Advanced Technologies to Enable Simulation of Life-Cycle Sustainment of Weapon Systems

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Major and Minor Theses

System engineering to optimize life-cycle sustainment of weapons systems and simulations of those systems are interconnected and mutually co-dependent.

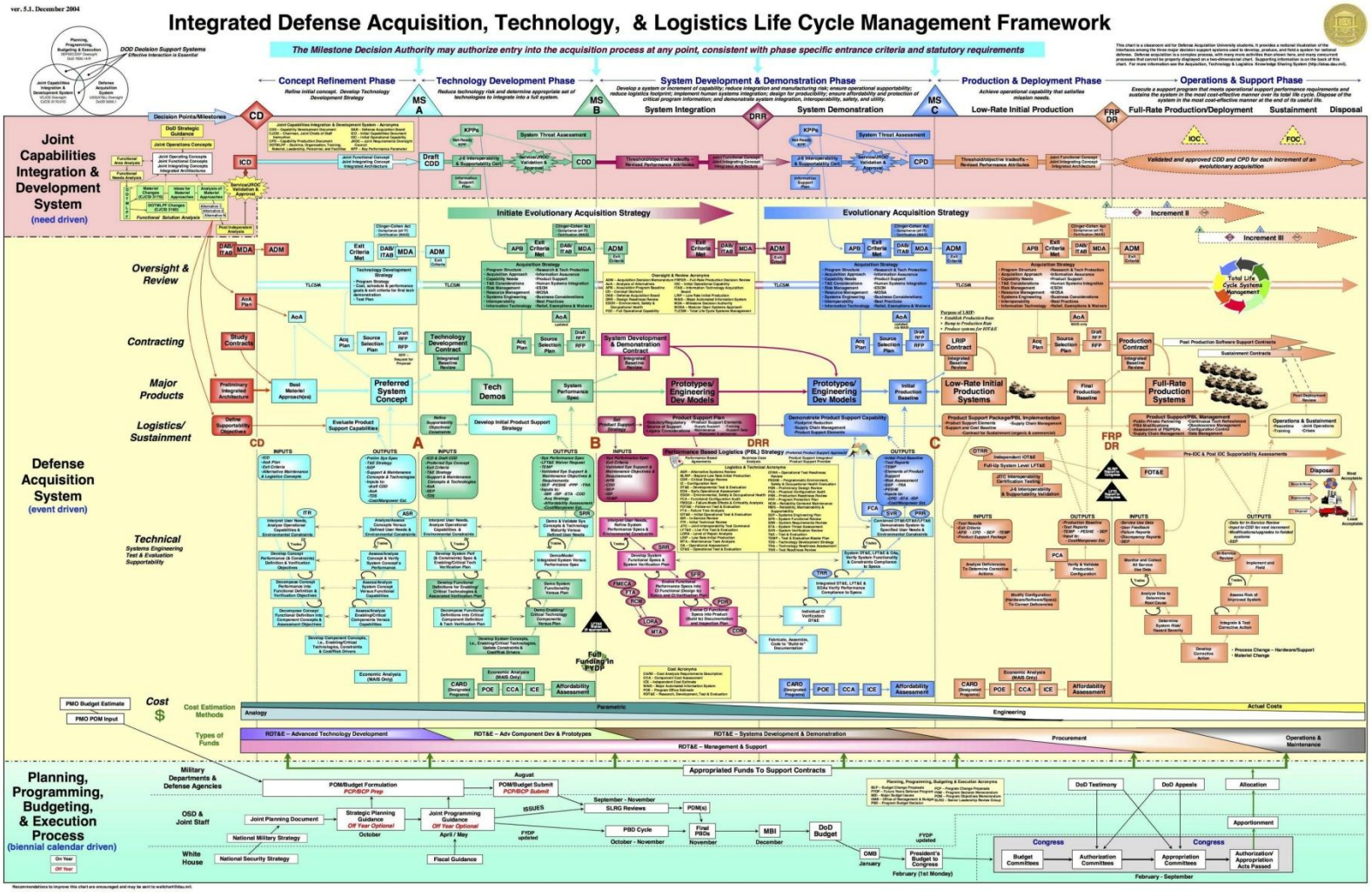
The two communities would do well to collaborate in providing their insights to each other and using the other's capabilities to enhance their own

New technologies will enable both and facilitate increased collaboration.

