A Primer on Modeling and Simulation

Published on behalf of the Modeling & Simulation Caucus Congressman J. Randy Forbes, Chairman
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Preface

Today, modeling and simulation is more important than at any time in our nation's history to provide the critical technology baseline and distributed infrastructure necessary to solve the myriad of serious problems facing the very security of the country.

In July 2007, U.S. House Resolution 487 officially recognized Modeling and Simulation (M&S) as a National Critical Technology. This was official acknowledgement of nearly seven decades of contributions by M&S to varied areas such as nuclear testing and disarmament, space exploration, homeland security, and economic development. These contributions have helped nurture and secure the U.S. status as a global leader.

The U.S. has led the world in the application of M&S to several sectors, particularly in defense, where M&S technologies have been used to support analyses of strategic operations and training of military forces. Estimates range from $4 billion to $7.5 billion spent each year by the U.S. Department of Defense (DoD) on M&S tools, processes, and products.

The U.S. has also leveraged M&S in the commercial sector, applying M&S technologies to support training, decision-making, and management practices. As computing resources become more affordable and M&S capabilities more advanced, M&S will offer even greater, farther-reaching benefits throughout industry, government, and society.

Despite the scope and prevalence of M&S in society today, for many Americans, M&S is still a bit of a mystery. What exactly is it? What does it do? How does M&S benefit our economy, society, and quality of life? At the request of Congressman Randy Forbes, the National Training and Simulation Association has assembled some information to address these questions. The contents of this work provide an overview of M&S for a better understanding of what M&S is and its economic and functional impact. It offers a brief historical perspective of M&S contributions across many disciplines, discusses the workforce required to support M&S applications and growth, and describes where and how M&S is being employed today and where and how it may be used tomorrow.

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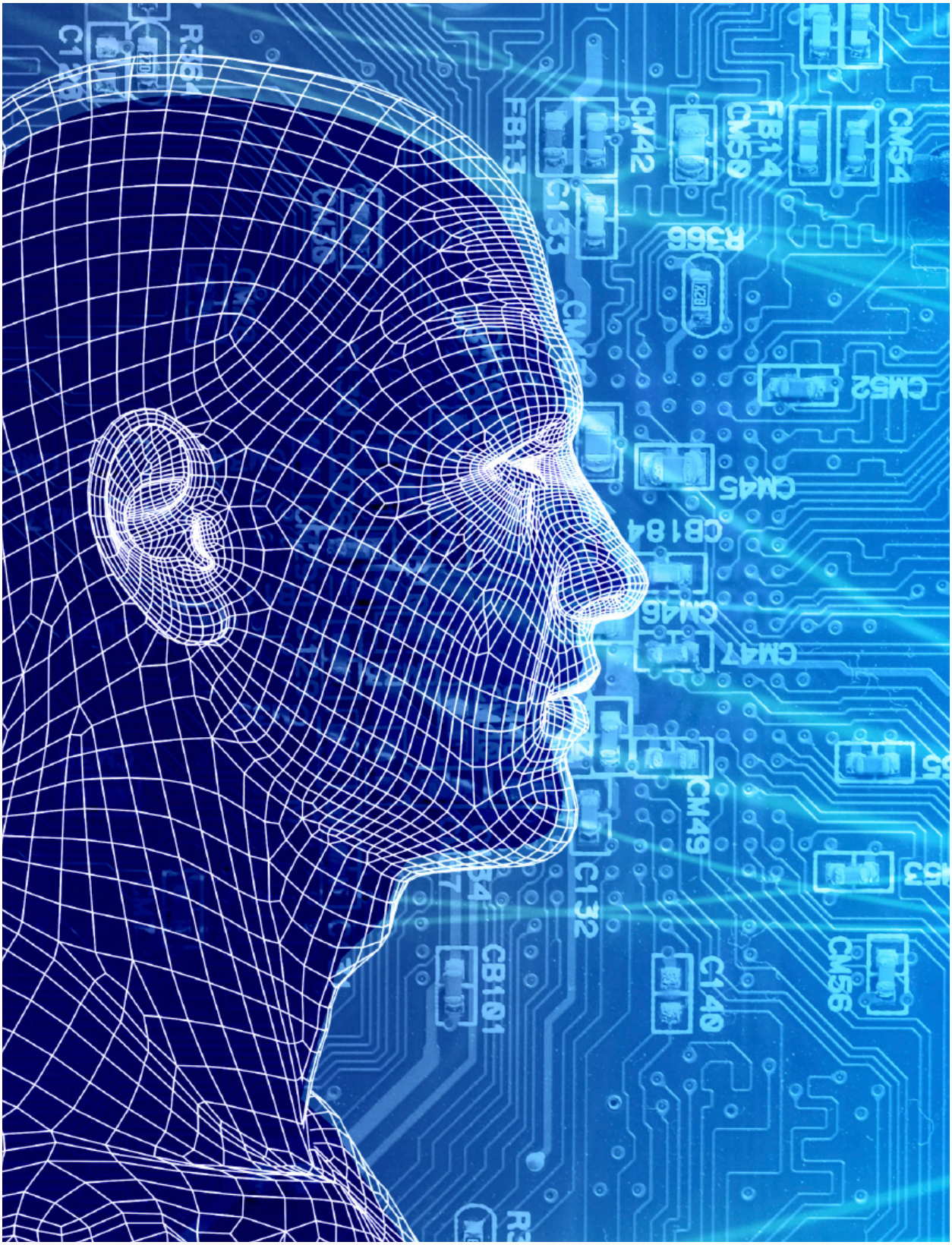
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SESSION 1

What is Modeling and Simulation?

