# Executive Risk Assessments for the Age of Algorithms

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## ABSTRACT

The authors led a three-year benchmarking effort crossing disciplines (including decision analysis, operations research, risk modeling, management science, conflict and combat simulation, and, logistics and supply chain simulation). Practitioners volunteered to describe their practices and learn from others. Modeling, simulation, and analysis (MS&A) supports a wide range of economic, academic and governmental efforts. Different practitioner communities have agreed on local practices, but unfortunately there is little interaction among communities.

Previous publications described best practices highlighted from the benchmarking. Two gaps discovered in the benchmarking was a disturbingly high fraction of poor practice, and, the absence of executive level risk assessments to detect and assess risks from poorly executed MS&A. Executives often lack the time and/or technical background to form risk assessments for analytics provided to them.

This paper offers a new, simple means for executives to assess risks in the age of algorithms; six non-technical questions addresses most of the risks seen in the benchmarking. The method is based on a checklist founded on the international benchmarking effort. The authors also conducted research into specific risks, including legal risks which arise from increased reliance on analytics. Among the risks are some unique concerns related to Artificial Intelligence.

The work to identify risks showed hazards arise from several sources, not just the absence of best practices. This led to development of a risk checklist which does not require in-depth knowledge of MS&A. This paper presents the checklist, as well as some of the deeper MS&A principles which support it. This is a dual framework, useful for both executives and practitioners.

The research was supported by several professional societies, industry groups and non-profit educational associations, including I/ITSEC, the Society of Petroleum Engineers, the Institute of Electrical and Electronics Engineers, and Probability Management.

**Key words (up to five):** Modeling and Simulation, Analysis, Best Practices, Artificial Intelligence (AI), Executive Risk

## ABOUT THE AUTHORS

**Steven Roemerman** Steven Roemerman is the Chair / CEO of Lone Star Analysis. In addition to previous CEO roles, he has served as an officer or director in more than a dozen corporations in technology, aerospace, finance, non-profits, and transportation. He holds more than a dozen patents and has published dozens of papers. He is a member of the SPE, and a Life Senior Member of the IEEE.

**John Volpi** is Emeritus Chief Technology Officer of Lone Star Analysis. He was responsible for all technical activities, Intellectual property evaluation, and process development. He continues to serve on Lone Star's board. He has over 30 patents awarded or pending. In 2012, John was awarded the Tech Titans Award for Corporate CTO by the DFW Metroplex Technology Business Counsel from a pool of 4,000. He is a Life Senior Member of the IEEE.

**Dr. Randal Allen** has over 20 years of industry experience and has been with Lone Star Analysis since 2006. As Chief Scientist, he is responsible for applied research and technology development including Kalman, H-infinity, and Bayesian filtering and nonlinear, non-convex optimization. A certified modeling and simulation professional (NTSA), he is co-author of the textbook, "Simulation of Dynamic Systems with MATLAB and Simulink". He is an Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA).

## SUMMARY OF THE STUDY AND PREVIOUSLY PUBLISHED FINDINGS

We have previously published (Roemerman *et al*)[i] [ii] the nature of the study, and our data collection. To recap; in 2014 and 2015, the authors proposed a cross-domain benchmarking study. As practitioners working across several domains, we noticed "normal" simulation and modeling practices in some fields were unknown in others. We proposed a multi-domain study to several organizations. Universally, the feedback was positive, but none wanted to lead the effort.

Eventually, we decided to proceed on our own, and began to recruit help. We were aided by many of the organizations we had approached, and others joined along the way.

- **The Institute of Electrical and Electronics Engineers (IEEE)** was the first to allow us to use one of their web forums to discuss the study, and solicit participants
- **The Society of Petroleum Engineers (SPE)** granted us the same web forum access
- **The Wharton School of the University of Pennsylvania** saw two Professors[iii] support the study with advice and access to unpublished literature and help from graduate students
- **INFORMS** provided access to their online forum
- **I/ITSEC** allowed us to survey portions of their membership
- **Probability Management** gave us access to their membership, and named one of us Chair of Best Practices
- The corporations **Lockheed Martin** and **Chevron** provided us access to their modeling and simulation communities for interviews and surveys

In all, these organizations had memberships of about 200,000 individuals (not including the two corporations, whose employees were presumably members of the societies we approached). Of these, we estimated less than 10% of the members were active practitioners in Modeling, Simulation and Analysis (MS&A). Of those, we estimated that about 2,100 of those saw our invitations to participate in the survey and interviews.

