"WORLD, WE HAVE PROBLEMS"
Simulation for Large Complex, Risky Projects, and Events

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Prior to a spacewalk during the NASA STS/129 mission in November 2009, Columbia Broadcasting System (CBS) correspondent William Harwood reported astronauts, "were awakened again", as they had been the day previously. Fearing something not properly connected was causing a leak, the crew, both on the ground and in space, stopped and checked everything.

The alarm proved false. The crew did complete its work ahead of schedule, but the incident reminds us that correctly connecting hundreds and thousands of entities, subsystems and systems, finding leaks, loosening stuck valves, and adding replacements to very large complex systems over time does not occur magically.

Everywhere major projects present similar pressures. Lives are at risk. Responsibility is heavy.

Large natural and human-created disasters introduce parallel difficulties as people work across boundaries—their countries, disciplines, languages, and cultures—with known immediate dangers as well as the unexpected.

NASA has long accepted that when humans have to go where humans cannot go that simulation is the sole solution. The Agency uses simulation to achieve consensus, reduce ambiguity and uncertainty, understand problems, make decisions, support design, do planning and troubleshooting, as well as for operations, training, testing, and evaluation.

Simulation is at the heart of all such complex systems, products, projects, programs, and events. Difficult, hazardous short and, especially, long-term activities have a persistent need for simulation from the first insight into a possibly workable idea or answer until the final report—perhaps beyond our lifetime—is put in the archive. With simulation we create a common mental model, try-out breakdowns of machinery or teamwork, and find opportunity for improvement. Lifecycle simulation proves to be increasingly important as risks and consequences intensify.

Across the world, disasters are increasing. We anticipate more of them, as the results of global warming prove more and more ominous—glaciers melting in Bolivia, floods in Saudi Arabia, the Maldives sinking and salt rising along the Nile. Fear grows about potential asteroid crashes and nightly television images raise awareness of victims of floods, hurricanes, cyclones and typhoons, fire, tornado, tsunami, bombings, landslides, and cross-boundary criminality.

The Red Cross says that disasters impact 250 million people each year. That means that 700,000 people are having a very bad day today.

Modeling and simulation is and must be part of the solution. We need resilient people, land, economy, and governance. We want less risk, fewer consequential errors and more affordability in our large projects whether digging a tunnel through a mountain,

exploring under the sea, reconstructing a city, creating a new transportation or power system or an innovative space craft.

The need for more effective planning, analysis, and rehearsal is increasingly apparent. We note the utility of simulation to track our tests, support the work and assess how it went. We have responsibility to reflect, research, teach and archive the lessons we have learned so they are accessible and visible. Only then can others build on our successes and failures and so be able to practice further risk reduction.

This summer, the Society for Modeling and Simulation International (SCS) will sponsor the first Grand Challenge International Conference in Modeling and Simulation for Emergencies and Risky Enterprises (GC/MS:ICCRE) at the International Multi-simulation Conference (IMc10) in Ottawa. That event includes plans to advance interest in these lifecycle challenges with various representatives of the McLeod Institutes for Simulation Sciences (MISS).

Opportunities range from technology to language, behavior, politics, and culture. Of particular interest is the role of simulation in risk prevention as well as in response and recovery following major human-caused and natural disasters.

Time and travel expenses make face-to-face meetings difficult when people work in different states, countries, and continents. Members of SCS and other professional simulation organizations have, however, for the past five years, held numerous discussions -- specifically on simulation and international cooperation-- at conferences in Canada, Italy, Holland, Scotland, Turkey, and the US. These meetings have included representatives from NASA, various military services, industry, the European Space Agency (ESA) in Noordwyck, and with others engaged in major enterprises that include harbors, shipbuilding, aviation, and aerospace. Kennedy Space Center and the National Center for Simulation (NCS) have partnered, in part through the US Department of Education and the European Union, on student, researcher and faculty international exchanges with the MISS and with universities in Magdeburg, Germany, Marseille, France, Genoa, Italy, and the US including the University of Central Florida. For most of our highly dispersed effort, we must accept inconvenient time zones while relying primarily on electronic media.

Large projects and major crises—all needing modeling and simulation-- are seldom confined by geography and national boundaries. Looking toward better solutions, we see mounting evidence that those who work with cross-functional and outside groups possess better information and perform more effectively than those whose information resources and experiences are limited to their own work units. Experts in one field can fail to see options obvious to knowledgeable generalists or experts in other fields. Although experience confirms that temporal distance is more challenging than spatial distance and language differences pose further "thought world" difficulties—there can be no question that expanded external knowledge sharing as reported by Cummings (1) and others is critical to performance improvement of large complex enterprises and systems. The most telling comment overheard at the 2008 Interservice Industry Training Simulation and Education Conference (I/ITSEC) was, "If you think you understand simulation; you are not getting out enough."

