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System Dynamics Modeling in the Legal Arena: Special Challenges of the Expert Witness Role

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Abstract

In the late 1970s System Dynamics models began to be employed in legal disputes as a means of proving and quantifying damages due from one party to another, and such use seems likely to increase in the future. But most System Dynamics practitioners are unfamiliar with the role of expert witness and the obligations and responsibilities associated with it. Admissibility of the would-be expert's testimony is now more significant a hurdle than ever, under recently established Supreme Court guidelines that lean heavily on the scientific method.

Best-practice System Dynamics work adheres to the scientific method and should prove admissible. But many System Dynamics applications are carried out to less stringent standards that leave testimony based on that work vulnerable to being ruled inadmissible. Beyond admissibility, the process of preparing to deliver expert testimony based on System Dynamics presents unusual challenges for the practitioner.

System Dynamics practitioners providing expert testimony in opposition to that of other System Dynamicists face some special challenges. In the experience of the authors and their colleagues, the quality of opposition testimony by System Dynamics experts has been poor. Opposing expert testimony must improve significantly to meet the Supreme Court's new admissibility standards. The stakes are high, since upcoming cases are likely to set precedents that will significantly affect future use of System Dynamics in the legal arena. In addition, legal admissibility will doubtless impact the more general perceived legitimacy and acceptance of System Dynamics in corporate and other non-legal settings.

Keywords: Legal disputes, expert witness, expert testimony, admissibility, Daubert, scientific method, hypothesis testing, System Dynamics.

The authors wish to acknowledge the long-term contribution of their PA colleagues who have devoted so much thought and effort to work in the legal arena, especially Ken Cooper and Tom Mullen. We would also like to acknowledge the tremendous amount we have learned about the legal arena and the role of the expert witness from our various attorney friends, especially Jeffrey Dorman of Freeborn & Peters.

1. Introduction

Ever since its founding by Jay Forrester, System Dynamics has been employed to analyze the past and potential future performance of dynamically complex systems. Many of these have been business systems involving customers and markets, companies or business units, product lines and services, value chains, and so on. In such applications System Dynamics has been appreciated for its ability to make the performance of such systems more understandable, more reliably quantifiable, and potentially more controllable.

In the late 1970s System Dynamics models began to be employed in legal disputes as a means of proving and quantifying damages due from one party to another. In such cases the damages are usually alleged to have resulted from some breach of contract. A System Dynamics model is usually employed to prove that the alleged damages did, in fact, occur and to differentiate them quantitatively from the performance that would have occurred in their absence. In the past twenty-five years System Dynamic models have been so applied by PA in 45 legal cases, and to an apparently lesser extent by other practitioners. In most such cases one party to the dispute employs a System Dynamics practitioner with the expectation that he or she will conduct dynamic simulation analysis and provide expert testimony that will help win the case.

Often the opposing party will also employ an expert to provide analysis and rebuttal testimony to refute that of the System Dynamicist. Increasingly the opposing expert is another System Dynamicist, pitting professionals from our relatively small field against each other in a head-to-head contest. With high stakes and pressure from clients and attorneys on both sides, these “expert wars” can easily become rather extreme. Under the press of circumstances it can be difficult to remember that the role of expert witness imposes requirements and obligations on the System Dynamicist. Those requirements and obligations are the subject of this paper.

Most of the legal cases in which System Dynamics has been employed have involved complex design/construction projects that overran planned schedules and budgets, with the dispute arising between an owner organization commissioning the project and a contractor organization hired to carry it out. A few cases have arisen between project owners and regulatory bodies, and others have arisen between project contractors and suppliers or subcontractors. Most legal applications of System Dynamics have been in support of the contractor organization as plaintiff in these cases. As the number and complexity of large projects continues to grow in a variety of industries, with attendant growth in the number and size of project performance “failures”, it seems likely that such disputes and dispute applications of System Dynamics will continue to grow in number.

There has been at least one legal application of System Dynamics that involved loss of profit and market share in an ongoing business rather than development project overruns, and other such cases are on the horizon. It appears that future non-project legal applications of System Dynamics are likely to grow even faster than will project-dispute applications.

The 45 legal cases on which PA Consulting has worked cover the shipbuilding, aerospace, oil and gas, civil construction, and software systems industries. They involve both court trials and formal arbitration proceedings in Europe and North America under US law, British law, and

International Chamber of Commerce arbitration rules. Disputed amounts have ranged from several tens of millions of dollars to several billions of dollars, with the average probably falling in the range of three hundred to four hundred million dollars. All but three of these cases have been resolved, all of them through negotiated settlements outside the court or arbitration proceedings. The three cases that have not been settled are still in process. PA's involvement in these cases has spanned the following range of activities:

- Rapid qualitative assessment of the strengths and weaknesses of a case based on expected dynamics of the organizations involved;
- Rough modeling and simulation analyses to support initial quantification of damages;
- Refined modeling and simulation analyses to withstand adversarial attack;
- Preparation of heuristics to guide settlement discussions;
- Submission of model and analyses during evidentiary discovery;
- Preparation for and participation in deposition sessions;
- Preparation of materials for delivering expert testimony;
- Delivery of expert testimony.

In the legal arena a System Dynamics model serves a dual quantitative purpose: 1) to determine what dynamics governed the performance of the subject organization; and 2) to employ those dynamics, once known, to determine what different performance would have resulted had the parties behaved differently or had different conditions prevailed. Differences in performance become the basis for determining damages. In such cases the different behavior and/or conditions that are the subject of the dispute are usually defined by the terms of some existing contract between the parties.

In legal disputes involving performance of complex organizations, PA's experience (and that of our clients) has been that properly executed System Dynamics analyses offer some powerful advantages over more conventional analysis methods:

- The model is not a black box -- causality is explicitly identified and quantitatively represented and can be audited and understood by the factfinder(s) – the judge, jury or arbitration panel charged with determining the facts in the case;
- Good System Dynamics analysis yields both the quantification of damages and the dynamic story or explanation of how those damages arose;
- System Dynamics analysis reveals clearly and quantitatively how each party contributed to the organizational performance that is the subject of the dispute, thus grounding damage claims in the broader dynamic story of "what happened";
- A good dynamic model is almost always a much richer and more complete representation of the organizational performance that is the subject of the dispute than those provided by more conventional (usually static and open-loop) analysis

tools. This makes a good System Dynamics analysis difficult to attack successfully;

- A good dynamic model can and should be used not only to prove "what happened" and to quantify resulting damages, but to disprove the opposition's alternative theories of the case and associated quantification of damages. This is much more difficult to do with conventional (usually static and open-loop) analysis tools, and is a fundamental strength of System Dynamics when employed in the legal arena.

In adversarial legal proceedings PA's work has been attacked by a variety of opposing experts in a wide variety of ways. Some of these opposing experts were from different disciplines and were quite unfamiliar with System Dynamics, while others were experienced System Dynamics practitioners. Regardless of their professional origins, opposition attacks have generally included some of the following range of assertions:

- It is not possible to build a reliable model of all the factors PA purports to have included in its analysis;
- Based on the particulars of the case in question, System Dynamics is not an appropriate analysis method;
- The simulation model developed by PA contains fatal flaws or is fatally biased;
- The data employed in developing the model are fatally flawed or fatally biased;
- The simulation analyses conducted are slanted and inappropriately favor PA's client;
- The model's simulated organizational performance under other-than-historic conditions is not credible;
- The behaviors and conditions that PA purports to have analyzed were not those that caused the problems that are the subject of this dispute;
- If the behaviors and conditions that truly caused the problems were properly reflected in PA's simulation model, the resulting analysis would not support PA's client's case.

Despite such attacks, the settlements obtained in PA's cases have almost always been regarded by clients as quite favorable. Attorneys with whom we have worked tell us that the average settlement obtained in those cases is nearly twice the size of those typically obtained in similar cases in which System Dynamics was not employed. In no case have opposition attacks on PA's work resulted in what the client regarded as an unfavorable settlement. Invariably, when opposing experts have been involved their critiques of PA's work have contained major mistakes of fact and/or methodology that rendered those critiques unreliable. In several cases the evidentiary discovery process revealed those mistakes and the credibility of the opposing experts and their criticisms was seriously undermined as a result.