The terms "modeling" and "simulation" are sometimes used interchangeably. In reality, they are distinct, though related, terms.

Modeling is the representation of an object or phenomena, which is used by simulation. Models may be mathematical, physical, or logical representations of a system, entity, phenomenon, or process.[1] Models are, in turn, used by simulation to predict a future state.

Simulation is a representation of the functioning of a system or process. Through simulation, a model may be implemented with unlimited variations, producing complex scenarios. These capabilities allow analysis and understanding of how individual elements interact and affect the simulated environment.

Generally, people most readily associate Modeling and Simulation (M&S) with training. M&S tools are used to train astronauts, commercial and military aircrews, nuclear power specialists, healthcare workers, and maintenance specialists, just to name a few professions. M&S provides rehearsal environments for civilian first responder and military personnel. Repeated rehearsal of procedures improves performance, saving countless lives as well as aircraft, ships, and other vehicles. Also, training individuals before allowing them to use actual equipment improves the safety of the individuals undergoing training, the participants around them and the safety of the actual equipment.[2]

While training is perhaps the most visible of M&S applications, M&S can be used to study any system or process. This ranges from human bodily systems and transportation networks, to vehicle systems, communities, and product design or manufacturing. M&S tools and processes help solve pressing issues across government, industry, and academic domains. M&S can answer "what if" questions or provide a robust experimentation or training environments that may not be otherwise realized.[3]

[1] DoD Modeling & Simulation Glossary, Jan 98 Did You Know Version 4.0
http://www.inventionreaction.com/famous-inventions/Internet
[2] CPT Boh Choun Kiat, "Advancement in Simulation Technology and its Military Application," Journal of the Singapore Armed Forces, V25 N2, April-June 1999, http://www.mindef.gov.sg/safti/pointer/back/journals/1999/Vol25_2/5.htm
[3] DoD Modeling & Simulation Glossary, Jan 98 Did You Know Version 4.0
http://www.inventionreaction.com/famous-inventions/Internet

SECTION 2

A Brief History of Modeling and Simulation

Models and simulations have been used to solve problems for centuries. The first known simulation, the game Chaturanga,[4] was a predecessor to modern chess. It simulated battlefield tactics in 7th century India. The birth of Monte Carlo simulation is credited to George Louis Leclerc, Compte de Buffon in 1777 who posed the problem of throwing needles randomly onto a plane with parallel lines in order to estimate pi.[5]

Mathematical models have been the centerpiece of scientific attempts to describe and predict the physical world, used in determining such theories as Kepler's Law of Planetary Motion in the 17th century.

In the U.S., M&S has a strong history of application to space exploration and national defense. It is safe to conclude that many of humankind's achievements, such as landing on the moon, would not have been possible without M&S contributions.

Modeling and Simulation Timeline

1910 Aviators experimented with ground based machines that could be used to teach powered flight. The outbreak of World War I accelerated the need to quickly train pilots. Devices such as the Ruggles Orientator and those of Lender and Heilderberg were early simulators used in flight training. (http://homepage.ntlworld.com/bleep/SimHist2.html accessed 22 March 2011)

1910

[4] http://en.wikipedia.org/wiki/Chaturanga accessed 20 March 2011
[5] Goldsman, Nance, Wilson, "A Brief History of Simulation Revisited", Proceedings of 2010

During **World War I**, wooden mechanical horse simulators were used for cavalry training. (http://en.wikipedia.org/wiki/Simulation, accessed 22 March 2011.)

Commissioned during **WWII**, the invention of the revolutionary electronic computer, ENIAC I, took one year to design, 18 months to build, and cost $500,000 tax dollars. The ENIAC contained 17,468 vacuum tubes, 70,000 resistors, 10,000 capacitors, 1,500 relays, 6,000 manual switches, and 5 million soldered joints. It weighed 30 tons and consumed 160 kilowatts of electrical power. (http://en.wikipedia.org/wiki/ENIAC, accessed 15 June 2011.)

1948 The first computerized simulation, an "air defense simulation" was created by the Army Operations Research Office (ORO) at Johns Hopkins University. The "Air Defense Simulation" was used to study North American air defense capabilities and naval anti-aircraft guided missile systems. (Shrader, C. (2006). History of Operations Research in the US Army. Available at http://www.history.army.mil/html/books/hist_op_research/CMH_70-102-1.pdf)

1910 1920 1930 1940 1950

1927-1929 Edwin Link designed his trainer to move on all three axes in response to the pilot's control input. Shortly after this, Link outfitted his trainer with navigational instruments and pilots were able to simulate instrument flying. (http://inventors.about.com/cs/inventorsalphabet/a/ed_limk.htm, accessed 15 June 2011.)