Beyond working with these large groups, we initially targeted more than 40 individuals for participation in our data collection because of the reputation of their organizations, or their personal reputation for excellence. We solicited these by-name targets and they proved to be a rich source of information. In the end, we approached 126 individuals from 65 organizations across many domains (see Figure 1).

We used two principle survey instruments, and an interview instrument. Both the principal survey and interview were long and required a significant effort from participants. In the end, we were surprised to see more data collected from the interviews (126) than useful survey responses (40). Overall our survey response rate was about 2%; respectable for a long, tedious survey. Because some individuals were both interviewed, and responded to the survey, we estimate[iv] the total number of individuals who participated at about 150. These responses were international.[v]

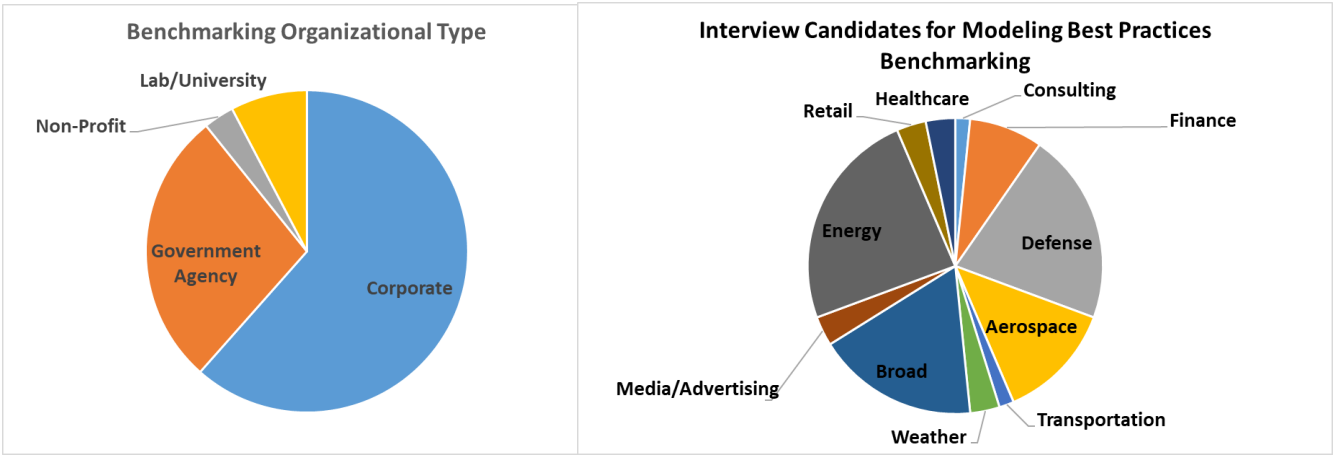



**Figure 1. Participants Were Drawn from A Variety of Domains**

By 2016, we gathered enough preliminary information to publish some early findings and to present at conferences.[vi] In 2017, we presented a preliminary summary of our findings at the Probability Management Annual Conference in San Jose[vii]. A special session of the conference was used to peer review the best way to list and explain the best practices. The result was fourteen best practices, grouped in three categorical themes:

- Strategy & Architectural Approach
- Implementation Disciplines
- Execution Disciplines

At the same conference we described four organizations who best exemplified and utilized the best practices: The Energy Information Agency (EIA) of the United States, the Metrology office of the United Kingdom, and two organizations who chose to remain unnamed. We dubbed them "A" and "Z."

**Key Findings Previously Published**

The most comprehensive peer-reviewed publication of the best practices work appeared at I/ITSEC 2018[viii] as a paper and presentation. All fourteen practices, and how they fit into three categories were discussed. Our findings showed that across most of the fourteen best practices topics *less than half of MS&A practitioners were exercising any single best practice*. Being consistent in all areas is clearly exceedingly rare (50%^14 = 0.006%).

This was a discouraging result because interview targets were chosen because someone claimed they were good to excellent, and survey respondents are biased toward better practitioners. We concluded the typical state of the MS&A practice is worse than we saw in our sample. This poor showing led to exploration of risks. In summary, we concluded:

- Risks were poorly understood by practitioners and by executive users of MS&A
- Risks were not merely the absence of best practice
- Artificial Intelligence as a special class of algorithms presented special classes of risk

Few areas of business and government can operate without some form of MS&A today. Complex topics require analytics to support decisions. Automatic algorithms run everything from securities trading to suggesting maintenance actions. Clinical trials, oil exploration, aerospace design, and flight training all depend on simulations. Yet, the executive user of MS&A results faces a serious challenge. While the executive must rely on MS&A to be competitive, few managers have the time or education to assess the risks posed by the MS&A used by their organizations.