Whether for the plaintiff or the defendant, whether in support or opposition, the role of the expert witness imposes requirements and obligations that should be carefully considered by System

Dynamicists, especially because those requirements have changed recently. The following discussion of those requirements and obligations is based on the latest legal standards in US Federal courts, but the courts of 19 states have also adopted the Federal standards (Mahle 1999) and the general issues involved are likely to be similar in other legal regimes.

Section 2 of this paper discusses admissibility standards for expert testimony established in recent case rulings by the United States Supreme Court. Section 3 discusses selected characteristics of good System Dynamics work and how those match up against the standards established by the Court's rulings. Section 4 discusses the tasks typically involved in preparing and delivering expert testimony based on System Dynamics; Section 5 discusses the ethical challenges inherent in the expert witness role and the special challenges System Dynamicists face when offering expert testimony in opposition to that of other System Dynamics practitioners. Section 6 concludes.

2. Legal Standards for Admissibility of Expert Testimony

On disputes involving performance of complex organizations, good System Dynamics analysis work has proven to be an unusually effective and reliable means of proving and quantifying damages resulting from the actions and omissions of the disputing parties. The effectiveness of System Dynamics analysis in the legal arena results from its ability to reveal the chains of causality connecting various acts and omissions of the disputing parties with the many resulting indirect effects of those acts and omissions on organizational performance – this yields a more complete and defensible proof and quantification of damages. Legal opponents have found it difficult to mount effective attacks on System Dynamics analyses when those analyses are properly carried out. But the potential probative and analytical advantages of System Dynamics will be useless if expert testimony based on it does not meet the new standards for admissibility in legal proceedings.

The Role of the Daubert Standards. Until 1993, admissibility of expert testimony in legal proceedings was governed by the Frye standard, also known as the "general acceptance" standard because it relied on general acceptance of the expert's analysis methods within the scientific community. In 1993, in *Daubert v. Merrill Dow Pharmaceuticals, Inc.* the Supreme Court ruled that the *Frye* standard was superceded by Federal Rule of Evidence 702 covering expert testimony based on "scientific, technical or other specialized knowledge". The court's *Daubert* ruling focused on expert testimony based on scientific knowledge, and laid down standards for admissibility of such testimony as evidence. Subsequently, circuit courts split on whether *Daubert* also applied to evidence based on "technical or other specialized knowledge" and whether "soft" sciences (psychology, economics, etc.) counted as science under *Daubert*. In 1999, in *Kumho Tire Company v. Carmichael* the Supreme Court extended its *Daubert* ruling to cover expert testimony based on other than scientific knowledge. In this paper, unless otherwise specified the term *Daubert* will be employed to refer to the ruling in that case and in all associated cases. In the broadest terms, then, *Daubert* now requires that all expert testimony be "scientific".

The importance of the Court's *Daubert* rulings is illustrated by the following (Mahle 2001).

> *"Even after having lost on liability, lawyers are winning cases by using newly available techniques, suggested by Daubert and Kumho Tire, to exclude the expert testimony that links money damages to the act or omission for which their client has been found liable."*

In other words, when an organization has lost the liability portion of its case and been found legally liable to pay damages to its opponent, the loser can still achieve an effective win if the testimony of the opposing expert hired to assist the court in quantifying those damages is ruled inadmissible. That's because establishing legal liability for damages is necessary but not sufficient to actually recover damages – an equally crucial second step is to prove the magnitude of the damages experienced. This is often done by means of expert testimony, testimony which is not admissible unless it meets the new *Daubert* standards. If there is little or no admissible testimony on the magnitude of the damages, then the factfinder or factfinders are unlikely to award significant damages. Thus, if the System Dynamics practitioner cannot survive a *Daubert*-based admissibility challenge then his or her testimony will not be heard, and the client may not be awarded any damages despite having previously proven that the opposing party is liable to pay such damages.

So far as the authors are aware, no case involving expert testimony based on System Dynamics analysis has yet faced an admissibility challenge under the *Daubert* rulings. Attorneys familiar with System Dynamics and with the Court's rulings believe that expert testimony based on System Dynamics analyses can meet admissibility standards if those analyses are carried out using best practices. Until that is tested in court, firms and erstwhile experts contemplating use of expert testimony based on System Dynamics must measure the characteristics of such analyses against the specific standards set in *Daubert* since, in any significant case, legal opponents are likely to challenge the admissibility of such testimony. The remainder of this section sets out the *Daubert* standards, and Section 2 matches the characteristics of good System Dynamics analyses against them.

<u>The *Daubert* Standards.</u> *Daubert* and related rulings oblige the trial court to be the evidentiary "gatekeeper" who screens proffered expert testimony for admissibility.

> *"The objective of [the gatekeeping] requirement is to ensure the reliability and relevancy of expert testimony. It is to make certain that an expert, whether basing testimony on professional studies or personal experience, employs in the courtroom the same level of intellectual rigor that characterizes the practice of an expert in the relevant field [when dealing with similar matters outside the courtroom]."*
>
> *United States Supreme Court in Kumho Tire Co. v. Carmichael*

Daubert made an explicit link between the reliability of an expert's testimony and the expert's use of scientific knowledge derived by the scientific method:

> *"…the subject of an expert's testimony must be scientific…knowledge…[it is] the requirement that an expert's testimony pertain to 'scientific knowledge'…[that] establishes a standard of evidentiary reliability."*
>
> *"In order to qualify as 'scientific knowledge', an inference or assertion must be derived by the scientific method."*
>
> *"Scientific methodology today is based on generating hypotheses and testing them to see if they can be falsified; indeed, this methodology is what distinguishes science from other fields of human inquiry."*
>
> *United States Supreme Court in Daubert v. Merrill Dow Pharmaceuticals, Inc.*

After the Court's ruling in *Daubert*, it became popular to proffer expert testimony as non-scientific to avoid having to apply the new standards for admissibility. The *Kumho Tire* decision closed off this option by extending the *Daubert* standards to other forms of expert testimony.

> *"Daubert's general holding…applies not only to testimony based on 'scientific' knowledge, but also to testimony based on 'technical' or 'other specialized' knowledge."*
>
> *United States Supreme Court in Kumho Tire Co. v. Carmichael.*

Building on the scientific method, *Daubert* and associated rulings provided factors for trial courts to use in evaluating the scientific validity and resulting evidentiary reliability and admissibility of expert testimony. Experts in the legal community have expanded on these factors with specific admissibility tests (Mahle 1999, Berger 2000, Black et al., 1994).

1) The proffered testimony should be based upon a testable hypothesis or hypotheses.
    a) The hypothesis must have explanatory power relative to the case – it must explain the how and why of the observed organizational performance. More than merely descriptive, the hypothesis must also be predictive.
    b) The hypothesis must be logically consistent – it must contain no internal inconsistencies and must not be self-contradictory.
    c) The hypothesis must be falsifiable – it must be amenable to empirical testing that would reveal flaws or shortcomings.

2) The hypothesis must have been tested to determine the known or potential error rate.

3) Hypotheses must have been formed and tested and analyses conducted in accordance with standards appropriate to the techniques employed, including:
    a) Standards regarding consistency with accepted theories – because scientific knowledge is usually cumulative and progressive, hypotheses should most often build from existing theories;
    b) Standards regarding the scope of testing – "…the more severe and the more diverse the experiments that fail to falsify an explanation or hypothesis, the more corroborated, or reliable, it becomes…" (Black et al., 1994);

   c) Standards regarding precision – precise results and statements are more readily testable than are broad generalizations;
   d) Standards regarding post-hypothesis testing – hypotheses must be capable of explaining more than pre-existing data.
   e) Adhering to the same standards as in non-legal applications.

