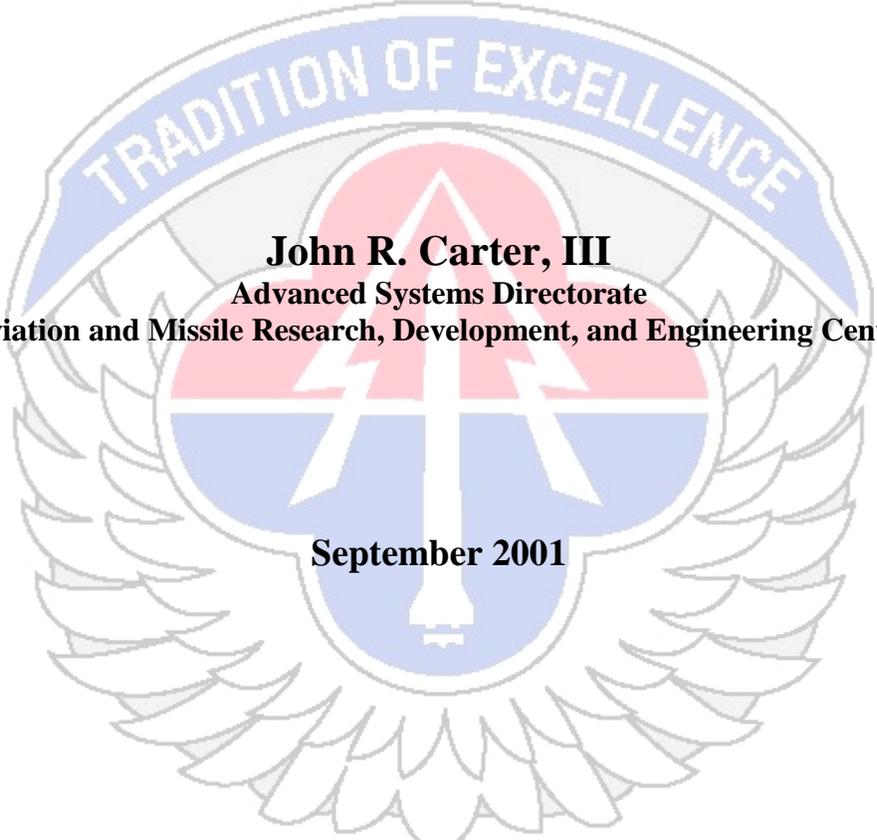




**SPECIAL REPORT-RD-AS-01-02**

**A BUSINESS CASE FOR MODELING  
AND SIMULATION**



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The Air Force seal is a large, circular emblem with a blue border containing the words 'TRADITION OF EXCELLENCE' in white. The center of the seal features a red and white stylized arrow pointing upwards, set against a blue background. The entire seal is surrounded by a white, feathered wreath.

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*Approved for Public Release; distribution is unlimited.*

## **ABSTRACT**

Simulation, once the rarefied domain of engineers, is increasingly subject to scrutiny and management. Once considered something of an oracle, it is now “business as usual” for many managers. As such, it must compete favorably for attention and funding with the very end-products whose development it facilitates. In a world of product development increasingly dominated by business-school and marketing managers, we must be able to articulate the quantifiable benefits of our efforts in both magnitude and duration. This report presents a “checklist” for Return On Investment (ROI) in four classes of simulation: “Constructive,” “Virtual,” “Live,” and “Smart.” Each is distinguished by its degree of simulation (versus “real”) of equipment (end products), people (end users), and the end-user/product environment. By establishing clear, reasonable expectations for ROI in simulation – across the spectrum of modeling and simulation disciplines, and throughout the product life span – we establish baseline cost estimation methods that can survive internal and external economic competition.

## **FOREWORD**

This special report combines a paper submitted to the Society for Computer Simulation (SCS) as part of the Summer Computer Simulation Conference (SCSC) 2001 with its accompanying presentation materials. The charts, illustrations, and notes are intended to encourage listeners to delve further into the details found in the paper rather than present findings in “the paper” as such. Consequently, the reader will find that reading of both sections of this report will comprise a much fuller story than either section taken alone.

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## I. BACKGROUND

Those of us who imprinted in the Modeling And Simulation (M&S) community remember the good old days when the word “simulation” automatically opened all sorts of doors. Software was the oracle, computers were its temple, and we were its priests. As the complexity, cost, and visibility of test and simulation has increased, the invitation to thoughtfully examine their value through the cold lens of Return On Investment (ROI) has sounded louder and louder [1,2].

We generally make simulation technology investments well in advance of formal Project Manager (PM) requirements; ideally, they are matured along with other key enabling technologies. If designed with adaptable architectures, they can be used and re-used many times by different PMs. A business case for M&S, then, would define expectations of return in specific business areas over specific phases of a program’s life. As validated case studies are scarce, this report attempts only to assert some order and expectations regarding the ROI of M&S, without attempting to defend their exact magnitudes.

## II. FRAMEWORK

Rather than address every species of simulation, Figure 1 illustrates M&S in a way tutorial to this discussion. A Three-Dimensional (3-D) framework offers a useful description of this domain. The first dimensional axis is the “equipment”, or the end product. The second is the equipment’s operator – the human customer, end-user, or beneficiary. The third is the environment in which the end product and its operator must operate. Each axis represents a continuum (illustrated for discussion’s sake as discrete combinations) from least “reality” to greatest. Frequently, the cheapest corner in this domain is found in the area of constructive simulations. By contrast, the most expensive corner of this cube is the gold standard for most PMs – Operational Test.

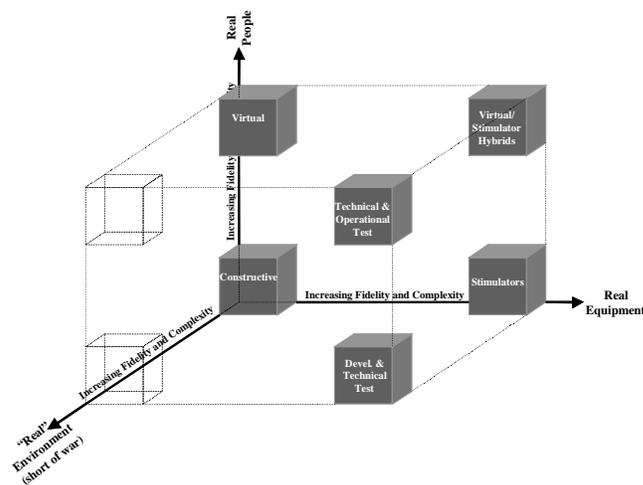


Figure 1. Framework for a Business Case View of M&S

Fundamentally, M&S and Test exist for the purpose of evaluation, and evaluation exists in order to enable and support decisions; e.g. what to do, which to buy, etc. Rational economic behavior would be to make effective, efficient decisions. Accordingly, we consider minimization of time spent in test, and reduction of risk in getting to it, a laudable goal technically *and* financially.

More importantly, by moving to a monetized system of valuation, we invite common-language discussion of the need for simulation vis-à-vis the market, the product itself, and the array of supporting processes. Most important of all, in a world of customers increasingly populated by Masters of Business Administration (MBAs) instead of engineers, we will choose to speak their language rather than insist upon their learning our own.

### III. UNDERLYING COST DRIVERS

The framework above suggests a three-lobed question that should be asked early in simulation definition and development: “To what extent must we simulate people, equipment, and environment in order to make our next decision?” Underlying cost drivers emerged as this cost model was developed. Many others may come to mind; two are addressed here.

#### A. Availability

Cost of evaluation is frequently proportional to fidelity and complexity, as asserted in Figure 1. For example, a statistical (constructive) model of missile reliability as a function of age, storage conditions, and temperature is far less “real” than a reliability firing test program – but if validated, is far simpler and more affordable. Similarly, Developmental Test (DT) and Operational Test (OT) under outdoor conditions, offers “the greatest realism short of war,” but places the test at the mercy of the outdoors. People are notoriously difficult to “model,” and many models simply abstract some initial operator state for their systems.

