IEEE NPEC Subcommittee SC-3
Operating, Maintenance, Aging, Testing, & Reliability
Meeting 14-1 Minutes

Tuesday Morning, January 28, 2014
Dallas, TX

Members Present:	George Ballassi John Beatty Suresh Channarasappa Tom Crawford (Vice Chair) Marie Cuvelier Edward Eustace Jim Liming Joe Napper (Secretary)	Jim Parello (C) Vish Patel Ted Riccio Rebecca Steinman John Stevens Yvonne Williams (Chair) Kang Zee
Members Absent:	Gopal Aravapalli (C) Tom Carrier (A) John Erinc Hamid Heidarisafa (C) Steve Hutchins Sharon Honecker (C)	Jacob Kulangara Kirk Melson Ed Muhtashemi Sheila Ray John Taylor (C)
Guests:	Malia Zaman (IEEE)	

1.0 Introduction

- **Opening Remarks and Meeting Agenda**

Yvonne called the meeting to order at 08:05. After introductions around the table, Yvonne reviewed and updated the agenda. Jim Liming moved to approve the agenda, as amended; and George seconded. The motion passed by acclamation.

2.0 Secretary's Report

- **SC-3 Approval of S13-2 Meeting Minutes**

Tom reviewed the draft minutes which had been previously distributed and posted on the website. He noted that we do have a quorum present (15 of 20 members) for general business and standards action. Tom agreed to add the AI List to the packet. After minor editorial updates, a motion was made by Ted to accept the minutes as amended, seconded by John Stevens, and passed by acclamation.

- **SC-3 Membership**

The rolling attendance report attached to the minutes was reviewed for the attendance of SC-3 members. The current report is contained in Attachment 2.

Joe Napper stepped up to fill the SC-3 Secretary position. Edward Eustace was appointed as a member. Kang Zee has returned to active Member status, and Tom Carrier has dropped to Alternate for Kang. Gopal Aravapalli, Sharon Honecker, and Jim Parello have dropped to Corresponding Member status. Peter Kang and Glen Schinzel have resigned as SC-3 members.

- **Alligator Fund**

  The status of the alligator fund was reviewed and we concluded that funds remain adequate at the present time. We agreed, once again, that there would be no collection for this meeting. The Alligator Fund status is contained in Attachment 3.

- **Action Item Status**

  The status of the action items was reviewed; the action item list is provided in Attachment 4.

  SC-3 Name Change ***(AI-11-2-C)*** **–** the subcommittee name change to "Operations, Maintenance, Aging, Testing, & Reliability" was discussed. It was previously identified that the NPEC P&P / O&P will have to be updated. Jim Liming submitted a request for the change in January, but there has been no NPEC action as of the close of the N14-1 meeting, and the name change remains pending.

  Strawman for gap analysis for SC3 standards ***(Action 12-2-B)*** **–** Development of a Template / Strawman for gap analysis for the SC3 standards remains open and is assigned to Yvonne.

  Master Scheduling Template for SC-3 WG's ***(Action 13-1-A)*** **–** Initial discussions were held during the S13-1 meeting, but there has been no follow-on. Ted provided a draft schedule for SC-3 standards (Attachment 10) for review and discussion at the next meeting. This completes the action on this item.

  Contact non-attending members and determine their intentions ***(Action 13-2-A)*** **–** Zedenko, Gopal, and Joe Napper had missed several meetings and had not contacted other members. Tom contacted them to determine whether they wished to remain as active members or not following the S13-2 meeting. Gopal requested transfer to "Corresponding Member" status. Zdenko previously resigned from NPEC and SC-3; however his letter never reached SC-3. Joe will remain active and has stepped up to fill the Secretary position. This completes the action on this item.

3.0 Chair's Report

- **Leadership Review / Succession Planning**

  Yvonne took over as SC-3 Chair, with Tom Crawford as Vice Chair. Joe Napper accepted the Secretary position, as noted above.

- **Leadership Telecons**

  A Leaderships telecon was held during December. During that meeting, the Action Items were reviewed and needs for the upcoming meetings were discussed.

- **PAR / Standards Status**

  The PAR for our new 1819 standard will require an extension. Yvonne has the action to submit the extension by July11, 2014 in order to be on the agenda for the September NESCOM meeting ***(Action 14-1-A)***.

  PAR / Standards Status was reviewed and updated on the Paul Yanossee Standards Status Spreadsheet provided in Attachment 5.

  Ted also discussed the proposed standards schedule that he has prepared (Attachment 10). This completes **Action 13-1-A.**

- **NPEC Preparations**

  SC-3 has no presentations or previews for the NPEC meeting, so no further action was required.

4.0 Working Group Reports

- **WG-3.1**

  The WG is continuing work on the preparation of the initial version of IEEE P1819. The PAR for this new standard was approved 25 March 2010 and expires 31 December 2014. As noted above, the PAR will require an extension.

- **WG-3.2**

  P692-D4d was successfully approved by the IEEE Standards Board on August 23, 2013. IEEE 692-2013 was then published on September 17, 2013.

  A WG meeting is planned for February 11th. At this meeting, it is expected that Dave Horvath will step down as chair and a new chair will be selected. Randy Flowers has tentatively agreed to act as the new chair, with Tom Worrell remaining as Vice Chair and Marie Cuvelier remaining as Secretary.

  The working group will also discuss future plans. One possible option is that the group may decide to become inactive for a few years. While inactive, Marie Cuvelier would act as the WG's liaison to SC-3. Marie was previously assigned action to coordinate development of a leadership plan for WG 3.2 following Dave's departure. The above completes **Action 13-2-B**.

During the balloting activities for the 1997 version of IEEE 692, several difficult comments on prescriptive requirements for security lighting occurred. The WG Chair contacted IES (Illuminating Engineering Society of North America) and requested IES participation to help resolve these comments. Since that time the prescriptive requirements have been refined to be more performance based and IES representation on the WG is no longer important. The current IES representative has recently resigned. The WG will need to decide whether the IES role should be continued because it has been difficult to find a replacement.

- **WG-3.3**

The Working Group discussed standards 577, 933, and 352. The first two standards, 577 and 933, are already submitted and released, thus need no further work at this time. Standard 352 is in working group review. Standard 352 was reviewed for changes that were made since the last meeting (N13-2) with several changes identified that are still in question. The chair agreed to discuss these changes with the past chair to confirm the new comments.

- **WG-3.4**

WG 3.4 is responsible for IEEE 1205 on aging management. The working group previewed the proposed revision to IEEE 1205 at NPEC 13-02 and held the initial ballot of the revised guideline (version D4) in September 2013. Nineteen comments were received from 54 balloters (88% of the ballot pool). Through the comment resolution process the WG decided to accept 5 suggested changes as they were written, reject 3 comments, and incorporate the other 9 comments in a manner slightly different than originally proposed by the balloter. The revised document (version D5) was recirculated in late December for three weeks with no comments returned by the recirculation ballot process. As a result, the document was sent to RevCom on 1/22/2014 with the relevant support files being provided to IEEE for editorial processing.

5.0 NPEC

George presented a brief history of the NPEC Operations & Procedures Manual and the Policies & Procedures Manual. An issue has arisen with the appointment of the Secretary, in that under the current procedures, the Chair and Past Chair must agree on the appointment of the new Secretary. A revision of the O&P is required to resolve the dilemma. One proposal to resolve the issue is to have the Secretary selected by the Chair, Past Chair, and actively participating Past Chairs, but that leaves a problem in that there could still be a tie. Several options that would provide an acceptable path to resolution were discussed. NPEC will have further discussion towards the final solution.

6.0 IEEE Patent Slides

Yvonne reviewed the IEEE Patent Slides, which are contained in Attachment 9

7.0 Liaison Reports

Liaison reports were provided as follows:

- NRC – Peter Kang has resigned and Sheila Ray was not present. The NRC Liaison Report presented during the NPEC meeting (N14-1) on Wednesday is provided in Attachment 7.
- ASME – Glen Schinzel has resigned, but Craig Sellers agreed to take over as ASME Liaison after the S14-1 meeting, which he was unable to attend. There was no update presented.
- NRMCC – George Ballassi provided notes from the NRMCC meeting in September, which are provided in Attachment 8. The next meeting is scheduled for February.

8.0 Old and New Business

Tom had prepared a draft WG Policies & Procedures Manual for the SC-3 WG's, which is based on the PES template that all WG's have been requested to conform with. This is a different template than the one we approved last year. Tom presented the notable differences between this version and our existing SC-3 OPM. Tom had previously suggested to NPEC that this be turned into an NPEC WG P&P Manual rather than an SC-3 document. The general consensus of SC-3 was that standardizing the P&P manual for NPEC WG's made sense and would minimize the diversion of resources from our primary task of working on standards. We agreed to await NPEC's action on this topic. Note that NPEC subsequently concurred during the N14-1 meeting and has submitted an NPEC WG P&P Manual for AudCom approval.

There is a requirement for an annual submittal of the Roster to IEEE SA in section 4.3. The question arose regarding who the roster should be submitted to. Malia took the action to find out and subsequently responded that the annual Roster submittal should go to:

[redacted]

It was further noted that the requirement for meeting notice distribution in section 6.0 is impossible to meet, as worded in the Standards Association template that was the basis for the PES template. Malia has the action to present the conflict to SA for resolution ***(Action 14-1-B)***.

The question of access to the SA IEEE Standards Dictionary arose once again. WG members who are developing or updating a standard need access to the IEEE standard definitions in order to perform their volunteer tasks. Even Public users of the standards need access to those definitions, since they are referenced in the standards and generally not repeated there. Malia took action to check on access to the dictionary ***(Action 14-1-C)***. Note that SA subsequently announced the availability of the Standards

Dictionary to IEEE SA members through their SA logins. That leaves the question of public access open.

The new Action Items from this meeting were reviewed, as discussed above and in Attachment 4.

A motion for adjournment was made by Jim Liming, seconded by Ted, and passed by acclamation.

Prepared by Tom Crawford, SC-3 Secretary.

SC-3 Website information:

http://grouper.ieee.org/groups/npec/private/sc3/sc-3.html
login name: [redacted] password: [redacted]

ATTACHMENTS

Attachment 1 Agenda	Attachment 2 Rolling Attendance	Attachment 3 Alligator Fund
Attachment 4 Action Items	Attachment 5 NPEC SC-3 Standards Status Spreadsheet	Attachment 6 ASME Liaison Report (None)
Attachment 7 NRC Liaison Report (From NPEC Mtg)	Attachment 8 NRMCC Liaison Report	Attachment 9 IEEE Patent Slides
Attachment 10 SC-3 Standards Schedule	Attachment 11	Attachment 12

Agenda – Meeting 14-1 Dallas, TX

NPEC Subcommittee SC-3, *Operations, Maintenance, Aging, Testing and Reliability*

Meeting Date/Time:	Tuesday, 01/28/2013 0800-1200	**Chairman :** **Vice Chair:** **Secretary:**	Yvonne Williams Tom Crawford

Desired Outcomes:	1. Review status/activities of each SC Working Group 2. Update SC3 standards master schedule 3. Reach agreement on WG P&P's

WHAT	WHO	WHEN
Welcome, Review Desired Outcomes • Meeting logistics • Introductions	Y. Williams All	0800-1815
Chairman's Introduction • Opening remarks • Review/approve agenda	Y. Williams	0815-0830
Secretary's Report • Approval of SC3 13-2 Meeting Minutes • Action Item review/status • SC3 membership review • Alligator fund report	T. Crawford	0830-0900
Chairman's Report • SC3 Leadership – Secretary and succession planning • Leadership telecons • NPEC meeting preparations	Y. Williams	0900-0920
Working Group Reports • WG-3.1 (Testing) • WG-3.2 (Security) with leadership status • WG-3.3 (Reliability) • WG-3.4 (Aging)	Y. Williams ?/M. Cuvelier J. Stevens R. Steinman	0920-0930 0930-0940 0940-0950 0950-1000
BREAK	All	1000-1020
NPEC	G. Ballassi	
Patent slides	Y.Williams	
Liaison Reports • NRC Report • ASME Report • NRMCC Report	S. Ray T. Riccio / C. Sellers G. Ballassi	1020-1100
Old Business • SC-3 / WG P&Ps • Master schedule for Std review/updates • Approach for next revisions of stds (gap analysis)	All	1100-1135
New Business • As identified during this meeting	All	1135-1150
Review of Action Items	T. Crawford	1150-1200
Next meeting	Y. Williams	
Meeting closeout/adjournment		1200

Attendance at SC-3 Meetings

Last	First	2012-1	2012-2	2013-1	2013-2	2014-1
Aravapalli	Gopal					Correspond
Ballassi	**George**	x	O	X	X	X
Beatty	**John**	x		X	X	X
Carrier	Tom	x	X	X		Alternate
Channarasappa	**Suresh**	x	X	X	X	X
Crawford	**Tom**	x	X	X	X	X
Cuvelier	**Marie**			X	X	X
Erinc	**John**				X	
Eustace	**Edward**				X	X
Heidarisafa	Hamid			Correspond		
Honecker	Sharon	x	X	X	X	Correspond
Horvath	Dave		X	X	Resigned	
Hutchins	**Steve**	x		X	X	
Kang	Peter		X	X		Resigned
Kulangara	**Jacob**		X	X	X	
Kyle	George				X	
Liming	**Jim**	x	X	X	X	X
Melson	**Kirk**	x			X	
Muhtashemi	**Ed**				X	
Napper	**Joe**		X			X
Parello	Jim	x	O	X	X	X
Patel	**Vish**	x	X	X	X	X
Ray	**Sheila**			X	X	
Riccio	**Ted**	x	X	X	X	X
Schinzel	Glen		X			Resigned
Simic	Zdenko	x			Resigned	
Steinmann	**Rebecca**	x		X	X	X
Stevens	**John**		X	X	X	X
Taylor	John					
Williams	**Yvonne**	x	X	X	X	X
Worrell	Tom			X		
Kang	**Zee**					X

Members are shown in **bold** and colored yellow as of end of most recent meeting.
Corresponding and Alternate members are shown in green.