We noted differences in the way high and low performing MS&A groups described their processes. As shown in Figure 2, even when good practices are used, low performers use them differently than high performers.

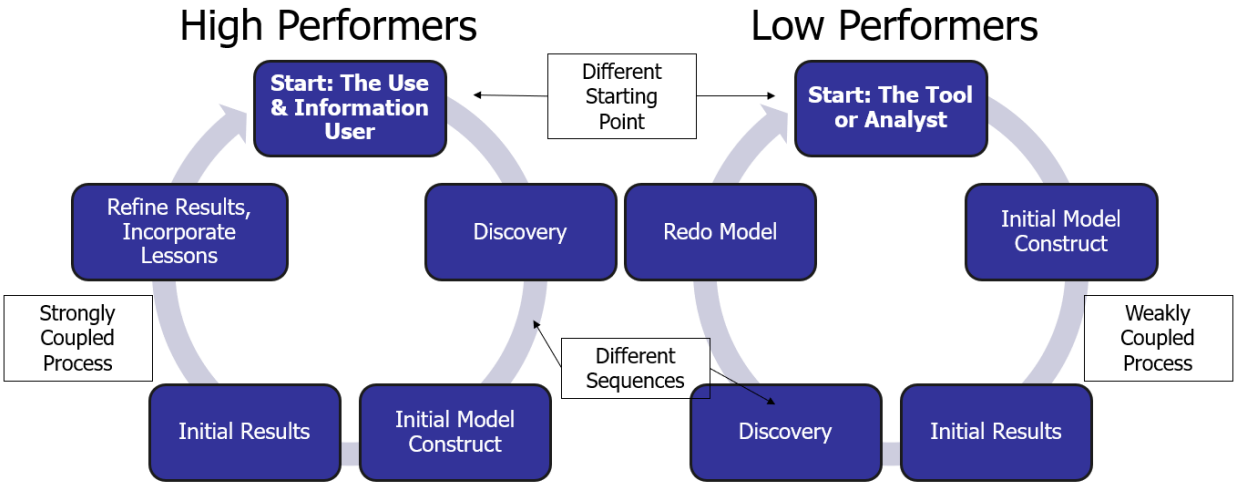



**Figure 2. Some Differences Between High and Low Performance**

This led us to create a risk checklist for executives, based on topics consistent with reasonable executive oversight. A full description of the risk checklist and its origin has not been published[ix] before. This paper addresses that gap.

**RISK IDENTFICATION PROCESS**

Early in our benchmarking process, the need to consider risks became evident.

A pair of questions in our survey instrument and in our interviews asked about the legal requirements related to MS&A. We had done research to understand the laws and regulations related to different industries and technical disciplines. In particular, we noted that dealing with uncertainty was specified in many different disciplines. We asked the following question:

> *A number of organizations issue guidelines or specifications for the representation of uncertainty. They include Society of Petroleum Engineers, U.S. Office of Management and Budget (OMB), European Medicines Agency (EMA), U.S. FDA Office of Regulatory Affairs, U.S. Federal Reserve, U.S. Office of the Comptroller of Currency, Bureau International des Poids et Mesure (BIPM), International Electrotechnical Commission (IEC), International Federation of Clinical Chemistry and Laboratory Medicine (IFCC), International Organization for Standardization (ISO), International Union of Pure and Applied Physics (IUPAP) and, International Organization of Legal Metrology (OIML).* ***Is your modeling subject to guidance or requirements of these, or similar organizations, regarding the representation of uncertainty?***