1946 Polish mathematician Stanislaw Ulam used computational modeling in the development of the hydrogen bomb.

Photo source: NASA

Photo source: NASA

1953 Drs James Watson and Francis Crick presented their model of DNA as a double helix. Watson and Crick build physical stick and ball models to test their theories about the possible structure of DNA. (http://nobelprize.org/educational/medicine/dna_double_helix/readmore.html, accessed 22 March 2011)

The Lunar Excursion Model Simulator at Langley's Lunar Landing Research Facility enabled astronauts to practice lading on the lunar surface for Apollo 11 flight to the moon. (http://www.nasa.gov/centers/langley/news/factsheets/Apollo.html, accessed 15 June 2011.)

1950 1960 1970 1980 1990

1961 Space War! – the first known computer-based simulation—was created at MIT. It allowed players to maneuver ships on a circular monitor and fire missiles at each other. (Smith, Roger, Mastering Simulation: Past, Present, Future, www.modelbender.com)

The DoD began the process of adapting business processes from industry to the government with systems analysis, enabled by computers and large, detailed cost models in the early 1960's.

Silicon-based computer-chips reduced the size and cost of computing platforms, setting the stage to a computer and technology revolution.

1990-1991 Troops with simulator training exceeded the performance of soldiers without simulator experience during the Gulf War.
http://www.flightglobal.com/articles/1995/11/08/21165/virtual-combat.html

2007 House Resolution 487 officially recognized Modeling and Simulation (M&S) as a National Critical Technology .

1990 2000 2010 2020 2030

1990s The Boeing Corporation pioneered a new technique of designing a passenger jet entirely using computer modeling and simulation.
(http://www.cds.caltech.edu/conferences/1997/vecs/tutorial/Examples/Cases/777.htm accessed 21 March 2011)

Visual "realism" has become one of the primary components in the realm of military training and education simulation. Visualization capabilities have evolved dramatically in the past 40 years, from the ability to create and manipulate wireframe models to fully shaded and textured images with realistic movement and lighting physics.

SECTION 3

Modeling & Simulation Workforce

Developing and using M&S technology relies on the intellectual capital of professionals with unique job skills, professional education, and training in M&S careers.[6] The M&S workforce is characterized by above average salaries, benefits, and levels of training and education which contribute positively to economic growth and stability. The prosperity of companies that employ M&S workers and success of schools that educate and train these workers, positively impact the state and local tax bases. Aspects of the M&S industry have been called "recession proof" in recent tough economic times. For example, the computer M&S industry has continued to expand and offer high-paying jobs.

Creating a Specialized Modeling & Simulation Workforce

The M&S industry continues to grow in importance in every area of the country, providing well-paying jobs and bolstering the economy, but the development of a qualified M&S workforce has been a challenge for industry, government, and academia. The broad nature of M&S application calls for a wide range of skills in practitioners—beyond mathematics, engineering, or computer science alone. This creates difficulty in identifying M&S with a single profession or following a clear course of education and M&S career path. It is also difficult for companies, managers, human resource professionals, and customers to identify the products and services they need from M&S or even the need for M&S professionals as a specialty beyond their particular domain expertise.

Several key initiatives have been identified to motivate and foster M&S workforce development. These M&S grand challenge projects could provide educational opportunities for the emerging pool of M&S professionals.

Academic degrees are offered at leading accredited colleges and universities, as well as technical trade schools and institutes focused on M&S. Programs draw upon expertise from Mathematics, Engineering, Computer Engineering, Computer Science, Psychology, and Occupational and Technical Studies. Core M&S course load focuses on simulation systems modeling principles and paradigms, exploration of specific simulation methodological approaches (e.g., discrete event and dynamic system simulation), and human–computer interaction. This may be supplemented by specialized instruction in fields such as simulation based instructional systems, animation, computer-aided design, analysis and decision making, operations research, and virtual and immersive environment simulations.
Old Dominion course catalogue, available at http://www.vmasc.odu.edu/

[6] H. Res. 487, In the House of Representatives, U. S., paragraph 2, July 16, 2007

SECTION 4

Modeling & Simulation Applications

The use of M&S applications is wide-spread and varied. M&S enables training, research, environmental monitoring, economic production and decision making.

Live Simulation

Training

Flight simulators, used in military and commercial aviation training, may be the most well known type of training simulation. There are many other uses for M&S in training in healthcare, transportation, first responder, and homeland security, just to name a few.

M&S applications are used to address multiple facets of military training, including cultural, social, and combat training. For example, the DoD uses sophisticated campaign simulations (i.e., wargames) to plan and refine battle strategies. Army and Marine forces have used simulators to train for fire-fights engaged in from Humvees and other urban combat vehicles and the Navy uses different mock-ups to train crews on ship operation and functioning. Also, interactive simulators provide experience to commanders in counseling by having a virtual military member "approach" them with an issue.