System Engineering Life-Cycle Sustainment for the DoD

- Weapon Systems are increasingly expensive, vital and fragile
- Prudence and regulations require planning for sustaining these systems, often long beyond their design life,
- Several mathematical models are implemented in this process: Markov, hidden Markov and martingale
- Effective and validated M&S can significantly reduce the cost of the "Design-Build-Test Repeat until right" scenarios
- Systems Engineers should make use of large-scale simulations to improve their planning
- Simulators should integrate sustainment functions and impacts into their simulations

Life-Cycle Framework



System Engineering and Simulation

- Systems Engineering (SE) analyses need valid and verifiable Modeling and Simulation (M&S) to adequately plan life-cycle sustainment for large and complex systems
- It is an accepted rule of thumb in the analysis community that if one has more than four parameters, personal analytics fail
- Some parameterization of the problem becomes necessary
- Various forms of linear algebra analysis were done by hand
- Advent of computer simulation opened up a new and valuable tool to analysts
- Reconsider the flow chart on the previous slide and contemplate the need for machine assistance in analysis

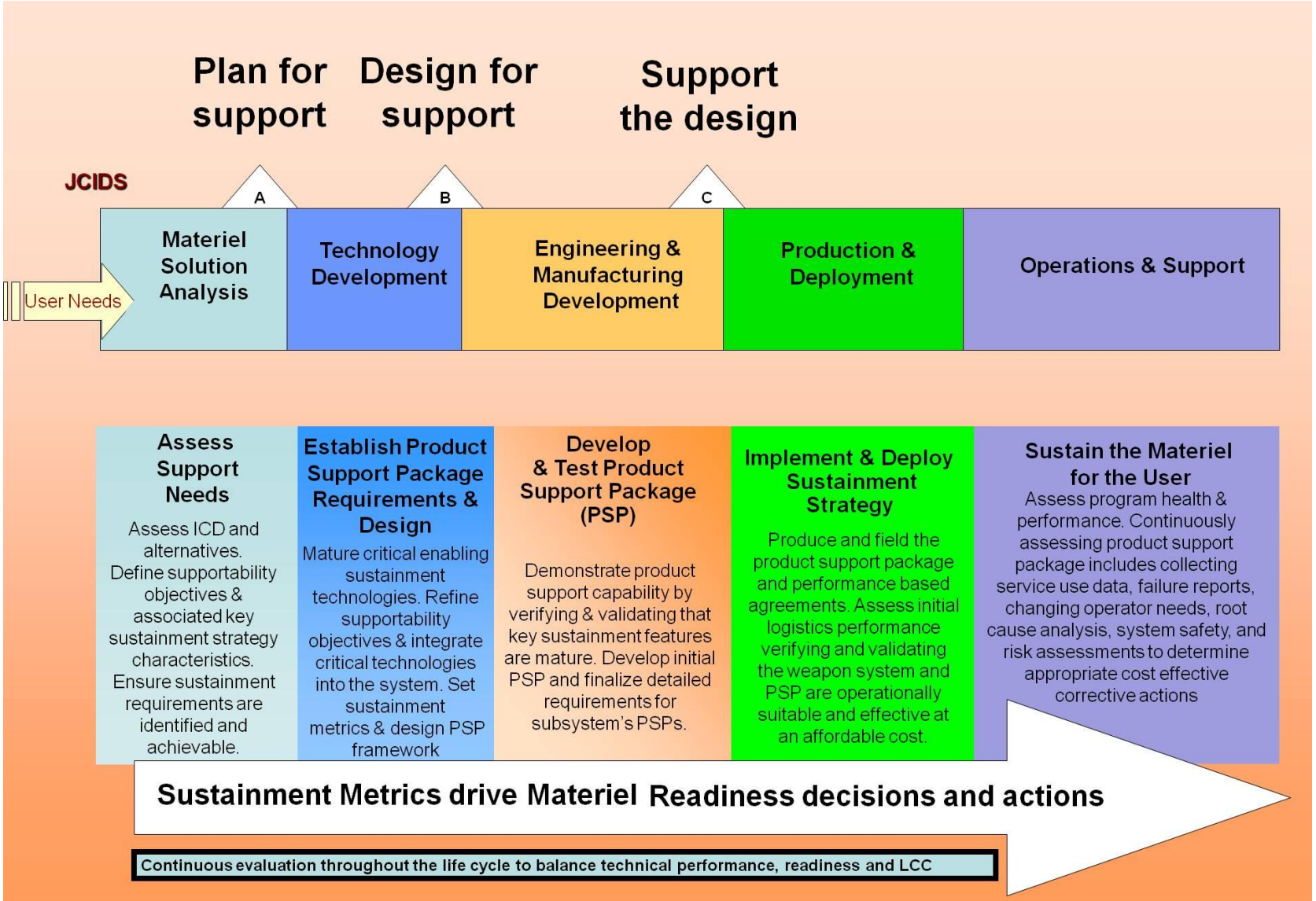
Simulation and System Engineering

- Battlefield simulation has often been accused of being too idealized to optimally represent live action
- Participant controllers with combat experience often comment on the fact that "blue forces" don't always follow doctrine as laid down by command authorities