4) The techniques employed used should have been peer reviewed.
   a) Initial peer review usually occurs in the run-up to publication in peer-reviewed journals.
   b) The techniques employed should also have withstood the broader peer review to which publication exposed them.
5) The techniques employed should have been generally accepted in the scientific community.

The first two of these five Court-supplied factors are the basis for determining whether the proffered expert testimony is appropriately based in the scientific method. The third factor is the basis for determining whether the putative expert witness employed good scientific practice. The fourth and fifth factors give confidence that the scientific methodology employed is generally viewed as sound.

3. How System Dynamics Matches Up Against the New Standards

Let's march through the Court's criteria and examine how closely best-practice System Dynamics work comes to meeting them.

1) *The proffered testimony should be based upon a testable hypothesis or hypotheses.*
   a) *The hypothesis must have explanatory power relative to the case.*
   b) *The hypothesis must be logically consistent.*
   c) *The hypothesis must be falsifiable.*

Testimony should be based upon a testable hypothesis or hypotheses. In PA's experience, use of System Dynamics in the legal arena involves forming and testing hypotheses at two different levels. The first hypothesis is at the whole-organization level, creating and testing a hypothesis of the organization's overall dynamics. The second hypothesis is at the level of the 'theory of the case' or each party's story of "what happened", and it reflects only the most relevant subset of the overall dynamics.

At the highest conceptual level a System Dynamics model constitutes a hypothesis about the dynamics of the organization(s) involved in the dispute, that is, the elements, interconnections between elements, and resulting feedback loops driving overall organizational performance. The hypothesis is stated in terms of computerized mathematical equations that explicitly identify each element and feedback loop and quantitatively characterize the strength and timing of those loops. This method yields a clear and unambiguous statement of the high-level hypothesis, one that is readily auditable and can be understood by anyone who takes a little time to learn some simple equation conventions.

The second hypothesis is narrower, including just those loops that were active in creating the damages that are the subject of the dispute, e.g., the impact of delay and disruption. The second hypothesis is developed from analyses that employ the 'whole-organization' hypothesis or model. This second hypothesis is not a model, rather, it is the dynamic story of 'what happened' that legal factfinders need to know to determine damages. While it is theoretically possible to begin forming and testing hypotheses in the form of models at the 'what happened' level, for reasons explained below such hypotheses are unlikely to be persuasive or to withstand a *Daubert* challenge. Good scientific practice calls for forming and testing hypotheses that broadly explain the performance of the subject organization, and then employing those hypotheses (models) to answer specific questions about that performance as a basis for determining damages.

Hypotheses must have explanatory power relative to the case. For the hypothesis or model to have explanatory power relative to the legal case, it must usually include far more feedback loops than will ultimately be found to have caused the damages that are the subject of the dispute. In other words, the model must be a hypothesis of the organization's overall performance and not just of those aspects of performance that one party believes led to the dispute. There are two main reasons for this: first, the parties to the dispute will rarely agree on the existence or the causes of damages, and any hypothesis framed narrowly around the "theory of the case" offered by one party will necessarily lack credibility as well as the dynamic breadth necessary to evaluate competing theories offered by the other party; second, relying solely or even primarily on human judgment (even that of experienced System Dynamics practitioners) to determine which feedback loops played a part in damages experienced by a complex organization would be quite inconsistent with the scientific method. Until we have properly carried out the dynamic modeling and analysis process we don't know which feedback loops played a part – we may think we know but we can't be sure. Through dynamic analysis we can determine which feedback loops caused the damages that are the subject of the dispute, as long as the model includes those loops. Since at the start we cannot be certain which loops resulted in the damages, we have a chicken-and-egg problem that can be resolved by starting with a hypothesis or model that embraces as many of the potentially important loops as possible for the subject organization(s). Finding which loops resulted in the damages confirms that the hypothesis/model has explanatory power relative to the case.

Hypotheses must be logically consistent. At the macro level a good System Dynamics hypothesis/model will, by definition, be logically consistent – it will clearly state the dynamic logic that is supposed to have driven the performance of the organization(s) involved. A good System Dynamics model will be logically consistent at the micro level as well – for example, it will not (without good reason) employ different dynamic structures to simulate similar operations and relationships in different parts of the organization(s) being simulated. Nor will it (again, without good reason) include different strengths or timings for similar cause-effect relationships in different parts of the organization(s) being simulated. It will not (without good reason) contain table functions defining non-linear relationships that include discontinuities. The presence of such logical inconsistencies would be grounds for questioning whether the expert's testimony is truly founded on the scientific method.

Hypotheses must be falsifiable. A hypothesis that cannot be tested cannot be falsified and hence cannot be subject to the scientific method. A falsifiable hypothesis that fails tests having the potential to falsify it has been rejected – obviously such a hypothesis would be an unreliable basis for proving and quantifying damages in the legal arena. When a hypothesis can no longer be proven false based on the available information (and when the error rate associated with the hypothesis is small – more on that shortly) that hypothesis can be considered a reliable basis for expert testimony. The iterative process of testing, falsification, and improvement of the hypothesis is described in more detail in (Lyneis 1999, Graham 2002, Ariza and Graham 2002).

Like the hypotheses themselves, hypothesis testing takes place on different levels when employing System Dynamics in the legal arena. Under the scientific method, one object of testing is to uncover flaws in the hypothesis so that a more reliable hypothesis can be developed. The System Dynamics model that constitutes the higher-level hypothesis is generally developed in steps beginning with diagramming of feedback loops, which leads to writing of equations that quantitatively characterize those loops, followed by numerical simulation and testing of those equations against known real-world performance. This sequence of steps is usually repeated numerous times during the development and refinement of the hypothesis/model, and the resulting iterative process does not differ from the formation, testing and refinement of hypotheses that is the foundation of the scientific method.

At the 'whole-organization' level the most visible hypothesis test is the ability of the System Dynamics model to re-create the known history of the subject organization within acceptable standards of fidelity – a model or hypothesis that cannot re-create organizational history has been rejected and is unlikely to survive a *Daubert* challenge. Organizational history includes both 'hard' data on organizational performance (data-based records of labor-hours expended, quantities bought/produced/sold, market share, pricing, etc.) and 'soft' information or first-hand knowledge of direct participants regarding the effects that various elements had on different aspects of performance. At the macro level the System Dynamics model/hypothesis must re-create the 'hard' data, and at the micro level it must do so for the right reasons – that is, consistent with available first-hand knowledge regarding the relationships that affected performance. Other high-level hypothesis or model falsification tests include assessing the robustness of simulated performance under extreme conditions different from those encountered historically, and comparing the model against models (hypotheses) for similar organizations when such models are available.

The more focused second-level hypothesis as to 'what happened' must be tested for plausibility in its own right and often against alternative theories of the case. The hypothesis that bases the claimant's plea must be explainable in terms of a sequential chain of quantified causes and effects that is demonstrably consistent with known organizational history, and each causal link in that chain must be understood by and make sense to the factfinder(s) who will decide the case. This level of plausibility is always necessary but may not be sufficient to obtain a fair award for damages, because the opposition usually offers alternative 'what happened' theories that, if accepted as more credible by the factfinder(s), would reduce any damage award and might even reverse it. These alternative theories usually appear plausible because they are tied qualitatively and sometimes even quantitatively (by means of some static, open-loop model or analysis) to the known history of the subject organization. This is a strong reason for conducting System Dynamics hypothesis/model forming and testing work at the 'whole-organization' level, because such a model can be employed to conduct falsification tests of the opposition's alternative theories of the case. If those alternative theories are incorrect then System Dynamics analysis should demonstrate that they are inconsistent with known organizational history or with the patterns of behavior and performance characteristic of such organizations, and show how they are so. Assuming that the opposition does not succeed in falsifying the System Dynamics model itself, then the opposition's theories and the analyses/models supporting them will both have been rejected. When falsification efforts have ended in the legal arena, the last (presumably dynamic) hypothesis standing is likely to be the basis on which the award for damages is determined.

2) The hypothesis must have been tested to determine the known or potential error rate.