As part of the solution, we must all foster and increase international exchange of ideas that enhance skills, documentation, research, rehearsal, analysis, and review. Success demands that we constantly challenge simulation technology improvement,

better understand and promote attention to interoperability and standards for equipment interfaces.

Increasingly simulation teams do address some of the planning, development, and operational needs of complex, consequential, geographically dispersed components and widely separated international teams—including those working on planetary exploration. In a crisis, many countries and organizations do call on the simulation industry for models to clarify what might and has happened, provide simulation of evacuation routes or define rebuilding needs.

Over time, and as budgets suffer, planning and training seldom remain at the top of any list. Memories soon fade and other priorities intervene. In many countries there is rarely an opportunity to plan ahead when all available resources are insufficient to feed and shelter its citizens today.

We also experience projects waxing and waning, being put on hold, restarted or forgotten. Space exploration is not alone. A healthy and sustainable environment, mass transit, new energy and power sources, better affordable health care, sufficient clean water and food and emergency preparedness seem trapped in similar pendulum swings of interest and indifference. It is never easy to maintain enthusiasm for funding infrastructure of systems or bridges or cities or education or exploration.

People move on to new projects. During a hiatus, information can become irretrievably lost. Time is a thief. Technology advances while the life of major projects lengthens. Often technology is the culprit—wire recordings, floppy disks, vinyl records, 8-millimeter film, Beta tape, hardware and software are soon obsolete. Companies and contractors come and go.

Without funds for record keeping, we discard or store information in an out of the way file. Some things get "excessed" and, to save them, people bring them home. Footage of the Moon landing was recently and fortuitously so rediscovered. This happens usefully and less dramatically from time to time. But still, we possess too little data from our visits to the Moon and must, of necessity, reinvent knowledge and think about how to manage it from here.

Moreover, while dispersed teams need good data, their time well spent, their work tracked and stored safely and accessibly; that is easier said than done. For space exploration, we began thinking of communication needs and synthetic collaborative environments in terms of 20 years, but management reminded us that we have all worked more than 20 years on the Space Shuttle. So we said 50 years and then realized that 100 years may be a more accurate number. One of our records managers has the challenge of developing the means to archive information for 1000 years with the full understanding that the sole reason to store something is to retrieve it. We have pieces and parts of such synthetic environment systems. None are ones which we can be sure will be around for 100 years, much less a thousand years. A colleague suggests, wryly but wisely, that we consider carving in stone.

As another example of the challenges we face, traditional problem solving states that identifying the problem is halfway to solving it. This is not the experience of far-flung teams working on disjointed elements of very large systems. It is not the experience of those facing catastrophic situations. Both encounter problems that cannot be definitively described, defined or solved, are essentially unique and, always, consequential. Every effort to solve them has cost, impact, and, often, penalty. Rittel and

Webber [2] state that such attributes describe planning problems which "are inherently 'wicked'."

Although a reference to social policy, that idea resonates with our experience and that of risk reduction managers everywhere as emergencies escalate. Solving one "wicked" problem may create new, different, and more difficult problems. Marginal short-term improvement can make needed structural change more difficult and more expensive. The term "unintended consequences" gains prominence. Apparent similarities among "wicked" problems can be deceiving and potentially dangerous. Moving off the planet seems to be like going to the Moon during the Apollo era but it is not. The technologies, teams, systems and subsystems are different. Direct transfer of any past solutions might prove useless and even harmful.

NASA, as everywhere, struggles with "wicked" problems aware, perhaps, that others down the hall, across the city or ocean may have a useful clue. That is what outreach though professional organizations tries to address by deliberately increasing networks of diverse and expert colleagues, reliable information resources, and the credibility and visibility of the work. This matters because success depends on more than technology.

Our worldviews, knowledge, skills, experience, biases, geography, and health determine what and how we think, the choices we make, how we select ideas for research or development and the methods we follow. These factors --even how we feel on a given day--frame the variables we consider and can obscure experiences and ideas that might alter findings and make us change our minds.

Daniel Goleman [3] notes that this problem is compounded because so much that we are aware of happens outside our awareness. Being open to the knowledge and insights of others is necessary to avoid either narrowness or "group think."