- "Red forces" don't always act as expected, especially asymmetric foes
- Failing to incorporate all of the parameters and sustainment functions identified by SE's introduces invalid tendencies
- Simulators have the computer power to properly implement the insights from the SE community

Life-Cycle Sustainment Analyses

- One glaring factor left out of many battlefield simulations that of degradation of systems and cost of operations
- Parsimonious funders and unsupportive executives have exacerbated the constraints on battlefield commanders
- SE's find that two thirds of a system's cost are in operations and maintenance, a function that could easily be simulated
- Inversely, properly predicting operations will help the SE community plan better, *ergo* reduce total expenditures
- SEs' *forte* is risk identification and mitigation
- The staffing of personnel with maintenance expertise is also highlighted by these analyses

Simulation Important at Every Stage



Markov, Hidden Markov & Martingale

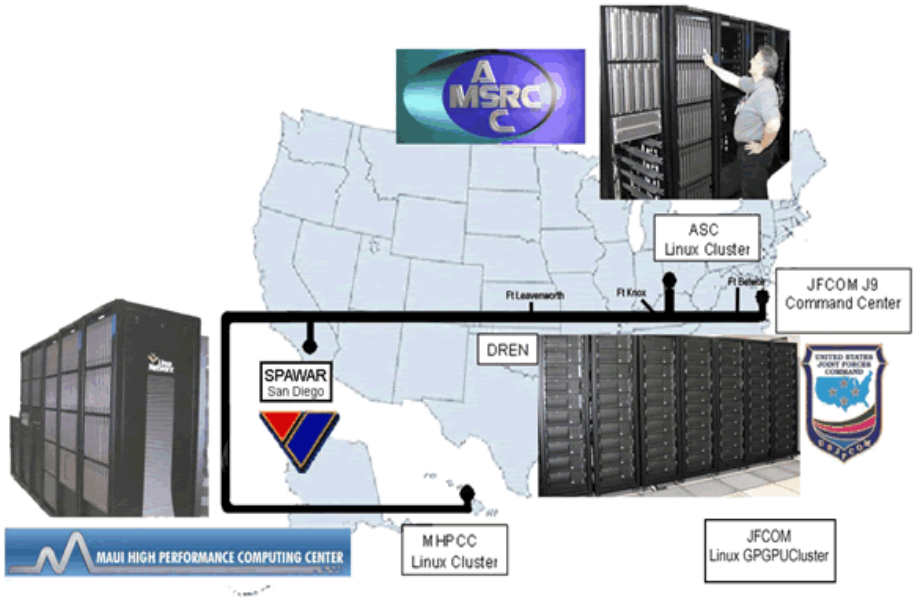
- Markov analyses posit the existence of a chain of events in which each even is independent of previous events
- A germane instance of a Markov chain is the fall of an artillery round within the trajectory dispersion ellipse
- Hidden Markov posits that the chain of event has some observable result but the state itself is not observable
- The paradigmatic instance of this might be the knowledge that some unobservable units never attack in the rain
- Martingale chains posit that the mean of all previous states equal the current and future states
- The fall of all of the rounds within the trajectory ellipse

