inserted paper casualties will have to go via the designated route through the various modules of the Role 2 as stated in the SOP/SOI, in the course of which each capability simulates the necessary (medical) interventions as realistic as possible.

During the first phase of the ETT it is important that the ETT organisation makes certain that the participants (especially if this is the first time they have participated in an ETT) know what is expected from them during the ETT exercise. Note should also be taken of whether all participants are on the same wavelength in terms of SOPs/SOIs.

If everything is going smoothly, you can increase the supply of casualties.

If things are not going well or according to plan, you could consider a short interruption of the ETT in order to explain things or to get everybody back on the "tabletop track".

On completion of the ETT you evaluate the event with the participants and state your observations and conclusions. You also ask them how they experienced the ETT and what their conclusions and recommendations are in relation to SOPs/SOIs, as well as the organisation and execution of this ETT. You ask what they think could be improved/adjusted in order to increase the effectiveness and efficiency of the various processes within the Role 2 MTF.

The lessons learned from this TT will be recorded by the designated staff member(s).

Desired Results

- After the ETT, all participating capabilities and key players know how to apply the SOP/SOI in the treatment and management of patients within the Role 2 MTF.
- Every participant knows his tasks and responsibilities within their module and those of the module within the Role 2 MTF.
- All module commanders and other key players know each other's responsibilities and fields of expertise.
- Because of the real-time exercise every participant will have an accurate insight into the various time spans that are involved in the procedures, management and treatment of casualties in the Role 2.
- All participants take a critical look at the SOPs/SOIs from within their own fields of expertise and their module. They indicate which elements of the SOPs/SOIs have to be changed or improved in order to work more efficiently and effectively.
- All modules take a critical look at their own internal modus operandi and adjust this if necessary.

Feedback and Evaluation

- Does everybody understand the principle of a tabletop exercise and what is expected of them in this event?

- Does every official within the capability know his tasks and responsibilities within the module?
- Is everybody aware of the current SOPs/SOIs and are these applied in the right way?
- Does every official know the regulatory process for requesting diagnostic services in the Role 2 such as laboratory or radiology?
- Were all important messages and decisions communicated promptly and effectively?
- Is everybody aware of the internal logistic supply lines within the Role 2 (for example, request for topping up medical supplies or removal of (medical) waste)?
- How is the communication and cooperation between the various members of a module within their module?
- How is the communication and cooperation between the various modules?
- Are personnel and means being deployed in an efficient and effective matter?
- Does the command and control staff have full situational awareness (a helicopter view!) of all of the processes and activities taking place in the Role 2?

Required Resources and Personnel

As mentioned in Section 4.2.4.

4.2.4 Planning and Organisation

4.2.4.1 PIOFAH-Factors

This section describes all the preconditions relating to personnel, infrastructure, ICT and other requirements for organising a Tabletop or Expanded Tabletop exercise.

It is difficult to point out exact requirements and numbers because the duration, size, location, participants, etc. can vary, depending on the purpose and setting of the exercise.

The subjoined summary below is based on the Two-day HOSPEX pilot as held in April 2017 at the DGOTC in Hilversum (Netherlands)

Personnel

Facilities:

- Personnel for requisition of the acquired materials and services;
- Personnel for the transport of the acquired materials;
- Personnel for construction and dismantling the TT setting;
- Personnel for catering; and
- Personnel for installing audio and ICT.

Training support:

- Personnel in charge of the overall management and overview of the tabletop;
- Personnel for the simulated PECC;
- Personnel for observation/training;
- External observers (if necessary); and
- Personnel responsible for recording lessons learned and any resulting points of interest or necessary adjustments to the internal MO and/or SOPs/SOIs.

Participating Personnel:

- Depending on the setup and purpose of the Tabletop.

ICT

- Laptop(s);
- Beamer(s) and associated accessories.

4.2.4.2 Organisation

Materials:

- Sufficient number of tables;
- Megaphone or sound system with a microphone;
- Walkie-talkies;
- Transport capacity for personnel and/or materials (if necessary); and
- HOSPEX set.

Documentation:

- Current SOPs/SOIs;
- Relevant doctrine publications;
- Relevant area and base maps (if available).

Financial and Procurement:

- Via DGOTC Training Centre

Accommodation and Infrastructure:

- Suitable location for hosting the TT or ETT, such as a large hangar or sports hall , depending on the size of your event.
- Signage (if necessary).
- Possibility of overnight accommodation for participants in a multiday tabletop.