TOTAL PAYING ATTENDEES	17	15	20	21	15
TOTAL NON-PAYING ATTENDEES	0	2	0	0	0

NPEC Subcommittee SC-3

Operating, Maintenance, Aging, Testing and Reliability

Alligator Fund

The Alligator Fund is made up of voluntary contributions from SC-3 members to defray the cost of meeting rooms, refreshments, etc.

Meeting	Beginning Balance	Meeting Contributions	Expenses	Ending Balance
S05-1	$312.14	$207.18	$359.82	$159.50
S05-2	$159.50	$240.00	$0.00	$399.50
S06-1	$399.50	$220.00	$178.67	$440.83
S06-2	$440.83	$160.00	$335.00	$265.83
S07-1	$265.83	$200.00	$201.70	$264.13
S07-2	$264.13	$600.00	$340.87	$523.26
S08-1	$523.26	$300.00	$347.80	$475.46
S08-2	$475.46	$320.00	$386.26	$409.20
S09-1	$409.20	$180.00	$12.00	$577.20
S09-2	$577.20	$210.00	$92.54	$694.66
S10-1	$694.66	$220.00	$380.90	$533.76
S10-2	$533.76	$425.00	$474.90	$483.86
S11-1	$483.86	$200.00	$14.00	$669.86
S11-2	$669.86	$430.00	$480.50	$619.36
S12-1	$619.36	$340.00	$203.00	$756.36
S12-2	$756.36	$150.00	$0.00	$906.36
S13-1	$906.36	$0.00	$0.00	$906.36
S13-2	$906.36	$0.00	$0.00	$906.36
S14-1	$906.36	$0.00	$0.00	$906.36

NPEC Subcommittee SC-3

Operating, Maintenance, Aging, Testing and Reliability

Action Items List

Item No.	Subcommittee 3.0 Actions	Owner	Due Date	Closure Comments
11-2-C	SC-3 name in NPEC needs to reflect reliability	Jim Liming	Next AdCom mtg	Bring up at AdCom meeting 11-2. 12-1 mtg: more complicated - Jim to bring up at 12-1 AdCom meeting to make sure what is required and then get those actions started. 13-1 mtg: Will affect NPEC P&P and O&P. Malia confirmed that it could be handled as an editorial change. It just will take time to process. Jim to bring up to ADCOM. Preferred name is: "Operations, Maintenance, Aging, Testing, and Reliability". Request Submitted 01/22/13; see S13-1 Meeting Notes, Attachment 5. No NPEC action, as of the close of the N14-1 Meeting.
12-2-B	Develop a Template / Strawman for gap analysis for SC3 standards	Yvonne	13-2 mtg.	No follow-on as of S14-1 meeting.
13-1-A	Lead a group to prepare a Master Scheduling Template for the SC-3 WG's.	Ted	13-2 mtg.	Initial discussions held 01/22/13. Ted provided a draft schedule for SC-3 standards for review following the S14-1 meeting. ACTION CLOSED.
13-2-A	Contact non-attending members and determine their intentions.	Tom	14-1 mtg	Zedenko, Gopal, and Joe Napper have missed several meetings and have not contacted other members. Tom contacted them to determine whether they wished to remain as active members or not following the S13-2 meeting. Gopal requested transfer to "Corresponding Member" status. Zdenko previously resigned from NPEC and SC-3; however his letter did not reach SC-3. Joe will remain active and has stepped up to fill the Secretary position. ACTION CLOSED.
14-1-A	Submit a PAR extension for P1819 to be on the September NESCOM Agenda.	Yvonne	07/11/2014	New item / Action pending.
14-1-B	Present the conflict to SA for resolution relative to meeting notice distribution in section 6.0 of the IEEE SA Working Group Policies & Procedures manual template.	Malia	14-2 mtg	New item / Action pending.
14-1-C	Check on access to the IEEE Standards Dictionary for (1) WG members and (2) public users.	Malia	14-2 mtg	SA subsequently announced the availability of the Standards Dictionary to IEEE SA members, which addresses part (1) of this action. Part (2) remains open.

Chair: Yvonne Williams

PROJECT	Year	Standard Expiration	Re-Affirmation	PAR Expiration	TITLE	Regulatory Guide	IEEE Revision Section B Discussion	IEEE Revision Section C Guidance	Working Group	Chair	Cycle Year	N13-1	N13-2	N14-1	N14-2	N15-1	Status/Comments
336	2010	2020			IEEE Standard Installation, Inspection, and Testing Requirements for Power, Instrumentation, and Control Equipment at Nuclear Facilities	1.30 - 1972	1971	1971	1	Y. Williams	3						Revision approved by the StdBd on June 17, 2010
338	2012	2022			IEEE Standard Criteria for the Periodic Surveillance Testing of Nuclear Power Generating Station Safety Systems	1.118 - 1995	1987	1987	1	Y. Williams	1						Revision approved by StdBd Feb. 6, 2012
352	1987	2020	2010	Dec-2016	IEEE Guide for General Principles of Reliability Analysis of Nuclear Power Generating Stations and Other Nuclear Facilities				3	J. Stevens	3						Submitted to RevCom for reaffirmation at the Sept Meeting PAR approved June 17. 2010 thru Dec 2014. PAR revision to change from recommended practice to standard approved by at NesCom Jan. 18th meeting. Reaffirmation approved by SB March 2010; PAR approved by ADCOM 1/25/2011; PAR approved by NESCOM 3/29/2012.
577	2012	2022			IEEE Standard Requirements for Reliability Analysis in the Design and Operation of Safety Systems for Nuclear Power Generating Stations				3	J. Stevens	1						Approved by SASB Aug. 30. 2012 Published on Oct. 19, 2012
692	2013	2023			IEEE Standard Criteria for Security Systems for Nuclear Power Generating Stations				2	D. Horvath	0						Revision approved by StdBd Aug 23, 2013
933	2013	2023			IEEE Guide for Definition of Reliability Program Plans for Nuclear Generating Stations and Other Nuclear Facilities				3	J. Stevens	2013						Revision approved by StdBd Dec 11, 2013
1205	2014	2024			IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Class 1E Equipment used in Nuclear Power Generating Stations	1.218 - 2012	2000	None	4	R. Steinman	2013						to RevCom Jan 22, 2014 Revision approved by StdBd xxx, 2014
P1819				Dec. 2014	Standard for Risk-Informed Categorization and Treatment of Electrical Equipment in Nuclear Facilities				1	Y. Williams	0		WIP				PAR approved by StdBD March 25, 2010. WIP to NPEC 7/31/2013.

NRC Liaison Report – NPEC 14-1

Fukushima Event-Related Activities Affecting Nuclear Plant Instrumentation and Controls

- Spent Fuel Pool Instrumentation (SFPI) Requests for additional information have been forwarded to licensees in preparation of reviewing action item responses.
  1. Clarification of requests for information have been discussed with industry.
  2. Some submittals have been received.
- FLEX strategy information is not available in this report.

Information notices, bulletins, generic letters, etc.

- Supporting development of RIS on embedded devices within safety components – public comments have been incorporated into the RIS.
- Drafting the rulemaking package for codification of IEEE 603-2009 into 10 CFR 50.55a(h).

Ongoing activities

- Working with Oak Ridge National Lab and RES on developing staff review guidance for digital safety systems used in Research and Test reactors
- Working with ISA on Setpoint Methodology Std. S67.04
- Reviewing PWROG submittal on treatment of EDG TS frequency and voltage
- Reviewing BWROG/PWROG submittal on TSTF-531- Revision of TS 3.8.1
- SBO Rulemaking (directed by Commission and recommended by the NTTF)
- Developed a design-specific SRP for a small modular reactor
- Continuing to work in the MDEP program to harmonize I&C for new reactors
- Research on the susceptibility of nuclear stations to external faults is examining the vulnerability of a nuclear station to faults that take place outside the nuclear station
- Research is underway on an extended battery operation study that will fully evaluate commercial NPP battery response to station blackout (SBO) events outside the scope of the current SBO rule (i.e., extended SBO events).
- Research on cable degradation in a submerged environment is evaluating the effects of submergence and water intrusion on cable insulation.
- Research on assessment of condition monitoring methods for electrical cables

- Research Information Letter 1002, Identification of Failure Modes in Digital Safety Systems – Expert Clinic Findings, Part 2, is being prepared.
- Research Information Letter 1003, Feasibility of Applying Failure Mode Analysis to Quantification of Risk Associated with Digital Safety Systems – Expert Clinic Findings, Part 3, is under development.
- Operating experience research is underway.
- RES is supporting the 10 CFR 50.55a(h) rule development effort.
    - Regulatory Guide 1.153, "Criteria for Safety Systems", will be revised in parallel with the 10 CFR 50.55a(h) rulemaking task.
- Regulatory Guide 1.105 on instrument setpoints is being revised to incorporate provisions from RIS 2006-17 and results from the many discussions with industry over the past few years. It will also address ISA 67.04.01-2006 (R2011). The schedule for this revision may be drawn out and is difficult to predict.
- RG 1.152 on digital systems is being revised to implement DI&C-ISG 4 and to address various issues related to accumulated experience in reviewing digital systems. It will also address IEEE Std 7-4.3.2-2010. The schedule for this revision may be drawn out and is difficult to predict.
- IRSN-NRC collaboration to develop criteria for assurance of software for highest safety grade systems
- NRC-INER collaboration on DI&C operating experience
- The Software Certification Consortium met on October 28-29, 2013 at NRC in Rockville, MD.
- Developing the Technical Basis for potential regulatory guidance on use of Automated Software Tools.
- NRC is working with NIST to conduct Electrical Cable Qualification and Condition Monitoring research

New Reactor Licensing Activities

The status of new reactor licensing under 10 CFR Part 52 is as follows:

Design Certification

The NRC is currently reviewing two design certifications:

- AREVA's EPR (evolutionary pressurized-water reactor design from France)
- Mitsubishi Heavy Industries' US-APWR (advanced pressurized water reactor design from Japan)

The Korea Hydro and Nuclear Power (KHNP) submitted a standard design certification application for its APR-1400 standard plant design to the NRC on September 30, 2013. The NRC staff reviewed the application for completeness, technical adequacy, and acceptability for docketing. The NRC has concluded the design submittal was not sufficiently complete to commence design certification. The KHNP APR-1400 standard plant design is based on Asea Brown Boveri/Combustion Engineering's System 80+ standard plant design.

In addition, the NRC staff is reviewing two applications for design certification renewal:

- ABWR GE-Hitachi (application submitted on December 7, 2010)
- ABWR GE-Toshiba (Revision 1 to application submitted on June 22, 2012)

Combined License (COL) Applications

5 COL applications (9 plants) currently scheduled:

-	1 ABWR	South Texas Project 3 and 4
-	3 AP-1000	William S. Lee Station 1&2, Levy County 1&2, and Turkey Point 6&7
-	2 ESBWR	Fermi 3, North Anna 3
-	2 EPR	Calvert Cliffs 3, Bell Bend
-	1 US-APWR	Comanche Peak Units 3 and 4

On April 25, 2013, Dominion Virginia Power revised its technology selection from the US-APWR nuclear technology and selected the GEH ESBWR nuclear technology for the North Anna Unit 3 project. The initial phase of the North Anna Unit 3 combined license application was submitted to the NRC in July 2013.

Advanced Reactors Program

NRC established an advanced reactors program in the Office of New Reactors. Currently, there are no applications under review, but several applications are expected in the next three years including:

- High Temperature Gas-Cooled Reactors:
  - Next Generation Nuclear Plant (DOE) – Pre-application interactions are continuing. The Secretary of Energy sent letters to Congress on October 17, 2011, describing his decision regarding continuation of the NGNP project. The Secretary informed Congress that the project will continue high-temperature-reactor research and development activities, interactions with the NRC to develop a licensing framework, and efforts to form a cost-shared public-private partnership. However, initial NGNP design parameters have not been selected, pending establishment of the public-private partnership.

Integral PWRs (iPWRs):

- NuScale (iPWR) – NuScale Power is developing a modular, scalable 45 MWe iPWR. Pre-application reviews are currently under discussion. In addition, NuScale LLC is working together with NuHub to pursue a small modular project (SMR) project at the Savannah River Site in South Carolina. The team's plan is to assist in the design certification licensing process and development of the reference combined-license application (R-COLA). The design certification is expected to be submitted to the NRC in 2015.
- B&W mPower (iPWR)– B&W is developing a modular, scalable 125 MWe iPWR. Pre-application interactions are underway. B&W will pursue a standard design certification under the alternative 10 CFR Part 52 licensing process. A standard design certification application is expected to be submitted in 2014. On November 20, 2012, the U.S. Department of Energy announced that they selected the Generation mPower Team (B&W, Bechtel, and TVA) as the recipient of cost-share funding to design and build an SMR in the United States. TVA Clinch River is planning to build an mPower plant under the 10 CFR Part 50 licensing process and plans to submit a construction permit application to the NRC in 2015.
- Westinghouse is developing a modular iPWR design. A standard design certification application is expected to be submitted to the NRC in 2014. Ameren (Callaway) is planning to submit a combined license application to the NRC referencing the Westinghouse iPWR design in 2015.

The New Reactor Licensing public web-site

http://nroweb1.nrc.gov/NRO/new-rx-status/index.cfm

has a list of expected new nuclear power plant applications, and an estimated schedule by fiscal year for new reactor licensing applications.