Underlying this cost increase is the pernicious tendency of test availability (the fraction of time in which all components work at the same time, correctly, together with all necessary measurement systems) to go down with complexity. Figure 2 illustrates “test availability” as the probabilistic combination of some dozens of parts, each with some assumed “part availability.”

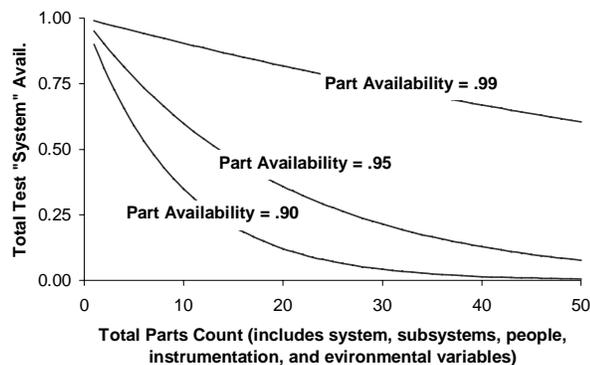


Figure 2. Inverse Exponential Relationship Between Test Availability and Complexity

It is immediately obvious that “more parts” means “more things to go wrong” (per Murphy’s Law) – and that compensating for breakage in complex test architectures means the expenditure of a great deal of money not to improve fidelity or thoroughness, but simply to execute the test. A useful rule regarding end-item, support, and instrumentation equipment for a test is: “If it’s worth taking one of something, it’s worth taking two... at least”. M&S consistently offers cost savings rooted in its far-higher availability when compared to field test.

## **B. Descriptive vs. Prescriptive M&S**

Descriptive models depict the behavior or properties of existing systems, while prescriptive models convey the expected behavior or properties of a proposed system. [3] The differences for cost estimation and business case development are frequently obscured, intentionally or unintentionally, but are profound.

Costs for use of descriptive models are composed of design, implementation, Verification, Validation, And Accreditation (VV&A), and employment. All but actual employment costs can be avoided entirely via reuse – hence decades of attempts to legislate, regulate, demand, compel, and beg for it. By now, if reuse were an economically rational behavior, we should expect libraries full of fully accredited models of everything that opens and shuts. Simulation developers should be able to select from a large catalog of models, and make “make vs. buy” decisions with regularity. With a few notable exceptions, this has not happened. By blandly asserting that we should build reusable M&S components for the common good, we shout against the tide of economic necessity, which is to first advance our own interests. As we assert cost’s role, however, imprecations from above to reuse M&S can be personalized and localized, saving money for your own program.

Prescriptive models are easier and cheaper in that they cannot be disproven by reality. However, costs for prescriptive models of systems that do not yet exist are notorious for hemorrhaging large amounts of cash with very little tangible return. By definition, they model things that may be years in the future; the customer is rarely satisfied with the video game because it creates in him a strong desire for the real thing – now that he knows what that will look like. But the major cost estimation problem with prescriptive models is the large number of cooks stirring the pot, many of whom are transitory. The result is a rubber baseline, from which no one’s wallet is safe.

Rational economic behavior for the product developer is to gain decision-making information effectively and efficiently, as discussed above. There are strong economic incentives to minimize descriptive M&S costs (in whatever way, be it reuse or simply choosing an appropriate level of fidelity), and focus prescriptive costs on the modeling of the new product alone. For example, a manager for a new sensor would tend to buy atmospheric propagation and target models off the shelf, while focusing prescriptive funding on the sensor itself.

#### IV. CASH FLOW MODELING FOR M&S

Discounted cash flows (Fig. 3) should be developed for quantifiable [2] M&S investments, using sensible ROI requirements, planning horizons, and consideration of the cost baseline (frequently, test). Methodical cross-checking of a requirements Test Verification Matrix (TVM) against the project's baseline cost estimate can identify additional, perhaps-unbudgeted M&S requirements. If the payback is negative (frequently the case for short-term M&S programs) then unquantifiable [2] paybacks should be explicitly listed. This offers a clear articulation of quantifiable payoffs and the collective cost to the program of “buying” the unquantifiable benefits.

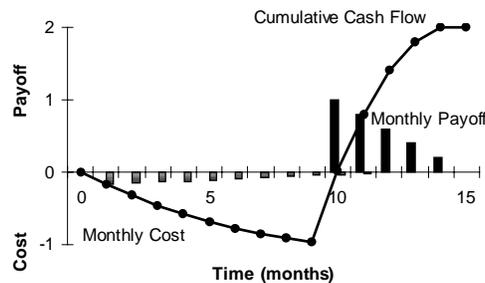


Figure 3. Simplified Cash Flows for a 15-month M&S Effort with 200 percent ROI

M&S as a business discipline is often outside of our customers' training. For example, would-be PMs at the Defense Systems Management College (DSMC) are familiarized with cost estimation, systems engineering, earned value, and test. However, the utility of M&S in the intersection of those disciplines is not currently part of their curriculum. Our business model must communicate to them the periodic and cumulative effects of our efforts, both forecasted and actual. Similarly, in most industries we have business people and engineers, but no clear educational or professional processes for the business of M&S as it applies to the entire enterprise. [1] Cost Estimating Relationships (CERs) are elusive in this environment, but ripe for assertion as we engage our customers in their language.

## V. ROI OF CONSTRUCTIVE SIMULATION (simulated people, equipment, and environments)

Payback of constructive modeling is frequently either unquantifiable, or only quantifiable in very gross terms; e.g., “rejected 3 other system architectures as impracticable, with a cost avoidance of \$10M.” A model familiar to all PMs is a program cost model – every budget, schedule, and network we’ve ever seen was simply a representation of a program. Looking at old budgets and schedules, we can easily conclude that these models frequently suffer from inaccuracies. Imagine a PM without his schedule chart, whose worth is entirely unquantifiable; yet, this most important of all models is very often simply *assumed* to exist in valid form.

Trade studies have the potential to save the most money (albeit unquantifiably), the earliest, during the concept and technology development phase of a program. By helping to make smart decisions (or at least avoiding really dumb ones) that commit the “90 percent cost” part of a system-to-be to the right path, they avoid false starts and save much time and money. While generally regarded as valuable, when misused they can easily contribute to “paralysis by analysis,” subtract value from a program, and squander M&S’s credibility for the future.

Simulation of processes throughout many disciplines allows managers to try alternatives before they buy them. These can be as physically realizable as production layout and material flow models, or as ethereal (but no less real) as business processes. Process simulations find lifelong application in value engineering and process streamlining applications; cost savings from these are particularly quantifiable as they have the status quo from which to baseline.

Trade studies are actually an early, special case of system and subsystem design and performance-prediction models of all types, including production process simulations. These “engineering simulations” may and should address key performance parameters such as vehicle range, maneuver envelope, weight, sensor range, etc. Again, most of their payoffs will be unquantifiable, although modelers should be encouraged and challenged to quantify savings as often as possible.

Computer-Aided Design (CAD) is now so ubiquitous that we tend to take it for granted in design, but investment in a well-conceived CAD model has far-reaching payoffs. CAD allows not just design, as the name implies, but analysis of all mechanical and (recently) thermal/environmental effects on systems. Its sister technology, stereo lithography, enables manipulative visualization, revealing hidden problems and opportunities. Expect a payoff of CAD in Computer Aided Manufacturing (CAM), as the now-analyzed design is transferred digitally to computer-driven machine tools for fabrication. Beware of cost-killers such as file transfer incompatibilities.

Prescriptive CAD models used with descriptive fluid flow modeling are the key elements of the versatile field of Computational Fluid Dynamics (CFD). Models as diverse as jet plumes, propellant flow, airflow, and even carotid artery flow can be developed to analyze mechanical, thermal, flowfield, and aerodynamic effects, reducing requirements for subscale, wave tank, or wind tunnel modeling. Cost savings are found in reduced reliance on such facilities.