At both the 'whole organization' and 'what happened' levels, hypotheses involve potential errors. At the higher level the model-as-hypothesis reflects uncertainties regarding the nature, strength and timing of the feedback loops driving organizational performance – in a strong modeling effort these uncertainties will be small relative to the analytical issues to which the model will be applied. Lower-level hypotheses regarding 'what happened' will reflect these higher-level uncertainties in a "band of uncertainty" around the damages quantified via analysis. For factfinders charged with determining liability and awards for damages in the legal arena, the error rate is relevant to the extent that it affects the proof and/or the quantification of those damages. The ideal is a narrow band of uncertainty around the most likely value of the damages – such an outcome helps to verify the proof that damages occurred and enables factfinders to be confident in the magnitude of the award for damages.

When System Dynamics models are used as the basis for expert testimony, error rates must be measured for both the 'whole organization' and 'what happened' hypotheses. Furthermore, as explained below, error rates at those different levels are linked in an important way. For a System Dynamics model, the error rate stems from the fact that neither the model nor the available data and other information on which it based can ever be perfect. As a result, the pertinent question is whether the error rate is sufficiently small given the purpose for which the model has been developed. At the 'whole organization' level the relevant error rate is the statistical measure of the fidelity with which the System Dynamics model re-creates the 'hard' data elements of known organizational history (Sterman 1999, Lyneis and Reichelt 1996, Lyneis Reichelt and Bespolka 1996). At the 'what happened' level the relevant error rate is the likelihood that uncertainties regarding the organizational data and the System Dynamics model and analyses could result in a significantly different quantification of damages. In other words, at this level the error rate can be expressed as the width of the band of uncertainty around the quantified damages resulting from modeling uncertainties.

Best practice in quantifying error rates associated with System Dynamics analyses is thus based on four elements:

- A database containing the best available data on the historical performance of the organization(s) involved in the dispute;
- First-hand knowledge regarding the nature of the cause-effect relationships that drove organizational performance;
- Appropriate statistical fit measures for the degree of fidelity with which the model independently re-creates known organizational performance, and standards for applying those measures. It is important to match the particular error statistic employed to the nature of the organization being simulated, otherwise unreliable and possibly misleading results will be obtained (Lyneis, Reichelt and Bespolka 1996);
- Fit-Constrained Monte Carlo multi-simulation testing to determine how sensitive the quantified damages are to uncertainties in the strength and timing of the simulated feedback loops.

In Fit-Constrained Monte Carlo analysis (Graham, Choi and Mullen 2002, Graham, Moore and Choi 2002) model parameters characterizing the strength and timing of organizational feedback loops are randomly varied (each within its own band of uncertainty) and thousands of simulations are then conducted based on those variations. Each simulation is conducted with a unique combination of parameters, and each is compared against the known performance history of the organization. Most of the simulations will not re-create organizational history within acceptable 'whole organization' error rates and will be discarded as demonstrably unrepresentative of the subject organization (this 'fit constraint' is how error rates at the 'whole organization' and the 'what happened' levels are linked). The remaining simulations adequately re-create organizational history, and each one constitutes an alternative 'whole organization' hypothesis or model from which an alternative quantification of damages can be obtained. Taken as a whole these alternative damage amounts constitute a sampling that reveals the probability that the 'real' magnitude of the damages differs by various amounts from the most likely magnitude quantified by the expert witness.

This approach makes it possible to express results from a System Dynamics analysis in terms of ranges of confidence rather than one-point answers. Such a range of confidence expresses the error rate resulting from uncertainties about the data and hypothesis-model in a form that is particularly useful for the factfinder(s), who can be most confident in the expert's testimony when the alternative damage amounts are tightly clustered and when they are significantly different from the damage amounts resulting from the opponent's alternative 'what happened' hypotheses. PA employs such testing of System Dynamics analyses, which can be used to support the following sorts of assertions regarding analysis results and error rates.

- "Simulation analysis shows that the Owner's extra-contractual acts and omissions are most likely to have caused 70% of the cost and schedule overruns experienced. Because of residual uncertainties regarding the model, the 95% confidence interval for the effects of Owner's acts and omissions is between 66% and 75% of the cost and schedule overruns experienced on the project. In other words there is less than one chance in twenty that the Owner's acts and omissions caused less than 66% or more than 75% of the project cost and schedule overruns."

- "In the face of the Contractor's extra-contractual acts and omissions, and given residual uncertainties regarding the data and model, there was only one chance in about 700 that the project could have been completed on the early date suggested by the Contractor."

This approach provides information on "the known or potential error rate" in a form that will be particularly useful to the factfinder(s) and to the decisions they must reach. It does so in a manner that would be difficult to match using static, open-loop analysis tools and methods. On this count, opponents in the legal arena should find it difficult to demonstrate that expert testimony based on good System Dynamics practice ought to be ruled inadmissible.

3) *Hypotheses must have been formed and tested and analyses conducted in accordance with standards appropriate to the techniques employed, including:*
    a) *Standards regarding consistency with accepted theories;*
    b) *Standards regarding the scope of testing;*
    c) *Standards regarding precision;*
    d) *Standards regarding post-hypothesis testing.*
    e) *Adhering to the same standards as in non-legal applications.*

<u>Standards regarding consistency with accepted theories.</u> Good System Dynamics modeling practice follows principles laid down in works by prominent practitioners including Forrester (1961) and Sterman (2000). These principles are solidly based on feedback control theory and the "bounded rationality" theory of management decision-making (Forrester 1961, Cyert and March 1963, Simon 1979, Morecroft 1985). Thus, at the highest conceptual level System Dynamics is consistent with widely accepted theories.

At the level of organizational causality and dynamic structure, most System Dynamics models are assemblages of semi-generic feedback structures previously identified, written about and employed in simulating many different kinds of organizations. These structures constitute widely accepted theories of causality and performance for various organizational components, and extensive previous use in other settings has led to widespread understanding of their behavior and generated considerable empirical evidence of use without falsification. As an example, System Dynamics models of complex development projects often draw on well established theory regarding the processes that drive project performance, as discussed in writings by a variety of practitioners (Abdel-Hamid and Madnick 1991, Cooper 1980, Cooper 1993, Cooper and Mullen 1993, Ford 1995, Rodriguez and Bowers 1995, Rodriguez and Williams 1997, 1998). A System Dynamics model containing such structures is, by definition, consistent with accepted theories.

At the level of individual equations, good System Dynamics modeling practice reflects widely accepted micro-level theories regarding non-linear cause-effect relationships and standard representational formulations as discussed in writings by noted practitioners such as Forrester 1961, Graham and Alfeld 1976, Coyle 1977, Richardson and Pugh 1981, Coyle 1996 and Sterman 2000, to name a few. Such theories are exemplified by the rule that a mathematical look-up table characterizing the causal relationship between two system elements should not contain "kinks" or significant first- or second-derivative discontinuities.

Standards regarding the scope of testing. The nature and scope of hypothesis/model testing must be based on the purpose for which that model is built (Forrester and Senge 1980). There are many different types of tests that can be considered standard for System Dynamics models, depending on the nature of the application. The adversarial nature of the legal process naturally demands the most rigorous testing and documentation. Discussion of the full range of tests required in legal applications of System Dynamics is beyond the scope of this paper, but that range is illustrated by the following list of tests performed by PA and by an independent expert in conjunction with a recent case:

- Structural logic testing
- Causal feedback testing against independent experts' views
- Equation-level dimensional consistency testing
- Parameter sensitivity testing
- Behavioral sensitivity testing under 'normal' conditions
- Behavioral robustness testing under extreme conditions
- Historical fidelity testing against 'hard' data
- Historical fidelity testing against first-hand organizational knowledge
- Table-function excursion testing
- Confidence testing of results given parametric uncertainties
- Testing of alternative causal theories

Many of these include test-specific standards, some of them quantitative. All of these tests are applicable to and have often been employed in conjunction with applications of System Dynamics outside the legal arena.