NUCLEAR RISK MANAGEMENT COORDINATING COMMITTEE (NRMCC) Minutes -- draft
Baltimore Marriott Inner Harbor
September 11, 2013

Members Attended	Members Absent	Guests
Ralph Hill, ASME co-chair	Robert A. Bari, BNL	Bilal Ayyub, University of Maryland
Charles (Chuck) Moseley, ANS co-chair	Craig Sellers, Enercon	Dennis Henneke, ANS JCNRM co vice chair
*Victoria Anderson, NEI	Bryan Erler, Erler Consulting	Tom Hiltz, U.S. DOE
*George Ballassi, IEEE	Gregory A. Krueger, Exelon	N. Prasad Kadambi, ANS RP3C chair
*Sidney Bernsen, Individual	Michael G. Stamatelatos, NASA-retired	Chip Lagdon, U.S. DOE
Robert Budnitz, ANS JCNRM co-chair		*James Limey, IEEE NPEC
Gary DeMoss, U.S. NRC (Alternate for Mary Drouin)		Mike Macfarlane, Southern Nuclear
Raymond Fine, PWROG RMSC		Patrick O'Regan, EPRI
Rick Grantom, ASME JCNRM co-chair		Barry Sloane, ERIN Engineering
Stuart Lewis, EPRI		
James O'Brien, U.S. DOE		
Robert Rishel, BWROG IRIR		
Patricia Schroeder; ANS staff		

*participation by phone

1) **Call to Order**
The meeting was called to order.

2) **Roll Call and Announcements**
Members and guests were welcomed and announcements were made.

3) **Approval of Agenda**
The agenda was approved as presented.

4) **Integrated Risk Management Milestone/Roadmap Schedule**
Ralph Hill provided members a recap of the morning's meeting on the Integrated Risk Management Milestone/Roadmap Schedule. He stated that they identified additional standards to be added to the schedule. The scope of the roadmap will include risk-management related activities of the entities holding membership on the NRMCC. The roadmap is an information and guidance document to enhance coordination and integration of risk management activities of NRMCC member entities. ASME ST LLC has agreed to act as custodian of the Integrated Risk Management Milestone/Roadmap Schedule. Dan Andrei has been identified as the project manager that will support this effort. The intent is to create a big picture of all risk-related projects. Updates will be

regularly provided by ANS, JCNRM, BCNS, DOE, and others to update the schedule. The NRMCC would review the roadmap and make recommendations if determined that coordination is needed. The roadmap would be available to all for reference and use. Members supported the process.

5) Industry Reports

a. Nuclear Energy Institute (NEI)
No report provided.

b. Pressurized Water Reactor Owners' Group (PWROG)
No report provided.

c. Boiling Water Reactor Owners' Group (BWROG)
Robert Rishel reported that the BWROG risk budget was reduced as the funds were diverted to Fukushima needs. As a result, some probabilistic risk assessment (PRA) work had been cut back. Some items of interest along with current and future activities of the BWROG include the following:

- Piloting the LPSD standard
- Looking for funding for seismic PRA peer review to be initiated next year
- A number of BWRs have completed the framework of a PRA
- Concerned about heat release rate and circuit failures
- Credit for cable coatings
- All but one BWR have completed a peer review of the fire portion of RA S
- Working on Fukushima FLEX strategy

Members discussed issues related to the fire PRA. There was agreement that methods needed to be mature before incorporating in a standard. A recommendation was made to communicate problems with the fire PRA standard at a Nuclear Energy Standards Coordination Collaborative (NESCC) meeting. A suggestion was made to prepare a white paper with the problem to present at the next NESCC meeting scheduled for November 7, 2013.

Action Item 9/2013-01: Robert Rishel and Ray Fine to prepare a paper with talking points/white paper summarizing the problems with the fire PRA standard to be brought to the NESCC. Reviewers include Victoria Anderson, Chuck Moseley, Prasad Kadambi, and Ralph Hill.

Additionally, cable aging was discussed and whether it could be risk informed. James Limey confirmed that IEEE had a standard on cable aging, IEEE Std. 1819 that recognized risk methods.

d. Electric Power Research Institute (EPRI)
Stuart Lewis provided a status of EPRI activities. Some of the major areas of work include the following:

- Guidance for response to Fukushima evaluations
- Guidance for seismic PRAs and NFPA 805
- Seismic research (long term)
- Fragility research (long term)
- Fire risk assessment
- Work on MAPCO software
- Standard method for spent fuel pools

Victoria Anderson confirmed that NEI had an executive oversight committee for fire PRA. She felt that progress was being made although it was slow. Anderson confirmed that a roadmap of significant issues had been prepared. Dennis Henneke provided an example of why it was taking so long to complete, which included lack of support and philosophical differences among executive oversight committee members.

e. U.S. Nuclear Regulatory Commission (NRC)
Gary DeMoss provided a report of NRC activities. He stated that they were working on a set of interim staff guidance (ISG) documents on related topic areas that were delayed as a result of the sequestration. Topic areas for the ISGs include uncertainties, screenings, advanced light water reactor (LWR) PRA requirements, external fire and hazards. Once completed, ISGs will be available for use until applicable regulatory guides can be revised. Hill asked that DeMoss provide a list of the NRC documents using risk methods so they could be incorporated into the roadmap.

Action Item 9/2013-02: Ralph DeMoss to provide Ralph Hill the list of ISGs, RGs, NUREGs with risk insights for inclusion in the roadmap schedule.

Some additional NRC current activities include the following:

- NUREG 2122 is in publication and should be issued next month
- Level 3 PRA pilot project on-going
- Working to disposition the recommendations from the NTTF
- Several working groups addressing Fukushima recommendations
- Preparing a high-level policy statement related to NUREG 2150
- Additional public meetings in the planning stage
- Research being conducted on seismic PRA

Action Item 9/2013-03: Gary DeMoss was asked to provide the list of NRC activities in writing for the minutes. (See Attachment A in completion of this Action Item.)

f. U.S. Department of Energy (DOE)
James O'Brien stated that the DOE was updating their nuclear policy statement to include the use of PRA and was developing a PRA. He stated that they decided not to include risk metrics in the DOE PRA standard. O'Brien added that the Congress provided direction to use consensus standards and recommended use of PRA. Additional items discussed include the following:

- DOE Standard 3009 looks at hazards but is qualitative and does not address frequency. The standard will be reviewed for possible inclusion of risk insights in a revision.
- The pilot at a waste treatment plant is differentiating between design basis and beyond design basis event.
- A training module pilot will be held September 17 – 19, 2013, on DOE specific training related to PRA focused on DOE applications.

g. Institute of Electrical and Electronics Engineers (IEEE)
No report provided.

Action Item 9/2013-04: Ralph Hill to check with George Ballassi to see if he has a written report to be provided with the minutes.

h. ASME/ANS Joint Committee on Nuclear Risk Management
   Rick Grantom reported on training issues for peer reviewers, process issues, and implementation issues that were being revisited. He stated that the NRC had a concern with some of the peer reviews; a small group will review and make recommendations. Additionally Grantom reported that Addenda B of RA-S was completed and being published. The scope for the next edition of RA-S had been decided. Many JCNRM working groups were meeting this week. Over the next year, several standards would be issued for ballot with the intent of release for trial use. Budnitz added that there were numerous cross-cutting issues for the revision of RA-S that needed to be addressed. A structure was in place to oversee the work. Budnitz added that many young professionals had been added to JCNRM working groups.

i. Other ASME
   Ralph Hill reported briefly on other ASME activities. The ASME Post-Fukushima Task Force continued to work with Japan Society of Mechanical Engineers (JSME) colleagues. They were currently looking at BWR containment; severe accident management was on hold. JSME informed them that new regulations and directives were put in place by the new Japanese regulator (NRA) and that some applications for PWR restarts had been submitted and were under review. Hill mentioned several new requirements that may be instituted in Japan.

j. National Aeronautics and Space Administration (NASA)
   No report provided.

6) Old Business

a. Action Item 9/2012-02: Mary Drouin to provide the NRMCC details on the NRC public meetings on NTTF recommendations when scheduled through Pat Schroeder.
   Meetings dedicated to the public were completed. CLOSED

b. Action Item 9/2012-07: Rick Grantom to follow up with Thomas Boyce on NRC's need for a technology neutral standard for small modular reactors (SMRs).
   Grantom reported that he held a discussion with Michael Case relevant to technology neutral standards for SMRs. CLOSED

c. Action Item 9/2012-09: James O'Brien to provide a summary of the DOE workshop to the NRMCC at the next meeting.
   James O'Brien informed the committee that the summary for the workshop was available on the DOE website. CLOSED

Action Item 9/2013-05: James O'Brien to send Pat Schroeder the link to the webpage with the summary of the DOE workshop for distribution to the NRMCC.

d. Action Item 9/2012-15: Craig Sellers to follow up with Steven Unikewicz on Action Item 2/2012-03 (below) on potential for individuals from other disciplines that use PRAs to address the NRMCC.
   Presentations from individuals outside the NRMCC were made. CLOSED

   Action Item 2/2012-03: Steven Unikewicz to provide names and contact information for individuals from other disciplines that use PRAs to the NRMCC co-chairs to extend an invitation to attend NRMCC meeting and make a presentation.

e. Action Item 2/2013-04: Chuck Moseley to facilitate a teleconference regarding interface details between the JCNRM Subcommittee on Risk Application (SCoRA), Risk-informed and Performance-based Policies and Principles Committee (RP3C – formerly RPBPPC), etc., in the July/August time frame
Interface addressed. SCoRA representatives attended ANS RP3C meeting in June of 2013. CLOSED

f. Action Item 2/2013-05: Ralph Hill to invite Dr. Ayyub to address the NRMCC on Resiliency at the September 2013 meeting in Baltimore
Dr. Ayyub presented at this meeting. CLOSED

7) New Business

a. Dr. Ayyub, University of Maryland, College Park, will address the NRMCC on Resiliency
Ralph Hill introduced Dr. Ayyub to the committee. Dr. Ayyub provided members a summary of his experience. He added that the focus of today's presentation (Attachment B) was Resiliency. Ayyub explained that he published a paper on this subject. The paper, entitled "Systems Resilience for Multi-hazard Environments: Definition, Metrics, and Valuation for Decision Making," is available as Attachment C. Ayyub noted several definitions for resilience and stated that he preferred the definition to include the word "persistence." His proposed definition for resiliency was reviewed. Time was provided for members to ask Ayyub questions regarding resiliency. How resiliency could be applied was discussed. Hill asked that Ayyub's contact information be provided to all in the minutes. His contact information is as follows:

Bilal M. Ayyub, Ph.D., P.E.
University of Maryland
A. James School of Engineering
[redacted]

b. Safety Classification and Risk Significance Classification – John Stevenson and Pat O'Regan (EPRI) will attend the meeting and provide presentations that address the following. Objective is for NRMCC to provide guidance on how these activities could or should be coordinated and integrated.
Ralph Hill informed the committee that John Stevenson was unable to attend the meeting to address areas in American Society of Civil Engineers (ASCE) standards that may need interface with the NRMCC. He stated that Stevenson provided him a few slides that he would present on his behalf (See Attachment D). Hill introduced Pat O'Regan to the committee to report on an ASME boiler pressure vessel (BPV) code case.

As an introduction, Hill stated that ANS provides standards for nuclear safety classification while ASME BPV XI has code cases that address risk significance for in-service inspection and repair and replacement in accordance with 10CFR 50.69. ASME BPV III had drafted code case (N-720) that addresses risk significance for new design and construction in accordance with 10CFR50.69. With risk significance, Hill asked Pat O'Regan to provide the NRMCC an update.

O'Regan reported that BPV XI has developed a repair/replacement code case that uses risk informed safety classification. He stated that they started by reviewing ANS standards and regulatory documents that addressed classification. The BPV XI committee believes that they resolved the classification issues and are currently piloting. BPV III is developing a code case (CC N-720) for new construction based on the BPV XI code case. Riley stated that they feel that draft code case N-720 could be applied to new builds. Hill added that Stevenson has identified that there are synergies between draft ANS-58.16 and ASME draft CC N-720. O'Regan reported that SECY 11-0024, Use of Risk Insights to Enhance the Safety Focus of Small Modular Reactor Reviews," addresses use of PRA and risk significance in licensing of SMRs.

Hill summarized John Stevenson's presentation (Attachment C) addressing several ASCE standards, their scope, and relationship to ANS and ASME standards. The four ASCE standards discussed include the following:

ASCE 1 N-725, Guidelines for Design or Nuclear Safety-Related Earth Structures
ASCE 4, Seismic Analysis of Safety-Related Nuclear Structures and Containments
ASCE 7, Minimum Design Loads for Buildings and Other Structures
ASCE 43, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

The status of all four was reviewed. Since all of these standards used risk-insights, members agreed that they should be added to the integrated risk roadmap and that an invitation should be extended for a representative of ASCE to join the NRMCC.

Action Item 9/2013-06: Ralph Hill to extend an invitation to ASCE for a representative on the NRMCC.

It was recognized that DOE has adopted ASCE 43-05 while NRC has endorsed only parts of the standard.

8) Review of New Action Items

The action items from the meeting were reviewed.

9) Next Meeting

The next NRMCC meeting was tentatively scheduled for Wednesday, February 19, 2014, during the JCNRM meetings proposed for West Palm Beach, Florida. The location of Atlanta, Georgia, will be considered if appropriate accommodations cannot be found in West Palm Beach.

Action Item 9/2013-07: Pat Schroeder to announce proposed next NRMCC meeting date to members.

10) Adjournment

The meeting was adjourned.