Well-done CAD is foundational to survivability models of our tactical systems. These models can and should also be expected to reduce the cost of field-testing. [4] Target/system signature and environmental effects models, against innumerable sensors, pay off in range avoidance. Signatures and effects can be re-used infinitely, versus chancy and variable signatures from the very few representative “real” targets. One model in current use, the Battlefield Environmental Weapons Systems Simulation (BEWSS), incorporates models whose “memory” extends back to the mid-70s. The Virtual Targets Center (a joint venture of AMREC and the Army Simulation, Training, and Instrumentation Command Targets Management Office) is an online repository of validated models, which is accessible to all the services and industry. [5] This is a kind of memory that improves with age and is shared with an entire community for re-use. Models such as these make examination of multi-dimensional target effects practicable in that the marginal cost per combination of target and weapon variables is very low when compared to DT and OT.

Similarly, CAD is foundational to weapons effects, survivability, and lethality models. These models pay off quantifiably by replacing real targets (destructive test) with simulated ones (nondestructive test; subscale or digital reuse). Digital targets can be “blown up” millions of times while “real” targets tend to be totally destroyed (or at least rendered “invalid”) in a few shots. Typically, these models are used extensively in early design. (In missile systems, they sometimes actually migrate into subsystem requirements and tactical hardware algorithms for target aimpoint selection— another quantifiable payoff.) Sound test and validation is essential. Savings are simple to compute as weapon, target, instrumentation, and range costs mount up quickly. Lethality models are also a form of memory, incorporating findings from many previous tests – thereby leveraging previous customers’ investments and improving ROI. Similarly to CAD, circuit simulation is now such an integral part of board design that it is difficult to separate as a “simulation” discipline. Current circuit design/simulation packages help with circuit design and board layout, then output a file that we can take to any board maker in town and have hardware in hand in a few weeks. However, when properly planned and leveraged, it can pave the way for fabrication of tactical equipment, test equipment, and “simulation” variants or modules sharing a common design process and family. Quantifying payoff of the shortened cycle time is not too difficult, given that each board simulation can be integrated with others to achieve “black box” and “major subsystem” levels of integration without a drop of solder.

One highly quantifiable area of constructive modeling is in predicting service life and reliability. These models pay off in system failure/crash avoidance (suspend equipment from service), spares cost savings (buy adequate but not excessive quantities of spares), and replacement cost savings (safe/reliable service life and defer replacement). Combined with validation-driven sampling, monitoring, and test programs, these models are indispensable to efficient, effective management of fleets and stockpiles of materiel.

Table 1. Duration and Quantifiability of Constructive Simulation ROI Throughout a System's Life

Constructive Simulation Application	Quantifiability of Simulation ROI Throughout Phases of a System's Life			
	Concept/ Tech. Dev.	Sys Design/ Demo	Production/ Deployment	Support/Operations
Market + Cost/program/schedule	Low (\$)	Low (\$)	Low (\$)	Low (\$)
Trade/concept Studies	Low (t,\$)	Low (t,\$)		
Process Simulation	Med (t,\$)	Med (t,\$)	Med (t,\$)	Med (t,\$)
Design/Performance Prediction	Med (t,\$)	Med (t,\$)	Med (t,\$)	Med (t,\$)
Mechanical CAD/simulation	Med (t,\$)	High (t,\$)	High (t,\$)	High (t,\$)
Computational Fluid Dynamics (CFD)	Med (t,\$)	High (t,\$)	High (t,\$)	High (t,\$)
Target & System Signature/Environ.	Med (t,\$)	High (t,\$)	High (t,\$)	High (t,\$)
Weapons Effects, Survivability, Lethality	Med (t,\$)	High (t,\$)	High (t,\$)	High (t,\$)
Circuit CAD/simulation		High (t,\$)	High (t,\$)	High (t,\$)
Service Life/Reliability Prediction				High (t,\$)

## VI. ROI OF VIRTUAL SIMULATION (real people, simulated equipment and environments)

The word “virtual” has taken a beating from overuse and overgeneralization. Here, we use it in a limited sense; somewhat facetiously, virtual simulation is about big video games in which real people operate simulated systems in (usually) simulated environments. Anyone who has ever “flown” a helicopter in a battle simulation quickly gains a visceral appreciation of just how lethal ground forces can be – and sometimes gets airsick in nap-of-the-earth flight.

Virtual simulation, taking CAD modeling to immersive, synthetic environment [3] levels for its users, can communicate the “art of the possible” to a customer community primarily focused on problems in the here-and-now. A major thrust of a PM will always be to invite the customer to explore a larger box of possibilities. And surely it is true that no customer can develop a passion for your product without envisioning himself and his part of the battle somehow transformed by it. We have successfully sold training and tactical systems by repeatedly, over a period of years, exposing users to virtual simulations of them. Education leads to realization. Obviously, very little of this is quantifiable...but it is more indispensable than ever today.

Virtual simulation’s utility as a communications medium designer and end user can be extended into the actual design phase of a system. By using end-users to help design the soldier-machine interface, we approach standard practices in the commercial software industry: Preliminary marketing data, alpha- and beta-test, test marketing, etc. Payoffs are again rarely quantifiable but usually undeniable: a better product, customer buy-in, and ultimately acceptance of the end-item. Payoff can be inferred, however, by observing rate of change in the design originating from the virtual simulation team. Beware of changes in the “test market” pool of end users; high turnover rates can lead to opinionated, circular design changes rather than disciplined customer feedback.

Armor tactics (as part of the *Blitzkrieg*) were not developed for over a decade after the introduction of the tank into warfare – and by the other side. Why? Most people cannot or will not imagine all the implications of new hardware and capabilities. But virtual simulations offer

the experience without the equipment – and the opportunity to develop new tactics, markets, and applications. Their value is again largely unquantifiable but demonstrably catalytic in both time and money to change and acceptance of new systems.

How much training time do you give the users who will operate your system during DT and OT? Are they competent? How much variation and operator error do they have? How will you know? Virtual simulation allows the PM to train users off-range, screen candidates and determine *in advance* the performance variation expected from the people. It can also discover design flaws, establish expectations, and reduce on-range surprises. The test community, which often has no experience in operating or measuring the new system, can be trained. Every hour of training time that can be avoided on the range is a direct saving.

The idea of OT in a virtual environment is problematic, but offers huge, quantifiable savings in time, risk, and money. Virtual simulation is not likely to replace OT; only a zealot would advocate fielding weapons that have never been tried in “free play.” However, in providing a basis for production decisions, virtual simulation offers major opportunities. Where typical DT/OT missile tests are focused on “does the missile fly,” while having only a few rounds to test, virtual simulation can answer the larger question “does it matter?”

Similarly, the same virtual simulation can be used for New Equipment Training (NET) while fielding the system. By taking training of users into the classroom instead of the range, savings can be realized in targets and range time. Other less quantifiable cost savings include increased likelihood of acceptance, more positive feedback, and a more data-based (using recorded data) acceptance process.

The huge payoff of virtual simulation, especially for complex, distributed systems such as Command And Control (C<sup>2</sup>) – lasting for decades – is after the NET team has left and the unit begins routine training and operations. Institutional and unit training systems have long been recognized as money-savers. Quantifiable savings should be expected in reduced “live” hours to maintain measured proficiency and readiness levels in the unit. Fewer tactical systems (and spares) should be allocated to the “overhead” of institutional training – a direct, large, early saving of both time and money in the program.

Then the big phone call comes. Load up, people, and head to Timbuktu. How to stay sharp, not to mention rehearse the particular mission, while your unit’s heavy equipment is loaded nose-to-tail in the bowels of a ship? The warfighting payoff of a virtual simulator that can “be” anywhere, any time of year, any time of day, any weather conditions is simply incalculable. The story is told of M1 Abrams tank crews training shipboard on virtual training systems below decks, while crossing the Atlantic on their way to the Persian Gulf during Operation Desert Shield. *That’s* the way to go into battle. At the time, they were limited to school training scenarios. Today, expect a mission-rehearsal capability to result from a virtual simulator. This implies infrastructure development well beyond the simulator as such: rapid scenario development, worldwide distribution, and a host of other issues. Payoff is not dollars, but lives.