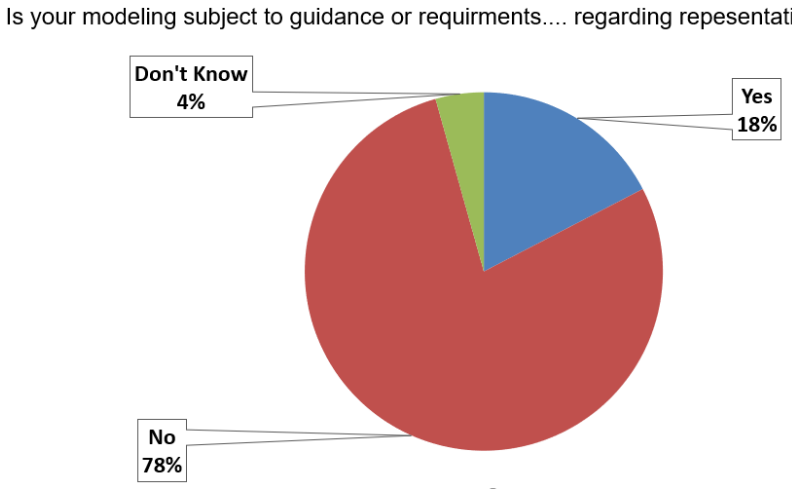



**Figure 3. Most Respondents said they were not subject to regulation in treatment of uncertainty**

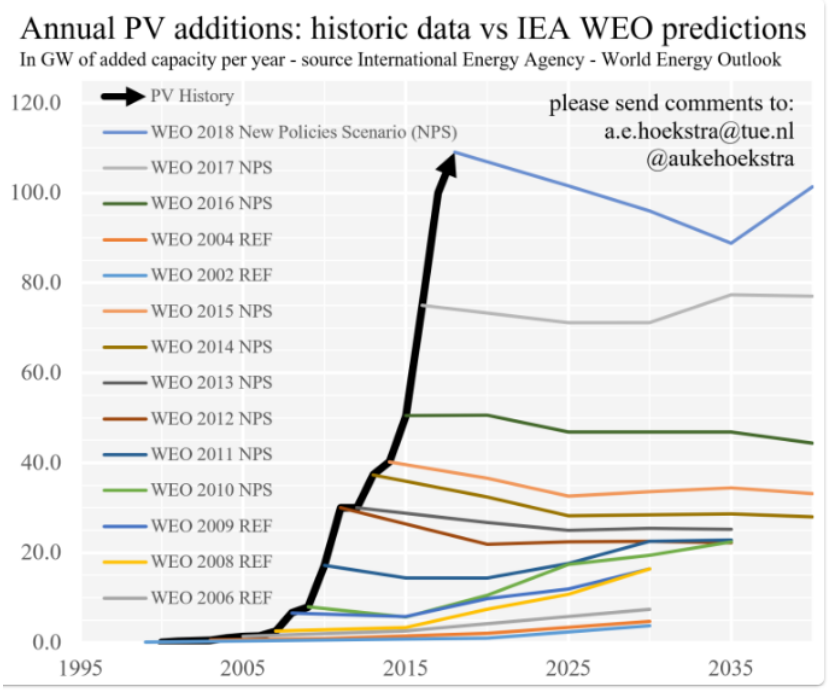
As seen in Figure 3, 78% of respondents said "No." Only 17% said "Yes." However, from their self-disclosed fields of MS&A, we know the majority should have said "Yes."

As this legal risk became apparent, we added additional questions in our interviews. Only 12% of interview respondents were found to be free from legal or regulatory violations. So, both survey findings and interview findings indicated substantial organizational risks, which executives might not understand. We found that in some cases, the MS&A practitioners knew they were violating a regulation with serious legal consequences. But, they offered several "reasons" why it was "ok."

One anecdote helps to explain what we found in one of the industries we benchmarked. In the Petroleum industry, upstream producers must estimate reserves of oil in the ground which are assets on their balance sheet. This is done using sophisticated reservoir modeling software. The Securities and Exchange Commission (SEC) and the Financial Accounting Standards Board (FASB) require these companies to state the reserves based on certain probabilistic standards and rely on industry professional society guidelines.[x] In addition to the official guidelines, societies like SPE publish training materials, with a key issue being shape of the uncertainty (the type of probability distribution).

A software vendor with a large market share in reservoir modeling agreed to an interview. We asked which probability distribution was favored. It was easily chosen with a drop-down menu. The head trainer for the organization told us that the software defaulted to a distribution NOT approved by the SPE (but easy to use), and that they had never seen a customer switch to a "correct" distribution. Interviews with oil company users seemed to confirm this observation.

While legal risks first alerted us to the need for executives to be wary about hazards lurking in the MS&A they consumed, other discoveries further highlighted risk as a topic worthy of separate consideration.




Our agreements with those we surveyed and interviewed preclude us from naming them, but one low performing organization we can cite is the International Energy Agency (the IEA).[xi] Shown in Figure 4 are 12 years of IEA forecasts (colored lines) and history (bold black) of Photovoltaic Energy Additions. In other words, the number of Gigawatts of PV power added worldwide each year. Clearly, the IEA is consistently using a flawed forecasting method.

Energy market forecasting is hard. No organization can hope to be highly accurate. But IEA problems are so persistent that it raised questions about the contrast between the IEA and the EIA, one of our best practitioners.

**Figure 4. Some MS&A Groups are Consistently Inaccurate[xii]**

The contrast of the EIA and IEA was part of another trend we noticed. While three of the four best practitioners were government agencies, all of the very worst practitioners were also from government. Some were so bad that we dubbed their self-described methods as "mathematical malpractice."