Markov and Martingale Analyses

- There are well-developed formulae and algorithms for all of the Markov and martingale processes
- See the paper for some of the mathematical details
- Depending on the topic in issue, programming these functions into simulations should be straightforward
- Much of the theory and application of these methods has been fostered and advanced by stock market analysts
- Significant differences of opinion do exist about which live processes are best described by which process model
- The argument as to the metaphorical derivations of the term martingale is a squabble in which only statistician could revel

Enabling Technologies - Clusters

- Moving simulation from the war game table to today's simulations did require the advent of computers
- Advancing it simulation to global scales required large, dispersed and powerful computer clusters



JFCOM's Project Joint Experimentation on Scalable Parallel Processor s running JSAF transcontinentally

GPGPU Acceleration

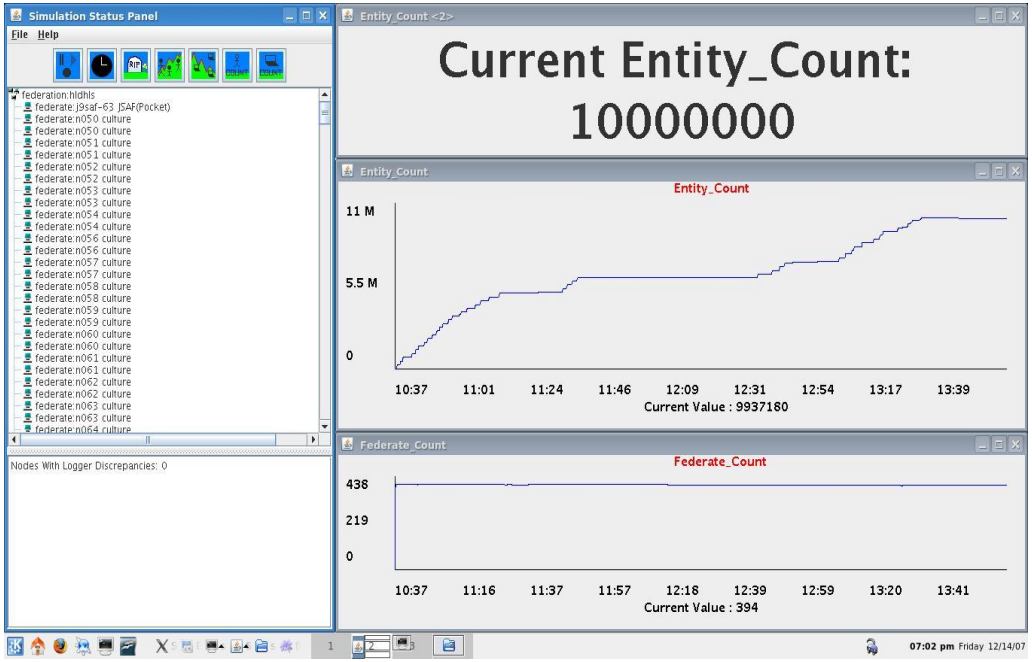
- Power and cost constraints were addressed by adding efficient General Purpose Graphics Processing Units to each node
- The DoD's High Performance Computing Modernization Office provided the machine which was installed in Norfolk