Liaison report

- Number of ISGs nearing readiness to be issued for public review and comment, delayed because of budget and internal comment resolutions. ISGs cover
    - Uncertainties,
    - Screening criteria
    - Advanced LWRs PRA requirements
    - Peer review for internal fire and external hazards

  Will be incorporated in next revision to RG 1.200

- NUREG-1855, public review and comment period closed, Rev 1 on its way to publication

- NUREG-2122 (Glossary) at publications, expect to be issued in October

- Level 3 PRA project
    - Looking to have a public meeting sometime next year
    - Have started dialogue with PWR Owner's Group for them to perform peer reviews, please contact them if you have an interest in participating
    - Wanting to use standards to the maximum extent possible

- NTTF Recommendation 1 staff SECY paper to go to Commission Dec 2, 2013; three recommendations:
    1. Establish a design extension category of events and associated regulatory requirements
    2. Establish Commission expectations for defense in depth
    3. Clarify the role of voluntary industry initiatives in the NRC regulatory process.

  ACRS Subcommittee meeting on October 17

- NUREG-2150 – Risk Management Regulatory Framework (RMRF)
    - Working group looking at the report recommendations
    - One recommendation is an overall agency policy statement, WG to issue a conceptual work-in-progress to solicit early stakeholder feedback (hopefully in the next month)
        - Public meeting to be scheduled this calendar year
    - Other reactor recommendation:
        - "reassess methods used to estimate the frequency and magnitude of external hazards"
        - "establish program to systematically collect, evaluate and communicate external hazard information"

      Is there a role for JCNRM here?

- Other staff work/interest: Commission SRM to look at seismically-induced fires from a PRA perspective
    - Understand that this is one of the cross-cutting issues, NRC willing to work closely with ASME/ANS to have early engagement on this issue, so hope this is a high priority item

 DOI: 10.1111/risa.12093

Systems Resilience for Multihazard Environments: Definition, Metrics, and Valuation for Decision Making

Bilal M. Ayyub*

The United Nations Office for Disaster Risk Reduction reported that the 2011 natural disasters, including the earthquake and tsunami that struck Japan, resulted in $366 billion in direct damages and 29,782 fatalities worldwide. Storms and floods accounted for up to 70% of the 302 natural disasters worldwide in 2011, with earthquakes producing the greatest number of fatalities. Average annual losses in the United States amount to about $55 billion. Enhancing community and system resilience could lead to massive savings through risk reduction and expeditious recovery. The rational management of such reduction and recovery is facilitated by an appropriate definition of resilience and associated metrics. In this article, a resilience definition is provided that meets a set of requirements with clear relationships to the metrics of the relevant abstract notions of reliability and risk. Those metrics also meet logically consistent requirements drawn from measure theory, and provide a sound basis for the development of effective decision-making tools for multihazard environments. Improving the resiliency of a system to meet target levels requires the examination of system enhancement alternatives in economic terms, within a decision-making framework. Relevant decision analysis methods would typically require the examination of resilience based on its valuation by society at large. The article provides methods for valuation and benefit-cost analysis based on concepts from risk analysis and management.

KEY WORDS: Community; consequence; infrastructure; measure; measurement; metrics; recovery; resilience; risk; robustness

1. BACKGROUND

The United Nations Office for Disaster Risk Reduction (UNISDR) reported that half of the world's inhabitants, expected by 2025 to increase to roughly two-thirds, and the vast majority of property and wealth are concentrated in urban centers situated in locations already prone to major disasters, such as earthquakes and severe droughts, and along flood-prone coastlines.[1] UNISDR[1] also reported that the 2011 natural disasters, including the earthquake and tsunami that struck Japan, resulted in $366 billion in direct damages and 29,782 fatalities worldwide. Storms and floods accounted for up to 70 of the 302 natural disasters worldwide in 2011, with earthquakes producing the greatest number of fatalities. Average annual losses in the United States amount to about $55 billion. It is anticipated that such disasters would occur in increasing trends of storm rates and disaster impacts because of a combined effect of climate change and increased coastal inventory of assets.[2] Although no population center or a geographic area can ever be risk free from natural or human-caused hazards, communities should strive to enhance resilience to the destructive forces or the impacts of resulting events that may claim lives and damage property. Gilbert[3] provided

Center for Technology and Systems Management, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD, USA.

*Address correspondence to Bilal Ayyub, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742, USA; tel: 301-405-1956 campus; ba@umd.edu, http://www.ctsm.umd.edu.

 0272-4332/13/0100-0001$22.00/1

population-and-wealth-adjusted loss and fatality count trends from 1960 to 2009 to demonstrate that both are about flat without significant slopes; however, it is noted that the United States is becoming more vulnerable to disaster because of increased population concentration in areas prone to natural disasters[4,5] and persisting inadequate condition of infrastructure.[6]

Enhancing system resilience at the structure, network, community, etc. levels could lead to massive savings through risk reduction and expeditious recovery. The rational management of such reduction and recovery is facilitated by an appropriate definition of resilience and associated metrics. Current definitions do not always lend themselves naturally and intuitively to the development of consistent resilience metrics with clear relationships to metrics of the relevant abstract notions of reliability and risk. The objective of this article is to review existing definitions and metrics, and to propose ones that meet logically consistent requirements drawn partly from measure theory. These metrics would provide a sound basis for the development of effective decision-making tools for multihazard environments. Appendix A lists selected urban areas, their respective population sizes, location attributes, and hazards as a summary of the data reported by UNISDR.[1] This summary demonstrates at a global level the extent of exposure to various hazards. The hazard most often listed is flooding, including coastal, and earthquakes.

Resilient systems should be developed to meet sustainability requirements defined by the three pillars of sustainability by reconciling environmental, social equity, and economic demands. These three pillars of sustainability are not mutually exclusive and can be mutually reinforcing. Similar to the long-lived and healthy wetlands and forests, as sustainable biological systems, humans should sustain their long-term well-being in the environmental, economic, and social dimensions and achieve resiliency.

2. RESILIENCE DEFINED

The concept of resilience appears in different domains ranging from ecology to child psychology and psychiatry to infrastructure systems. It was formally introduced in ecology, defined as the persistence of relationships within a system,[7] and measured by the system's ability to absorb change-state variables, driving variables, and parameters and still persist. In discussing the philosophical basis of risk analysis, Starr *et al.*[8] characterized the resilience of a system in agreement with the *Webster's New World Dictionary & Thesaurus*[9] as its ability to bounce or spring back into shape or position, or to recover strength or spirits quickly. The common usage, including technical ones, of the word *resilience* permits some elasticity in its placement in declarative statements, for example, the following are meaningful forms that are structurally identical: (1) infrastructure resilience is desirable and (2) storm resilience is desirable. In the former statement, resilience is an explicit quality of infrastructure, whereas in the latter resilience is an implicit quality of whatever is affected by a storm. Generalizing the latter form to "event resilience is desirable" might imply the event itself is the resilient one, not its subject. This ambiguity in usage is indicative of the elastic nature of the word, and perhaps this elasticity partly explains the confusion in its definition in the literature. Park *et al.*[10] tenuously described some aspects of this ambiguity by describing resilience as an emergent property of what an engineering system does, rather than a static property the system has; therefore, resilience is better understood as the outcome of a recursive process that includes sensing, anticipation, learning, and adaptation, making it complementary to risk analysis with important implications for the adaptive management of complex, coupled engineering systems.

In psychology, resilience is an individual's tendency to cope with stress and adversity. In material science, it is the capacity of material to absorb energy when it is elastically deformed. In engineering, many definitions exist and a succinct definition is the ability of the system to return to a stable state after a perturbation. In systems science, a resilient system returns to an equilibrium state after perturbation, with more resilient systems having multiple equilibrium points. The notion of resilience is used not only for ecological systems, infrastructure, and individuals, but also for economic systems and communities.[11–16]

The use of the term resilience with respect to hazards and disasters is a logical step, as discussed by White and Haas[17] and Mileti,[18] and was used in the 2005 Hyogo Framework for Action by 168 members of the United Nations to enhance its priority for governments and local communities.[19] A substantial number of studies focused on defining the notion of resiliency for infrastructures and the development of resiliency metrics. For example, Bruneau *et al.*[20] defined a resilient system to have reduced failure probability, reduced consequences from failure, and reduced time to recover. Little[21] examined resilience in the context of infrastructure interdependencies in terms of how to react when a disruption occurs. Lebel *et al.*[22] defined resilience as the potential of a particular configuration of a system to maintain its structure and function in the face of disturbance, and the ability of the system to reorganize following disturbance-driven change. Walker *et al.*[23] defined it as the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks. Holling and Gunderson[24] identified the rate and speed of return to preexisting conditions after disturbance as key elements for measuring resilience. Fiksel[25] examined resilience relating to infrastructure systems that have rigid operating parameters with intrinsic resistance to stress in some narrow bounds and with vulnerability to small, unforeseen perturbations. He conceptually extended the resilience concept from a process to an enterprise. Hollnagel *et al.*[26] examined resilience in the context of anticipating the changing potential for failure on the basis of plans and procedures. Norris *et al.*[27] and Sherrieb *et al.*[28] described disaster resilience as a process, whereas Kahan *et al.*[29] described it as an outcome. Cutter *et al.*[30] described it as a process and outcome. Colten *et al.*[31] defined it to embrace inputs from the engineering, physical, social, and economic sciences. Gilbert[3] defined it from the perspective of economics as the ability to minimize the costs of a disaster, to return to a state as good as or better than the *status quo ante*, and to do so in the shortest feasible time. He also classified definitions reported in the literature as process-oriented or outcome oriented. This classification appropriately covers and is consistent with the definitions provided in this section.

Several reputable entities defined resilience in their high-impact documents, most notably:

- In the Presidential Policy Directive (PPD-21)[32] on Critical Infrastructure Security and Resilience, the "term *resilience* means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."
- The National Research Council[33] defined resilience as the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events as a consistent definition with U.S. governmental agency definitions (SDR,[34] DHS,[35] and PPD-8[36]) and NRC.[37]
- The ASCE Committee on Critical Infrastructure[38] states that resilience refers to the capability to mitigate against significant all-hazards risks and incidents, and to expeditiously recover and reconstitute critical services with minimum damage to public safety and health, the economy, and national security.
- The National Infrastructure Advisory Council defines infrastructure resilience as the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient system depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event.
- The Multidisciplinary Center for Earthquake Engineering Research (MCEER)[39] of the State University of New York at Buffalo lists characteristics of resilience to include robustness, redundancy, resourcefulness, and rapidity.
- UNISDR[19] characterized a resilient city by its capacity to withstand or absorb the impact of a hazard through resistance or adaptation, which enable it to maintain certain basic functions and structures during a crisis, and bounce back or recover from an event.
- The Civil Contingencies Secretariat of the Cabinet Office, London, United Kingdom[40] defined resilience as the ability of a system or organization to withstand and recover from adversity.

Based on these definitions and an understanding of the needs of its broad use ranging from buildings to other structures to infrastructures to networks to communities, an operational definition of resilience should enable its measurement by meeting the following requirements for which metrics are either available or needed:

(1) Building on previous notional definitions and particularly presidential policy directives (PPDs[32,36]);
(2) Considering initial capacity or strength, and residual capacity or strength after a disturbance, i.e., robustness;
(3) Accounting for abilities to prepare and plan for, absorb, recover from, or more successfully adapt to adverse events as provided in the NRC[33] definition;

(4) Treating disturbances as events with occurrence rates and demand intensity, i.e., modeling them as stochastic processes;
(5) Enabling the inclusion of different performances based on corresponding failure modes for various things at risk, such as people, physical infrastructure, economy, key government services, social networks and systems, and environment (MCEER,[39] Gilbert[3]);
(6) Accounting for systems changes over time, in some cases being improved, in other cases growing more fragile or aging;
(7) Considering full or partial recovery and times to recovery;
(8) Considering potential enhancements to system performance after recovery;
(9) Relatable to other familiar notions such as reliability and risk, i.e., building on the relevant metrics of reliability and risk; and
(10) Enabling the development of resilience metrics with meaningful units.

A proposed resilience definition that builds on the PPD-21[32] and lends itself for measurement by meeting the above requirements is as follows:

> Resilience notionally means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from disturbances of the deliberate attack types, accidents, or naturally occurring threats or incidents. The resilience of a system's function can be measured based on the persistence of a corresponding functional performance under uncertainty in the face of disturbances.

This definition is consistent with the ISO[41] risk definition of the "effect of uncertainty on objectives." The proposed measure includes three key words that offer a basis for quantification. These words are listed in a suggested order for their analysis as follows:

- System's performance defined in terms of requirements or objectives, and examined in the form of output, throughput, structural integrity, lifecycle cost, etc.;
- Uncertainty relating to events such as storms, disturbance, conditions, and system states;
- Persistence examined in terms of enduring the events, recovery, continuance, and/or resumption of performance.

Most resilience definitions do not always lend themselves naturally and intuitively to the development of consistent resilience metrics with clear relationships to the most relevant metrics of the abstract notions of reliability and risk. The use of the operative word of *ability* sometimes has resulted in setting the measurement process on tracks that focus on the abilities rather than the outcomes of these abilities. The primary outcome of these abilities is the continuance of performance of a system, including bouncing back, a characteristic that could be appropriately termed as performance persistence for a particular function of the system. Performance persistence would naturally set measurement in terms of availability of the performance or continuance of system's states of normalcy. Subsequent sections of this article provide metrics based on this definition that meet logically consistent requirements drawn partly from measure theory, and provide a sound basis for the development of effective decision-making tools for multihazard environments.

