KEYNOTE ADDRESS

THE CHALLENGES (AND OPPORTUNITIES) FACING THE RISK SCIENCES

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I consulted my colleague David Johnson, the General Chairman of PSAM 14, for advice on what I could present that would warrant having this opportunity to speak to you today. David suggested I express my views on the “challenges” facing the risk business. I believe he was thinking that at my advanced age with over 60 years of preaching and practicing the risk sciences, surely I should have something useful to say about the most important challenges we face as a risk community. It did sound like a good topic for me to tackle and that’s what I decided to do. My spin on this is that they are not only challenges, but opportunities; opportunities to achieve even greater accomplishments for society than the risk sciences have thus far.

First, a comment on my choice of the words, “risk sciences.” The late Stan Kaplan, a close personal friend and colleague for more than half a century, wrote a wonderful paper on “The Words of Risk Analysis” (Kaplan, 1997) in which he pointed out the linguistic chaos it entails. He noted that the subject of “probability,” the foundational discipline of the risk sciences, is in a swirl of semantic confusion, its own “Tower of Babel,” so to speak. Quoting from his paper, “People have argued about the meaning of the word ‘probability’ for at least hundreds of years, maybe thousands. So bitter, and fervent, have the battles been between the contending schools of thought, that they’ve often been likened to religious wars. And this situation continues to the present time.”

So, with Kaplan’s paper ringing in my ears—what do I mean by the term “risk sciences.” Simply put, what I mean is the integration of the principles and algorithms of science, engineering, social science, and other disciplines as necessary to explicitly and quantitatively answer the question, what is the risk of something, whatever it may be. I like the term because of its all-encompassing meaning and rigorous overtone.

The question is, what would we like to see the risk sciences achieve? Of course, at the highest level we would like to see more direct evidence of how their application contributes to saving lives, improving systems performance, and our quality of life. How can we measure this? How can we elevate "risk" to that of a "vital sign" of a system, say in the manner that vital sign is used in the health care field? Just as body temperature, blood pressure, heart rate, and blood oxygen saturation levels are "vital signs" for human health, I think we would all like "risk" to rise to the level of being generally accepted as a critical vital sign for the health of a complex system. And of course, just as a variety of metrics constitutes the vital signs of the health of a human being, so should it be for any kind of complex system. No one metric gets the job done. What are some of the challenges to meeting this goal? I don't know for sure what they are, but I have some opinions of what some of them might be. I have chosen to discuss six of them.

Challenge 1. Increasing Public Awareness and Acceptance of the Benefits of the Risk Sciences

How do we go about doing this? Well, one thing we need to do is make a better case for the value added of the risk sciences. That is, we need to better communicate the virtues of their application, not with words and sales pitches, but with concrete evidence, with numbers, with "before and after" performance comparisons, with measurable metrics, with good decision outcomes. We need to better communicate, especially to the public, how decisions are made and how they are tied to the risk assessment process. There needs to be a more transparent bridging of risk analysis with decision analysis to provide the strongest possible foundation for effective and measurable risk management. One of the keys to making this happen is introducing more in-depth costs and benefits into our analyses. Quantifying costs and benefits together with risks greatly facilitates making good decisions, which is why we do risk analysis.

Besides costs and benefits there should be metrics having to do with environmental impact such as ground contamination and other offsite consequences, in spite of the fact that typically only a regulatory defined metric or two is chosen. Diligent application of the risk sciences can provide a scientific and economic basis for meaningful risk management to save lives and avoid economic and environmental disasters or mitigate their consequences.

The take-away message of Challenge 1 is public awareness of the benefits of the risk sciences is essential to their acceptance. Until risk assessments make the connection to their costs and benefits, including the costs and benefits of the actions taken to manage the risk, the awareness of the "value added" of quantification will be limited and slow in development.

Challenge 2. Achieving Completeness in the Risk Models

If I could point to one criticism of quantitative risk analysis that stands out over all others, it would be that our risk assessments are not complete. Consider the matter of nuclear power plant risk assessment often touted as the most mature in terms of quantifying the risks involved. In the 1970s and early 1980s the breakthrough Reactor Safety Study, WASH-1400 (USNRC, 1975), the early private nuclear utility studies such as the ones on the Zion and Indian Point plants (PLG, 1981 and 1982), and the Seabrook plant (Garrick, Fleming, et al., 1983), represented a new direction of safety analysis based on probabilistic risk assessment. There were others as well. But these are the ones in which I was directly involved. Initially, the nuclear regulators didn't pick up on the concept, perhaps thinking it was more burdensome on the licensees than necessary. In any event, they opted for a gradual transition towards a "risk-informed" process of safety analysis.