Table 2. Duration and Quantifiability of Virtual Simulation ROI Throughout a System’s Life

Virtual Simulation Application	Quantifiability of Simulation ROI Throughout Phases of a System's Life			
	Concept/ Tech. Dev.	Sys Design/ Demo	Production/ Deployment	Support/Operations
Concepts and Sales	Low (\$)			
Design	Low (t,\$)	Low (t,\$)		
Employment/Tactics	Low (t,\$)	Med (t,\$)		
Test design & Operator Familiarization		High (t,\$)		
Operational Testing		High (t,\$)		
New Equipment Training			High (t,\$)	
Skills sustainment				High (t,\$)
Mission Rehearsal				High (t, lives)

**VII. ROI OF “STIMULATOR” SIMULATION  
(simulated people and environments, real equipment)**

Stimulator simulation is defined here to particularly include such simulations as Hardware-in-the-Loop (HWIL), but also include other “real thing” simulators such as subsystem stimulators and wind tunnels. A major use of such systems is during system design; use of various subscale models can keep designers near the right path. Savings are difficult to estimate – how do you separate costs for development from those for simulation? Nonetheless, a program absent such simulation support is conspicuous. Stimulators’ descriptive environments, in which the new system can be exercised, are today nearly irreplaceable.

At a slightly higher level of system aggregation – say, multiple “black boxes” – stimulators can provide considerable payoff in pre-test risk reduction. As test becomes increasingly integral to design, [4] this may manifest itself in much problem-finding and fixing, which again is difficult to quantify. Additionally, however, these tools can be used to “pre-test” the system under the conditions and scenarios expected to be encountered in the field. The phrase “test for success” takes on real meaning, and cost savings can readily be quantified. Serendipitously, pre-testing of the system can also reveal hidden shortfalls in the test plans, conditions, and apparatus – before range-time bills begin to accumulate.

Stimulators by definition involve extensive interfaces with the real equipment; as such, they manifest gathered knowledge about the system and the ways in which it can be instrumented and measured. Qualification and field-test, seeking to determine similar information, can often benefit from re-use of the people who developed the stimulation systems, if not the actual stimulator instrumentation outright. Test cost savings are easily quantified using actual costs for development of the stimulator instrumentation, data recording, analysis packages.

As in the virtual OT discussion above, the Department of Defense (DoD) M&S Master Plan specifically envisions use of stimulators for regimes of test and evaluation which are impossible in that they pose substantial risk to human life. [6] Wind-tunnel and HWIL helicopter flight-control performance assessments at and beyond the “edge of the envelope,” for example, allow the assessment of “impossible” regimes of flight. Even where human life is not at risk,

stimulators can save large sums, like CAD, in avoidance of destructive testing. Savings can be quantified as they are proportional to range time avoidance and test article replacement costs.

Well-done stimulation paves the way for stimulator-based acceptance testing – units can be accepted from production based on a combination of performance in the simulated environment and current statistical quality control data from the production line. By leveraging already-available data, the customer can avoid paying for expensive, redundant flight tests for lot acceptance. This payoff is particularly marked for expendable products such as munitions, and products with very high unit costs.

As in qualification, field, and acceptance testing, the same stimulator data acquisition and analysis systems can be applied to the design of plant-floor test equipment. The industrial engineer is most likely to find the most knowledge about his product's various parts among the people who first evaluated (and frequently designed) those parts. Drawings, designs, instrumentation, and evaluation methods are available for re-use to the entrepreneurial plant designer, offering highly quantifiable savings. Again, a basis of estimate exists from the actual costs incurred during initial stimulator buildup – and replication is nearly always cheaper than reinvention. Savings from this re-use can pay off throughout the life of the system's production, through simplified configuration control. Further, design tolerances can be loosened or tightened from hands-on experience. Value engineering opportunities abound, as stimulators tend to accumulate large quantities of system performance sensitivity data.

In-field test equipment, while generally smaller and less sophisticated than plant-floor production equipment, benefits similarly from already-bought knowledge. Additionally, if end-product designers are brought together with the stimulator designers, the field-test team can leverage all the lessons-learned on how the product tends to break – and how to fix it. Like plant test equipment, quantifiable savings accrue throughout production and deployment, and beyond throughout the system's entire life.

Hands-on expertise gained from stimulator development can be combined with reliability monitoring and modeling to reduce ongoing “does it still work” testing through a product's life. Munitions and airframes, for example, are notoriously subject to aging, with potentially catastrophic outcomes. Knowledge gained from years of experience in finding a system's tolerance for out-of-spec operation can be applied directly to improving constructive reliability models as discussed above, with reduced requirements for additional “fly to keep” testing and inspection processes. Quantifiable savings can accrue through the system's lifetime.

Table 3. Duration and Quantifiability of “Stimulator” Simulation ROI Throughout a System’s Life

"Stimulator" Simulation Application	Quantifiability of Simulation ROI Throughout Phases of a System's Life			
	Concept/ Tech. Dev.	Sys Design/ Demo	Production/ Deployment	Support/Operations
Design		Low (t,\$)		
Checkout/pre-test risk reduction		Med (t,\$)		
Qualification/Field Test Instrumentation		Med (t,\$)		
"Impossible" Tests (e.g. lethal)		Med (t,\$)		
Acceptance Testing		High (t,\$)	High (t,\$)	
Plant-floor Test Equip. Design		High (t,\$)	High (t,\$)	
Field Automatic Test Equip. Design			High (t,\$)	High (t,\$)
Refine RAM fail/spare models				High (t,\$)

**VIII. ROI OF VIRTUAL/STIMULATOR HYBRIDS  
(real people and equipment, simulated environments)**

Hybrid simulations (in this definition) offer substantial opportunities for savings in human-operated systems. They seek efficiencies by combining both man-in-the-loop and HWIL simulation, often in the same lab with the primary products. A counter-example is instructive; consider a C<sup>2</sup> system whose training device typically led the end-product in development, with 100 percent rewrite of code for the end product. Wouldn't it have been easier and cheaper to re-use the training system user interfaces in the end product? Wouldn't it have been easier to simply use the end-product processor hardware and software to host additional simulator hardware/software and avoid much of the VV&A associated with prescriptive M&S code?

Hybrids - taking many forms – reap many of the benefits of both virtual and stimulator simulation. While a man-in-the-loop simulator might cost more to build using some key end product components such as flight control computers, its VV&A costs will be far lower – the validation of “peripherals” and already-validated environmental models can be far simpler (to the extent of being off-the-shelf, in some cases) than a whole-system validation effort. Fundamentally, hybrids seek to make an optimal cost tradeoff between buying/validating descriptive models of “new” components and simply buying the components themselves.

Hybrids offer the promise of high levels of commonality between end products, training devices, and laboratory testbeds, developed under a unified team. Savings are quantifiable during development in that as costs accrue for development of the combined effort, some reasonable estimates for a more traditional “divided house” are easily obtainable. Further, quantifiable savings can continue to accrue through the production and deployment phase; even the operations and support phase of the product life can realize payoffs. Consider the end product and its support products: the end-item, its training devices, its development lab, and its production/test equipment must all be kept in synchronized configuration control. (This often means keeping several versions – in-development, in-production, and in-field, for example – proximal to each other.) But the payoffs are very large, and can extend well beyond even individual product lives.