3. MONOTONE MEASURES FOR RESILIENCE

According to Ayyub and Kilr,[42] a *measure* in the context of mathematics is a function that assigns a number to quantify a *notion* as a *metric* representing a subset of a given set, e.g., size, volume, or probability. Some notions are abstract in nature, such as probability and resilience, whereas others are not, such as distance and volume. Measures, in general, build on the concepts of a universal set (X), a nonempty family C of subsets of X with an appropriate algebraic structure, sets (such as A), and the power set (P_A) to establish a logical measure that can be used to characterize some system attributes of interest, i.e., resilience, probability, uncertainty, belief, etc. Classical measures formulated for a universal set X and a family of subsets C such that if $A_i \in C$, it leads to $A_i \subset X$. The family C is called an *algebra*, if the following conditions are met:

$$C \text{ contain the empty set, i.e., } \phi \in C, \tag{1}$$

$$C \text{ contains the entire set } X \text{, i.e., } X \in C, \tag{2}$$

$$\text{For any } A_i \in C, \text{ the complementary set } \bar{A}_i \in C, \tag{3}$$

where ϕ is the empty set, $\in$ means belonging, and the $\subset$ means subsethood. The family is called a σ*-algebra* if it has the following additional property:

$$\text{For } A_i \in C,\ i = 1, 2, \ldots, \bigcup_{all\ i} A_i \in C, \tag{4}$$

where $\bigcup$ means the union over all *i*. In other words, Equation (4) states that the countable union of any family of subsets in *C* belongs to *C*.[43,44]

A measure μ can be defined in its broadest form as a function that maps *C* on to the real line (*R*). This function can be defined mathematically as follows:

$$\mu : C \to R. \tag{5}$$

Of special interest for the purposes of this article is a function that is limited to nonnegative real values (R_+). In probability theory, the probability measure imposes additional requirements on μ consisting of the following:

$$\mu : C \to [0, 1], \tag{6}$$

$$\mu(\phi) = 0, \tag{7}$$

for disjoint $A_j \in C$,

$$i = 1, 2, \ldots, \mu\left(\bigcup_{all\ i} A_i\right) = \sum_{all\ i} \mu(A_i), \tag{8}$$

where any events A_i and A_j meet the following condition:

$$A_i \cap A_j = \phi. \tag{9}$$

Equation (6) limits the mapping to the closed interval of [0,1] with the measure for the null set being zero according to Equation (7). Equation (8) states that the function μ for the union of several disjoint subsets, i.e., with null intersections, is the sum of the measures (i.e., μ values) of these subsets. This *additive property* is unique to this *classical measure* of *probability*. Although the development and evolution of probability theory was based more on intuition rather than mathematical axioms during its early development, an axiomatic basis for probability theory was established and it is now universally accepted.

Generalized measures are employed for representing other than likelihood notions where it makes sense to require that the additivity property of classical measures used in probability theory be replaced with a weaker property of monotonicity with respect to the subsethood relationship. Such measures are called *monotone measures*. Their range is usually the unit interval [0,1], as in probability measures, and it is required that the measure of the universal set be 1. Such measures are called *regular monotone measures*.

A *regular monotone measure* can be defined based on a nonempty family *C* of subsets from P_X

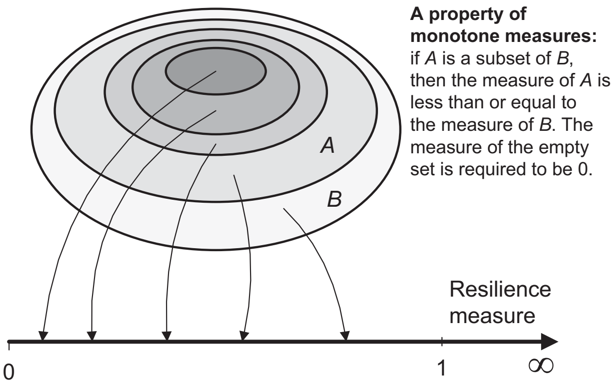


Fig. 1. A monotone measure for resilience.

(i.e., the power set of *X*) for a given universal set *X*, which contains ϕ and *X*, with an appropriate algebraic structure as a mapping from *C* to [0,1]. A monotone measure must satisfy the following conditions:

(1) Boundary condition: The monotone measure must meet the following *boundary conditions*:

$$\mu(\phi) = 0 \quad \text{and} \quad \mu(X) = 1. \tag{10}$$

(2) Monotonicity: This property is illustrated in Fig. 1.

$$\text{For all } A_i \text{ and } A_j \in C, \text{ if } A_i \subseteq A_j, \text{ then } \mu(A_i) \leq \mu(A_j). \tag{11}$$

(3) Continuity from below:

$$\text{For any increasing sequence } A_1 \subseteq A_2 \subseteq \cdots \text{ of sets in } C, \text{ if } \bigcup_{all\ i} A_i \in C, \text{ then } \lim_{i\to\infty} \mu(A_i) = \mu\left(\bigcup_{all\ i} A_i\right). \tag{12}$$

(4) Continuity from above:

$$\text{For any decreasing sequence } A_1 \supseteq A_2 \supseteq \cdots \text{ of sets in } C, \text{ if } \bigcap_{all\ i} A_i \in C, \text{ then } \lim_{i\to\infty} \mu(A_i) = \mu\left(\bigcap_{all\ i} A_i\right). \tag{13}$$

Functions μ that satisfy Equations (10), (11), and either Equations (12) or (13) are called *semicontinuous from below and from above*, respectively.

For any pair A_1 and $A_2 \in C$ such that $A_1 \cap A_2 = \phi$, a monotone measure μ is capable of capturing any of the following situations:[42,45,46]

$$\mu(A_1 \cup A_2) > \mu(A_1) + \mu(A_2), \tag{14}$$

called *superadditivity*, which expresses a cooperative action or synergy between A_1 and A_2 in terms of the measured property,

$$\mu(A_1 \cup A_2) = \mu(A_1) + \mu(A_2), \tag{15}$$

called *additivity,* which expresses the fact that A_1 and A_2 are *noninteractive* with respect to the measured property, and

$$\mu(A_1 \cup A_2) < \mu(A_1) + \mu(A_2), \tag{16}$$

called *subadditivity*, which expresses some sort of inhibitory effect or incompatibility between A_1 and A_2 as far as the measured property is concerned.

Probability theory, which is based on the classical measure theory, is capable of capturing only the situation of Equation (15). This demonstrates that the theory of monotone measures provides us with a considerably broader framework than probability theory for formalizing a measure for resilience. The metric for resilience should be consistent with the way mathematical measures are developed by (1) having a state space defined by the desired performances, (2) using real lines for the performance metrics to define appropriate sigma algebra over the state space, and (3) meeting the monotonic property.

4. RESILIENCE MEASUREMENT AND METRICS

In previous sections, a resilience definition of "the persistence of a system's performance under uncertainty in disturbances and its states" is proposed to be consistent with the ISO[41] risk definition of the "effect of uncertainty on objectives." Before proposing metrics for resilience, the article examines other models found in the literature and discusses their purposes and limitations. It should be noted that some of the limitations stem from not only the resilience notion's ambiguous nature but also from its ambiguous definition as an abstract notion. In this section, available metrics are summarized followed by a proposed model.

4.1. Available Resilience Metrics

Bruneau and Reinhorn[20] proposed metrics for measuring resiliency based on the size of expected

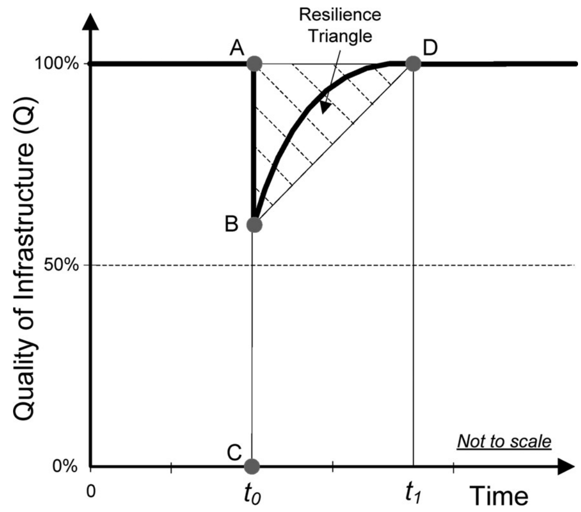


Fig. 2. The resilience properties and triangle.

degradation in the quality of an infrastructure by quantifying robustness, redundancy, resourcefulness, and rapidity to recovery. Garbin and Shortle[47] outline an approach to quantitatively measure the resilience of a network as the percentage of links damaged versus the network performance and the percentage of nodes damaged versus the network performance. Tierney and Bruneau[48] suggested measuring resilience based on observing that resilient systems reduce the probabilities of failure and enhance recovery, and therefore resilience can be measured by the functionality of an infrastructure system after an external shock including the time it takes to return to initial level of performance. They illustrated the concept as shown in Fig. 2 calling it the resilience triangle. Attoh-Okine *et al.*[49] used several potential paths of infrastructure performance during normal operation and cases of unexpected events, for example, a path demonstrating sudden failure as shown in Fig. 2, a path demonstrating decrease in service life, and a path for the normal operation of the system. They used the concept of resilience as illustrated in Fig. 2 to define a resilience index as follows:

$$\text{Resilience} = \frac{\int_{t_0}^{t_1} Q(t)dt}{100(t_0 - t_1)}, \tag{17}$$

where Q is the infrastructure quality, or the performance of a system, t_0 is the time of incident or disturbance occurrence, and t_1 is the time to full recovery. According to this model, the units of resilience are performance per unit time, where performance can be measured in percent according to

Table I. Definition of Resilience Properties

Property	Models (Points A, B, C, and D per Fig. 2)	Units	
Robustness	Robustness = B – C	Percentage	(18)
Redundancy	Not defined		
Resourcefulness	Not defined		
Rapidity	Rapidity $= \frac{A-B}{t_0-t_1}$	Average recovery rate in percentage per time	(19)

Equation (17). Equation (17) was also used by the earthquake community[48] with a suggested framework of resilience, called the four "Rs," as follows:

- Robustness as the ability of the system and system elements to withstand external shocks without significant loss of performance;
- Redundancy as the extent to which the system and other elements satisfy and sustain functional requirements in the event of disturbance;
- Resourcefulness as the ability to diagnose and prioritize problems and to initiate solutions by identifying and monitoring all resources, including economic, technical, and social information; and
- Rapidity as the ability to recover and contain losses and avoid future disruptions.

These properties are defined in Table I with reference to Fig. 2 based on models provided by Shinozuka *et al.*[50]

Li and Lence[51] refined the resilience index developed by Hashimoto *et al.*[52] by using the performance ratio over two different time periods. Omer *et al.*[53] measure resilience for Internet infrastructure systems as the ratio of the difference in information transmission before, i.e., initial, and after an event divided by the initial information transmission. Attoh-Okine *et al.*[49] also provided formulation of a resilience index of urban infrastructure using belief functions. McGill and Ayyub[54] related resilience concepts to regional capabilities performance assessment for human-caused hazards in homeland security.

Gilbert[3] provides extensive coverage of and mathematical models for recovery after a storm in the context of a disaster cycle consisting of response, recovery, mitigation, and preparedness. He includes in his discussion partial recovery and full recovery including instant urban renewal of population recovery, physical infrastructure, economy, social networks, government services, and environments. He also develops simulation models of recovery and provides validation examples for the Kobe Earthquake.[55] Generally, the recovery trends shown have decreasing slopes as shown in Fig. 2.

4.2. Proposed Resilience Model

Fig. 3 provides a schematic representation of a system performance (Q) with aging effects and an incident occurrence with a rate (λ) according to a Poisson process. At time t_i, it might lead to a failure event with a duration ΔT_f. The failure event concludes at time t_f. The failure event is followed by a recovery event with a duration ΔT_r. The recovery event concludes at time t_r. The total disruption (D) has a duration of $\Delta T_d = \Delta T_f + \Delta T_r$. The figure shows for illustration purposes three failure events: brittle ($f1$), ductile ($f2$), and graceful ($f3$), and six recovery events: expeditious recovery to better than new ($r1$), expeditious recovery to as good as new ($r2$), expeditious recovery to better than old ($r3$), expeditious recovery to as good as new ($r4$), recovery to as good as old ($r5$), and recovery to worse than old ($r6$). These events define various rates of change of performance of the system. The figure also shows the aging performance trajectory and the estimated trajectory after recovery. The proposed model to measure resilience is:

$$\text{Resilience}\,(R_e) = \frac{T_i + F\Delta T_f + R\Delta T_r}{T_i + \Delta T_f + \Delta T_r}, \qquad (20)$$

where for any failure event (f) as illustrated in Fig. 3, the corresponding *failure profile F* is measured as follows:

$$\text{Failure}\,(F) = \frac{\int_{t_i}^{t_f} f\,dt}{\int_{t_i}^{t_f} Q\,dt}. \qquad (21)$$

Similarly for any recovery event (r) as illustrated in Fig. 3, the corresponding *recovery profile R* is measured as follows:

$$\text{Recovery}(R) = \frac{\int_{t_f}^{t_r} r\,dt}{\int_{t_f}^{t_r} Q\,dt}. \qquad (22)$$

The failure-profile value (F) can be considered as a measure of robustness and redundancy, and is proposed to address the notion offered by Equation (18), whereas the recovery-profile value (R) can be considered as a measure of resourcefulness and rapidity, and is proposed to address the notion offered by Equation (19). The time to failure (T_f) can be