Standards regarding precision. The early applications of System Dynamics were primarily academic and practitioners placed little emphasis on the precision of results. With increasing commercial use precision and reliability of results gained steadily in importance, and new techniques of model calibration, validation and testing were developed to meet more stringent demands. It is becoming more common to measure error rates, and standards of precision have gradually emerged (Lyneis and Reichelt 1996).

In the legal arena standards of precision are relevant to hypotheses at both the 'whole organization' and the 'what happened' level. At the 'whole organization' level the primary standards are those pertaining to the fidelity with which the model is able to independently re-create known organizational history. The appropriate numerical standards of precision depend significantly on the nature of the organization being simulated, the characteristics of the data concerning that organization, and the type of model variables involved (Lyneis, Reichelt and Bespolka 1996). PA has developed statistically-based standards of fidelity for models of project organizations (the type of organization involved in most of the legal disputes in which System

Dynamics has been employed), and the application of these standards has improved the model calibration process and resulted in more reliable models.

Fidelity standards at the ‘whole organization’ level also make it possible to assess the precision of damage quantification and other analytical results at the ‘what happened’ level, by providing a foundation for filtering out non-applicable alternative hypothesis-models based on Fit-Constrained Monte Carlo analyses (Graham, Choi and Mullen 2002, Graham, Moore and Choi 2002). This enables the expert witness to be more precise in his or her statements regarding the case. For example, instead of testifying that “Under the specified conditions the project would have been completed around the third week of April”, he or she can testify that “Under the specified conditions there was a 60% probability of project completion between 12 April and 25 April and a 95% probability of completion between 5 April and 5 May.”

Standards regarding post-hypothesis testing. Post-hypothesis testing is both the *raison d’etre* and one of the great strengths of System Dynamics modeling in the legal arena: the model exists so that the expert witness can demonstrate what organizational performance would have resulted given different conditions or different behavior by the parties. The different conditions and/or behavior that are the subject of the legal dispute necessarily require analysis of organizational performance outside the range of performance that actually occurred. For confidence in analyses it is necessary to confirm that the simulated organizational dynamics are robust under conditions different from those observed historically. That is the purpose of the Behavior Sensitivity Testing and Behavior Robustness Testing listed earlier in this paper, and such testing is standard in PA’s legal work.

Adhering to the same standards as in non-legal applications. *Daubert* specifies that the expert’s testimony must be based on at least the same level of intellectual rigor that characterizes expert practice when dealing with similar matters outside the courtroom. The majority of PA’s System Dynamics applications, and, we believe, the majority of all Systems Dynamics applications conducted to date, have involved matters outside the courtroom. In such work PA employs the same methods and computer simulation technology that we use in applications on legal cases. The standards described above apply to and have been used in applications of System Dynamics outside the legal arena. Where standards differ between legal and non-legal applications, the difference is one of degree – the standards in legal cases are the most rigorous that we employ in any application. Applications outside the legal arena are not usually subjected to adversarial scrutiny and attack, hence the extensive (and expensive) use of all of the most stringent standards of testing and documentation is rarely justified in such applications. Non-legal applications usually benefit from the fact that the simulation model structures employed have previously been tested to the highest standards, and many tests do not need to be repeated for each subsequent application.

4) *The techniques employed should have been peer reviewed.*
   a) *Initial peer review usually occurs in the run-up to publication in peer-reviewed journals.*
   b) *The techniques employed should also have withstood the broader peer review to which publication exposed them.*

Daubert established peer-reviewed publication as an important means of verifying the scientific validity of the methods employed as the basis for expert testimony. For the more respected journals in the scientific and technical communities, publication is the purpose of peer review and passing peer review is required for publication. *Daubert* makes three important presumptions regarding peer-reviewed publication:

- Publication in peer-reviewed journals indicates that the expert's scientific peers have sanctioned his or her work and methods as credible;
- Publication exposes the work and methods to further review by the relevant scientific community, and scientists may show their approval by citing the work as authoritative or by extending the work;
- Withstanding the scrutiny of the relevant scientific community indicates general acceptance in that community.

With respect to the "relevant scientific community", the Court said the inquiry should focus on *"the non-judicial uses to which the scientific techniques are put"* -- so the relevant community consists of those real-world scientists who pursue science for non-litigation purposes. To date all of the legal applications of System Dynamics of which we are aware have involved the operation of managed business organizations (rather than biological systems or national economies, for example). With respect to System Dynamics analysis of managed business organizations there are two relevant scientific communities, one being a subset of the other. The larger is the community of those who study the practice of management, which includes practitioners of a wide range of analysis techniques in academia, large corporations and consultancies. The community of System Dynamics practitioners analyzing business performance is a subset of this larger community, and practitioners are likewise found both in academia and, increasingly, in corporations and consultancies. Since most scientific management work (including System Dynamics work) is for purposes other than litigation, there is room to judge scientists' acceptance of System Dynamics business analysis techniques based on peer-reviewed journals publishing articles on non-judicial applications of those techniques.

There have been many peer-reviewed articles describing analyses employing System Dynamics, nearly all of them about non-judicial applications. The following are among the journals publishing such articles, indicating acceptance of the methodology by the management science community:

- *Administrative Science Quarterly*
- *American Journal of Physiology*
- *Behavioral Science*
- *Energy Systems and Policy*
- *Engineering Management Journal of the IEEE*
- *European Journal of Operational Research*
- *European Management Journal*
- *Harvard Business Review*
- *Interfaces*
- *International Journal of Energy Systems*
- *International Journal of Forecasting*
- *Journal of the American Statistical Association*
- *Journal of Economic Behavior and Organization*
- *Journal of the Operational Research Society*
- *Management Science*
- *Organizational Behavior and Human Decision Processes*
- *Project Management Journal*
- *Science*
- *Sloan Management Review*
- *Strategic Management Journal*
- *System Dynamics Review*
- *Technological Forecasting and Social Change*
- *TIMS Studies in the Management Sciences*

Among these articles relating to the practice of System Dynamics is a significant subset of peer-reviewed articles and papers on the application of System Dynamics to analysis of performance on complex development projects, including the following authors and journals. These articles are by System Dynamics practitioners and indicate acceptance of System Dynamics for analyzing project performance among that segment of the management science community. Since most of the journals reviewing and publishing the articles are devoted to broader topics of management investigation and application rather than the narrower System Dynamics methodology, these articles and papers also demonstrate that the broader management science community accepts System Dynamics for analyzing performance on complex development projects.

- Akerman, Eden & Williams, *Interfaces*
- Alfeld, Wilkins & Pilliod, presented at SNAME's Ship Production Symposium
- Cooper, *Interfaces*
- Eden, Williams, Akerman & Howick, *Journal of the Operational Research Society*
- Ford & Sterman, *System Dynamics Review*
- Graham, *Project Management Journal*
- Howick & Eden, *Journal of the Operational Research Society*
- Repenning, *System Dynamics Review*
- Rodrigues & Williams, *Journal of the Operational Research Society*
- Williams, Eden, Akerman & Tait, *Journal of the Operational Research Society*

Kenneth Cooper's article in *Interfaces* illustrates how System Dynamics analysis of complex projects has been broadly accepted by the management science community. He wrote the article about PA's first-ever complex-project application of System Dynamics at one of the leading US shipyards in the late 1970s. The article was submitted in competition for the Edelman prize, probably the most prestigious annual contest for management science work in the US. That contest is conducted by INFORMS, the Institute for Operations Research and the Management Sciences, one of the leading US professional societies in the field. Following extensive review by a jury of peers representing a wide range of management science disciplines, the article was awarded the second-place prize and subsequently published in the Institute's journal *Interfaces*. Since then, that and other peer-reviewed articles by PA consultants have been cited numerous times in articles by other management scientists. Given the abundance of publication-based evidence, it is difficult to imagine a successful *Daubert* admissibility challenge based on peer-review issues.

5) The techniques employed should have been generally accepted in the scientific community.

In addition to the strong evidence that such peer-reviewed publications provide, evidence that System Dynamics is generally accepted in the scientific community can be found in the large number of colleges and universities that offer regular undergraduate and graduate-level instruction in System Dynamics. There are at least 80 institutions of higher learning offering such courses around the world, as listed in the Appendix.