Table 4. Duration and Quantifiability of Hybrid Virtual/Stimulator Simulation Payoffs Throughout a System's Life

Hybrid Virtual/Stimulator Simulation Application	Quantifiability of Simulation ROI Throughout Phases of a System's Life			
	Concept/ Tech. Dev.	Sys Design/ Demo	Production/ Deployment	Support/Operations
Design		Low (t,\$)		
Test design & Operator Familiarization		High (t,\$)		
Checkout/pre-test risk reduction		Med (t,\$)		
Operational Testing		High (t,\$)		
"Impossible" Tests (e.g. lethal)		Med (t,\$)		
Employment/Tactics		Med (t,\$)	Med (t,\$)	
Product Development and Support		Med (t,\$)	Med (t,\$)	Med (t,\$)

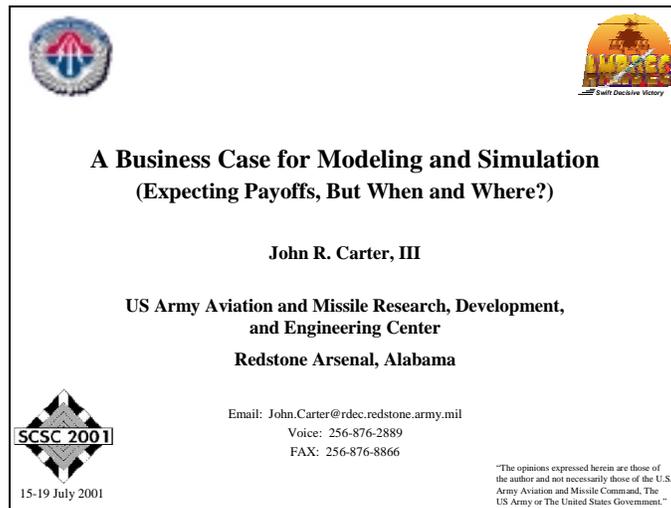
## IX. CONCLUSIONS

Simulations have saved many customers money for many years. Oftentimes, we have failed to fully appreciate or recognize the magnitude and duration of those savings. Use of some simple framework for allocating not only simulation costs, but savings, could help our industry to thrive in an increasingly-outsourced world. The key to realizing nearly all of the savings identified here is the intentional, effective transition of technology and information amongst the components and phases of a system development program. The disciplines required to accomplish this are widely known, but strangely under-applied. By developing shared teams, language and technologies in M&S to “narrow the bandwidth of problem solving” [2] we can transform simulation from a mere technology to a relevant, viable business which is indispensable to our customers – and known by them to be so.

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3. *DoD 5000.59-M, DoD Modeling and Simulation (M&S) Glossary*, part II, Definitions, p. 102ff, January 1998.
4. Johnson, Michael V. R. Sr., McKeon, Mark F., Szanto, Terence R., *Simulation Based Acquisition: A New Approach*, Defense Systems Management College Press, p. 4-8, December 1998. Internet [http://www.dau.mil/pubs/mfrpts/mrfr\\_1998.htm](http://www.dau.mil/pubs/mfrpts/mrfr_1998.htm).
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**APPENDIX**  
**A BUSINESS CASE FOR MODELING AND SIMULATION**



Bio - 20 years with the Army  
Monte Carlo simulation development in commo and radar performance analysis; C2 systems design/sim  
Managed weapon system product improvements; fire control systems and sensors, controls and displays  
Staff for missile technology development and transition  
DSMC – but system engineering was very weak, especially in simulation  
MS IE – showed me where I had succeeded in wasting incredible amounts of time and energy in the 80's



## What I Hope Will Happen ("Ah-ha!")



### LEARNING

- Our **customers see things differently** than we do: cost, schedule, performance
- We can provide value to the customer by **controlling the variables** and finding the answers to his questions and problems
- "Faith-based simulation" must be followed by **products** the customer can and will appreciate
- We have a **good story** here

### DECISION

- Tell it so that the customer can **understand and appreciate**
- **Leverage** each others' efforts to realize larger ROIs than ever

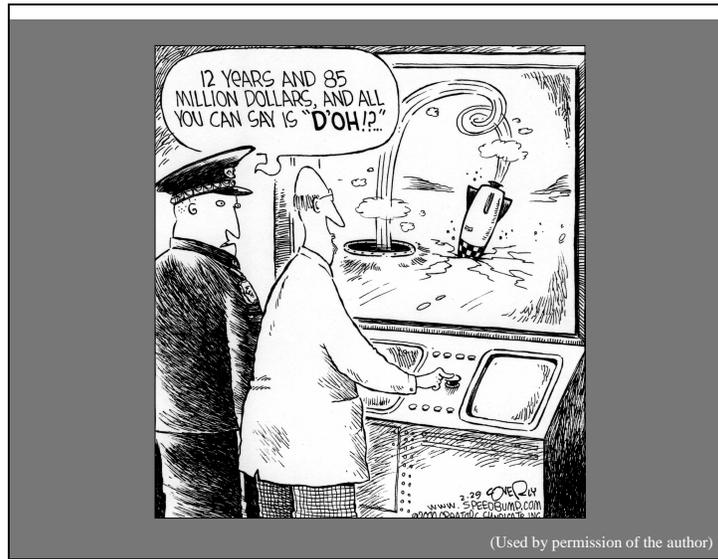
This business of simulation is not new, nor is the economic basis of its use. Major General, Doctor of Engineering Walter Dornberger, the PM for the German A-4 rocket program (later, better known as the V-2) spoke for every PM in 1942: "the makers of our test simulators had been given the task of substituting simulators for time-consuming experiments carried out with the assembled missile on expensive test stands." Time, money, and test articles – the 3 bottlenecks in a PM's life. (source: V-2, p 138, Viking Press, 1954)

I want to persuade you of some things. I also want you to make some decisions based on what we talk about. I want to see you again in a year or two, changed, and more successful than ever.... Changed, in a good way.

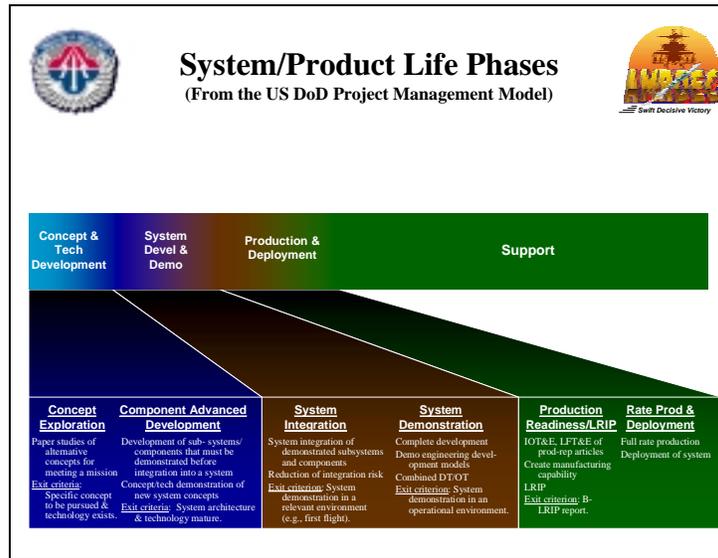
The paper is where the information is – I'm hoping to convince you to invest your time reading it, sifting it, and applying some of these concepts to your business.

Per Hank Dubin, dir AMSO, at May 2001 SBA conference: "...the most difficult part is learning how to measure benefits."

I also hope you will educate me about your business model, and where I have done violence to it.



Cartoon of rocket scientist watching missile crash; Army officer caption says, “12 years and 85 missions dollars, and all you can say is “D’OH!?”  
We’ve done this! (in half the time, by the way...)



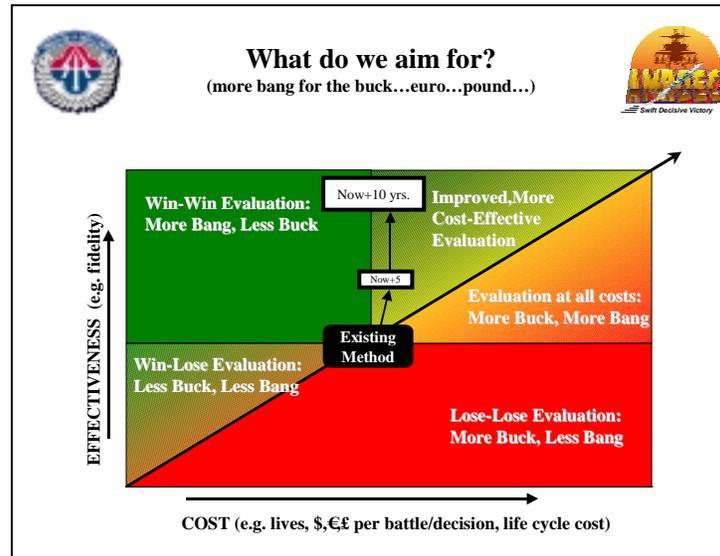
This is the life of a project manager, at least in the US DoD.

More and more managers are MBAs, not engineers. Wall Street rules, not rocket science. The commoditization of technology has hurt us; the mystique is gone from much of what we do. The hardware costs have shrunk – but the manpower to do good M&S is more costly than ever, at least on a per-hour basis.