Because nearly 30% of our respondents were government agencies, we used this cadre to explore the concept of risk identifiers, separate from best practices, or their absence. In particular, contrasting the 17 government groups we interviewed provided us with richer insights than broadly assessing survey responses alone.

## EXECTUIVE RISK CHECKLIST

We compiled a list of proposed hypotheses for risk indicators and risk mitigators. We tested the hypotheses against the data from respondents. In many cases our small data set meant our correlation statistics had marginal value. As a result, many hypotheses were untested. What follows is the list of findings we felt to have value and validity.
The following six attributes are arranged from least diagnostic, ending with most suggestive.

We used three methods to correlate each hypothetical risk indicator; quality of MS&A results, degree of process discipline, and a weighed average of the two, biased toward results.

### *Repetition*

One theory was that repetition leads to superior performance. But we saw no correlation between "one-of" MS&A work products vs. repetitive outputs and best practice. Among our best practitioners in government, we found some

organizations doing repeated forecasting, and others doing unpredictably eclectic MS&A. Among our worst practitioners, we found roughly the same diversity. This was something of a surprise. The correlations were 26% to -39%, and this split is one reason repetition alone is a poor predictor. It was clear many respondents didn't use repetition as a means to improve their processes and results. We thought repetition might lead to more process discipline, but emphasis on practitioner excellence seems unconnected, or very weakly correlated.

Repetition alone is not a risk mitigator. Claiming repetition alone to be a risk reducer is misguided at best. Repetition may reduce risk, if some third party (or the executive user) keeps score on the accuracy of predictions.

***Budget***

This theory suggested that better funded MS&A teams would perform better because they had adequate resources. But, we saw only weak correlation between the budget and good practice. Agencies with larger budgets for modeling, simulation, and analysis could not be proven to be "better." In most cases, it was impossible to determine budgets, so the assessment was qualitative at best. MS&A spending is rarely broken out separately.

One of the unnamed best practitioners operated with very limited resources. So, if there is a connection between resources and process discipline, it is weak. One high performance organization had high standards *because* it was resource limited. They seemed to feel process discipline was a means to overcome budget challenges.

Budget was the weakest of the suggested risk indicators, with adequate funding being correlated 15% with results. But oddly, budget was negatively correlated with process discipline (-32%). So, here too, we saw mixed results in predictive power. At any funding level, the MS&A providers have limitations. What seems more important than budget *per se* was whether the practitioners could explain whether limited funding, time and staffing was a constraint. Severe underfunding (or lacking the resources of time and talent) is a risk indicator, but even modestly funded MS&A teams can do excellent work.

These first two hypotheses are worth considering by executives but lack predictive power for quick assessments. We list them because they were frequent questions, unlike other hypotheses we rejected or found to be untestable. The following four had more value.

***MS&A Mission***

The hypothesis here was that a team dedicated to a specific MS&A mission was better than a team whose role included other responsibilities (not pure MS&A). Since the authors are specialists, we have some bias toward belief (or at least hope) in this theory. We saw weak, correlation between a mission focused on MS&A, and best practice. Across our benchmarking, all our best practitioners were MS&A specialists. We also noticed the best MS&A specialists could advise their leadership which efforts should be outsourced, and which should be retained.

Within the cadre of government agencies, there was a striking finding. The degree to which an organization had a team with a dedicated MS&A mission, was negatively correlated with process discipline (-74%). For example, the worst offender was part of an organization whose only mission was to provide analysis. This "worst offender" was described in pre-interview notes as, "Guilty of mathematical malpractice, and proud of it." So, specializing in MS&A is no guarantee of quality. Instead, it can become a license for poor practice.

This worst offender resisted all attempts at meaningful outsourcing, which suggests a diagnostic question, "has this MS&A organization advocated for bringing in meaningful outside support?"

Dedicated teams who provide analytics, simulations and models may be more reliable than non-specialists. But other factors which follow were better risk indicators. In particular, a team truly focused on the mission of providing superb MS&A, they should be able to articulate their own limits, and when other providers should be used.

***Use of Static Toolsets and Methods***

We saw a correlation between frozen MS&A tools and methods, and risky poor practice. The degree to which frozen tools and methods were use was the third best predictor of bad results (29%), was weakly correlated with

poor processes (18%), and for the weighted process/results metric (-32%). Static tools and methods themselves may not be the root cause. They were often connected to monopoly providers, lacking accountability. Hence, this seemed to be a weak proxy for accountability. But frozen tools and methods also resisted process improvements.

The worst offenders tended to use tools which were both "validated" and "standard." However, the tendency to want "certified" MS&A seemed to be the most dangerous of these risk factors. Here is a list of the poor practices we found related to static methods and tools.