4. Preparing and Delivering Expert Testimony Based on System Dynamics

A detailed discussion of the process of preparing and delivering expert testimony based on System Dynamics is beyond the scope of this paper. Therefore, what follows is a short summary of key tasks involved in providing expert testimony based on System Dynamics analysis and how those tasks relate to possible *Daubert* admissibility challenges.

Preparation of System Dynamics analyses. The process of model-building and simulation analysis is well documented and is one with which most System Dynamics practitioners are very familiar. As has been described earlier in this paper, that process should not change when the analyses are for application in the legal arena. In fact, due to the deliberately adversarial nature of most court systems, applications of System Dynamics in the legal arena should be carried out with the most scrupulous care and use of best practices. This will do much to ensure the admissibility of resulting expert testimony and its subsequent effectiveness before the factfinder(s).

Guidance for settlement discussions. As observed in the Introduction to this paper, nearly all of the legal cases in which PA has applied System Dynamics have been resolved and all of those have been resolved by means of negotiated settlement outside the formal legal process. This seems to exemplify the general rule that litigation for recovery of damages usually leads to some form of out-of-court settlement. Sometimes, System Dynamics work intended to support expert testimony finds an earlier application in support of negotiations aimed at reaching such a settlement. Although this might appear to be a very different sort of application, it must be remembered that in formal legal proceedings the expert witness is there to assist the factfinder(s) in arriving at the facts in the case, and not to be an advocate for one party or the other. A negotiation support role is likely to be most effective if it is carried out from a similarly nonadvocative position. It should be noted that what the opposition learns during negotiations about the expert witness and his or her employment of System Dynamics may provide the grounds for a subsequent *Daubert* admissibility challenge, should negotiations fail to yield a settlement.

<u>The evidentiary discovery process.</u> In advance of trial most cases involve a formal discovery process during which each party is required to furnish the other with the evidence (including expert testimony) it will employ in court to make its case. In PA's experience the discovery process usually requires that the modeler supply the opposing party with the simulation model(s) employed, the data and other information employed in developing the model(s) and analyses, the simulation software required to run the model(s), any technical information and possibly technical support needed to run the model(s), any report(s) prepared on the analysis work, and the analyses themselves. The opposition can employ this body of information in a variety of ways including giving it to their own experts to assess its quality and reliability, and this may require some form of protective order covering the opposing experts' access to and use of proprietary information and/or intellectual property. Obviously weaknesses or inconsistencies in the documentary materials provided to the opposition may provide grounds for a *Daubert* challenge and are likely to reduce the expert's effectiveness in court.

<u>The deposition process.</u> In advance of trial most courts permit each party to question or depose the other's witnesses (including expert witnesses) to determine their qualifications to testify and the basis for and nature of their testimony. An opposing attorney conducts the deposition with a friendly attorney in attendance to ensure that the rules of the deposition process are followed. The opposing attorney may be accompanied by an opposing expert who will assist in formulating deposition questions. As may be imagined, depositions allows each party to judge the strengths and weaknesses of the opposing witnesses' testimony in advance of trial, and to plan how to cross-examine those witnesses in court. The deposition is conducted under oath and a complete transcription is made of the proceedings. Portions of the transcript may be read back in court as a cross-check on testimony given. If sufficient weaknesses are revealed during deposition, the usefulness of the witness and his or her testimony may be so completely undermined that the party employing the witness will not wish to risk having him or her testify in court. When preparing for deposition and while being deposed, it is useful to remember that the opposition is seeking to find or to create the appearance of weaknesses and inconsistencies in the expert's testimony and in the foundations of that testimony. Any such weaknesses (whether real or perceived) may provide grounds for a *Daubert* challenge and are likely to reduce the expert's testamentary effectiveness in court.

<u>Preparation and delivery of expert testimony.</u> In the absence of an out-of-court settlement, and assuming that the expert witness has survived the deposition process and any *Daubert* challenge, the final step is likely to be the preparation and delivery of expert testimony. The difficulty of these tasks should not be underestimated because the objective is to make dynamically complex facts understandable to the factfinder(s) who will know little or nothing about organizational dynamics or dynamic simulation. This usually requires considerable education of the factfinder(s) in a short period of time, all without boring them or confusing them with technicalities. This challenge may well be more significant than those of the modeling and analysis process, and poor testamentary materials or bad delivery of testimony can quickly destroy the effectiveness of even the best analysis. In creating testamentary materials and

preparing to use them in giving evidence, there is no substitute for repeated rounds of revision and practice.

5. Handling the Ethical Challenge Inherent in the Expert Witness Role

The Ethical Challenge. In legal cases that revolve around the performance of complex organizations, the factfinder(s) often need assistance from expert witnesses to understand the issues and the facts involved in the dispute. An expert witness is there to employ his or her knowledge and analysis in an impartial manner to assist the factfinder(s). The expert is not there to act as an advocate or to argue for either party to the dispute. But experts are provided and paid by the disputing parties, not by the factfinder(s). Naturally, each party will select experts whose testimony is expected to be favorable to their case. The tension between the expert's ostensibly impartial role and his or her employment by a party to the dispute creates a potential ethical challenge that must be carefully addressed. That challenge forces the factfinder(s) to guard against partial, biased, distorted or incomplete testimony aimed at producing a particular legal outcome, and that is the aim of the Supreme Court's *Daubert* admissibility standards. That inherent ethical challenge also suggests that an expert witness should be unusually scrupulous about his or her work and testimony.

Because of the ethical tension inherent in the role, expert witnesses from a wide range of scientific and technical disciplines tend to be viewed by the cynical as credentialed charlatans who will support any position for money. It is a sad fact that the behavior of some (perhaps many) expert witnesses fuels that reputation. With lots of money being paid to experts and lots more money riding on the outcome of legal disputes, it is not surprising that some clients and their attorneys (and even some expert witnesses) feel that the expert should provide whatever testimony is needed as long as it's not too obviously wrong to help win the case.

Since PA's consultants are regularly employed as expert witnesses, we have adopted the following policies to minimize the ethical tension that would otherwise prevail. We inform the prospective client of these policies before we are hired:

- Before accepting the assignment PA will learn enough about the case to determine that the prospective party is probably the party that has been most wronged. Good System Dynamics analysis will show quite clearly which party bears the primary responsibility for the damages done, and PA is much less likely to be pressured to change our analyses if we're not working for that party;
- PA's consultants will work to the highest professional standards and will not be influenced by what the client and the client's attorneys might regard as a "desirable analytical outcome";
- As results from PA's work become available, no amount of pressure will induce us to change our analyses to better support a desired legal outcome, and PA will resign the assignment in the face of any such pressure. PA's responsibility is to answer to the best of our ability the questions our client asks us to address, and those answers are valuable to the client whether or not they support his desired

outcome. PA makes no assurances that our results or testimony will support the desired outcome, and it is up to the client to decide whether to tender us as experts;

- Once hired, PA will review and revise our work only in the normal, iterative course of refining (for increased precision and confidence) the data, the simulation model, and analyses conducted with that model. We will employ what we judge to be the best available data and other information, and PA's modeling and analysis work will be consistent with that data and information and with our experience and database from similar past assignments. In reviewing and revising our work we will not be influenced by what the client or the client's attorneys might regard as a "desirable analytical outcome".
- If asked to, PA will provide expert testimony on what our analysis has revealed about the facts of the case. We will make no assertions that we cannot back up based on our own work and knowledge. We will not speculate unless asked to do so in an area where our experience and work reasonably support such speculation.

PA consultants have followed these policies in all of our assignments involving legal disputes. That such policies are effective is evidenced by the fact that in dozens of assignments in the legal arena we have never been pressured by a client to alter our findings or testimony to better support their case.

The Difficult Role of the Opposing Expert. Lawyers generally have come to expect that different experts, even when working from the same set of "facts", can conduct different analyses, reach significantly different opinions and provide very different testimony. So when one party to a dispute employs an expert to provide important testimony, it is common for the other party to employ an expert to conduct analyses and provide testimony in opposition. PA has encountered opposing experts in many of the legal disputes with which we have been involved.

