

What We Did Last Summer

Depicting DES Data to Enhance Simulation Utility and Use

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Abstract

At Kennedy Space Center (KSC), an important use of Discrete Event Simulation (DES) addresses ground operations of missions to space. DES allows managers, scientists and engineers to assess the number of missions KSC can complete on a given schedule within different facilities, the effects of various configurations of resources and detect possible problems or unwanted situations. For fifteen years, DES has supported KSC efficiency, cost savings and improved safety and performance. The dense and abstract DES data, however, proves difficult to comprehend and, NASA managers realized, is subject to misinterpretation, misunderstanding and even, misuse. In summer 2008, KSC developed and implemented a NASA Exploration Systems Mission Directorate (ESMD) project based on the premise that visualization could enhance NASA's understanding and use of DES.

The Premise

Expanding the use and utility of simulation in creating and maintaining massively complex systems demands advances in technology, as well as interoperability among data, simulation, hardware and humans. Less obviously, perhaps, it requires communicating findings in a clear, consistent and effective manner. We must ensure that others can see, accurately and immediately, exactly what we want the simulation to show them. Our goal is to elicit insight that supports understanding and better decision-making. Through inattention or ignorance of the challenges inherent in visual communication, we may, instead, confuse or discourage the viewer. This is important when simulation addresses complex systems and serious hazards and situations involving time, money, and potential loss of equipment, missions and lives. This also suggests that universally accepted standards for visual communication of such simulation are not merely a nicety but a necessity. [1] At the John F. Kennedy Space Center (KSC) in Florida, simulation supports ground processing that may include check-out, assembly, test, integration, evaluation, training, launch and landing.

Problem as Given

The project focused on the KSC ground processing DES for the NASA Constellation

program and its two spaceships in development: ARES I and ARES V. Ares I is the vehicle that will allow Orion, the crew exploration vehicle, to return humans to the Moon to stay and, then, in time, go on to Mars and beyond. Ares V, Constellation's cargo launch component, is a heavy lift spacecraft to support human and automated missions.

Simulation, including discrete event simulation (DES), is essential at every stage of the operation. We believed that visualization would add to our understanding of DES that mathematically represents KSC ground processing as a chronological sequence of events. With DES, KSC engineers and scientists can simulate ground operations of missions to Space, enable them to assess facility utilization, analyze systems and plan operations as well as experiment and predict potential outcomes. This is designed to support planning, operations, testing and improvement. However, the DES model of ground processing operations over 15 years is dense and abstract. It is difficult to understand, even by its creators. The potential for misunderstanding is a serious concern. Data visualization, it was believed, could play an important role in making data more useful and accessible to a broader audience.

Recognizing that underutilization of DES, despite its reputation for high value, rested on problems related to failure to communicate, the organization made a simple request to the KSC DES Simulation Visualization team (DES/VIZ), "make Kennedy Space Center (KSC) Discrete Event Simulation (DES) more visual."

The DES/VIZ team, sponsored by the NASA ESMD as a summer intern project, accepted the premise that visualization would add to critically important understanding of DES.

Because KSC is so large-- 10 times the size of Manhattan or 219 square miles -- any attempt to show the entire flow of ground processing activities presents an image of an army of tiny frantic ants running all over the place. This was never a serious choice for the project. NASA can, at far less cost or effort, show the flow of activities on a map or in a film or animation. Depiction of entities and events or their location fails to indicate the depth of information that DES could and should make more available and useful for decision-making.

The final scenario does open with a map of KSC, but it highlights only the key facilities that the simulation addresses including the Vehicle Assembly Building (VAB), the Rotation, Processing and Surge Facility (RPSF) and the Launch Pad.

When adding visualization to DES, others traditionally insert simple images (building, people, animal, equipment or vehicle) to a particular event stage. The team departed from such an approach and, instead, worked on the problem of depicting the data hidden within 15 years worth of simulation. This is easier said than done. The data is dense, and we understood that abstract concepts are more easily misinterpreted than concrete ones. The premise of the DES/VIZ project was to do the job more concretely and, therefore, better with the ultimate goal of more frequent and effective use.

The Problem as Understood

After redefining the problem to "depict data within DES to improve decision-making capability," the DES/VIZ team worked specifically on creating a 3-D visualization of data embedded in NASA's DES Exploration Launch and Landing Analysis (ELLA). Ella is a DES model created in Rockwell Arena. Some believed the size and complexity of ELLA's data

made this an impossible task. They suggested reducing expectations by reframing the project merely as a study of the problem. The DES/VIZ team rejected this course and, instead, determined to follow an innovative results-driven approach in a process of framing the issue, optimizing their limited resources and substantiating their approach. [2] In its initial research, the team found no example, no findings nor useful methods to simply copy. With only 50 days to do the work, the DES/VIZ team faced a steep learning curve. In almost no time, the team had to learn about KSC ground processing, DES, game technology and NASA's Distributed Observer Network (DON) and understand ELLA.