- *Over reliance on "p-values"* which are supposedly a measure of "significance." We found widespread misuse and misunderstanding of procedures and "canned" software to compute p-values, and ignorance (perhaps willful ignorance) of the growing revolt against the use (and misuse) of this measure. For example, a spokesperson for the American Statistical Association said, "The p-value was never intended to be a substitute for scientific reasoning," [xiii] Yet, it remains easy to put data into a standard tool to generate a p-value, and then assume it means something, or worse, assume it means everything. P-values often mean next to nothing.

- *Over reliance on "our standard software."* This was related to reliance on VV&A (discussed below) but was a broader observation. Organizations with specialized tools tended to rely on the tools, even when they were ill suited for some applications. In other cases, cyber security practices made it difficult to select the best tool for the job. No one disputed the benefits of established standards, tool, and methods. However, being trapped in a decades old toolset is not "standardization" in most case. It is stagnation.

- *Over reliance on "our approach."* This tended to be a combination of process and organizational stagnation. Organizations relied on the same people, and the same processes, even when they were ill suited for some applications. These organizations were not adaptive even when their stakeholders faced dynamic challenges.

- *Over reliance on "our single approach and expert."* This is the extreme form of the prior two problems. Three organizations we considered all exhibited a very dangerous pattern; an old Excel spreadsheet which had become the de facto official tool, and one person who was using it without ongoing peer review, audits, or testing. In all three cases, others in the organization knew the spreadsheet and the analyst were flawed. But, these organizations had become dependent on the static tools, and felt they had no real alternatives.

- *Over Reliance on formal validation*. We saw what seemed to be a significant connection between formal validation and poor practice. We spoke with instructors at prestigious government universities. One was the first to suggest reliance on formal validation was, at best, a placebo, and at worst, permission for malpractice. Broadly, we found this to be confusion about the audit of a tool, and the audit of results. Good results are not assured because of some past assessment of software.

No expert we spoke with felt formal "Validation, Verification and Accreditation" was as useful as claimed. This was true for MS&A which fell under U.S. DoD Instruction 5000.61, and other forms of "official" validation. No one disputed the benefits of audits and peer reviews. But lengthy VV&A seemed to be a poor value. One senior government executive we spoke with said her organization was required to use tools with VV&A, even though they were several years old and no longer represented the reality of her department. Billions of dollars were being allocated based on these tools. She was frustrated because policy required use of VV&A, which in turn meant three years to change toolsets. It was simply too hard to change.

More disturbing, a pre-interview with one analyst in a government agency exposed the following. This individual claimed ONLY they could perform certain assessments because they had the ONLY approved tool which created a monopoly, and personal power for this individual.

***Misuse of averages and single number proxies***

We saw what seemed to be a clear pattern which related use of single numbers with poor practice. This was tied with accountability as the best predictor of risk we tested; 92% correlated with bad results. It is related to a benchmarking topic, "Accommodate Uncertainty" (in cognition, representation, computation). It was not correlated with poor process discipline. It makes sense – highly disciplined process is distinct from the quality of the process. Cargo Cults showed extremely good process discipline as they asked the gods to send them loot from the sky.[xiv]

But beyond bad math, we suspected we observed apparent willful misrepresentation by use of averages. For example, an agency we benchmarked published a proposed rule in the U.S. Federal Register seeking public comment (as required by law) and "estimated" the average time to comply with the new rule (also required). The agency estimated 'the average firm' would need 15 minutes to file the necessary reports. It appears this "average" is sleight of hand. The "average" firm is one which is 80% exceedingly small (who don't file and have zero time to do so), 15% medium sized, and 5% large. In other words, the "average" represents a company which does not exist. This is only an illustration. Obviously devious or incompetent agencies can abuse averages other ways.

***Accountability***

All the best practice exemplars were accountable to stakeholders for the accuracy of their MS&A results, and none of the worst offenders seemed to have meaningful accountability. This also seems to hold true outside of government. This was tied for the best predictor of risk. Accountability is 82% correlated with satisfactory results, and 42% correlated with good practice.

Accountability seemed to have at least three forms:

The first form of accountability: direct, repeated accountability to end users of MS&A results. The EIA and UK Met Office publish their forecasts. Everyone knows when they are wrong. They are critiqued when they are wrong. Stakeholders complain when they are wrong. This led them to an emphasis on adopting best practices to improve their performance. Of course, their forecasts are still wrong at times. Best practices do not assure operational perfection. But this is a contrast to the worst offenders.