Virtual Simulation

Today, simulations come in three forms: live, virtual and constructive. People operating in the simulation may not be totally aware of these differences, because they approach each training exercise as they would a real life scenario.

Live simulation involves real personnel training on ranges with actual assets. A live environment can be augmented with virtual scenes through "augmented reality".

Constructive Simulation

Virtual simulation calls for the use of simulators that enable an individual or team to perfect their skills in a virtual world, before confidently performing them in reality.

Constructive simulation is used to display groups of forces and vehicles on the battlefield and for training, analysis, planning and mission rehearsal exercises.

These three methods, in combination with state-of-the-art technology, offer tools to deliver some of the most effective and advanced training possible. This is particularly true in the case of team-oriented training. For example, new networking technologies have created training situations where multiple trainees operate together in a simulated environment and battlefield, confronting a common threat. Today, four F-16 fighter pilots can practice together in simulators stationed at different locations. In addition, ships, submarines, aircraft, tanks, personnel carriers, and even dismounted infantry can be added to the battlefield. They can all engage in the same exercise.

Simulation is changing the way we educate and train workers in the healthcare industry. Medical simulation provides education and training in medical procedures and emergency response. In particular, the development of Emergency Room Simulation suites and Paramedic Vehicle Simulators, such as Florida's Mobile Simulation Lab , has shown to produce many benefits in training emergency room teams and paramedic squads.[7] Simulators train communication skills and team approaches necessary to handle crisis situations.

Simulations are used to replicate emergency situations resulting from terrorism attacks, nuclear detonations, hurricanes, and pandemic flu outbreaks. They provide the capability to train the responder, track learner response to the simulated emergency event, and identify choke points in response plan implementation.

[7] http://www.emlrc.org/pr30-112108.htm accessed 22 March 2011

M&S also plays a vital role in training civilian transportation personnel including air traffic controllers, commercial pilots and maintenance personnel, bus drivers, and train conductors.

Production and Delivery

M&S enables efficient production and delivery of many services. Automated models have been used in everything from power distribution over our national grid to provision of clean drinking water and wastewater treatment.

As applied to production and delivery of goods and services, M&S is used to evaluate performance boundaries. In the past, many systems had to be tested until they failed in order to understand their safe operating boundaries and limitations. Today, models and simulations are set up to locate the peaks and valleys in performance envelopes, so systems and supporting components can be optimized prior to development. Virtually building an aircraft in 3D prior to any physical mock-up has now become the standard for aircraft design.

Decision-Making

M&S can be utilized to evaluate strategies at the national, market, industry, and corporate levels. M&S can also be used in a decision support role where M&S tools can authoritatively represent many operational, information driven environments. This facilitates decision making in finance, healthcare, the military, transportation, and other areas. For example, today the DoD employs M&S as a key tool in determining cost tradeoffs and supporting major decisions from a wide spectrum of functional areas. All major DoD programs must be supported by cost benefit analyses that provide insights into cost tradeoffs and overall savings over the life of the proposed system or force structure enhancement. In acquisition, the process is supported by detailed analyses and M&S tools, from the beginning stage of military operational requirements to concept design, to initial prototyping, and finally to detailed design development and production decisions.

Research and Testing

M&S is frequently employed in research and testing. Applications complement or replace experimentation where experimentation is hazardous,

Modeling & Simulation Improves Manufacturing Design Efficiency

In the 1990s, the Boeing Corporation pioneered a new technique of designing a passenger jet entirely using computer modeling and simulation. Compared with traditional design methods used for the Boeing 757 and 767 designs, which involved physical mock-ups, the virtual design process resulted in the following design efficiencies:

- Elimination of > 3000 assembly interfaces
- 90% reduction in engineering change requests (6000 to 600)
- 50% reduction in cycle time for engineering change request
- 90% reduction in material rework
- 50x improvement in assembly tolerances for fuselage.

http://www.cds.caltech.edu/conferences/1997/vecs/tutorial/Examples/Cases/777.htm accessed 21 March 2011

expensive, or impossible. It is frequently cheaper and safer than using a prototype of the real thing. For example, M&S has played a significant enabling role in nuclear research and atomic testing.

Environmental Monitoring

M&S is frequently used in environmental monitoring and protection. M&S allows researchers to gain insight into climate changes, predict volcanic activity, and anticipate earthquake effects. M&S contributions are as diverse as forecasting the weather and protecting rivers, waterways and endangered species. For example, the Environmental Protection Agency's (EPA's) hydrology Dynamic Stream Simulation and Assessment Model predicts impact on water quality for the Truckee River, including its effect on Lake Tahoe and other portions of its basin.

SECTION 5

The Value of Modeling & Simulation

The benefits of using M&S include saving resources such as time and money, promoting public safety and well-being, and ensuring economic strength and vitality.