Joshua – JFCOM's Cluster 256 nodes, 1025 AMD Santa Rosa Cores, 256 NVIDIA 8800 GPUs, 18 GB RAM

The GPUs more than doubled the compute power

Performance Gains

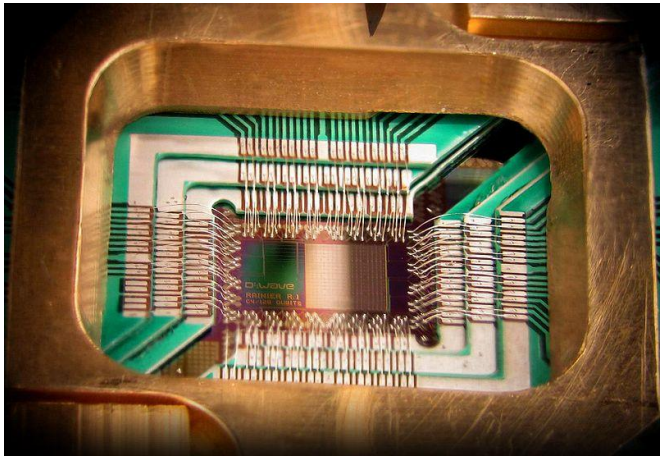
- GPGPU's provided enough power to radically extend the simulation using JSAF to model Baghdad
- Also modeled demographically correct populations and infrastructure along with red and blue forces
- A total of ten million entities were easily displayed with no suggestion that scalability was limited at all



Emerging Quantum Capability

- Richard Feynman of Caltech proposed the unfathomable power of a "Quantum Computer" in the 1980's
- Instead of a binary switch with a value of one or zero, the units would be a "cubit" with a quantum range of values.
- General purpose quantum computing is still the stuff of speculation and vociferous argument.
- A Canadian company, D-Wave has delivered a few operational quantum annealers, one to USC in California
- The other is Google's and is in the San Francisco Bay Area
- They operate at a rather chilly 0.0015K (15 milikelvins)

USC's D-Wave Quantum Annealer



- D-Wave 2
- ~ 1,000 cubits
  (stable after cooling)
- Six way connectivity
- Marina del Rey California

D-Wave Quantum Annealer

- Quantum Annealing (QA) is the analog of simulated annealing, *i.e.* a very effective optimization process
- Instead of optimizing by repeated iteration of binary parameters, QA can optimize by virtually limitless representations of parameters by the cubit's quantum state
- Like classic Christensen disruptive technologies, quantum annealing has its detractors and suffers from growing pains
- Most now agree that it is showing consistent and reliable quantum computing, but has not yet shown anticipated computational advantage over large digital clusters

Future for QA, Simulation and SE

- Expectation is that continued programming advances will see the exponential power growth anticipated
- Current machine has 2,200 cubits, with half turned off, so doubling power is immanent
- Six-way connectivity may limit number of parameters to be considered during optimization, but there are plans to increase connectivity limits
- Both M&S and SE have repeated and large optimization functions that are inherent in their activities.
- QA should provide a new tool in overcoming these hurdles

Conclusions

- SE and M&S could both benefit by closer collaborations
- Experience has indicated that just the act of parameterizing the various functions often is insightful
- Coding challenges in implementing known M&S and SE function in the Quantum Annealer are still in the future but past experience would suggest success
- The capability of the D-Wave and subsequent quantum computing devices remains to be seen
- Current progress in QA is expected to continue
- The costs of applying SE principles to simulation would be justified by the increase validity of the data

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