These "worst offender" organizations had all, or most of the following attributes:
- Regulatory or statutory authority, with few checks or balances
- Rare comparison of predictions with reality
- Restrictions on peer reviews
- Reliance on a certification, VV&A or other endorsement
- Rotation of executive oversight
- Rejection of outsiders

These six "Rs" form a checklist to suggest risk factors for lack of direct, repeated accountability, which in turn seems to be the best predictor of MS&A pathologies.

It is worth noting that some of the best practitioners must deal with some of these six Rs. For example, some highly sensitive matters make peer reviews, or including outside viewpoints very difficult. Best practitioners recognize these risks and find ways to lessen their impact.

The second form of accountability: clear knowledge of limitations. All the best in class, or near best in class benchmarking participants had clear understanding of their limits. This went beyond a defense of their budget, or a request to grow resources. Rather, they could clearly explain why they faced limiting factors that either impacted their MS&A, or which created risk.

Part of accountability for exemplars was the duty to articulate the bounds of what they could not do. In contrast, the worst performers seemed quick to claim they could do anything, and to reject outside help.

The third form of accountability; lack inherent bias. This was an attribute of the exemplars. In contrast, inherent bias seemed a feature of most of the worst offenders.

Bias can appear in several forms:
- Power to pursue an agenda, supported by biased MS&A
- Power accrued to an organization or individual maintained by biased MS&A
- Pursuit of funding and resources by biased MS&A
- Confirmation of shared expectations, aspirations, and dogma
- This is not a complete list

Inherent bias seemed to be a feature of many Benefit/Cost Assessments (BCA) we reviewed. Many English-speaking nations have national laws requiring agencies to publish their estimate of the costs (and in some cases the benefits) of a new rule, law, or regulation. Some BCA estimates are breathtaking in the bias they seem to include. The nature of human limitations is ripe with examples of subtle bias and blind spots. Addressing all bias may be too much to hope for. We only report here on what we think to be gross bias, which in many cases seems to be unchecked and unchallenged.

Bias is a good example of how pathologies can combine. Inherent bias, with authority lacking accountability, along with misuse of averages is a very toxic combination. We saw this particular combination on more than one occasion.

***About AI***

Because AI has attained almost magical status, we wanted to understand the risks of automatically derived analytics. To do this, we conducted a separate exploration of risks in Artificial Intelligence. Full treatment of that work is not in the scope of this paper. Generally, we saw was two classes of AI practitioner, with different associated risks.

The first class of AI practitioner was trying to be "less wrong." There are many problems where being even slightly less wrong can be unbelievably valuable. For example, product recommendations to on-line shoppers (Smith and Linden 2017)[xv] may be wrong most of the time, but still generate billions of dollars of revenue for Amazon, and others. Making recommendations at random is wrong essentially all the time. So, being wrong most of the time is a vast improvement.

For this first class of AI practice, the primary risk is that a decision maker relies too heavily on the recommendation. A human who asks you, "do you want fries with that?" is not responsible for your dietary choices. In the same way, these low precision recommender systems, and other AI systems who just aim to be less wrong are offering hints for decision makers, not high confidence forecasts or predictions. When this reality is ignored, risk follows.

The second class of AI practitioner was attempting to make forecasts and predictions. They sought to do more than hints and being "less wrong." Among this class who participated in our benchmarking, all exhibited serious errors in their work. We have been conducting follow-on research to understand why this seemed widespread. That work continues with the support and involvement of others[xvi]. We hope to publish findings in the future.

**SUMMARY**

For the I/ITSEC community, the risk list is a means to improve performance, lessen the frequency of risk emergence, and lower the consequences when risk manifests.

Because the I/ITSEC community deals with a wide range of topics, it might be wise to begin with consequences. Life and death consequences mandate a conservative approach. With lesser consequences, acceptable risks and implementing with the goal of being "less wrong" can provide agility.

Understanding risk and accepting it for the sake of speed is acceptable in some cases, while in others, avoidance of risk is paramount.

For MS&A practitioners, the risk list offers a means for self-assessment. These are the questions decision makers should be asking. As a matter of professional ethics and standards, practitioners should do a risk assessment, even if not directed to do so.

Executives can encourage best practice and avoid consuming risky MS&A results by taking two actions. First, the risk checklist is an effective way to gauge how the risk in MS&A products is distributed across your organization. It was written for non-technical personnel and does not require practitioner level knowledge to use. Second, we suggest asking your MS&A practitioners to use the work on best practices, published in 2018 (Roemerman *et al*) [xvii], to conduct a self-assessment, and to suggest near term actions for improvement.