In areas such as healthcare, aviation, and energy production and conservation, significant cost savings have been realized from the widespread use of model-based design, development, and testing of products. M&S applications have reduced system development costs, shortened time-to-market, and improved initial product quality, durability, and survivability. The ability to model key exploration and manufacturing processes from a global perspective can produce even greater cost savings as our nation enters a period of critical fiscal constraints.

M&S provides significant benefits to training, improving overall training efficiency and effectiveness while reducing costs. M&S training applications improve performance, save lives and other resources, and compress time required to develop skills in training. M&S provides a means to create realistic training conditions that can either not be physically attained, or are considered too dangerous or economically infeasible to create. In some cases, simulators can even provide more effective training than other methods can.

M&S offers a number of advantages over other forms of training such as classroom lectures, drills, or live exercises. M&S enables instructors to control training content and to monitor student performance. This can increase training effectiveness and shorten the training cycle. Students can achieve the expected level of competence before actually having hands-on experience with an actual device or system. A validation exercise done by the South African Army showed that students going through a gunnery training simulator achieved 30% to 40% quicker reaction time and scored 14% better on their first hits than those who did not use a simulator.[8]

The financial cost of operating a simulator is routinely only a fraction of the cost of operating an aircraft or other actual vehicle for numerous reasons (e.g. fuel and manpower expenditures). For example, a military fighter pilot can practice firing weapons many times at a substantially lower cost in comparison with firing a live missile. Furthermore, using simulators in training reduces costs associated with actual equip-

[8] Helmoed-Romer Heitman. "Core Element of SA Army Simulation." Jane's Defence Weekly, Jan 1997, pp 9

ment maintenance. Cost can also be saved because networked simulators can link activities for trainees thousands of miles apart, instead of transporting individuals to a central location to perform exercises together.

Simulation training positively impacts the healthcare industry. Simulations pose no risk to actual patients and recreate uncommon scenarios that provide training for rare events. By training medical professionals prior to performing high-risk procedures or those uncommonly encountered, performance improves. The cost of health care decreases in correlation with a decrease in the odds of a poor performance by a medical professional. For example, medical malpractice insurance rate discounts are provided to anesthesiologists and obstetricians who include simulated procedures in their biennial training requirements.[9]

M&S applications enable comprehensive planning for national disaster and emergency preparedness response, improving response time and coordination efficiency.

M&S provides the ability to cope with environmental limitations, overcoming availability issues and constraints. In the case of military training for example, databases can be created which replicate overseas environments which might be encountered on future deployments by military troops, and enable training despite airspace limitations. Units and individuals can train at their home base without the need to travel to other areas located many miles away, and can train to "fire" weaponry without causing damage to the environment. This also allows units to undertake mission rehearsal exercises where actual combat missions can be pre-fought.[9] The same benefits can be realized for first responder and other types of training.

M&S promotes environmental protection and conservation. M&S serves as a foundational element of the Stockpile Stewardship Program, which has enabled the certification of the safety, security, and reliability of the nuclear stockpile for more than ten years without the use of live nuclear testing. This demonstrates the nation's commitment to nuclear nonproliferation.[11]

M&S has played key roles in operations analysis and systems engineering processes, enabling smart acquisition, planning, and development. Modeling coupled with the traditional simulation of aerodynamics, stress loading, and flight characteristics has minimized design time and increased reliability in aircraft production. The economic benefits are impressive, including significantly accelerated time to market, drastically increased employment opportunities, whole-market growth and innovative new products. Yet, this is only a glimpse of the potential impact M&S can have. It has been documented[12,13] that M&S can realize:

[9] H. Res. 487, In the House of Representatives, U. S., paragraph 2, July 16, 2007
[10] CPT Boh Choun Kiat, "Advancement in Simulation Technology and its Military Application," Journal of the Singapore Armed Forces, V25 N2, April-June 1999, http://www.mindef.gov.sg/safti/pointer/back/journals/1999/Vol25_2/5.htm
[11] H. Res. 487, In the House of Representatives, U. S., paragraph 2, July 16, 2007
[12] SMLCPublicPrivatePartnership.pdf, version 1, 12/23/2010 as published by the Smart Manufacturing Leadership Coalition, www.smart-process-manufacturing.ucla.edu
[13] Council on Competitiveness, Case Studies in American Manufacturers Adopting HPC, various.

- 98% reduction in prototyping and testing
- 25% reduction in safety incidents
- 55% improvement in energy efficiency
- 35% improvement in overall operating efficiency
- 55% reduction in water usage
- 30% reduction in consumer packaging

The environments encountered today challenge decision makers with uncertainty, complexity, and rapid change. M&S offers great potential to inform thinking by enabling the examination of complex problems. M&S offers an efficient and effective way to inform individuals at every level, from large industrial headquarters to small organizations and individuals in every national sector. Application to business decision-making at the strategic level enhances American competitiveness on the world market by enabling faster product delivery, at less cost to end users.