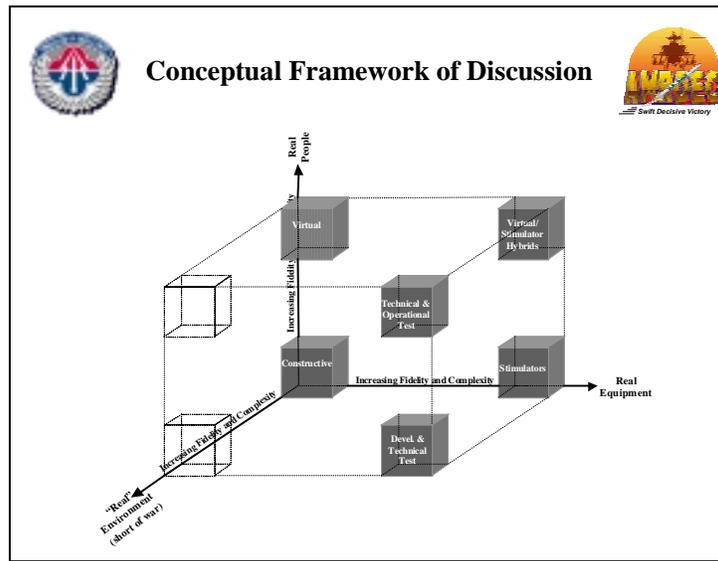
Duration of this chart – you need to know which part of this timeline your customer cares about. “Support” in military systems may be up to 30-50 years. Also in public works – dams, roads, bridges. But in telecomms, may be around 1 year.

In my world, almost all of our M&S business is in the first 2 phases, tapering down in third, and very little in 4<sup>th</sup>.

Again – your value is constantly held up to this yardstick. Frequently, your product is information which allows the project manager to make a decision about which way to go...or even whether to go on at all. Be aware of HIS decision points, and his departure date.



We are in a competitive marketplace.  
 Our products are frequently information, prototypes, designs, test equipment, and (gasp!) opinions.  
 Our customers make decisions – influenced by us – about the relative cost effectiveness of our products compared to other alternatives.  
 Our job is to develop products above the “slope” defined by existing products in the market – ideally, in the green areas.



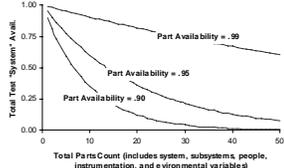
I have looked at a fair amount of literature – some of yours. Everyone picks different dimensions on which to describe the domain we call “modeling and simulation.” I wanted a way to subdivide the domains of M&S into something that a cost analyst or a project manager would understand. Here is a breakout based on “how much reality” an evaluation architecture will contain. It conveniently matches expectations of many cost analysts – you have to have a product, it has to have an operator/user, and its performs within some sort of environmental constraints defined by physics, law, culture, or some other boundary condition.



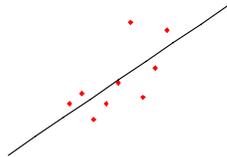
## Some Underlying Cost Drivers



### Test "System Availability"



### Descriptive vs. Prescriptive



- Complex System... Complex Simulation
- Test Instrumentation & Calibration
- People...Human Error
- "Weakest Link" effects

"One more thing to go wrong."  
- an old ME's comment on a turbocharger

- Regression Model (plot data first) vs. Speculative (draw line first)
- Descriptive "should" be easier to make/buy
- "Reinvent the Wheel" - if Necessary
  - Scope and Detail; Range of Validity
  - End-Use(s) and Versatility
  - Resolution in Time, Space, etc.

Availability – like Reliability combined with “how to fix it” time

Some of the best advice I received about test ranges was, make a pile of stuff a week ahead of time, and keep adding to it until EVERYTHING is on it. Then ship it.

“If its worth taking one of something...its worth taking two.”

I was once on a test range whose tracking system would be used to cue an air defense system – but whose accuracy was so poor that it cued the gunners as much as 90 degrees off azimuth. (A good simulation would have exhibited no more than 5-10 degrees bias. Note bias worse than Normally distributed errors.) Worse, no one had mapped where it experienced those biases. It was a simulation...an incredibly bad one.

People are not only “components” of the test system architecture – they are highly variable.

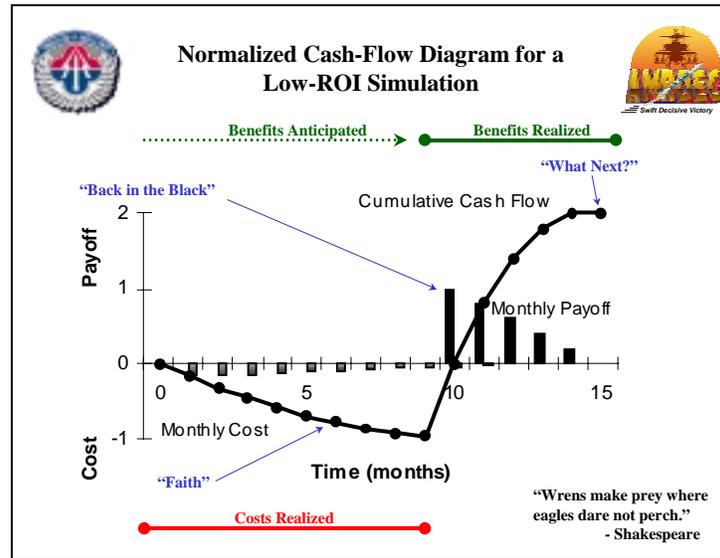
Descriptive vs. Prescriptive - Credit to Paul Fishwick in the M&S magazine for illustrating two kinds of models.

Prescriptive suggests a possible future; descriptive is limited to the present.

The easiest curve to draw is the one with the least data – fewer degrees of statistical freedom gives more latitude for artistic freedom.

Descriptive is fundamentally different – able to, and expected to, faithfully represent “the real thing”. Implications in make/buy, VV&A, and emulation/simulation/HWIL

Most M&S involves a prescriptive system operating in a descriptive environment



We said “cost-effectiveness” was important to customers.

You can tell me about “effectiveness.” What should your model of “cost” look like?

What kinds of simulation are available to solve my customers’ problems?

Are the payoffs quantifiable?

How high is the ROI?

Over what duration?

How long must my faith exceed my bills? Hank Dubin (Dir, AMSO) talked about the “faith factor” at the SBA conference in May 2001.

Every PM in the US DoD is taught about earned value – the idea that cost and schedule status on a project can be denominated in dollars. (Not all actually learn it – but their cost analysts know it forwards and backwards.) Most don’t experience the nice graphics here – they just get cries for help when variances exceed, say, 10%.

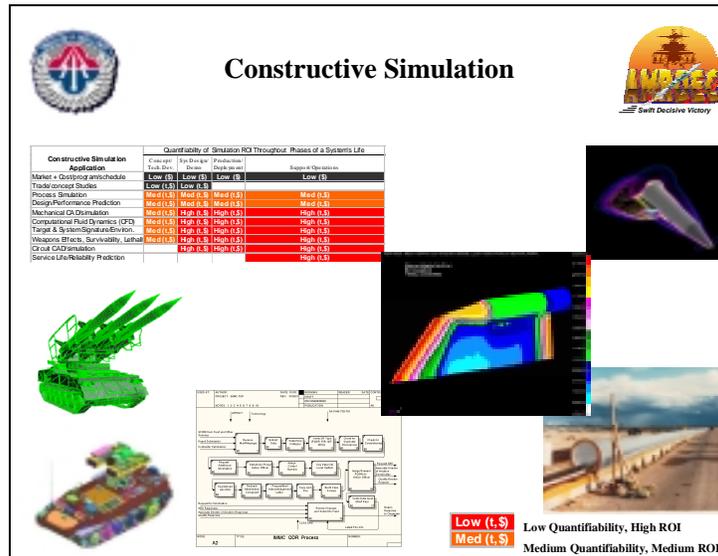
Notice the “faith factor” after you’ve made the sale – but are still developing the product. The longer this is, the better your initial sale better have been...lest the customer decide to cut his losses. Remember, in his schools he was taught not to make decisions on the basis of sunk cost...only future.