A one-page version of the checklist with the four most predictive topics is shown in Figure 5.

# Executive Risk Checklist for the Age of Algorithms

Assessing the risks of Modeling, Simulation, and Analytics (MS&A) Used in an Organization

1. **Accountability:**
   a. Is the provider of MS&A accountable for accuracy, and is anyone monitoring performance, such as accuracy?
   b. Is the provider shielded from accountability by <u>any</u> of the following:
      i. Regulatory or statutory authority, with few checks or balances
      ii. Rare comparison of predictions with reality
      iii. Restrictions on peer reviews
      iv. Reliance on a certification, VV&A or other endorsement
      v. Rotation of executive oversight
      vi. Rejection of outsiders
   c. Can the MS&A provider describe credible limits of accuracy and appropriate use?
   d. Is there reason to suspect bias (even if unintentional) has crept in to the provider's culture or delivered MS&A? Is there cause for concern that any of the following might be a source of bias?
      a. Power to pursue an agenda, supported by biased MS&A
      b. Power accrued to an organization or individual maintained by biased MS&A
      c. Pursuit of funding and resources by biased MS&A
      d. Confirmation of shared expectations, aspirations, and dogma
      e. Any other reason to suspect bias without accountable oversight
2. **Using single numbers as proxies for spans of uncertainty:**
   a. Does the provider offer point predictions without any context of a range of possible outcomes, or of the odds associated with the number?
   b. Are averages used as proxies for all possibilities?
3. **Are MS&A systems and tools static?**
   a. Is there reliance on historical validation or certification?
   b. Are out of date methods, like “p-value” confidence still in use?
   c. Is there reluctance to change from “our standard software”
   d. Is there dependence on supposedly irreplaceable gurus?
4. **If there is a dedicated MS&A team, can they explain why/when other providers should be used?**

**Figure 5. The Executive’s Risk Checklist**

**ACKNOWLEDGEMENTS**

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**REFERENCES**

[i] Roemerman, S. *et al.*, (2018). Best Practices in Modeling and Simulation; Multi-Community Benchmarking, I/ITSEC paper 18125.

[ii] In-process results were presented at the 2017 and 2018 Probability Management Annual Conferences and published on line in those proceedings.

[iii] Professor Daniel Zweidler has extensive experience in business strategy analysis and has worked portfolio modeling in the Petroleum and Pharma industries. Professor J. Scott Armstrong has published extensively on modeling and simulation across a range of domains and topics, ranging from market forecasting to political science.

[iv] The survey was optionally anonymous, so in many cases we don't know who the respondents were. We can provide an educated guess at the overlap between interviews and survey responses.

[v] Responses were (apparently) received from Australia, Britain, Canada, India, Israel, and the United States, based on what interviewees told us, email addresses, and other suggestions of origin.

[vi] The first peer-reviewed in process publication and presentation was at the 20th International Conference on Petroleum Data Integration, Information, and Data Management, May 2016, in Houston Texas. No proceedings were published.

[vii] *ibid*, ii

[viii] *ibid*, i

[ix] *ibid*, i

[x] The guidelines are titled *Petroleum Resources Management System*, sponsored by Society of Petroleum Engineers (SPE), World Petroleum Council (WPC), American Association of Petroleum Geologists (AAPG) Society of Petroleum Evaluation Engineers (SPEE), Society of Exploration Geophysicists (SEG), Society of Petrophysicists and Well Log Analysts (SPWLA), and, the European Association of Geoscientists & Engineers (EAGE).

[xi] IEA is low performing in our vernacular because they are low transparency (no one seems to know how they generate forecasts), and because they generate forecasts which are persistently bad.

[xii] Figure was downloaded from https://steinbuch.wordpress.com/2017/06/12/photovoltaic-growth-reality-versus-projections-of-the-international-energy-agency/

[xiii] Ronald L. Wasserstein & Nicole A. Lazar (2016) The ASA's Statement on p-Values: Context, Process, and Purpose, The American Statistician, 70:2, 129-133, DOI: 10.1080/00031305.2016.1154108

[xiv] Worsley, Peter M. (2009) 50 Years Ago: Cargo Cults of Melanesia, Scientific American https://www.scientificamerican.com/article/1959-cargo-cults-melanesia/

[xv] Smith, B. and Linden, G., (2017). Two Decades of Recommender Systems at Amazon.com, IEEE Internet Computing, vol. 21, no. 03, pp. 12-18.

[xvi] We are grateful for the interest of faculty members at The University of North Texas, Stanford, and The University of California-Berkeley, among others who have contributed and are contributing to the exploration of AI pathologies.

[xvii] *ibid*, i