The ELLA output files were so huge (hundreds of thousands of lines) that just opening and trying to browse in them was a challenge. Lacking documentation, the technical lead built a custom tool to facilitate pattern identification. This opened a means for reading the events and led to a plan to parse the output and create a sequence to playback in the 3D visualization tool.

Facing uncertainty and ambiguity, the team asked questions. They added consultants and colleagues across disciplines and organizations. These included at least 12 specialists and generalists. Some played multiple roles: customer, technical adviser, discrete event simulation developer and analyst, modeler, engineer, computer scientist, software development supervisor, human factors and simulation engineer, integration expert, strategist, film maker, scenario writer, project manager, game development technologist and game player.

People with different viewpoints brought important and critically different talents to the task. Various studies link success in reducing uncertainty with multiple sources of knowledge, skills and experience. Eric Raymond [3] suggested that a large base of distributed users could help improve design outcomes rapidly and become indispensable co-developers. Each views problems and opportunities "with a slightly different perceptual set and analytic toolkit." The literature, Herstatt and others [4] also speak not only of value, but of the leadership opportunity awaiting organizations that actively create and use such multidisciplinary teams. Few have done so.

The necessary expertise to solve difficult problems cannot easily be found in any one institutional setting. The DES/VIZ experience confirmed the importance of early multi-disciplinary interest and input that studies say can produce improved performance, save time, reduce later unplanned changes that add to cost and obstruct opportunities for success. Goguen states: "Ambiguity and informality facilitate gradual evolution of requirements for complex systems without forcing too early resolution of conflicts and ambiguities inherent in the system, avoids prejudging tradeoffs (cost, speed, functionality). [5] An analogy might be the journalists who spend three- fourths of their time writing the first or lead sentence. Once that difficulty is mastered, the copy follows logically, economically and with a clear focus.

The team sought help and worked cooperatively with all who came in and participated in the friendly chaos of Room 2111 in the KSC Operations and Checkout Building (O&C) where they soon covered white boards, walls and, even, floors, with research results, ideas, quotations, and questions. New problems require trial and error. The point is to do so quickly, learn and move on. This became the pattern of work.

They experimented, changed direction several times and created models, charts and rapid prototypes showing potential answers. As a framework for sharing perception, these probably helped dampen biases especially from those who thought the project could not be done.

Research on best practices in integrating visualization into DES is absent. The team invented and chronicled how to do this work. They defined and faced many challenges and discovered both problems and opportunities. They kept notes and built charts showing the "Steps to make DES Visible in DON" and "The Path of Flight Hardware in the Exploration Launch and Landing Analysis (ELLA)" as well as numerous models and simulations. Iteration and loop backs appear to have been important because the team considered, tested and eliminated many options. Using simulation during upfront development guided the design toward optimally satisfying performance.

The customer recognized the need for a new product and supported a changing custom solution as the team learned more. The literature reports that such support is meaningful and,

even, critical. [6] However management involvement may not be beneficial and may damage creativity by constantly changing goals. [7] Interesting projects inspire added ideas. Indeed, such enthusiasm nearly derailed progress on this project by suggesting a totally new--and probably useful and exciting but irrelevant--project. Wisdom prevailed after strong opposition.

Framing the task

The KSC DES analysis team, concerned about potential under-planning that could result in over-utilization of resources, posed as a problem that the Crew Exploration Vehicle (CEV) transporter was broken and out-of-service for 200 days. The transporter, a one-of-a-kind resource in ESMD ground operations, has the job of moving the spacecraft from facility to facility for processing and ultimately to the pad for launch into Space. There is no back up. What impact would such a breakdown have on the 123-day schedule for ground processing?

To the surprise of the analysts, the DES indicated a domino effect almost obscured by the mass of data. DES data told them, but obscurely, that delays shall occur, and they will be very bad.

The DES/VIZ team, working with the DES analysts, constantly reminded themselves that they only had to "crack" one small amount of simulation data to establish a pathway for future advancements in depicting pertinent DES information. By focusing on a small example of valuable DES data, the team never lost sight of the mission and seemed to breeze past formal requirements.