Payoffs are great – but in a world subject to Moore’s Law (computing capacity of microprocessors doubles every 18 months) our customers have become addicted to today’s miracles becoming tomorrow’s doorstops.

Your golden moment to sell follow-on work is after the ROI goes positive, and before it goes flat.

If you can plan your miracles to occur during changes of customer, so much the better – you acquire an instant reputation as a miracle-worker.

When you are displacing an incumbent, you may not know all the pitfalls of the situation; hence, Shakespeare’s dictum.



The unreadable table is excerpted from the paper; here's some eye-candy to illustrate several high-payoff forms of simulation

The wireframe CAD model is obvious, and well-known. This particular one is of a foreign SAM system. CAD is especially nice where you have only a few "real" things to tinker with. These models pay off for a long time, and, unlike bad news, improve with age.

That flowfield model around a CAD drawing (notice the linkage) is a product of CFD. Electronics versus wind tunnels, themselves a form of simulation. Remember that wind tunnels are literally one-of-a-kind, in the world. "Fly" on your schedule, not the windows left around everyone else's schedule. Design changes are CAD, versus machine shop. You can go into Mach numbers unattainable or unaffordable in wind tunnels. Ditto payoff, especially during design.

The funny-colored CAD-looking model is a radar cross-section model – think of survivability analyses from the vehicle's point of view. Turn that around, and this would be part of a performance analysis for a sensor system. Especially ditto payoff for major system-engineering problems like lifetime RCS reduction and control.

The pretty-colored picture is a thermal model of a Mach-5 missile fin about 2.5 seconds after launch. That leading edge has gone from ambient air temperature to around 2000 degrees F. The center portion is around 600. That pod has RF electronics in it, with skin temperatures around 1000 degrees. OK, why bother? The only alternative is a rocket sled test track, like the one at Holloman AFB in New Mexico. That track is around 10 miles long; peak speed is around 6000 fps for recovery (9000 for non-recoverable). Why not higher? Things come off the track! The workaround is a 3-mile-long gasbag filled with gas of different density than air. Argon and CO<sup>2</sup>, with higher density, is used to simulate hypersonic missile flight within the safety limits of the track. 4000 fps in CO<sup>2</sup> compares for aerothermal effects to 9500 ft/sec in air. Helium can be used to simulate other effects – high altitude, faster heat rate, etc. (Other facilities are blow-down, laser ablation, and wind tunnels) Any way – what a nightmare, and none really "complete." Hence, validated thermal modeling is of great utility in this extreme environment. "Free" compared to the alternative.

Process simulation is old hat to IEs, but not always recognized in the larger simulation community. Nonetheless, it has saved a fortune in diverse applications such as traffic flow, communications networks, production line design, supply and distribution systems, and even business process re-engineering (here).



## Virtual Simulation



Virtual Simulation Application	Quantifiability of Simulation ROI Throughout Phases of a System's Life			
	Concept Phase 0-1	Design Phase 2-3	Production Phase 4-5	Support & Operations Phase 6-7
Concepts and Sales	Low (L)	Low (L)	High (H)	High (H)
Design	Low (L)	Med (M)	High (H)	High (H)
Employment Tactics	Low (L)	Med (M)	High (H)	High (H)
Test Design & Operator Familiarization	Low (L)	High (H)	High (H)	High (H)
Operational Testing		High (H)	High (H)	High (H)
New Equipment Training			High (H)	High (H)
Skills Sustainment				High (H, Sust)
Mission Rehearsal				High (H, Sust)



**Low (L)** Low Quantifiability, High ROI  
**Med (M)** Medium Quantifiability, Medium ROI

You are all well familiar with virtual simulation applied to training systems; here are 3 variations which saved the Army a lot of money, and are still saving money. Gunners went from 1 in 5 to 5 in 5 performance. This has a quality all its own – saved lives, victory with fewer casualties.



## Stimulator Simulation



"Simulator" Simulation Application	Quantifiability of Simulation ROI Throughout Phases of a Systems Life		
	Concept	Pre-Design	Production
	Tech. Dev.	Design	Build/operate
Design	Med (L,S)		Support/Overhaul
Characterize-test risk reduction	Med (L,S)		
Qualification Test Instrumentation	Med (L,S)		
Responder Tests (e.g. left)	Med (L,S)		
Acceptance Testing	High (L,S)	High (L,S)	
Plant-floor Test Equip. Design	High (L,S)	High (L,S)	High (L,S)
Field Automatic Test Equip. Design			High (L,S)
Refine Field/Response models			High (L,S)





<b>Low (L,S)</b>	Low Quantifiability, High ROI
<b>Med (L,S)</b>	Medium Quantifiability, Medium ROI

That picture is of a helicopter-in-the-loop – around 60 feet from front to back. Programmable hydraulics. How else would you find out about fatigue effects without flying it and finding out the hard way? Huge cost savings, for life.

The funny looking picture is the nose of a missile – radar guided in this case – that thinks its flying toward a target. The stuff around it is anechoic foam to produce a “free-space” environment. We have surely flown millions of flights this way by now – we literally can’t build a missile without it anymore. This way, first flights can actually succeed! Huge cost savings in design and production/acceptance test.

The Carco table – the thing that looks like a gyro in its gimbals – is part of the same idea. One like this was recently used for a semi-active laser guided missile. First flight was this spring...successful. How do you measure the payoff of that?

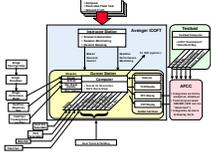
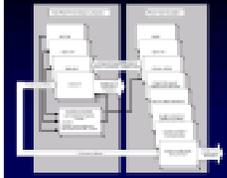


## Virtual/Stimulator Hybrid Simulation



Hybrid Virtual/Stimulator Simulation Application	Quantifiability of Simulation ROI Throughout Phases of a System's Life		
	Concept/Early Dev.	Dev/Proc.	Production/Deployment/Operations
Design	Low (L,S)		
Test design & Operator Familiarization	Med (L,S)		
Chockout/pre-test risk reduction	Med (L,S)		
Operational Testing	Med (L,S)		
Prepositioned Tasks (e.g. lethal)	Med (L,S)	Med (L,S)	
Employment/Tactics	Med (L,S)	Med (L,S)	
Product Development and Support	Med (L,S)	Med (L,S)	Med (L,S)



Low (L,S) Low Quantifiability, High ROI

Med (L,S) Medium Quantifiability, Medium ROI

Two examples of an extremely valuable hybrid here – especially so for things that fly, like helicopters and missiles.

Testbed combines real fire-control hardware with the Avenger training system and some specialized I/O drivers. Can also run the fire control as software-in-the-loop by simply changing the I/O file name declarations in the front of the program.

Here, fire control is the real thing, so no descriptive simulation needed.

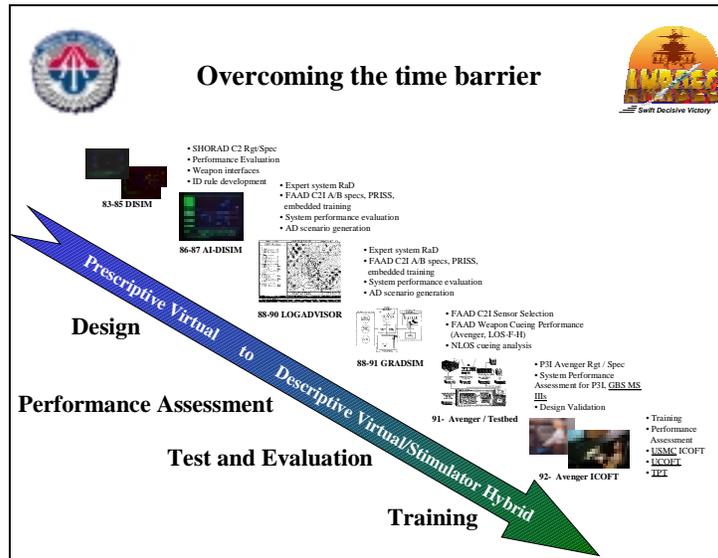
Operator displays/controls are highly descriptive and operator-validated.