We know how to do more complete risk assessments; we just choose not to do them. Why? Unfortunately, too often the answer is given that it is not required by the regulations. Of course we have to comply with the regulations, but compliance management should never be our strategy; it should always be risk management. In my view, focusing on compliance numbs the creative use of the risk sciences, simply because the devil is in the details—details that just may not be covered by the regulations because all systems and plants are different with different operators and have their own special and sometimes hidden peculiarities. The problem is getting the decision makers on board with the "value added" of more complete risk assessments. The decision makers might think differently about the risk sciences if they were able to realize the depth and breadth of their potential, not just with respect to system safety risk, but other types of risk as well such as technology, programmatic, investment, and infrastructure.

We have made progress in many areas, particularly the health and safety risk of complex systems such as nuclear power plants. We now do a much better job of accounting for different operating states and the interaction of systems, structures, and components. But we need to do much more. I'm referring to what I would want to know if I were responsible for say a 10 billion-dollar nuclear power plant asset. For example, I would want to know the offsite risks in terms of health effects and land contamination—the real risks to the public and the environment. I would want as an integral part of my risk assessment a recovery model that makes transparent the timing and duration of events to know more clearly the options for truncating the progression of a severe accident. Recovery scenarios need to be articulated with the same sense of importance as core damage and containment release scenarios to provide guidance on which systems need to be the most resilient. Examples are communication and instrumentation and control systems. It was failure to fully understand valve operation safety logic under degraded conditions that led to the loss of decay heat removal capability from Fukushima Unit 1 during the tsunami event from the 2011 Great East Japan Earthquake. Reactor depressurization and containment venting system protocols during different severe accident scenarios are often not adequately analyzed with respect to timing and sequence. The detailed treatment of reactor depressurization scenarios for severe accidents is critical to making the right decision on alternative sources of cooling.

I would also want to know how accidents and recovery from accidents can be impacted by changes in site accessibility and infrastructure failures. And for a 10 billion-dollar asset, I would like to know more about the disposition of in-vessel and ex-vessel debris during a severe accident in order to make decisions on how best to manage and control the recovery process. This is best achieved by more in depth analysis and extension of the accident progression duration.

The MAPP[1] and MELCOR[2] computer codes developed by industry and government respectively are tools available for in-depth analysis of severe accident progression. The key is to consider different scenarios of in-vessel and ex-vessel processes, with the aid of such programs to assist in prioritizing recovery actions and the safety systems involved. Most importantly, comprehensive recovery models provide insights and guidance for training on the use of ad hoc responses for bringing reactors to safe shutdown during extreme beyond-design basis events.

Of course I would like to have a quantification of the uncertainties as they are the major contributor to the risk of rare events with high consequences. Some do uncertainty analysis, some don't. Knowing the uncertainties explicitly enables focusing on the right things to reduce risk. Knowing the uncertainties enables economically scoping the risk analysis of external or natural events. That we still seem to be struggling with such basic issues as the treatment of uncertainty and external events is surprising.

Speaking of external events, they should not be treated independently from the basic risk model. They should be integrated into the initiating event set to provide the necessary resolution between contributors in the same manner as the uncertainties. They should only be treated to the extent that they have an impact on the overall risk. The question is not what is the risk of the external event, but rather what is the contribution of the external event risk to the risk of the system being assessed—two very different questions generally leading to important simplifications to the risk model. Knowing the uncertainties is key to answering the right question.

For completeness, I would want to not only know the impact of external events, but the impact of coupled systems such as multiple units, degraded infrastructures (e.g., electric power, communications, site accessibility, first responders, etc.) and life sustainability requirements such as potable water, emergency food, and sanitation facilities. And yes, I would want to know something about the risk of sabotage and terrorist attacks.

The take-away message of Challenge 2 is there is sufficient technology and knowhow to greatly elevate the role of the risk sciences to the level of having metrics that can serve as critical "vital signs" of the health of any kind of system, á la the health care field. It just isn't done. Why? Because the regulations don't require it and too many of the decision makers believe that compliance is adequate. Completeness requires more breadth and depth to the risk assessment, especially with respect to developing a comprehensive recovery model and quantifying the uncertainties.

[1] https://www.fauske.com/nuclear/mapp-modular-accident-analysis-program
[2] http://energy.sandia.gov/energy/nuclear-energy/nuclear-energy-safety-technologies/melcor/

Challenge 3. Expanding the Applications

Except for the nuclear power industry and possibly a limited number of other cases, the risk sciences have barely scratched the surface of their potential for quantifying risks and providing a meaningful basis for risk management. There have been applications of the elements of the risk sciences in many industries, but none where quantifying risk has become entrenched into the culture of the industry as it has in nuclear power, which is necessary to enable risk metrics to become a reliable "vital sign" of a system.