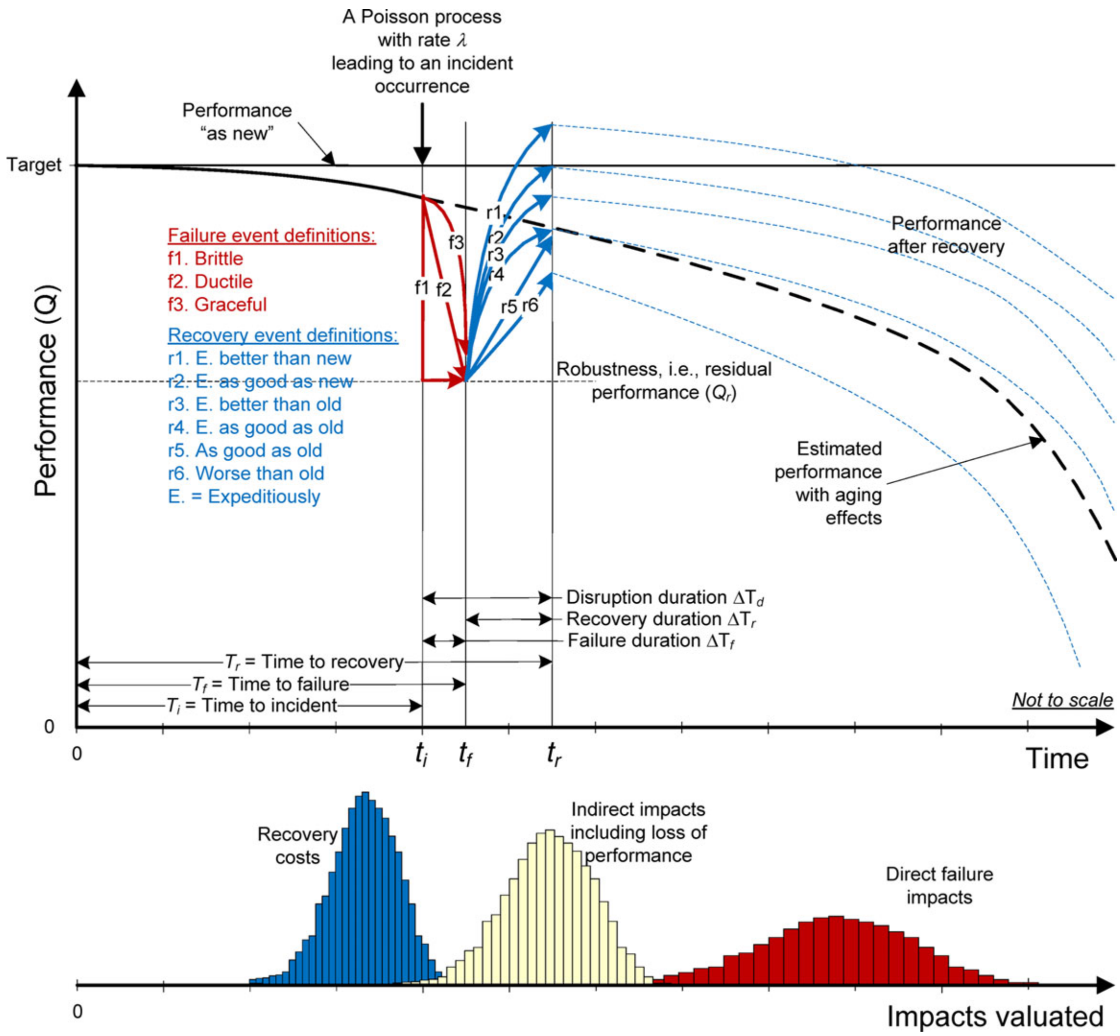


Fig. 3. Proposed definitions of resilience metrics.

characterized by its probability density function computed as follows:

$$-\frac{d}{dt}\int_{s=0}^{\infty}\exp\left[-\lambda t\left(1-\frac{1}{t}\int_{\tau=0}^{t}F_L(\alpha(\tau)s)d\tau\right)\right]f_{S_0}(s)ds, \tag{23}$$

where Q is defined as the system's performance in terms of its strength (S) minus the corresponding load effect (L) in consistent units, i.e., $Q = S - L$. Both L and S are treated as random variables, with $F_L =$ the cumulative probability distribution function of L, and $f_S =$ the probability density function of S. The aging effects are considered in this model by the term $\alpha(t)$ representing a degradation mechanism as a function of time t. It should be noted that the term $\alpha(t)$ can also represent improvement to the system. Equation (23) is based on a Poisson process with an incident occurrence, such as loading, rate of λ, and is based on Ellingwood and Mori.[56] The probability density function of T_f as shown in Equation (23) is the negative of the derivative of the reliability function.

The proposed model of Equation (20) for measuring resilience meets the set of requirements described in the section on the resilience definition according to the following list of respective items:

(1) The model is consistent with the PPD-21[32] definition.
(2) The model accounts for the initial and residual capacities as noted in Fig. 3 with the performance "as new" and the robustness.

(3) The use of the time to failure and time to recovery accounts for the abilities to prepare and plan for, absorb, recover from, or more successfully adapt to adverse events as provided in the NRC[33] definition.
(4) The disturbances are treated as events with occurrence rates and demand intensity, i.e., modeling them as stochastic processes.
(5) The model permits the use of different performances based on corresponding failure modes for various things at risk, such as people, physical infrastructure, economy, key government services, social networks and systems, and environment.
(6) The model accounts for systems changes over time, in some cases being improved, in other cases growing more fragile or aging.
(7) The model accounts full or partial recovery and times to recovery as illustrated in Fig. 3.
(8) The model accounts for potential enhancements to system performance after recovery.
(9) The model can be related to other familiar notions such as reliability and risk according to Equation (23).
(10) The model requires input with meaningful units, is unit-consistent, and produces results with meaningful units.

The model of Equation (20) also meets the monotone conditions of Equations (6)–(13) by having the following attributes:

$$R_e : (f \cap r) \in C \rightarrow [0, \infty), \tag{24}$$

$$R_e(\phi) = 0. \tag{25}$$

For disjoint $A_i \in C,\ i = 1, 2, \ldots,$

$$R_e\left(\bigcup_{all\ i} A_i\right) = \sum_{all\ i} R_e(A_i). \tag{26}$$

It should be noted that $F{:}f \rightarrow [0, 1]$ and $R{:}r \rightarrow [0, \infty)$. The times T_i, T_f, and T_r are random variables as shown in Fig. 3, and are related to durations as follows:

$$\Delta T_f = T_f - T_i, \tag{27}$$

$$\Delta T_r = T_r - T_f. \tag{28}$$

The disruption duration is given by:

$$\Delta T_D = \Delta T_f + \Delta T_r. \tag{29}$$

4.3. Performance Measurement for Resilience Metrics

The resilience model of Equation (20) can be used for systems, such as buildings, other structures, facilities, infrastructure, networks, and communities. The primary basis for evaluating Equation (20) is the definition of performance (Q) at the system level with meaningful and appropriate units, followed by the development of an appropriate breakdown for this performance, using what is termed herein as performance segregation. The performance segregation should be based on some system-level logic that relates the components of the performance breakdown to the overall performance at the system level as the basis for a system model. This model can be used to aggregate the performance of components to assess system-level performance. Such performance segregation and aggregation analysis is essential for examining the resilience of systems for buildings, other structures, facilities, infrastructure, networks, and communities. The uncertainties associated with the performance components can be modeled as random variables with any necessary performance events to use Boolean algebra and the mathematics of probability to characterize the performance Q in Equation (20).

MCEER[39] proposed the use of resilience index (R_i) in the range [0, 1] for each (the ith) quality of service, and an aggregation model for these resilience indices using an independence assumption. For example, in the case of two indices, the aggregated index is as follows:

$$\text{Resilience}\,(R_{12}) = \frac{R_1 . R_2}{R_1 + R_2 - R_1 . R_2}. \tag{30}$$

Fig. 4 shows a plot of Equation (30) for the case of two identical indices, i.e., resilience components, for the entire range of values of R_i. The figure also shows the effect of increasing the number of components from one to ten. The downward intensification is attributed to the independence assumptions.

The development of such a system-level model relating components' performances to a system performance is beyond the scope of this article. Such a model is domain specific; however, future studies should set meta-methodological requirements for the development of such models. Anthony[57] discussed challenges associated with the treatment of system-level resilience, such as communities, and provided illustrations.

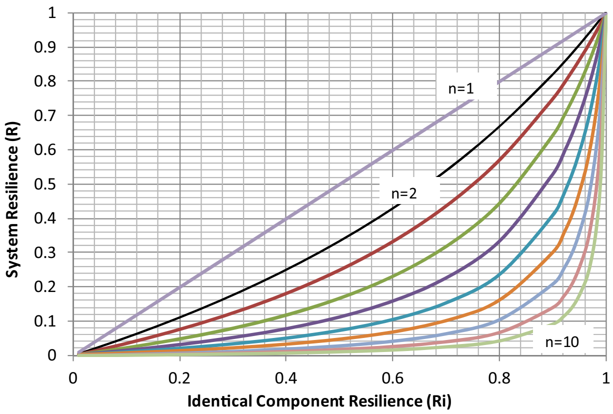


Fig. 4. System resilience aggregate based on two identical resilience components.

Table II. Systems and Performance Measurements

Systems	Performance	Units
Buildings	Space availability	Area per day
Other structures: Highway bridges	Throughput traffic	Count per day
Facilities: Water treatment plants	Water production capacity	Volume per day
Infrastructure: Water delivery	Water available for consumption	Volume
Network: Electric power distribution	Power delivered	Power per day
Communities	Economic output	Dollars
Communities	Quality of life (consumption)	Dollars

The units of performance at the system level vary depending on the system type and the objectives of the analysis. Table II shows examples of performance types and units of measurement for selected systems for demonstration purposes.

5. ECONOMIC VALUATION AND BENEFIT-COST ANALYSIS

Improving the resiliency of a system to meet target levels requires the examination of system enhancement alternatives in economic terms, within a decision-making framework. Relevant decision analysis methods would typically require the examination of resilience based on its valuation by society at large. Methods for the total economic valuation of resilience are needed, and should satisfy the essential requirement of consistency with respect to the definition and metrics of resilience. Concepts from risk analysis and management can be used for this purpose.[58]

Valuation can be approached broadly from philosophy and particularly from ethics to make distinctions among values such as (1) instrumental and intrinsic values, (2) anthropocentric and biocentric (or ecocentric) values, (3) existence value, and (4) utilitarian and deontological values.[59,60] The focus of this section is on economic valuation; however, it is necessary to introduce and discuss these distinctions. An ecosystem is used as an example to discuss these distinctions.

For an ecosystem, the instrumental value is derived from its role as a means toward an end other than itself, i.e., its value is derived from its usefulness in achieving a goal. In contrast, intrinsic value, also called noninstrumental value, is its existence independently of any such contribution defined by usefulness. For example, if an animal population provides a source of food for either humans or other species, it has instrumental value that stems from its contribution or usefulness to the goal of sustaining the consuming population. If it continues to have value even if it were no longer useful to these populations, e.g., if an alternative, preferred food source were discovered, such a remaining value would be its intrinsic value. For example, a national park, such as the Grand Canyon, has an intrinsic value component that exists unrelated or independent of direct or indirect use by humans for recreation or investigation. Such an intrinsic value can also stem from cultural sources, such as monuments and burial grounds.[60]

An anthropocentric value system considers humankind as the central focus or final goal of the universe, human beings as the only thing with intrinsic value, and the instrumental value of everything else is derived from its usefulness in meeting human goals. On the other hand, a biocentric value system, i.e., nonanthropocentric, assigns intrinsic value to all individual living systems, including but not limited to humans, and assumes that all living systems have value even if their usefulness to human beings cannot be determined or can be harmful to human beings.

Existence value reflects the desire of human beings to preserve and ensure the continued existence of certain species or environments to provide for humankind welfare, making it an anthropocentric and utilitarian concept of value and within the domain of instrumental value system. Therefore, utilitarian values are instrumental in that they are viewed as a means toward the end result of increased human welfare as defined by human preferences, without any value judgment about these preferences. The value of particular species or environments comes from generating welfare to human beings, rather than from the intrinsic value of these nonhuman species. This definition permits the potential for substitution or replacement of this source of welfare with an alternative source, i.e., the possibility of a welfare-neutral tradeoff between continued existence of species or environments and other things that also provide the same utility.

The deontological value system is based on an ethical doctrine for assigning worth for an action by its conformity to some binding rule rather than by its consequences. In this case, a deontological value system implies a set of rights that include the right of existence. Something with intrinsic value is irreplaceable and its loss cannot be offset by having more of something else. For example, the death of person is a loss of an intrinsic value because it cannot be offset or compensated by that person having more of something else. The contentious issue is whether this concept should be extended to nonhuman species, for example, animals, either individual animals or species, or all biological creatures, i.e., all plant and animal life, collectively called the biota. In the context of ecosystem valuation, the modern notion of intrinsic value extends the rights beyond human beings. On the other hand, utilitarian values are based on providing utilities.

In this article, the use of a valuation approach with the following characteristics is proposed:

- Anthropocentric in nature based on utilitarian principles.
- Consideration of all instrumental values, including existence value.
- Its utilitarian basis to permit the potential for substitution among different sources of value that contribute to human welfare.
- Individuals' preferences or marginal willingness to trade one good or service for another that can be influenced by culture, income level, and information, making it time and context specific
- Societal values as the aggregation of individual values.

This approach is consistent with NRC[60] and does not capture nonanthropocentric values, e.g., biocentric values and intrinsic values as related to rights. In some decisions, including environmental policy and law, biocentric intrinsic values should be included in agreement with previous practices, e.g., the Endangered Species Act of 1973.

A total economic value (TEV) framework can be constructed based on the above characteristics and using individual preferences and values. The TEV framework is necessary to ensure that all components of value are recognized and included while avoiding double counting of values.[61,62]

Economic valuation, as commonly used in decision analysis, is defined as the worth of a good or service as determined by the market. Economists have dealt with this concept initially by estimating the value of a good to an individual alone, and then extend it broadly as it relates to markets for exchange between buyers and sellers for wealth maximization.

Traditionally, the value of a good or service is linked to its price in an open and competitive market determined primarily by the demand relative to supply. Therefore, goods, property, assets, safety of people, service, etc. are treated as commodities, and if there is no market to set the price of a commodity then it has no economic value. Therefore, the value refers to the market worth of a commodity, which is determined by the equilibrium at which two commodities are exchanged. The limitation herein is in its inability to set a value to things that are not exchanged in markets.