4.2.5 Contents and Application of the HOSPEX Set

4.2.5.1 Contents (Figure 4-6, Figure 4-7)

- Scenario Cards
- Blood and Plasma cards
- Patient Cards
- Instructor Briefing Cards
- Treatment Area Cards
- Personnel Cards
- Status Cards
- Card holders
- Aeromedevac simulation
- MTF maps
- Base and area maps (not pictured)

Figure 4-6: Hospex Set.

Figure 4-7: Content Hospex Set.

4.2.5.2 Application

The set contains many individual trauma and Disease & Non-Battle Injury (DNBI) cases, and four major incident scenarios:

- Chinook crash scenario;
- Coach bombing scenario;
- Bagram scenario; and
- Ambush Scenario.

Every scenario has its own **scenario card** with casualty insertion times and corresponding messages and other instructions for the tabletop organisation (Figure 4-8).

Every scenario has its own corresponding patient card sets (Figure 4-9). Every **patient card set** consists of a number of cards that give information about the state of the patient at different stages of care, which should lead to prompt decisions and simulating the necessary medical interventions. Most card sets contain a duplicate Primary Survey card with footnotes for the instructor (this card should not be given to participants !!!).

Every HOSPEX set contains a collection of **personnel cards** for the various (medical) officials within the system of operational medical care who have a role in the diagnosis, treatment and transport of wounded within the medical chain of evacuation (Figure 4-10).

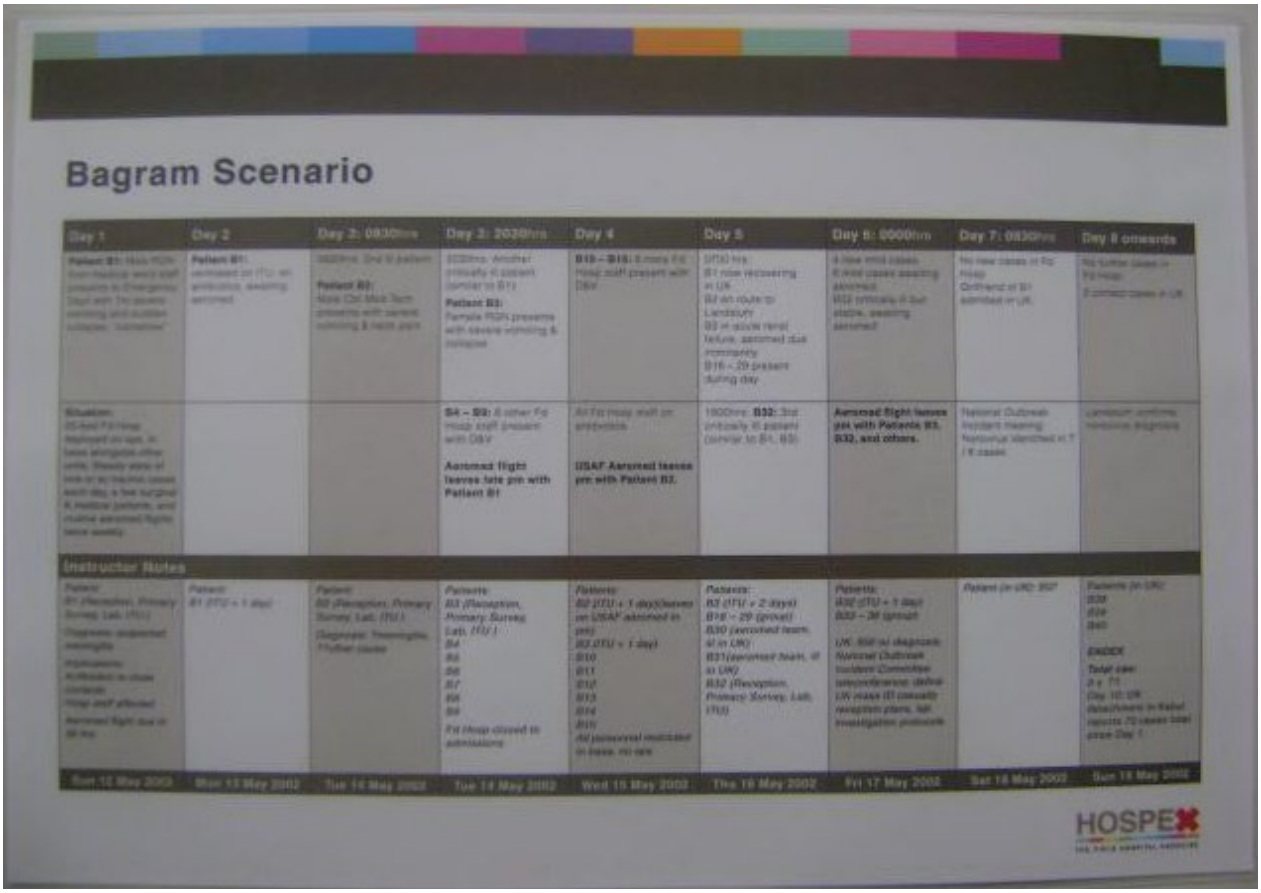

Figure 4-8: Scenario Card.