With "wicked" problems, we are told, the aim "is not Truth but improvement." We muddle through. Gladwell [4] asserts that expert awareness--thinking without thought -- combined with equally expert rational analysis might be an approach for would-be solvers of such difficult, problems. But nowhere do we have a guarantee.

Professional problem solvers prefer answers. "Improvement" as a best solution is a difficult idea to accept, but it may be all we can do.

With our experience in Space -- a hostile environment, daunting distances, dangerous multi-decadal work of massive complexity-- comes the awareness, the good news, that with simulation we see things from a new, previously unimagined perspective. Simulation surprises us. In fact, surprise is its essence. We understand concepts that had eluded us and grasp how to do work that seemed impossible.

Simulation does energize and make the job go better. Many European, Japanese and US studies affirm that multidisciplinary teams modeling, optimizing and planning intensively together-- from the beginning of projects-- show promise for innovation and success in risky businesses. The numbers are both startling and credible. But few people or organizations have seized this leadership opportunity.

Furthering the complexity and enhancing the challenge are the many disciplines; we encounter now and will in the future. **Twenty years ago, almost all simulation "experts" were physicists, engineers and computer sciences. Those disciplines predominate, but we have added psychologists, graphic artists, designers, and specialists in acoustics, as well as game developers, marketers, analysts, storytellers,**

and scenario writers. We will add other as yet undetermined disciplines. The challenge of leveraging such growing diversity suggests the need for numerous investigations including the currently under-researched sociology of complex and risky situations.

The actual management of lifecycle projects, as with risk reduction management, can be seen as mere common sense, "seat of the pants" work. It has taken several decades for both the simulation and emergency management industries, to be taken seriously, to be seen as professions built on ideas worth studying. Too few universities worldwide are involved in necessary research and exploration of either. Of interest are overlapping concerns about risk reduction and prevention, hazard assessment and communication as well as research into operational management and, particularly, analysis of principles and practice of complexity including crises.

Earthquakes, landslides and flood create 80% of the costly disasters that, for example, impact Turkey each year-- socially, economically and politically. Following the devastating earthquake of 1999, Turkey enhanced its approach working with the Red Cross and the United States Federal Emergency Management Agency (FEMA), now part of the Department of Homeland Security. They improved communication capability and with FEMA, supported a substantial train-the-trainers program that has, following analogue exercises and online capability, grown and developed to become a respected university degree program through TUBiTAKE, Turkish Scientific, and Technical Institutes Universities. The first 13 graduates found immediate employment in industry and government. Only 8 universities in the US provide similar education and too few exist around the world, especially in the southern hemisphere where disasters seem more common and costly.

University level courses encourage systematic introduction to and treatment of risk prevention in complex situations and systems. Related research findings directly aid practice. The need increases for decision-support systems that include shared models, team building, training exercises—especially online capability and innovations that can be inexpensively applied anywhere and anytime.

Situations involving complexity require advanced simulation technology addressing human performance, situational awareness and communication. Studies advancing knowledge and modeling of air, land and water use policies as well geology, oceanography, astrophysics, topography, rainfall, deforestation, health, agriculture, and aquaculture benefit from simulation and add value to simulation of large complex systems.

Emerging awareness and interest has enabled both simulation and risk management to be accepted as higher education subjects in their own rights. Many people realize distinct advantages from linking operational effectiveness with empirical research. Decision-makers are seeing the benefit of recruiting people who are academically trained and familiar with the research literature that underpins simulation applied to massive complexity including major crises as well as very large systems.

There is much to learn from security, environmental and safety management experiences involving natural disasters as well as biological and chemical accidents, criminality, sabotage or financial crisis. Recently flawed economic models were suggested as being at the base of much of our financial recession. That is a both a worry and opportunity.

We all know that models lie. They are a simplification, a selected abstraction, of reality. Nonetheless, all of us, everywhere base decisions on models—computational, visual, tactile and written. We always hope that we do not leave anything out that impacts the desired outcome especially when we deal with absolutely consequential consequences.

John Sterman [5], a Massachusetts Institute of Technology (MIT) computer scientist says, "we cannot validate any model in terms of truthfulness." The task, he sees, is to "help one another develop skills and confidence --the courage-- to challenge the models, uncover biases, find flaws in the models and work together for improvement."

This summer in Ottawa, we cannot solve our dilemmas but hope to share both present and past lessons of modeling and simulation cooperation in international projects, programs and events. These could include aerospace exploration and military-civilian emergency exercises and training as well as rapid response that involves unplanned for remote assistance and training.