Simple, modular models of various sensors – FLIR, turret stabilization rates, IFF, etc.

Environment simulated.

More on this in our case study in a minute.

Boeing VITAL (Vertical Motion Simulation/VMS Integration Technology for Affordable Life Cycle costs) system does similar thing for helicopters – man in the loop, simulated flight control functions, real aero. (Here, Apache.) Big design phase savings, but also during life – these things are out there for 30-40 years, and a lot of modifications get made in that time.



This chart illustrates the payoff of M&S efforts which span two decades. No substitute for a graphical representation of the simulation. If you haven't got it, get it. Evolution from a PDP 11-23 (ouch) design prototype to SGI machines used in virtual/stimulator hybrid.

Funds from 3 PMs (ADCCS, Stinger, NLOS), one capital equipment fund, 2 tech base projects (AI, LOGADVISOR, ID sensor fusion)

Successful M&S must transcend PMs, whose only observable motivation to date is "on my watch." Continuity of people is essential. Preservation of intellectual and relationship capital was primary enabler. Necessary, and nearly sufficient. Time is enemy number two.

 **Overcoming the Islands** 

**Boss**  
Type title here

Sensors  
Type title here

Simulation  
Type title here

Reliability  
Type title here

Mechanical Design

**“Where” are the Players?**



Watch for islands of simulation...geographic and organizational.  
Many barriers and disincentives to unity of effort in M&S



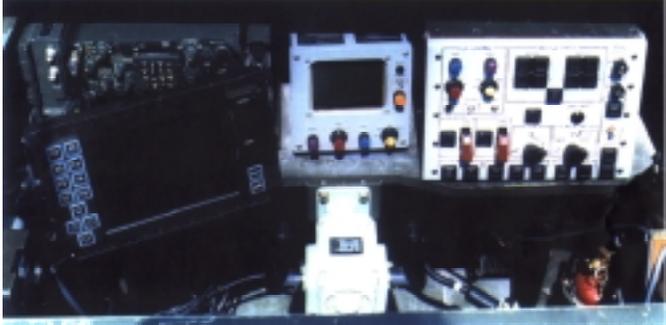
**A Case Study from 1994: Partnering with Test**  
(Get the answers the customer needs, when he needs them.)

Question: "What do you call 100 detailed test plans at the bottom of the Grand Canyon?"

1994 effort



 **Real or Simulated?**   
(both – Virtual/Stimulator Hybrid Simulation)



**Simple apparatus – high reliability of hardware and software.  
Descriptive weapon and radar models; Prescriptive C<sup>2</sup> cueing model.**

1994 case study

Is it real or is it Memorex? This happens to be real hardware – the only way I can tell it's the real thing isn't the control panel, it's the fire extinguisher. In the simulator, all the hardware looks like this.

The left display/control group is the item being evaluated.

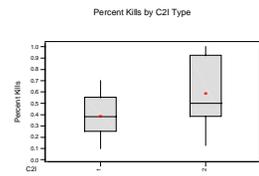


# Counter-UAV Simulation Findings



Scenario	Percent of Targets Killed by SHORAD Fire Unit Gunners							
	C2I Manual				C2I Automatic			
	1	2	3	4	1	2	3	4
1a	0.38	0.63	0.13	0.25	0.50	0.50	0.63	0.25
1b	0.38	0.38	0.38	0.25	0.38	0.38	0.63	0.38
1c	0.13	0.38	0.38	0.25	0.38	0.38	0.38	0.13
2		0.54	0.69	0.46		0.77	0.85	0.69
3		0.50	0.44	0.38		0.72	1.00	0.67
4		0.42	0.58	0.25		0.58	0.83	0.33
5	0.30	0.70	0.40	0.30	0.50	0.70	1.00	0.60
6	0.70	0.70	0.60	0.10	1.00	1.00	1.00	1.00

Missing Data; not analyzed



What the customer was hoping to hear: Cueing improves performance.

But that isn't the whole story...

1994 case study

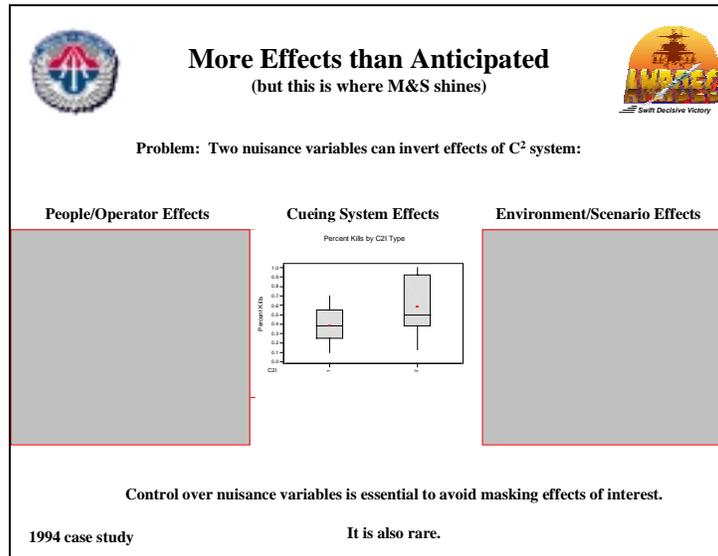
Three dimensions of interest here (known sources of variation).

Scenario

Operator

Type of target cueing – automated system just shown, or another, semi-automated “manual” system with a voice-tell in the process.

We found the answer to the question – the new system was a quantum improvement over the old.



BUT

Mostly, we got lucky. Here's a comparison of the relative magnitude of the three dimensions of the scenario, using bar-and-whisker charts. All have "number of kills" as their vertical axis, scaled the same.

Variation is larger from the two variables we thought we had control of.

4 different operators - #4 a loser.

5 different scenarios - #5 like shooting fish in a barrel, apparently. Tends to wash out differences we're looking for.

The good news (other than a validated hypothesis): The field test exercise was scoped to reduce some of this, the results were consistent, the GBS was bought, the C2I system was bought, the fire control was bought...and today this stuff is in the field.

"Real simulation" can put a drive in a program that nothing else can.



## Moral of the Story (and the paper)



Costs could have been higher... much...  
Success could have been avoided... easily...  
Schedule could have been stretched... to "next year"...  
Test/analyst/customer teamwork could have been prevented...  
Travel to "exotic" test ranges could have been greater...

...if only we hadn't used that doggone simulation!

"A closed mouth gathers no feet."



## Backups





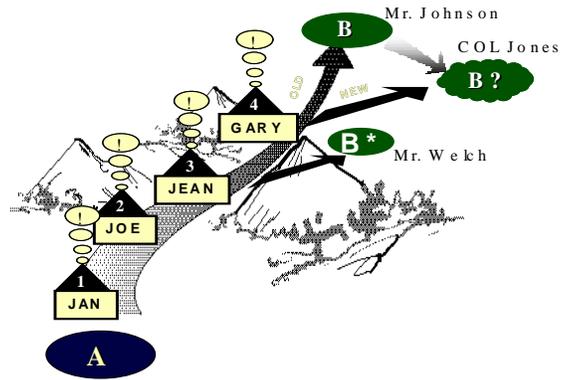
## Tying it Together (A 10-Step Program)



1. Define the simulation's product and its customer.
2. Identify customers for specific deliverables (paper, demo, hardware, evaluation, etc.).
3. When does the customer need the simulation?
4. How mature are the M&S components, relative to what the customer is able and willing to accept, and when he wants it?
5. Make or buy? Is maturation of the M&S components adaptive, evolutionary, or revolutionary? Are there other constraints (legal, monetary, etc.)?
6. Just how important is this technology and customer need compared to all others?
7. Who in our company will lead the program? Can they amass sufficient intellectual and relationship capital to succeed?
8. Can a single simulation serve several customers, together or in stages? Make or buy?
9. What are interim milestones, incentives, metrics, and exit criteria?
10. How, and to whom, will we transition evaluations and other deliverables into the customers' decision processes?



# Defining "The Path from A to B"



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