There are many opportunities for the risk sciences to broaden their base of application. We mentioned several earlier: technology, programmatic, investment, and infrastructure risk. Quantifying the risks of natural and anthropogenic hazards have received the most attention. Natural hazard examples are volcanoes and earthquakes, wild fires, severe storms, space weather, and the natural evolution of the planet. Anthropogenic hazards include pollution, human initiated fires, industrial accidents, nuclear and bioterrorism, out of control technologies (e.g., nanotechnology weaponry, synthetic biology, and machine super intelligence), failure of infrastructures, pandemics, and nuclear war. Collateral or combinations of events to consider are infrastructure collapse (electric grid, potable water systems, communications, and sanitation system failures), tsunamis (earthquakes and undersea landslides), flooding (severe storms and tsunamis), nuclear winter (super volcanoes and nuclear weapons), and climate change (pollution and natural evolution of the planet).

Improving health care may be one of the most productive applications of the risk sciences when considering saving lives. Health care is a unique and extremely fertile area. For example, prescription drug risk quantification has great potential for not only saving lives, but dramatically improving health care. This is especially true in the U.S. where 40% of the world's pharmaceutical drugs are consumed by only 5% of the population, while the World Health Organization gives very low marks to the efficiency of the U.S. health care system.

One of the greatest challenges and opportunities for the risk management community is the complex network of interconnected and interdependent infrastructures that exist nationally and globally (EIS Council, 2017). By infrastructures I mean electricity, fuel, freshwater, waste water, food, communications, transportation, and electronic manufacturing. We also mean the modern internet, cable, fiber optics, microwave and satellite-based communications, and complex financial, banking, insurance and regulatory systems. How to increase the resilience of such a vast system of interconnected and interdependent infrastructures may be one of the most important issues facing modern society. The Harvey and Marie hurricanes of 2017, and the Florence hurricane of 2018 demonstrate just how interdependent such infrastructures as electric power, water, and sanitation are to cope with such disasters.

The take-away message of Challenge 3 is we have only scratched the surface of employing the risk sciences to save lives and improve our quality of life. Application opportunities are almost unlimited. Untapped, but promising areas for expanding the *beneficial application of the risk sciences are prescription drugs, natural hazards, the collapse of infrastructures, and roadmaps for recovery from catastrophic events.*

Challenge 4. Filling the Analytical Gaps

The point was made earlier that the capability exists for our quantitative risk assessments, our probabilistic risk assessments (PRA) to be more complete than is generally practiced. With respect to nuclear plant risk, the treatment of external events and uncertainty can't be considered major gaps in risk assessment methodology as both have been done with success, just not as well and as often as probably they should. So, what is an area where new methods would significantly add to our risk assessment capability? One area is a risk assessment platform that would better enable the treatment of human performance and the dynamics and timing of complex accident scenarios. The motivation is the concern that current risk assessments may not be adequately representing the interactions between plant physical processes, hardware systems, software, and human actions. This concern has been known for decades as was pointed out in a paper by Siu as early as 1994 (Siu, 1994) and expanded on by Mosleh in 2014 (Mosleh, 2014).

Time dependent logic diagrams are necessary to provide context to degrading components, systems, and structures. Two of the most important advancements of this evolving dynamic PRA platform are the use of simulation methods that make treating system dynamics feasible and the integration of human actions into the basic model.

Different investigators from different research centers have been involved in this work. Some of the details will be presented by Mihai Diaconeasa later in this conference (Diaconeasa, 2017). Mihai is a post-Doctoral scholar in our risk sciences institute. While the PRA dynamic platform scope has not been extended to modeling recovery, the cognitive operator models it contains could represent a major breakthrough for those unexpected situations where recovery guidelines do not exist, as occurred at Fukushima.

The take-away message for Challenge 4 is a dynamic simulation-based PRA platform is needed and being developed to enable a more comprehensive treatment of (1) human performance in complex systems and (2) better representation of the impact on risk of system dynamics and the timing of degrading events. Such a platform is also needed to more easily facilitate upgrades with new methods and algorithms. While not yet applications tested in an industrial setting, there is considerable evidence that the intended goals of the research will be successful.