When the testimony to be rebutted is based on a good System Dynamics analysis, the opposing expert has a tough row to hoe. Because System Dynamics is less well known than some other analytical methods commonly employed in the legal arena, the opposing expert may not be at all familiar with System Dynamics. This can result in naïve or mistaken pronouncements about the System Dynamics analyses and the testimony based on them, but such assertions are usually easy to counter. When the opposing expert's more glaring mistakes are highlighted, his or her credibility is often irreparably damaged.

One cannot blame the resulting testimonial ineffectiveness on the opposing expert alone, because the opposing party and attorneys have usually left the work of evaluating and countering the System Dynamics analysis until shortly before expert reports must be delivered to the factfinder(s). This is a common failing by opposing parties and attorneys who are unfamiliar with System Dynamics, and it is not surprising that an expert who is also unfamiliar with it would be unable to offer a meaningful critique with just a few weeks to prepare. In most cases such opposing experts do not even run the simulation model before they comment on it and the analyses conducted with it. What is surprising is that, even with little time and few if any test analyses, many opposing experts are still willing to criticize System Dynamics work. Such criticisms are not likely to withstand a *Daubert* challenge.

In opposition it can be difficult even for an experienced System Dynamics practitioner to offer effective counter-testimony against a thorough-going System Dynamics analysis. He or she will usually be hired late in the game, and further valuable time will be lost before the opposing attorneys remember to pass along the model and related data files for evaluation. A quick review of a thorough-going System Dynamics analysis is unlikely to uncover any serious weaknesses, no matter how much the opposing party is hoping to find such a "smoking gun". It is impossible to thoroughly assess in just a few person-days a model and analyses that are the fruits of several person-years of development and refinement effort.

We have often seen an experienced System Dynamics practitioner placed in a difficult opposing position by their client's failure to appreciate what is required for good expert testimony and what can be expected from it. Under such conditions a careful System Dynamicist will want to set and manage client expectations regarding what can and cannot be accomplished in the time available. When those expectations are not properly set from the beginning, the opposing expert may come under heavy pressure to "find something wrong" with other party's System Dynamics analysis and to do so in a hurry. Such pressure may explain some of the surprising testimony System Dynamics practitioners have offered in opposition to PA's work. Three typical real-life examples follow, drawn from the written testimony of experienced System Dynamicists in the role of opposing experts.

- "System Dynamics is an inappropriate tool for modeling complex development projects and will give misleading answers when so applied."
- "[PA] used an automated model tuner in calibrating the model to artificially maximize the size of their client's claim for damages."
- "This formulation serves no useful purpose and appears to exist only to inflate the size of the damage claim."

It is interesting to consider how such testimony is likely to fare under the *Daubert* standards. The first assertion is a hypothesis regarding the suitability of System Dynamics for a particular analytical purpose. To be admissible the hypothesis ("System Dynamics is an inappropriate tool…") must have been tested and error rates evaluated. Given the fact that PA and other practitioners have successfully employed System Dynamics in modeling well over 100 complex development projects, and done so in compliance with *Daubert* standards even before those were articulated, the hypothesis is clearly rejected. Even if that were not so, it is difficult to imagine how an opposing System Dynamics expert could go about testing such a hypothesis, and the absence of testing reduces it to the level of an unsupported assertion. On either basis, the proffered testimony leaves the expert vulnerable to a *Daubert* challenge. Even if the testimony is ruled admissible, an unsupportable statement of this sort will greatly damage the credibility of the opposing expert when wielded by a capable cross-examining attorney.

The second assertion, it should be noted, is mistaken on two counts. First, PA is unaware of the existence of tuning software with the practical capability to automate the calibration of a large System Dynamics model. If we had employed such a tuner in the case in question, we would have furnished that tuner to the opposing expert along with our simulation model, as required by the factfinder(s) in that and most legal cases. Second, as had been explained in detail in our written testimony in that case, PA's calibration of that model was carried out against the sole benchmark of the simulated organization's historical performance – the size of the client's damage claim played no part at all in the tuning process. What could lead the opposing System Dynamics expert to make such an assertion despite his awareness of PA's written statement to the contrary? When asked that question following the conclusion of the case, he replied "Well, I had heard that [PA] had a tuner." Offering a hypothesis ("PA tuned to maximize the claim value…") without testing or supporting evidence exposes the opposing expert to a *Daubert* admissibility challenge before he or she reaches the witness stand, and to a painful cross-examination experience if their testimony is ruled admissible.

The third assertion is typical of many equation-level criticisms PA has received at the hands of experienced System Dynamicists serving as opposing experts. Such criticisms are frequently and appropriately accompanied by disclaimers and qualifiers, usually (as in this particular case) because the opposing expert has not had time to conduct simulation tests of the model PA provided. The qualifiers are words like "appears" or "seems" or "is likely to", which soften the assertion in the absence of actual testing. These opposing experts have been put in a difficult position, usually by the failure of their client's attorneys to allow adequate time for a thorough evaluation of the work about which the expert is to testify. Without thorough dynamic analysis, statements about the effect of a particular formulation on the magnitude of computed damages remain untested hypotheses that are unlikely to withstand a *Daubert* challenge (especially since, in our experience, those hypotheses are usually factually incorrect).

Based on considerable experience with legal applications of System Dynamics, we believe that any practitioner engaged to provide expert analysis and testimony should pay close attention to the Supreme Court's new admissibility standards. Specifically, practitioners should carefully evaluate their work in the legal arena in light of those standards and modify both their own work and their statements about the work of other practitioners where that is necessary to ensure admissibility. Upcoming legal cases are likely to yield the first-ever *Daubert* admissibility challenges to expert testimony based on System Dynamics, and those cases will set a precedent that is likely to be referred to in subsequent cases. If expert testimony based on System Dynamics is ruled inadmissible, few outside the System Dynamics community will stop to consider whether it was the methodology itself or specific testimony that failed the admissibility tests. Ideally, when System Dynamicists meet in court as opposing experts their discourse will be on the highest professional level and their testimony will all be admissible. If they are not, court rulings may effectively cast System Dynamics into legal disrepute as "junk science", painting practitioners as pseudo-experts who trash peers and their own methodology in the heat of legal battle. We would have no one to blame but ourselves.

6. Conclusions

Expert testimony based on rigorous System Dynamics modeling work can meet the US Supreme Court's *Daubert* criteria for admissibility:

- Best-practice System Dynamics work relies on the processes of hypothesis formation and testing inherent in the scientific method cited by *Daubert* as vital for evidentiary reliability and admissibility;
- Best-practice System Dynamics work includes explicit error testing as required under *Daubert*, in forms that are particularly useful to trial courts;
- Best-practice System Dynamics work employs rigorous standards for the formation and testing of hypotheses;
- Best-practice System Dynamics work in the legal arena employs at least the same level of intellectual and quantitative rigor typically involved in more numerous applications that do not involve judicial proceedings, as required under *Daubert*;
- System Dynamics work by PA and other practitioners has successfully withstood extensive peer review within the management science community, as required under *Daubert*;
- System Dynamics is taught in many leading universities around the world, indicating broad acceptance in the management science community;
- As a result, best-practice System Dynamics work can satisfy the factors laid down by the Court in *Daubert* for evaluating the scientific validity and resulting admissibility of expert testimony;

The expert witness role involves tasks and processes that are unique to the legal arena and may be unfamiliar to the System Dynamics practitioner. Some of these can provide opponents with the basis for a *Daubert* challenge. A considerable investment of time and energy is usually required to ensure that these tasks and processes do not undermine the effectiveness of solid dynamic analysis work.