Figure 4-9: Patient Card Set.

Figure 4-10: Personnel Cards.

4.2.6 Outline of TT Session (Instructors' Brief)

4.2.6.1 The HOSPEX Tabletop Exercise

Instructor's Notes

Version 1 Feb 2018

Aim: The HOSPEX Tabletop Exercise focuses on important aspects of command and control, safety, communication, assessment, triage, treatment and transport of ill and wounded personnel through the various stages in the military medical chain of evacuation (i.e., the CSCATTT principles applied throughout the Operational Patient Care Pathway) [20], [21][1].

[1] The HOSPEX Tabletop and Expanded Tabletop Exercises were developed by Colonel David Vassallo of the UK's Royal Army Medical Corps, with design work by UK Army Reprographics.

The emphasis in this low-tech but high fidelity simulation exercise is on decision making and situational awareness. It follows a 'Crawl, Walk and Run' educational sequence together with the more demanding Expanded Tabletop exercise, both being purposely designed for in-unit training. It prepares personnel and units for full scale simulation field exercises and operational deployments.

Summary: These instructions cover each Tabletop in turn, from prehospital (Role 1) through increasingly sophisticated Role 2 Medical Treatment Facilities (MTFs) up to Role 3 within a deployed operational environment, including land and sea [22]. The Tabletops can be exercised individually or in any combination.[2]

Outline of Tabletop session: The exercise will practise decision making and standard operating procedures applied to current inpatients, DNBI casualties, trauma team callouts, major incident scenarios, and unexpected events in the selected Tabletop setting.

Duration: The recommended duration of the exercise is about 3 hours, undertaken as either a morning or an afternoon session. Individuals' coffee or tea breaks must not interrupt continuity of play. Allow extra time for preparation and clearing up.

Instructors' Brief: These Notes are to be read alongside the 'Role 1 RAP' and 'Hospital' Instructors' Brief contained in the HOSPEX set.

Figure 4-11: Typical HOSPEX Tabletop Exercise Layout, 10 – 30 Minute Simulated Flying Time (Quadrupled for Ground Moves) Between Locations.

[2] Tabletops currently in use represent Role 1 (Land: Urban and Forward Operating Base [FOB]; Navy: Role 1 Medical Reception Station), Role 2 (Land: Role 2 Basic 2-1-2-6 [indicating a capability of 2 Emergency Department bays, 1 Operating Theatre, 2 Intensive Care beds, and 6 intermediate care ward beds), Op TRENTON 2-1-2-16, 2-1-2-12 Vanguard Field Hospital, 4-2-4-48 Vanguard Field Hospital, a generic Role 2 Enhanced hospital; Navy: Role 2 Afloat, Commando Forward Surgical Group; RAF: 1 -1-2-15 Hospital Staging Unit, 1-1-4-25 Hospital Staging Unit), and Role 3 (Camp Bastion Hospital). Tabletops have been developed for MTFs in Sweden and Denmark. Tabletops in development include an Ambulance Exchange Point, a Medical Regiment's Field Dressing Station, and RFA Argus.

Table 4-1: HOSPEX Tabletop Session.

Phase	Action	Comment
Setup prior to student arrival (minimum 60 mins)	Classroom • Ensure adequate space for planned tabletop combination. • Remove chairs. • Leave ample room between tables for students to circulate. The space between tabletops represents road moves or helicopter evacuation distances. • Lay out tabletop playboards. Ensure playboards do not overlap edges of tables. • Set up instructor table with case cards and major incident scenario.	Potential tabletop combinations: • Single at any Role. • FOB, Role 2 Enhanced. • Urban, FOB, Role 2 Enhanced. • Urban, FOB, 2-1-2-12 Vanguard (equivalent to Role 2 Basic), 4-2- 4-48 Vanguard (equivalent to Role 2 Enhanced or Role 3 depending on attached capabilities). • Any of above, alongside Navy playboards (Role 1 MRS, CFSG, Role 2 Afloat). • Any of above, with RAF HSU 1-1-2-15 or 1-1-4-25 situated at AirPort of Departure (APOD).
	Tabletop • Lay out personnel cards on tabletops. • Use plastic wallets on metal holders to represent Resus Bays, etc., (e.g., two wallets per FOB RAP area.) • 4 wallets in Resus area in Role 2 Enhanced). • Insert selected case cards into plastic wallets on instructor's table, ready for insertion.	As per Staff Distribution lists in HOSPEX set. Place Hospital personnel cards in stacks next to the relevant department area (leaving department areas solely for cases).
Student familiarisation (up to 30 minutes)	Brief students as a group first. Identify individuals to fill Commander Medical and Patient Evacuation Co-Ordination Centre roles. Identify people with command or senior or prehospital experience and assign appropriately; divide rest among tabletops.	Typical briefs: • 'You have deployed to a MTF in 'Bestonia' in a near-peer NATO Article 5 confrontation. Air is contested, and cyber- attacks have occurred. The hospital has to rely on paper records…' • 'You are deploying on a counter-insurgency mission. Road move is dangerous…'