It has been widely documented that M&S with analysis provides end users with the ability to better understand "what if" and "so what" questions. As systems become more complex, so do M&S applications that support and analyze them. For this reason, M&S will continue to play a role in future strategizing, planning and execution.[14]

[14] Fargnoli, Thomas, Common Modeling & Simulation Framework Services, Lockheed Martin MS2 White Paper, 2008

SECTION 6

The Future of Modeling & Simulation

The next ten years presents even greater potential for M&S utilization. This is due largely to the reach and power of the Internet. Below are a few areas where M&S is poised to have a significant impact on our society and our lives.

Healthcare Education & Treatment

Simulation products developed for military and video gaming have largely focused on representing hard objects engaged in combat. This has driven the design of software algorithms, rendering technologies, computer graphics cards, and global networks. These advances have the potential to address much more challenging problems, specifically dynamic visual models of the human body.

Hard objects are relatively easy, soft objects are more difficult.

Surgical M&S will open up entirely new options for surgical education without the use of the human and animal tissue which has been standard for centuries. There have been logical and mathematic models of the functioning of the human body for many years. However, the accurate visual and behavioral representation of tissue in a real time simulation has remained beyond the reach of computer hardware and modeling techniques. Today, it is possible to represent this soft tissue in great detail and give it all of the dynamic properties of real tissue. It will be soon possible for a surgeon in training to manipulate models of internal organs and see them move, bleed, and twitch, just as they do during a real operation.

Virtual World Integration Spaces for National Security

M&S is well positioned to support the DoD's Key Mission Areas (KMAs) for military forces. In light of these KMAs, it is evident that new business models are needed for the DoD to operate in the 21st

century, particularly given the challenges the U.S faces economically as well as militarily. M&S, through virtual worlds and immersive integration on the Internet, enables the creation of new business models for the DoD.

Whether defending our homeland or supporting remote contingency operations, warfighters must plan and train collaboratively to solve complex tasks and problems. Immersive technology's power lies in its integration across all aspects of modern warfare by providing access and collaboration for decision-making and operations. Full exploitation of immersive visualization, training, and simulation requires further imagination and experimentation. This includes widespread deployment of virtual worlds, integration with social networking, and the use of mobile internet devices.

KMA 1: Defend the U.S. and Support Civil Authorities at Home

A wide variety of potential threats and, the large strata of jurisdictions, and varied responsibilities make Homeland defense complex, necessitating real-time collaboration and extensive planning. Immersive simulation can provide the common playing field for exploring potential threats while building teamwork and partnership among separate agencies.

Today it is feasible to model every city in the U.S. High resolution terrain and imagery data are now available for every major city and can rapidly create virtual cities. When integrated with high resolution physics models (e.g. blast, dispersion), the immersive environments can be powerful training and exercise tools for both military commanders and civilian leaders. Both DHS and DoD are exploring virtual worlds and immersive simulators in a number of different use cases.[15]

DHS is using a virtual world for a component of the National Level Exercise 2011, and is conducting research into the use of the technology for virtual emergency operations centers. In another example, the Federal Law Enforcement Training Center is working in partnership with the DoD simulation community, and has adopted many of virtual techniques and technologies from the military.

KMA 2: Succeed in Counterinsurgency, Stability, and Counterterrorism Operations (COIN)

DoD is engaged in research of COIN immersive training. Multiplayer gaming technology has demonstrated that immersive environments can be used to train individuals and teams. Critical to achieving the use of immersive environments for COIN training are the development of adaptive models and of human behavioral simulations. The construction of a knowledge base of different cultures and the translation of that information into realistic, virtual humans, specific to a culture, will be key in enabling soldier training in environments prior to deployment.

KMA 3: Build the Security Capacity of Partner States

Immersive technology can aid in developing language skills and cultural understanding for U.S. forces and our partners, through remote training across the globe. Research using gaming technology can be

[15] http://www.nationaldefensemagazine.org/blog/Lists/Posts/Post.aspx?ID=165

applied to both U.S. forces and our allies bringing them together virtually, unhampered by distance, establishing long-term relationships in the virtual world versus periodic interaction during missions.

One example of using immersive technologies in cyberspace is the virtual mission operation center (VMOC) for space operations managed by Navy Research Labs. VMOC is a collaborative environment designed to eliminate the command and control stove pipes found in traditional space environments.

KMA 4: Deter and Defeat Aggression in Anti-Access Environments

Immersive technology origins go back to early command and control systems for missiles and aircraft. Immersive technology remains essential to the preparation for long range strikes, as M&S based training exercises have advanced, more closely approximating actual missions than ever before. The capabilities provided by these applications have become increasingly important given the expanded lethality, precision, and range of U.S. weapon systems, such as Unmanned Aerial Vehicles (UAVs). Future research must address how training applications and command and control systems can more fully utilized immersive environments, one day realizing training scenarios which have no difference between the virtual and the "real" one.

KMA 5: Prevent Proliferation and Counter Weapons of Mass Destruction

The U.S. Army has funded much of the technology presently used for immersive medical training. A key area has been the development of a virtual world for chemical, biological, radiological, nuclear and high explosive (CBRNE) training. There is a significant opportunity to provide both hospital and first responder communities with simulation-based training using avatars for CBRNE events.