A Harvard study of Innovation [8] provided a partial framework. It was clear that whatever the team did had to be simple, frugal and straightforward, providing quick results that would be easy for a wide constituency to understand and voluntarily accept. The project also included deliberate attention to creativity standards. These are similar to those for innovation but have differences that could produce tensions and require integration. These are: the importance of openness to options, delaying closure, attention to discovery, questioning and engagement as well as to the pragmatic need for change and redefinition of problems. [6] Integration of these ideas combining innovation and creativity, proved relatively easy, both doable and valuable.

Optimizing options

The DES/VIZ team found no easy answers. The data and technology remained a challenge. Nonetheless constant questioning did produce possibilities. Planning and openness to ideas suggested more ideas that eventually worked and helped "crack" the essential problem.

The decision to depict DES data grew into the refined determination to show the relationship among delays involving the Crew Assembly (CEV) transporter, Solid Rocket Booster (SRB) segment inventory in the Rotation, Processing and Surge Facility (RPSF) and aft skirt processing and stacking in the Vehicle Assembly Building (VAB). The aft skirt forms the base of the solid rocket booster. After refurbishment and assembly, NASA moves the aft skirt hardware to the RPSF where SRB segments, loaded with solid propellant, arrive by rail for ground processing. NASA next moves that assembly to the nearby VAB for remaining integration and preparation for the move to the launch pad.

The model assumes an extreme case, a breakdown requiring 200 days to fix. Late in the project (day 42 of 50), the data finally revealed a delay of 666 days in delivery of the aft skirt to the VAB. This suggested a clear problem for investigation. After this delivery, the stacking in the VAB would take 257 days. The vehicle would leave for the Pad on Day 1123 and be on the Pad for 13 days prior to launch. The latter is normal. Nothing else is. Processing is supposed to take 123 days. Because of the 200-day delay with the transporter, the launch would be delayed, unacceptably, over 1000 days.

These startling numbers demand attention, and it is visualization that makes them clear. Even DES analysts assessing the abstract DES data had difficulty evaluating the relationship between the transporter and the length of the delays. Without the visualization, some might well assume that a delay of 200 days in the use of the single transporter would mean a delay of little more than 200 days.

The DES scenario traces what might seem counterintuitive to many managers. If the CEV transporter is in use 100% of the time, some may see this as efficient and cost-effective. It is not. Such use is over-use. It allows no time for maintenance or contingencies (unavailability of human resources, breakdown either in the schedule or, as in this case, equipment). Ground

processing personnel prefer 75% usage to allow for opportunities and contingencies.

The project depicts two essential pieces of data: utilization and cumulative time. The design uses a gauge with a pointer to indicate when the utilization is nominal and when it is not (under or over-utilized). For utilization the team showed nominal use as green. Everyone could see this as a positive piece of data. Some confusion arose when the design showed both under-utilization and over-utilization as "red" to indicate problems (with yellow as warnings on either side). Over-utilization is not, of course, exactly the same as under-utilization. Under-utilization may be wasteful, but it does not cause delays that impact the mission.

The current design shows under-utilization as blue. This choice reflects the conclusion that under-utilization is a "cooler", less problematic issue, and blue is a "cool" color in the spectrum. Nominal, in the simulation, remains as the color green. Over-utilization is now clearly and solely indicated in the warmest color in the spectrum, red, which universally indicates danger or "stop." This differentiation seems obvious in retrospect, but it is an example of how, as use of visualization expands in simulation, we must develop both awareness (leading to standards) and behavior (based on standards) that result in correct action taken correctly.

The team considered several means to visualize the cumulative days at each major stage of the simulation. They selected a clock image with relevant numbers against a background that turns red when there is a delay. This is consistent with the use of red solely for over-utilization. This may, in future, be a percentage chart.

What the data makes clear is that if the transporter is over-used (or out-of-service for any reason), delays shall occur. The data does not tell why the ground processing took more than 1000 days. It suggests the need to look again more closely to see what else is happening regarding the RPSF, solid rocket boosters, the aft skirt and the VAB. It reminds us to challenge the model. The latter reflects the admonition of simulation scientist, John Sternman who has declared, "models lie...because we cannot validate any model for truthfulness." [9]

From the beginning, the plan had been to display the work on NASA's Distributed Observer

Network (DON). DON had been built for ESMD using the Torque Game Engine from Garage Games. Unfortunately, more than midway through the project, the team understood that in order to achieve DON's amazing ability to brilliantly display advanced 3-D simulation, the DON team had disabled a number of Torque game technology elements. These, desirable to the DES/VIZ project, included text, health meter, flashing lights, moving lights, a window for an orientation map, object shaking, object moving and camera freedom. Without them, the team had fewer visualization options.

For Plan B, the team laid out a matrix and selected Torque, the original game engine that powers DON. The experience with DON, however, was useful since it did open the link between Ella and 3-D visualization capability. This led to the technical lead creating a 3_D visualization tool using MilkShape 3d which can create models with both a very light polygon count and an acceptable appearance.