We all need ideas for new and easier tools. Game technology is helping us with its ability to disseminate high volumes of data as well as augmented reality, visualization and story to capture and maintain interest, and, of course, its capacity to lower cost. We need more research into multidisciplinary and highly dispersed teams, international interoperability of data, simulation, hardware (including robots) and humans—standards that reinforce reuse and usability.

Disaster studies including Apollo 1, Challenger, Columbia and Katrina all pointed to failure of imagination. As "second-guessers", we easily see the poor decisions and ineffective actions that plagued these events. Synthesizing and integrating imagination systematically into our work –and thus our success—is, however, a challenge. Many engineers report discomfort with the words *imagination* and *creativity*. Our Western culture seems hostage to ancient pre-scientific thought that continue to value one discipline over another and can hamper innovation. One such example is the human-engineered split between art and technology seen in similar divisions between intuition and analysis, perception and thought, empirical and rational reasoning and, even, within organizations between those doing engineering design and others doing engineering analysis.

Snow [6] notes that this split leads to lost potential, The analyst seeking breakthrough cannot look solely to what has worked in the past but must use intuition while the artist and humanist seeking to influence cannot be effective without attention to logic, information, and analysis. Rudolf Arnheim [7] too, wrote that all thought is perceptual in nature, that perception gathers things for thought and without such sensory perceptual material "the mind has nothing to think with."

These all suggest challenge. If we are to take on a "wicked" problem; we need to know *why*. We need to see the value of the story and understand our roles. When we move off the planet, we will no longer be visitors elsewhere but residents. This is a truly awesome idea. The changes that will follow are incalculable.

To develop means to achieve such a shared model we must start the correct story correctly and keep it up-to-date and on target. That is easy to say but not so easy to do. It matters because teams lacking a shared vision or model lose focus and can lose sight of their mission and goals. Mishap studies show that technology is rarely the culprit-- that teams without a shared model face a likelihood of failure.

A shared vision resonates, energizes and drives collaboration. A best practice is a coherent documentation strategy to reinforce the story. Few organizations institutionalize this activity. It calls for elevated skills in approximation and perceptual exploration as well as verifiable information and attention to the links among knowledge, communication, learning, and reasoning.

But if done well, such a shared model challenges our thinking and elicits ideas on how best to keep the momentum going. With it, an organization can tell the correct story in terms of logic and surprise to evoke right action. When such a story works, in time, no one remembers where it began or with whom. That is alright because the listener's story is what matters. What really matters is what the listener does.

It takes discipline, skill and effort to create that story and make it so clear, so sound intellectually and emotionally that new people can carry out the mission for years and years telling, retelling with less and less attribution and acting on it as their own. This "wicked problem" is no job for amateurs.

Interactivity is also a difficult issue and is not a job for amateurs. It requires skill in the little known practice of persistent, unending, give and take. Interaction has its basis in Newtonian physics. Every action has a reaction and that is what matters. This further underscores that it is what the listener does that matters, not what the speaker says.

Interactivity requires perception of what happens in the time between the action and reaction. It is how an actor on stage reacts to another actor and to the audience's reaction. Endless choices are reflected in a moment's hesitation or clear determination, in puzzlement, anger, despair or glee as a person or team reacts to a surprising threat or unexpected opportunity.

A friend once remarked that the simulator had been the unsung hero of Apollo 13. It is true. NASA engineers on the ground used their experience, and more importantly, reflection and their simulation research to prevent disaster. NASA had to abort the plan for Apollo 13 to be the third mission to land on the Moon when an explosion in an oxygen tank crippled the spacecraft. The situation was grim. Needing to devise a safe return using the lunar module, as a "life raft"—despite limited power, heat or potable water—was no simple answer. Using simulation, NASA engineers called on everything they knew to both enable the astronauts to orbit the Moon in a slingshot maneuver and also take advantage of what power could be coaxed out of the ailing spacecraft in order to bring them home. The task was compounded by a complicated series of switch throws and circuit breaker pulls that had proven to be too time consuming in an Apollo 10 training simulation that left the "virtual crew dead". It was reflection and research following that undesirable event that resulted in a new activation list cutting procedures to a feasible minimum. NASA used the new procedure although it was not yet certified, and it did its job.

The simulation technology that helped save the crew is scarcely remembered. It proved to be unobtrusive and undemanding of attention. That is an appropriate use of appropriate technology setting the standard for simulation that includes international cooperation supporting risky enterprises and crises.

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