KMA 6: Operate Effectively in Cyberspace

Immersive technology will be necessary for the rapid formation of teams and their global operation in cyberspace, and a key element for effective cyberspace use. Immersive technologies leverage capabilities and reach to provide training and rehearsal. The same kind of virtualization can be achieved in cyberspace with the addition of immersive training and virtual worlds. As our dependency on cyberspace increases, so does the risk of cyber-warfare. Key to combating cyber-warfare is an experienced human operator. These operators, distributed globally, are in high demand, and it is necessary to have them participate virtually.

Mobile Simulations and Cloud Computing

Information technology advances have brought mobile devices with very good visual capabilities and excellent network connectivity. Together with cloud

computing technologies, any government official, military leader, business analyst, or game player will be able to run complex simulations on a personal mobile device such as a smart phone or tablet. Cloud computing services handle heavy computations and large databases, while menus, graphs, 3D images, and flow charts can be displayed on any cell phone or tablet computer connected to the cloud network.

This structure makes it possible to access and run any model in the world as long as it is hosted on a computer connected to an open network. Cloud computing and mobile computing provide a degree of access not previously available, providing complex "just in time" training, data, and resources to support both civilian and military needs. Models and simulations could be used by a variety of people regardless of location. This technology also creates a new business, distributing development and maintenance costs across multiple users. Customers no longer need to purchase a full license for a complex simulation, but can instead rent the model just for the time that they need it. A mobile device is a portal into all of the computing power and all of the software applications in the world. In the near term, increased access and reduced cost will allow users to access models of traffic flow, construction processes, surgical education, military operations, or weather changes, just to name a few applications.

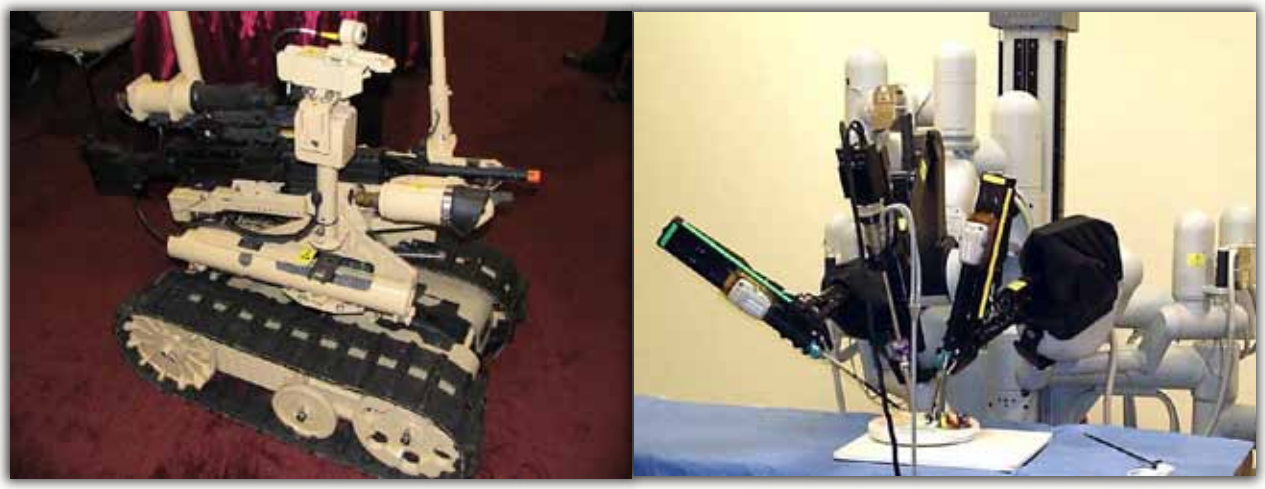
New Media Environments

Simulation is quickly becoming a major element of new media environments. Games already abound in social media such as Facebook, but simulation technology is becoming more feasible for novel and rapidly growing applications. Devices like smart phones and tablets have created a form of digital newspaper that can support full-color and dynamic animation. Popular children's books and movies have already introduced the idea of animated newspapers in which the printed pictures are actually looping movies—this no longer requires magic, but can be done through simulation.

Simulation embedded into media could increase the information provided and actually educate readers. For example, a news report on a hurricane bearing down on the outer banks of North Carolina could include a simulation driven by multiple hurricane models. Readers could alter model parameters to see the projected path of the storm under various conditions. Simulations could also accompany news reports of man-made or natural disasters, instructing the public on the underlying factors and conditions of the event. Such capabilities could potentially turn every American into an avid news reader again. People might spend just as much time thinking about how the world works as they would when interacting with friends on social networking pages.

Robots and Thinking Machines

Robots were originally envisioned as autonomous, artificially intelligent machines that could replace humans. Engineers in the 1960's felt that it was just a few short steps to make machines dexterous, safe,



and smart enough to operate without human control. Today, robots are machines built for a specific job, with almost every robotic action controlled by human operators. This model can be seen very clearly in ground combat robots and those used to perform surgeries.