In the labor theory of value, a good or service is associated with the amount of discomfort or labor saved through the consumption or use of it. According to this theory, the exchange value is recognized without recognizing its equivalence to an economic value, i.e., price and value are considered as two different concepts. Accordingly, a value is determined based on the exchange price, which does not necessarily represent its true economic value.

An economic measure of the value of a good or the benefit from a service can be defined as the maximum amount a person is willing to pay for this good or service. The concept of willingness to pay (WTP) is central to economic valuation. An alternate measure is the willingness to accept (WTA) of an amount by the person to forgo taking possession of the good or receiving the service. WTP and WTA produce amounts that are expected to be close; however, generally WTA generated amounts are greater than WTP generated amounts due primarily to income levels and affordability factors.

The economic concept of value, including its exchange value, can be criticized as being stripped from moral and ethical considerations. For example, having an exchange value for a good or a service that is harmful in nature, e.g., markets of illegal drugs or gambling or prostitution or weaponry, have value in some open markets, in some underground markets, and no value in others. Contrarily, not having an exchange value for a good or a service that is good in nature, e.g., volunteer work, might not have a market value but this does not necessarily make it without any value. Accounting for such moral and ethical considerations in economic models can be contentious, and commonly such goods or services are ignored. To perform tradeoff analysis, resilience should be treated in these economic terms.

The valuation of resilience can be based on the savings in potential direct and indirect losses, and cost of recovery as illustrated in Fig. 3. Alternatives for enhancing resilience that can reduce these potential losses can be analyzed using models for benefit-cost analysis, where the benefit (B) is the potential savings in losses and recovery costs because of the implementation of an alternative and the cost (C) is the cost of the alternative. The benefit and costs are treated as random variables.[58] Assuming B and C to be normally distributed, a benefit-cost index ($\beta_{B/C}$) can be defined as follows:

$$\beta_{B/C} = \frac{\mu_B - \mu_C}{\sqrt{\sigma_B^2 + \sigma_C^2}}, \tag{31}$$

where μ and σ are the mean and standard deviation. The probability of cost exceeding benefit can be computed as:

$$P_{f,B/C} = P(C > B) = 1 - \Phi(\beta), \tag{32}$$

where Φ is the standard normal cumulative distribution function. In the case of lognormally distributed B and C, the benefit-cost index ($\beta_{B/C}$) can be computed as:

$$\beta_{B/C} = \frac{\ln\left(\frac{\mu_B}{\mu_C}\sqrt{\frac{\delta_C^2+1}{\delta_B^2+1}}\right)}{\sqrt{\ln[(\delta_B^2+1)(\delta_C^2+1)]}}, \tag{33}$$

where δ is the coefficient of variation. In the case of mixed distributions or cases involving basic random variables of B and C, other reliability methods can be used as described by Ayyub.[58]

6. CONCLUSIONS

Enhancing the resilience of a system, including buildings, infrastructure, network, and communities, could lead to massive savings through risk reduction and expeditious recovery. In this article, a resilience definition is provided that meets a set of requirements with clear relationships to metrics of the relevant abstract notions of reliability and risk. Those metrics also meet logically consistent requirements drawn from measure theory, and provide a sound basis for the development of effective decision-making tools for multihazard environments. The proposed metrics provide a strong basis for the rational management of such reduction and recovery facilitated by an appropriate definition of resilience and associated metrics. Also, the article provides a framework for the valuation of resilience by society at large, methods for benefit-cost analysis based on concepts from risk analysis and management. Although resilience valuation is in its infancy and additional work is necessary along with case studies, this article offers a basis for such efforts.

ACKNOWLEDGMENTS

The author would like to acknowledge the discussion and insights provided by the University of Delaware Professor Nii Attoh-Okine, and Dr. Emil Simiu of the National Institute of Standards and Technology (NIST). Initial versions of this work were presented at a panel discussion on resilience engineering at the sixth Congress on Forensic Engineering, San Francisco, CA, on November 1, 2012, and NIST's Engineering Laboratory on December 19, 2012, and the article benefited from the comments received. On April 11, 2013, the University of Maryland, the National Academy of Engineering and the State of Maryland, in cooperation with the National Science Foundation, Virginia Tech, the University of Delaware, the University of the District of Columbia, and the University of Virginia hosted a by-invitation symposium to examine the state of knowledge with respect to the development of infrastructure, regional, and community resilience to natural and human-caused disasters, and to discuss actions that might be taken by governments, academe, and the public and private sectors to achieve resilience. Symposium participants represented federal, state, and local governments from Delaware, Maryland, Virginia, and the District of Columbia, and businesses and universities with interests and expertise in infrastructure and community resilience. The author would also like to thank his co-chair of this symposium, Professor Gerry Galloway of the University of Maryland, and the participants at this symposium for comments received based on his presentation of some aspects of this article.

APPENDIX A: SELECTED URBAN AREAS AND HAZARDS

Table A1. Selected Urban Areas, Their Respective Population Sizes, Location Attributes, and Hazards as a Summary of the Data Reported by UNISDR(1)

Urban Area and Population	Location Attributes	Hazards
Santa Fe, Argentina 400,000	The flood plain of the Parana and Salada Rivers	Flooding and intense rainfall
Cairns, Australia 164,356	A coastal town in the wet tropics, northern Queensland	Cyclones, flooding, storm surge, and tsunamis
Tyrol Province, Austria 712,077	Western Austria, consisting of nine districts	Flooding and landslides
Thimphu, Bhutan 79,185	Landlocked state in South Asia, east of the Himalayas	Prone to earthquakes, landslides, cyclones, and flooding
North Vancouver, Canada 82,000	Coastal municipality in southwest British Columbia on the mountainsides	Landslides, flooding, and wildfire
Valle de Itata, Chile 80,762	Northwest of the bio region of Chile	Flooding, extreme wind and rain, wildfire, and earthquakes
Baofeng, China 498,000	Henan Province	Drought, flooding, wind, snowstorms, and earthquakes
Siquirres, Costa Rica 59,000	Limon Province, in the plane of the Talamanca mountains	Flooding, landslides
Copenhagen, Denmark 1,213,822	Eastern shore of the island of Zealand, partly on the island of Amager and on a number of natural and artificial islets	Flooding and landslides
Dubai, United Arab Emirates 2,200,000	Southeast of the Persian Gulf on the Arabian Peninsula	Drought, heat waves, sand storms
Quito, Ecuador 2,197,698	Northeast of the country at 2,800 m above sea level	Volcanic hazards, earthquakes, landslides, and flooding
Santa Tecla, El Salvador 200,000	Part of the metropolitan area of the country's capital, San Salvador	Earthquakes, landslide, and flooding risks
Bonn, Germany 300,000	About 25 km south of Cologne on the river Rhine	Flooding from the Rhine and recently extreme heat waves during summer
Bhubaneswar, India 1,000,000	In the Khurda District, Orissa	Earthquakes, flooding, cyclones, heat waves
Pune, India 5,000,000	At the confluence of three rivers: the Mutha, Mula, and Pavana at 560 m above sea level	Flooding
Mumbai, India 19,700, 000	A coastal megacity built on what used to be a group of seven islands, many areas are only 5 m above low tide level	Coastal flooding
Makassar, Indonesia 1,400,000	Southwest coast of the island of Sulawesi, facing the Makassar Strait	Tsunamis and flooding
Jakarta, Indonesia 9,800,000	Situated in the northwest coast of Java, at the mouth of the Ciliwung River on Jakarta Bay, which is an inlet of the Java Sea	Earthquakes and flooding
Mashhad, Iran 2,420,000	850 km east of Tehran at 950 m elevation in the valley of the Kashaf River between two mountain ranges	Flooding, cyclones, earthquakes, and drought
Venice, Italy 263,996	On a group of 118 islands in the Venice Lagoon	Flooding as a result of low (and falling) elevation
Ancona, Italy 100,000	Adriatic coast, south of Venice	Most significant hazard is landslides
Saijo, Japan 114,625	Mountainous terrain in Ehime Prefecture	Extreme rainfall, typhoons, mudslides, landslides, and flooding
Aqaba, Jordan 108,500	Coastal city situated at the northeastern tip of the Red Sea	Drought, heat waves
Narok, Kenya 60,000	Southern side of the Rift Valley and has varied topography, with a predominantly agricultural economy base	Flooding and drought

(*Continued*)

Table A1. Continued

Urban Area and Population	Location Attributes	Hazards
Kisumu, Kenya 200,000	Port city in western Kenya	Flooding
Beirut, Lebanon 1,500,000	On a peninsula at the midpoint of Lebanon's Mediterranean coast	Earthquakes, flooding, wildfires, and landslides
Kathmandu, Nepal 1,000,000	Situated in central Nepal bowl-shaped valley between four major mountains, at high elevation	Earthquakes and landslides
Telica, Quezalguaque and Larreynaga-Malpaisillo, Nicaragua 71,000	Basin of the Leon	Volcanic, seismic, hurricanes, flooding, epidemics, environmental risks linked to gold mining, and monoagriculture
Pakistan 30 cities	Varies	Landslides, flooding, storms, cyclones, earthquake, drought, fire, epidemics, riots, and conflicts
Chincha, Pisco, Cañete, and Ica, Peru 536,000	Peru's Pacific coast	Earthquakes and flooding
Albay, Philippines 1,000,000	Albay Province	Typhoons, storm surge, volcanoes, landslides, tsunamis, and flooding
Amadora, Portugal 175,135	Northwest of the Lisbon metropolitan area	Earthquake, flood, heat wave, land slide, technological disasters
Makati, Philippines 510,383 to 3,700,000 (daytime)	West valley fault system	Earthquakes, flooding, and landslides
San Francisco, Philippines 48,834	Small island within the Camotes Island group and part of the province of Cebu	Flooding and landslide
Quezon City, Philippines 1,700,000	Largest and most populous	Flooding, earthquakes, fire, and epidemic
Cape Town, South Africa 3,700,000	Coastal area	Storm surge, heat wave, flooding, fires, and drought
Johannesburg, South Africa 3,500,000	In the eastern plateau area of South Africa known as the Highveld, at an elevation of 1,753 m	Intense rainfall and flooding
Overstrand, South Africa 76,000	Situated in the Western Cape Province of South Africa	Drought, flooding, and fire
Batticaloa, Sri Lanka 515,857	Situated in the East Province, and the administrative capital of the Batticaloa	Civil unrest in the area (ended in 2009), Indian Ocean tsunami
Colombo, Sri Lanka 647,100	On the west coast of the island and adjacent to Sri Jayawardenapura Kotte	Flooding, typhoons, earthquakes, landslides, fires, and tsunami
Moshi, Tanzania 150,000	A market hub town in northeastern Tanzania at the foot of Mount Kilimanjaro	Drought and flooding
Bangkok, Thailand 9,700,000	Coastal in Southeast Asia	Flooding
Istanbul, Turkey 13,000,000	In northwestern Turkey within the Marmara Region on a total area of 5,343 km^2	Earthquakes
San Francisco, California, USA 805,235	West coast of the United States, at the tip of the San Francisco Peninsula including significant stretches of the Pacific Ocean	Wild fire, tsunami, landslide, heat wave, flooding, earthquake, drought
Chacao, Venezuela 71,000	Mideastern portion of the Caracas Valley, north of the Guaire River	Earthquake and flooding