The expert witness role involves inherent ethical challenges that must be surmounted in order for the expert to be confident of surviving a Daubert challenge. To effectively meet these challenges we must acknowledge that some System Dynamics work in the legal arena falls short of best practices and is therefore vulnerable to admissibility challenges under Daubert. This has been true particularly of expert testimony offered by System Dynamicists in opposition to the work of other System Dynamics practitioners. Upcoming cases are likely to set precedents for the admissibility of expert testimony based on System Dynamics, and those precedents may prove difficult to change. Practitioners should take pains to ensure that their work and testimony meet the standards set in *Daubert*.

Appendix – Institutions of higher learning where System Dynamics is taught

(From a web search for schools offering at least one course in System Dynamics)

In the Americas:

- American University, DC
- Arizona State University
- Boston University, MA
- Central Connecticut State University
- Dartmouth College, NH
- Fairleigh Dickinson University, NJ
- George Washington University, DC
- Illinois State University
- Instituto Tecnologico y de E. S. de Occidente (ITESO), Mexico
- Instituto Tecnologico de Sonora, Mexico
- ITESM Tecnologico de Monterrey, Mexico
- Massachusetts Inst. of Technology
- National Defense University, DC
- Portland State University, OR
- Universite Laval, Canada
- University of Alaska Anchorage
- University at Albany, State Univ. of New York
- University of Los Andes, Venezuela
- University of California at Davis
- University of Illinois at Urbana-Champaign
- Univerdidad Nacional de Columbia
- University of Southern Maine
- University of Vermont
- University of Virginia - Darden Graduate School of Business
- United States Military Academy, NY
- Washington State University
- Worcester Polytechnic Institute, MA

In Europe:

- Aristoteles University of Thessaloniki, Greece
- Bogazici University, Turkey
- Catedra UNESCO en la Universidad Politecnica de Catalunya, Spain
- Centro Universitario Studi Aziendali, Italy
- CERAM and University of Paris Pantheon ASSAS
- City University Business School, UK
- Copenhagen Business School, Denmark
- Cranfield University, UK
- Department d'Organitzacis d'Empreses, , Spain
- Johannes Gutenberg Universitaet Mainz, Germany
- London Business School, UK
- London School of Economics and Political Science, UK
- Luigi Bocconi University, Italy
- LUMES, Sweden
- Lund University, Sweden
- Masaryk University
- Nymegen University, Holland
- South Bank University, UK
- Strathclyde University, UK
- Sunderland University, UK
- Technical University Delft, Netherlands
- Technical University of Denmark
- Telinges, Spain
- Universidad de Valladolid, Spain
- Universitaet Mannheim, Germany
- Universitat Stuttgart, Germany
- University of Belgrade, Yugoslavia
- University of Bergen, Norway
- University of Klagenfurt, Austria

- University of Palermo, Italy
- University of Plymouth, UK
- University of Salford, UK
- University of St. Gallen, Switzerland
- University of Sevilla, Spain
- University of Split, Croatia
- Westminster Business School, UK

In Asia / Pacific

- Australian Defence Force Academy, University of New South Wales, Australia
- Bandung Institute of Technology, Indonesia
- Chuo University, Japan
- Deaking University, Australia
- De La Salle University, Manila, Philippines
- Fudan University, Shanghai, China
- Indian Institute of Management, Calcutta
- The Institute for System Science, Tokyo, Japan

References

Abdel-Hamid, T. and Stuart E. Madnick 1991. *Software Project Dynamics: An Integrated* Approach. Englewood Cliffs, NJ: Prentice-Hall.

Ariza, Carlos A. and Alan K. Graham 2002. Quick and Rigorous, Strategic and Participative: 10 ways to improve on the expected tradeoffs. *Proceedings of the 2002 International System Dynamics Conference.* Palermo, Italy. Forthcoming.

Berger, Margaret A. 2000. The Supreme Court's Trilogy on the Admissibility of Expert Testimony. In *Reference Manual on Scientific Evidence, 2nd ed.* Federal Judicial Center.

Black, B., Ayala, F. J., and Saffran-Brinks C. 1994. Science and the Law in the Wake of Daubert: A New Search for Scientific Knowledge. *Texas Law Review*, March 1994.

Coyle, R. Geoffrey 1977. *Management System Dynamics.* New York: John Wiley and Sons.

Coyle, R. Geoffrey 1996. *System Dynamics Modelling: A Practical Approach.* CRC Press.

Cyert, R. M. and March, J. G. 1963. *A Behavioral Theory of the Firm*. Englewood Cliffs, NJ: Prentice-Hall .Cooper, Kenneth G 1980. Naval Ship Production: A Claim Settled and a Framework Built. *Interfaces* 10(6), 20-36.

Cooper, Kenneth G. 1993. The Rework Cycle: Benchmarks for the Program Manager. *Project Management Journal,* March 1993.

Cooper, Kenneth G. and Thomas W. Mullen 1993. Swords and Plowshares: The Rework Cycle of Defense and Commercial Software Development Projects. *American Programmer* **6**(5).

Ford, David N. 1995. *The Dynamics of Project Management: An Investigation of Projects' Process and Coordination on Performance*. Cambridge, Mass.: Massachusetts Institute of Technology PhD dissertation, Department of Civil and Environmental Engineering.

Forrester, Jay W. 1961. *Industrial Dynamics.* Waltham, Mass: Pegasus Communications.

Forrester, Jay W. and Peter M. Senge 1980. Tests for Building Confidence in System Dynamics Models. *TIMS Studies in the Management Sciences* (North Holland) 14, 209-228.

Graham, Alan K. and Louis Alfeld 1976. *Urban Dynamics*. Waltham, Mass: Pegasus Communications..

Graham, Alan K. 2002. On positioning system dynamics as an applied science of strategy. Forthcoming. *Proceedings, 2002 International System Dynamics Conference.* Palermo, Italy.

Graham, Alan K., Carol Y. Choi and Thomas W. Mullen 2002. Using Fit-Constrained Monte Carlo Trials to Quantify Confidence in Simulation Model Outcomes. *Proceedings of the 2002 Hawaii Conference on Complex Systems*.

Graham, Alan K., Jonathan Moore and Carol Y. Choi 2002. How robust are conclusions from a complex calibrated model, really? A project management model benchmark using fit-constrained Monte Carlo analysis. *Proceedings of the 2002 International System Dynamics Conference,* Palermo Italy (forthcoming).

Lyneis, James M. 1999. System dynamics for business strategy: a phased approach. System Dynamics Review 15(1): 37-70.

Lyneis, James M. and Kimberly Sklar Reichelt 1996. Calibration Standards. Cambridge, Mass.: *PA Consulting Group Internal Document*. April 11, 1996.

Lyneis, James M., Kimberly Sklar Reichelt, and Carl G. Bespolka 1996. Calibration Statistics for Life-Cycle Models. *Proceedings of the 1996 System Dynamics Conference*.

Mahle, S. 1999. The impact of Daubert v. Merrell Dow Pharmaceuticals, Inc., on expert testimony: with applications to securities litigation. *Florida Bar Journal* March 1999, **73**.

Mahle S. 2002. Daubert and the Law and Science of Expert Testimony in Business Litigation. Retrieved December 21, 2001 from http://www.daubertexpert.com.

Morecroft, J. D. W. 1985. Rationality in the Analysis of Behavior Simulation Models. *Management Science,* **31**(7), 900-916.

Richardson, George, Alexander Pugh 1981. *Introduction to System Dynamics Modeling.* Portland, OR: Productivity Press.

Rodrigues, A. and John Bowers 1995. System dynamics in project management: a comparative analysis with traditional methods. *System Dynamics Review* **12**(2), 121-139.

Rodrigues, A. and T. M. Williams 1997. System dynamics in software project management: towards the development of a formal integrated framework. *European Journal of Information Systems* **6**, 51-66.

Rodrigues, A. and T. M. Williams1998. System dynamics in project management: assessing the impacts of client behaviour on project performance. *Journal of the Operational Research Society* **49**(1), 2-15.

Simon H. A., “Rational Decision-Making in Business Organizations”, *American Economic Review* **69**(4), 1979.

Sterman, J. D. 2000. *Business Dynamics*: Systems Thinking for a Complex World. Irwin/McGraw-Hill: New York.

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