M&S technologies can be applied to robots to produce more "intelligent" machines with a reduction in reliance on human operators. Unlike virtual entities that can move within the environment, observe objects, and make basic decisions and reactions to those objects, robots today lack algorithms that determine how to react to surroundings. Further development of these "intelligence" technologies can be applied to robots used in physical environments.

Medical researchers are applying the same principles to make robotic surgery more autonomous. Open heart surgeons typically spend 20 minutes opening a chest cavity and splitting the sternum before beginning an operation. The procedure is well-suited to automation with a robot. The exact location of the ribs and sternum can be captured with a CT scan and loaded into a simulation environment. This 3D representation of the patient can then guide a robot to perform the procedure under the observation of a surgical technician, but in the absence of the heart surgeon that it is programmed to emulate. This kind of automation may not be necessary for every patient, but the technology would be invaluable for operating on patients at a distance - such as a soldier on the battlefield or an astronaut in orbit.

M&S in K-12 Education

M&S is poised to have a profound impact on American K-12 Education, particularly in Science, Technology, Engineering, and Mathematics (STEM) disciplines. Converging factors of lower costs, networked schools, IT-capable teachers and students, and M&S tools relevant to education are coming together to create new instructional strategies for American students.

M&S is particularly well-positioned to support inquiry-based education. Since 1961, the National Science Foundation (NSF) has consistently supported inquiry-based, hands-on approaches to elementary

(K-8) science education. The broad efficacy of inquiry-based science education is widely endorsed by educator groups, academics, and national standards. Despite this support, the adoption of inquiry-based approaches remains limited. Its use in classrooms, peaking at 33% in the mid-1970s, steadily declined to an estimated 20% in 2006.[16]

M&S-based Multi-User Virtual Environments (MUVEs) allow students to interact with a virtual environment and test hypotheses, key requirements of inquiry-based learning. For example, River City, a promising MUVE developed at Harvard University with NSF funding, has taught principles of acute disease epidemiology by investigating a disease outbreak in a virtual 19th century frontier town. Students learned in the virtual environment by maneuvering through the town, collecting evidence, testing hypotheses, and interacting with avatars representing other students or computer-generated entities.

M&S technologies are also well-suited to teach other concepts in math and science. Simulations are used to create visual representations of mathematical equations. They also allow students to manipulate factors associated with scientific processes and observe the outcome of multiple influences. Virtual laboratories have been created allowing students to conduct experiments that would otherwise be impossible due to time, resource, or safety constraints.

Another example of how M&S is being used in education is Microsoft's Worldwide Telescope. It is a web-based software application anyone can download to a local personal computer. It stitches together images from the world's best ground- and space-based telescopes to enable a seamless exploration of the universe. This tool is particularly powerful because it allows educators to produce planetarium-like "tours," which can be accessed by any user.

Together, M&S tools have the potential to transform tomorrow's education through interactive lessons. M&S capabilities can provide virtual environments for safe experimental and exploration of math and science and concepts can reach students regardless of geographic location, providing opportunities that may not be otherwise accessible in a local school environment.

[16] Pine , Jerome, Aschbacher, P., Roth, E., Jones, M, McPhee,C., Martin, C., Phelps, S. Kyle, T., Foley, B. (2006). Fifth graders' science inquiry abilities: A comparative study of students in hands-on and textbook curricula. *Journal of Research in Science Teaching*, 43(5).

American students' declining interest and achievement in STEM education is well-documented.[a] STEM education is a vital component of America's economic vitality and stability. The 1990s saw a dramatic shift in the United States' standing as a producer of high-technology products. The US trade balance in high-technology products shifted from a positive $54 billion balance in 1990 to a negative $50 billion balance in 2001.[b] This trend has continued – in 2001 China overtook the US to become the leading exporter of information-technology products.[c] Americans' declining interest and achievement in STEM related disciplines can logically be correlated with this declining leadership role in technological production and innovation.

[a] National Academy of Sciences. (2007). Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology, National Academy of Sciences, National Academy of Engineering, Institute of Medicine.
[b] National Science Board. (2004). Science and Engineering Indicators 2004. NSB 04-01. Arlington, VA: National Science Foundation.
[c] Organisation for Economic Co-operation and Development. (2005). China Overtakes U.S. as World's Leading Exporter of Information Technology Goods. Available at: http://www.oecd.org/.

SECTION 7

Last Word

The computer in your cell phone today is a million times cheaper, a thousand times more powerful, and about a hundred thousand times smaller than the computer built at MIT in 1965. Micro and Nano technologies continue to miniaturize the physical size required to house computer components. According to Ray Kursweil,[17] inventor and futurist at the core of advances in Artificial Intelligence, what used to fit in a building now fits in your pocket, and what fits inside your pocket now will fit inside a blood cell in 25 years. With investment in future M&S activities, applications will become increasingly powerful in the immediate and long-term future, and continue to revolutionize and transform the world in which we learn, train, analyze, build, and live.

[17] CNET Interview, Q@A: Kurzweil on tech as a double-edge sword, November 19, 2008 http://news.cnet.com/8301-11386_3-10102273-76.html

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