Phase	Action	Comment
	MTF Tabletops: assign individuals to departments. Ask them to identify 'on' and 'off' duty staff cards, and to manage cases already on tabletop. Identify visual aids according to CSCATTT principles. Identify chain of communication for effective action upon messages received in Ops Room.	Followed by: • 'Comd Med and PECC are at Bde HQ, co-located with 2 Medevac helicopters, alongside a Role 2 Enhanced MTF. Town 'Urban' is 2 miles from 'FOB Arduis' across dangerous terrain. Both 'Urban' and 'FOB' are 15 minutes flying time from Bde and R2E. A civilian Level 1 Trauma Centre is 30 mins away by helicopter. Stratevac to home country is 6 hrs; Stratevac flight is due this evening.' CSCATTT – emphasise throughout exercise.
Urban Tabletop	Place infantry patrol in town, deployed from FOB. Brief students. Ambush scenario.	Typical patrol: • 2 x 4 man teams (trained to combat lifesaver or Team Medic level), patrol leader, interpreter, MP, attached combat medic. Typical brief: • Danger from IEDs, ambush Typical ambush: • Incoming fire, two men down… Immediate action drills:
FOB Tabletop	Place infantry patrol in or approaching village (400 metres from camp entrance). Place RMO, SNCO, 2 – 3 combat medics alongside RAP. Brief students.	Typical patrol: • 2 x 4 man teams (trained to combat lifesaver or Team Medic level), patrol leader, interpreter, MP, attached combat medic. Typical brief: • Regimental Medical Officer – 'She is a junior medical officer, newly qualified, on her first operational deployment'.
Role 2 Enhanced Tabletop:	Ambush scenario.	SNCO – 'Very experienced, 4 previous deployments'. Combat Medics – 1st deployment. Typical ampbush: • Incoming fire, two men down… Immediate action drills:…

Chapter 5 – SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

Modelling, simulation, and gaming are important components of training for all personnel within the current and future survival chain, who provide medical care on the battlefield, through patient movement (evacuation), or at hospitals. Validation studies need to be conducted on currently available simulation technologies and objective metrics need to be developed for accurate assessment of learning. Collaboration among the medical community and across NATO is important to realize benefits from future advances in training. Future advances should focus on developing technologies that are capable of supporting real-time, multi-national medical training and exercises across NATO for the range of future military operations. The future battlefield also requires evaluation of new and emerging areas of medicine, including robotic, autonomous and Artificial Intelligence (AI) enabled medical systems, which will need simulation.

In order to achieve these recommendations, the NATO M&S COE should be leveraged to produce a strategic plan which supports future medical simulation and training needs. The strategic plan needs to contain guidance, coordinated across operational and medical communities of interest, and cover medical care in the survival chain from the battlefield, through patient movement, and at hospitals. Developed guidance must include future robotic, autonomous and AI-enabled systems, C5ISR, robotics and automation of transportation and medical care of casualties.

5.2 CHAPTER 2 RECOMMENDATIONS FOR CONTINUING RESEARCH

The United States effort in the JETS program is focused on patient en route care and transport. The Enabling Capabilities Areas are applicable to other medical M&S areas such as point of injury and autonomous evacuation.