Challenge 5. Analyzing Global and Existential Risks

Global catastrophic risks, referred to simply as "global risks," are risks of events that could significantly harm or even destroy human civilization at the global scale (Hempsell, 2004; Baum, 2010). Existential risk could be considered the limit of the global risk spectrum. An existential risk has been defined (Bostrom, 2002) as "a risk where an adverse outcome would either annihilate Earth-originating intelligent life or permanently and drastically curtail its potential." Except for the limiting case, global risks can be distinguished from existential risks as being generally endurable. While there are global and existential risks beyond our control, many are not. It is believed that if there were greater attempts to understand them while quantifying their likelihood of occurrence and priority, many could actually be prevented, mitigated, or at least delayed. But we must act to have an impact.

If we are to believe the experts, and I tend to, there is an urgent need to give much higher priority to global and existential risks than currently exists. For example, at a Global Catastrophic Risk Conference at the University of Oxford in 2008, a group of distinguished scientists and global risk experts suggested there is a 19% chance of human extinction over the next century (Sandberg and Bostrom, 2008). Now that is a very high risk; certainly worthy of the attention of everyone. Why is it not getting more attention? I guess it's because of the perceived extremely low frequency of occurrence of global and existential risks and their "out of sight, out of mind" character. The risk science community as a whole has not seriously engaged such risks.

The problem with many global risks is they lack direct human experience. Evidence of their occurrence exists, but in non-conventional and indirect forms. Global risk footprints, that is, evidence of their occurrence can be biological, geotechnical and from observations inside and outside our solar system. Many global risk experts now categorically believe that anthropogenic activities represent the greatest threat of a global disaster and an existential event. Regretfully, of the sources of evidence available to us on global risks, anthropogenic activities are the most dynamic and complex. This may be why some global risk experts are pessimistic about our long term existence on the planet. If there was ever a field that could benefit from the rigorous application of the risk sciences, this would seem to be one.

Global risk research and study generally resides in scholarly institutions, mostly academic (Garrick, 2017). Global risk assessment methods lag facility methods probably due to the lack of public pressure and a strong industry involvement. The nuclear power industry has been the leader in the field of facility risk and has been transitioning into quantitative risk management practices for almost five decades. Public concern about safety has been the principal driver. The same concern has not existed for the risk of global catastrophic events, most probably due to the lack of public awareness.

The take-away message for Challenge 5 is global catastrophic risks are a special category of risks of limited public awareness. The urgency of such risks is grossly under represented. Their importance is they represent pathways to human extinction. To be sure, the risk community is challenged to bring transparency and order to the existence of global risks and guidance on their elimination, mitigation, or recovery where feasible. Support for such action is limited.

Challenge 6. Generalizing the Methodology for Quantifying Risk

The principal elements exist for a general theory or methodology for quantifying any type of catastrophic risk. The challenge now is to add refinements for greater completeness, to enhance the credibility of the methods of analysis, and to make more transparent the benefits to society from the wider use of the risk sciences. Of course this is not like Einstein's quest for a way to combine gravity and electromagnetism into a single elegant unified theory. Nevertheless, increased generalization of risk assessment would facilitate making the risk sciences more relevant and friendly. Such actions will increase the chances of "risk" indeed becoming an important "vital sign" and an essential asset for any complex system capable of rendering harm to society or the environment.

Hoping to provide a framework for generalizing an approach for quantitative risk assessment, the late Stan Kaplan and I published a paper, Paper 1 Volume 1, in the Risk Analysis journal in 1981 proposing the triplet definition of risk (Kaplan & Garrick, 1981), a definition with its roots in my PhD thesis of 1968. Sometimes the triplet definition of risk framework is referred to as the scenario based approach to risk assessment. The key to the approach is developing a complete set of the important scenarios to represent the risk. The triplet definition of risk together with the basic steps of risk quantification have evolved over several decades into a general approach to quantitative risk assessment (Garrick, 2008). Advancements need to be made, but the basic definitions, protocols, standards, and practices are in place now that with only changes in boundary conditions enable developing risk models for essentially any type of threat.

The take-away message for Challenge 6 is there is sufficient evidence that the elements of a general and unified theory for quantitative risk assessment exist. To make it more credible and embraced by society, we need to better integrate the pieces and parts while filling in some analytical gaps. A more refined general theory will accelerate the applications of the risk sciences and the lifesaving and environmental protection benefits.

Overarching Challenge

This completes my list of some of the challenges for the risk sciences to reach their potential, except there is one more overarching challenge that supersedes all of the above. And that is the challenge to you the risk community to have the vision, creativity, and initiative to make the risk sciences not only relevant to society, but an essential factor in its sustainability. To achieve such a goal requires seeking out new applications, developing new innovative methods, complementing the decision making process with a new dimension and depth of information, by which we mean evidence, and engaging the public to achieve consensus. So, the challenge falls on the shoulders of you who are here today. So let's get on with it. Thank you.

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