The DES/VIZ team simplified the component models as compared to the advanced 3-D models NASA displays on DON for two reasons. One, the DES data is so large that it was important that the model not compete for memory. Two, model detail and fidelity were not issues. The goal was to enable the viewer to see and understand the data that the DES contains. Generic and simple models helped to both clarify complex information and not overtax the system.

Torque has the capabilities the project needs to show the data. Moreover, its Torque script, similar to C language, allowed an easy learning curve, leveraging the technical lead's C programming skills

Torque is not, however, designed to show time, as DON can, so it was not a perfect fit. A new version of DON became available but, with 15 days remaining, the team did not have time to learn it. Torque was the best available answer. Fortunately, anything the DES/VIZ team did in Torque would be transferable to later versions of DON based on Torque

Substantiating the Idea

The team tracked and stored its notes regarding challenges, concepts, resources, technical notes, expert consultants, descriptions, online links, images, models, simulation and other

information in a strategic archive. This will serve as an informal design "notebook" for future DES visualization of critical information including adaptation to a future DON or new tools. This strategic DES Visualization archive includes the charts, simulation screen shots, sources of information and other materials referenced in this paper.

The project provides a pathway for future efforts to identify and show other examples of specific data in order to not only maintain but improve operations and make DES more understandable, more useful and used effectively.

The DES data alone tells us, but obscurely, how bad the delay could be. Visualization enables people to see it, concretely, for themselves. This demonstration is just the beginning of future opportunities, including a use case in development, to correct and improve operations using clear, tested and consistent depictions of the DES information.

The team determined the future value of a nominal model showing the CEV processing as 123 days with the Utilization Gauge showing normal (green) and the clock also green. The team sees value in gathering more data to depict visually the problems that led to the 666-day delay in the delivery of the aft skirt. This is a mystery worth solving. It would be advantageous if DES/Visualization could support a process reducing the 123-day ground-processing schedule to increase cost-effectiveness and improve performance.

The DES visualization project provided the DES/VIZ team with an opportunity to work on a practical problem of real value to the space exploration program and learn by doing. They accepted technology, time and learning curve constraints as they defined, gathered, tested and systematically maintained a variety of information resources. Throughout the project, the team members initiated and maintained a method of light but focused planning, identified and regularly revisited outcome, criteria, and priorities as they explored uncertainties and consulted within a wide range of multidisciplinary individuals.

Concentrating considerable time and energy to an upfront planning effort paid off. Many companies now spend up to 60% of their engineering budget before detailed design begins. Such an approach informed the approach

on this project. This emphasis on early design provided many opportunities for innovation and supported the move from the problem as given-- "add visualization to DES"-- to the more substantive-- "depict DES information visually in order to improve decision-making capability."

The results demonstrated that careful visualization of the data commands attention as it enables others to see concretely that a 200-day delay would grow overtime to a launch delay of more than 1000 days. This successful DES/VIZ project confirms the importance of further attention to (1) visualization as discipline, (2) the early stages of framing an idea and (3) optimizing that idea as well as to DES use case studies and future opportunities.

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Biographies

Priscilla Elfrey, NASA. SISO/Grand Challenges conference committee, SimSummit, Liophant & BOK advisory board member, produces simulation activities and projects and serves as broker for simulation partnering and related activity to strengthen modeling and simulation for Space. She was both project manager and mentor for the KSC DES/VIZ project.

Jose Lagares, ASRC, an ESMD summer intern, is a graduate of the University of Puerto Rico (PR) at Ponce, he earned his M.S. in computer science from the Polytechnic University of PR, had previously interned at Goddard Space Flight Center and was student technical co-lead for this project. He created models, developed the tools and designed and programmed the simulation and, then, Alaskan Slope Regional Corporation (ASRC) hired him to work at KSC.

Mona Fahmi, an ESMD summer intern, is currently a senior at the California State University in San Jose where she is a student leader of engineering groups and also works at the NASA Ames Research Center (ARC) on technology transfer. She was student co-lead on this project developed the presentation showing the steps needed to make the DES data visible and clarified the KSC ground processing path of flight hardware in ELLA.

Michael Conroy, NASA Technical Advisor for IT/C modeling and simulation, leads NASA's ESMD Data Processing and Visualization Team and initiated its Distributed Observer Network (DON) program. He served as customer for the DES/VIZ team

David Mann Ph.D. (ASRC) supported DES/VIZ as the ASRC project manager and facilitated the transition from the problem as given: add visualization to DES to the development of the problem as understood: depict data within the discrete event simulation.