Non-medical industries and applications recommended for continued analysis and technology scouting include the following:

- **Industrial Automation** – Extensive work is being done on “collaborative robots” or “cobots,” meant to work together with humans in a shared workspace. Such robots need to be smart and highly-sensored in order to maintain safety. Leading companies (or those worth watching) include ABB, Fanuc, Epson, Festo, Locus Robotics, Rethink Robotics, and Vecna.
- **Soft Robotics** – This is a developing subfield within robotics and involves building robots of flexible and compliant materials for highly-varied applications. Often the designs seek to exploit biomimicry to achieve desired results. Potential applications include agriculture and food preparation/service. Soft robotics could benefit JETS in the areas of Patient Surrogates and Moulage/Simulated Tissue. Its research agenda also overlaps with Haptics/Tactility. In 2018, IEEE held its first International Conference on Soft Robotics. Companies to watch include robotics leaders ABB, Fanuc, and KUKA AG as well as specialists Cyberdyne, Soft Robotics, Inc., Ekso Bionics Holdings, and Bionik Laboratories Corp.
- **Human-like Robots in Adult Entertainment** – The adult entertainment industry is perhaps the industry sector with the greatest incentive to produce pseudo-humans that look and behave like the real thing. Several companies have made product announcements in 2017 – 2018 concerning AI-assisted “dolls” or robots. According to a report by Foundation for Responsible Robotics [1] these include: RealDoll, Sinthetics, Abyss Creations, Android Love Dolls, TrueCompanion, and the Sex Bot Company.

- **Aircraft/Engines, Mining Equipment, and Agricultural Equipment Manufacturing** – These makers of large, complex capital equipment are at the forefront of AI-based self-monitoring and self-maintenance capabilities. They are also at the forefront of providing AR/MR assists and training to their assembly and maintenance workers. Companies include Boeing, Airbus, Caterpillar, Deere, General Electric, Komatsu, Volvo, and many others.
- **Warehousing and Fulfilment** – Amazon is the known leader in all aspects of smart warehousing and automated delivery.
- **Gaming/Entertainment Industry** – Entertainment gaming is the big source of commercial industry demand for VR/AR/MR devices and capabilities. Current leaders in VR device sales are Sony (PS4 VR), Facebook (owners of Oculus Rift), and HTC (Vives). Experiential entertainment developers (including for amusement parks and museums) are expected sources of 3D immersive holography and haptics. Disney and Google Expeditions are among the leaders here.

5.3 CHAPTER 3 CONSIDERATIONS FOR FUTURE RESEARCH

Prototype versions of a number of simulation models suitable for training of military medical skills have been developed. All models have the potential to enhance future training regimes but need to be evaluated and tested under appropriate conditions and compared to existing training practice.

Further consideration required includes:

- What training needs could be provided through simulation?
- Where future investment should be made e.g., in virtual reality environments, synthetic models or a blended approach and should it focus on specific injures, body regions or a modular "whole body"?
- How could models be used and integrated into training courses?
- How models would be benchmarked and accepted (including measures, metrics and competencies).
- What procurement/acquisition strategies would be appropriate?

5.4 ADDITIONAL RECOMMENDATIONS

Likely sources of relevant technical advances exist outside of the usual medical simulation orbit. Serious games, computer based simulations, and alternate realities (e.g., virtual, mixed, augmented) are methods that have potential to generate options that work across NATO countries and in austere environments. Models have the potential to enhance future training regimes but need to be evaluated and tested under appropriate conditions and compared to existing training practice.

Tangentially, is also recommended that NATO explore development of medical plans and guidance on the expected future proliferation of unmanned systems for casualty transport, implementation of safe ride standards, interoperability of medical equipment, platform and C5 systems, and mission planning for casualty treatment and evacuation using unmanned systems. A strategic roadmap should be developed, for future research and development requirements to incorporate simulation for these into the continuum of care and expanding medical capabilities across the operational spectrum.

Finally, there is no standard for evaluating the effectiveness of simulation training. NATO countries should work together to create a standard for evaluation of modelling and simulation exercises. Similarly, there is no centralized, standard, or common method of recording and maintaining records to indicate which medical personnel have attained what level of training in medical modelling and simulation.

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14. Abstract

This NATO effort focused on identifying ways to use modelling and simulation technologies to prepare and train military medical professionals for operational and peacekeeping deployments. These tools should help healthcare providers recognize and deal with combat casualty care issues, perform under highly stressful conditions, and function effectively as a member of a medical team. Modelling and Simulation tools are important across the spectrum of military medicine, from forward care through evacuation to definitive care at fixed facilities. Validation studies need to be conducted on currently available modelling and simulation technologies, and metrics for accurate assessment of learning/skill improvement need to be established. Given the international scope of modelling and simulation industries, NATO is strategically placed to leverage national expertise and devise innovative strategies to best utilize current and future technologies in these areas. These strategies will be important to meet the ever-increasing demands of combat medicine and peacekeeping missions, especially in Joint/Multi Domain Environments.

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