REFERENCES

1. UNISDR. Making cities resilient: My city is getting ready! A global snapshot of how local governments reduce disaster risk, United Nations Office for Disaster Risk Reduction Report, Geneva, Switzerland, 2012. Available at: www.unisdr.org/campaign.
2. Ayyub BM, Braileanu HG, Qureshi N. Prediction and impact of sea level rise on properties and infrastructure of Washington, DC. Risk Analysis, 2012; 32(11):1901–1918.
3. Gilbert, SW. Disaster Resilience: A Guide to the Literature. NIST Special Publication 1117, Office of Applied Economics, Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, 2010.
4. Burby R (ed). Cooperating with Nature: Confronting Natural Hazards and Land-Use Planning for Sustainable Communities. Washington, DC: Joseph Henry Press, 1998.
5. Berke P, Kartez J, Wenger D. Recovery after disaster: Achieving sustainable development, mitigation and equity. Disasters, 2008; 17:93–109.
6. ASCE. Report Card for America's Infrastructure, Reston, VA: ASCE, 2009.
7. Holling CS. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics, 1973; 4: 1–23.
8. Starr C, Rudman R, Whipple C. The philosophical basis for risk analysis. Annual Review of Energy, 1976; 1:629–662.
9. Webster's New World Dictionary & Thesaurus. New York: Macmillan Publishers, 1998.
10. Park J, Seager TP, Rao PSC, Convertino M, Linkov I. Integrating risk and resilience approaches to catastrophe management in engineering systems. Risk Analysis, 2012; 33(3):356–367.
11. Bruneau M, Chang SE, Eguchi RT, Lee GC, O'Rourke TD, Reinhorn AM, Shinozuka M, Tierney K, Wallace WA, vonWinterfeldt D. A framework to quantitatively assess and enhance the seismic resilience of communities. Earthquake Spectra, 2003; 19:733–752.
12. Flynn, S. The Edge of Disaster: Rebuilding a Resilient Nation. New York: Random House, 2007.
13. Gunderson, L. Ecological and human community resilience in response to natural disasters. Ecology and Society, 2010; 15(2):18. Available at: http://www.ecologyandsociety.org/vol15/iss2/art18/, Accessed June 25, 2013.
14. Rose A. Economic Resilience to Disasters, CARRI Research Report 8. Community and Regional Resilience Initiative, Available at: http://research.create.usc.edu/cgi/viewcontent.cgi?article=1015&context=published_papers, Accessed June 25, 2013.
15. Cutter SL, Burton CG, Emrich CT. Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management, 2010; 51: 7(1); DOI: 10.2202/1547-7355.1732.
16. Plodinec MJ, Definitions of Resilience: An Analysis. Community and Regional Resilience Initiative, Oak Ridge, TN, 2009. Available at: http://www.resilientus.org/library/CARRI_Definitions_Dec_2009_1262802355.pdf
17. White GF, Haas JE. Assessment of Research on Natural Hazards. Cambridge, MA: MIT Press, 1975.
18. Mileti D. Disasters by Design: A Reassessment of Natural Hazards in the United States. Washington, DC: Joseph Henry Press, 1999.
19. United Nations Office for Disaster Risk Reduction (UNISDR). Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters. Geneva, Switzerland, 2007. Available at: http://www.unisdr.org/files/1037_hyogoframeworkforactionenglish.pdf, Accessed June 25, 2013.
20. Bruneau M, Reinhorn A. Exploring the concept of seismic resilience for acute care facilities. Earthquake Spectra, 2007; 23(1):41–62.
21. Little RG. Toward More Robust Infrastructure: Observations on Improving the Resilience and Reliability of Critical Systems, in Proceedings of the 36th Annual Hawaii International Conference Hawaii, IEEE, 2003; 1–9.
22. Lebel L, Anderies JM, Campbell B, Folke C, Hatfield-Dodds S, Hughes TP, Wilson J. Governance and the capacity to manage resilience in regional social-ecological systems. Ecology and Society, 2006; 11(1), 19. Available at: http://www.ecologyandsociety.org/vol11/iss1/art19/, Accessed June 25, 2013.
23. Walker B, Holling CS, Carpenter SR, Kinzig A. Resilience, adaptability and transformability in social–ecological systems. Ecology and Society, 2004; 9(2), 5. Available at: http://www.ecologyandsociety.org/vol9/iss2/art5/, Accessed June 25, 2013.
24. Holling CS, Gunderson LH. A working hypothesis for participation: Panarchy, sustainability and panarchies. Pp. 63–102 in Gurdeson LH, Holling CS (eds). Panarchy and Understanding in Human and Natural Systems. Washington, DC: Island Press, 2002.
25. Fiksel J. Designing resilient and sustainable system. Environmental Science and Technology, 2003; 27:5330–5339.
26. Hollnagel E, Woods DE, Levensen N. Resilience Engineering: Concepts and Precepts. Aldershot, UK: Ashgate Publishing, 2006.
27. Norris FH, Stevens SP, Pfefferbaum B, Wyche KF, Pfefferbaum RL. Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. American Journal of Community Psychology, 2008; 41:127–150.
28. Sherrieb K, Norris FH, Galea S. Measuring capacities for community resilience. Social Indicators Research, 2010; 99(2):227–247.
29. Kahan JH, Allen AC, George JK. An operational framework for resilience. Journal of Homeland Security and Emergency Management, 2009; 6(1):1–48. Available at: www.bepress.com/jhsem/vol6/iss1/83, Accessed June 25, 2013.
30. Cutter SL, Barnes L, Berry M, Burton C, Evans E, Tate E, Webb J. A place-based model for understanding community resilience to natural disasters, Global Environmental Change, 2008; 18:598–606.
31. Colten CE, Kates RW, Laska SB. Three years after Katrina: Lessons for community resilience. Environment, 2008; 50(5):36–47.
32. Presidential Policy Directive (PPD), Critical Infrastructure Security and Resilience. PPD-21, Released February 12, 2013. Available at: http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil, Accessed June 25, 2013.
33. National Research Council (NRC). Disaster Resilience: A National Imperative. Washington, DC: National Academies Press, 2013.
34. Subcommittee on Disaster Reduction (SDR). Grand Challenges for Disaster Reduction, Washington DC: National Science and Technology Council, 2005.
35. DHS Risk Steering Committee. DHS Risk Lexicon. Department of Homeland Security, 2008. Available at: www.dhs.gov/xlibrary/assets/dhs_risk_lexicon.pdf, Accessed June 25, 2013.
36. Presidential Policy Directive (PPD). National Preparedness. PPD-8, Released March 30, 2011. Available at: http://www.dhs.gov/xabout/laws/gc_1215444247124.shtm, Accessed June 25, 2013.
37. National Research Council (NRC). National Earthquake Resilience: Research, Implementation, and Outreach. Washington, DC: National Academies Press, 2011.
38. ASCE Policy Statement 518. Available at: http://www.asce.org/Content.aspx?id=8478, Accessed June 25, 2013.

39. MCEER. PEOPLES: A Framework for Defining and Measuring Disaster Resilience. Working Paper, Multidisciplinary Center for Earthquake Engineering Research (MCEER) of the State University of New York at Buffalo, 2010.
40. Civil Contingencies Secretariat of the Cabinet Office, London, UK, 2003. Available at: www.cabinetoffice.gov.uk, Accessed June 25, 2013.
41. International Organization of Standardizations (ISO). Risk Management—Risk Assessment Techniques, ISO Standard IEC/FDIS 31010, iso.org, Geneva, Switzerland, 2009.
42. Ayyub BM, Kilr GJ. Uncertainty Modeling and Analysis in Engineering and the Sciences. New York: Chapman & Hall/CRC, Taylor & Francis Group, 2006.
43. Halmos P. Measure Theory. Princeton, NJ: Van Nostrand, 1950.
44. Royden H. Real Analysis. Upper Saddle River, NJ: Prentice-Hall, 1988.
45. Wang Z, Klir GJ. Fuzzy Measure Theory. New York: Plenum Press, 1992.
46. Klir GJ, Wierman MJ. Uncertainty-Based Information: Elements of Generalized Information Theory. New York: Physica-Verlag, 1999.
47. Garbin DA, Shortle JF. Measuring Resilience in Network-Based Infrastructures, In McCarthy JA (ed). Critical Thinking: Moving from Infrastructure Protection to Infrastructure Resiliency. Fairfax, VA: George Mason University, 2007.
48. Tierney K, Bruneau M. Conceptualized and measuring resilience. TR News, 2007; 250:14–17.
49. Attoh-Okine N, Cooper AT, Mensah SA. Formulation of resilience index of urban infrastructure using belief functions. IEEE Systems Journal, 2009; 3(2):147–153.
50. Shinozuka M, Chang SE, Cheng T-C, Feng M, O'Rourke TD, Saadeghvaziri MA, Dong X, Jin X, Wang Y, Shi P. Resilience of Integrated Power and Water Systems, MCEER Research Progress and Accomplishments: 2003–2004, MCEER-04-SP01, 2004; 65–86, NY. Available at: https://mceer.buffalo.edu/publications/resaccom/04-sp01/06_shino.pdf, Accessed June 25, 2013.
51. Li Y, Lence B. Estimating of water resources systems. Water Resources, 2007; 43:W07422; doi:10.1029/2006WR005636.
52. Hashimoto T, Stedinger JR, Loucks DP. Reliability, resiliency and vulnerability for water resources system performance evaluation. Water Resource Research 1982; 18(1):14–20.
53. Omer M, Nilchiani R, Mostashari A. Measuring the Resilience of the Global Internet Infrastructure System, 2009. 3rd Annual Systems Conference, IEEE, 2009; 156–162.
54. McGill WL, Ayyub BM. Regional capabilities performance assessment for homeland security. IEEE Systems J. 2009; 3(2):192–198.
55. Miles S, Chang S. Urban Disaster Recovery: A Framework and Simulation Model. MCEER, Multidisciplinary Center for Earthquake Engineering Research (MCEER) of the State University of New York at Buffalo, 2003.
56. Ellingwood BR, Mori Y. Probabilistic methods for condition assessment and life prediction of concrete structures in nuclear plants. Nuclear Engineering and Design, 1993; 142:155–166.
57. Anthony L. Community resilience and decision theory challenges for catastrophic risk. Risk Analysis, 2012; 32(11):1919–1934.
58. Ayyub BM. Risk Analysis in Engineering and Economics. New York: Chapman & Hall/CRC, Taylor & Francis Group, 2003.
59. Callicott JB. Explicit and Implicit Values in the ESA. In Davies F, Goble D, Heal G, Scott M (eds.). The Endangered Species Act at Thirty: Retrospect and Prospects. Washington, DC: Island Press, 2004.
60. National Research Council. Valuing Ecosystem Services: Toward Better Environmental Decision-Making. Washington, DC: National Academies Press, 2004.
61. Bishop RC, Boyle KJ, Welsh MP. Toward total economic value of great lakes fishery resources. Transactions of the American Fisheries Society, 1987; 116(3):339–345.
62. Randall A. Total and nonuse values in measuring the demand for environmental quality. In Braden JB, Kolstad CD (eds). Measuring the Demand for Environmental Quality. Amsterdam: Elsevier Science Publishers, 1991.

American Society of Civil Engineers National Consensus Standards Activities Associated with Safety Related Nuclear Structures, Distribution Systems and Mechanical and Electrical Components

While none of these Standards have been accepted by the US NRC as a whole, parts of them have been cited by the U.S.NRC in their Regulatory Guides and Standard Review Plans.

Presentation Prepared by:

John D. Stevenson, Ph.D., P.E., Former Chairman and Current Member of ASCE Nuclear Standard Committee and Former Chairman of the ASCE Standard Executive Committee

Email: [redacted]

Tel: [redacted]

Prior to 1980 ASCE was not a Standards Development Organization accredited to ANS I nor did it develop standards of any kind. Since that time it has developed over 60 standards using ANS I consensus procedures and 4 of them have been Nuclear Safety related.

STRUCTURAL DESIGN OF BUILDING DISTRIBUTION SYSTEMS AND COMPONENTS IS DIVIDED INTO THE FOLLOWING ACTIVITIES

- Load and Load Combination Definition and Determination
- Analytical procedures to develop member or component forces, moments or stresses from applied loads.
- Design Basis Acceptance Criteria

There are 4 ASCE Standards related to Nuclear Structures Distribution Systems and Components Structural Design

- ACSE 1 N-725 Guidelines for Design or Nuclear Safety related Earth Structures
- ASCE 4 Seismic Analysis of Safety – Related Nuclear Structures and Containments
- ASCE 7 – Minimum Design Loads for Buildings and other Structures.
- ASCE 43 Seismic Design Criteria for Structures Systems and Components in Nuclear Facilities

STATUS ASCE ASCE 1:
FIRST PUBLISHED IN 1982 AND REVISED IN 1988. REVISION PUBLICATION IS SCHEDULE FOR 2014

It has the following Basic Table of Contents:

1.0 Purpose, Scope and Administrative Requirements
2.0 Definitions
3.0 Site Investigation
4.0 Ultimate Heat Sink Earth Structure-Dams, Dikes and Embankments
5.0 Site Protection Earth Structures-Dams, Breakwaters, Seawalls, Revetments
6.0 Site Contour Earth Structures-Retaining Walls, Natural Slopes, Cuts and Fills
7.0 Inspection, Instrumentation and Monitoring for Construction
8.0 References
9.0 Index

STATUS ASCE 4-98:
2014 REVISION IS IN THE LAST STAGES OF BALLOTING AND IS EXPECTED TO BE PUBLISHED BY THE END OF 2013
AND HAS THE FOLLOWING BASIC TABLE OF CONTENTS:

Standard

The ASCE 4 Standard in cooperation with ANS 2.26 and ANS 2.29 Standards defines the seismic hazard and 4 Limit State loadings. It provides analytical procedures to analyze nuclear safety related structures. The acceptance criteria for concrete and steel structures are found in ACI 349/359 and ANSI N690 respectively. The methods of analysis for mechanical and electrical distribution systems and components and their acceptance criteria are contained in ASME and IEEE Standards.

Status: ASCE 7:

The Standard first published in 1988 addresses loads, load combination for normal service loads for buildings and natural hazard (earthquake, wind, flood and precipitation) loads on site, structures, distribution systems, and components and analytical procedures for conventional and low hazard facilities. Current edition is 2010 and is due for revision in 2015. The probabilistic defined hazards for nuclear facilities for wind, flood and precipitation loads developed in ANS 2.3, ANS 2.8 and ANS 2.31 Standards respectively are generally applicable for Nuclear Safety related SSC. It should be noted that analytical procedures developed for wind, flood, precipitation in this Standard are also used for Nuclear Safety related structures.

TABLE OF CONTENTS

TABLE OF CONTENTS(CONT.)

TABLE OF CONTENTS(CONT.)

STATUS: ASCE 43:

The original and current edition was published in 2005 and work has begun on a revision to be published in 2015. Consideration is being given to expanding its scope beyond earthquakes to consider other natural hazard loads (wind, flood, precipitation) on nuclear safety related structures distribution systems and components.

ASCE 43 TABLE OF CONTENTS

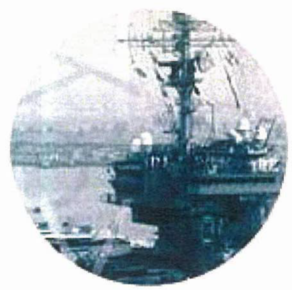
THE A. JAMES CLARK SCHOOL *of* ENGINEERING

Designing for Resilience as a New Nuclear Safety Construct

Bilal M. Ayyub, PhD, PE
Professor and Director
Center for Technology and Systems Management
Department of Civil & Environmental Engineering

Telephone: [redacted]
[redacted]
http://www.ctsm.umd.edu





September 11, 2013
ASME Nuclear Risk Management Coordination Committee (NRMCC), Baltimore, MD

CTSM
Technology for Intelligent Decisions

UNIVERSITY OF MARYLAND

UNIVERSITY OF MARYLAND

Outline

- Background
- Resilience
  - Definition
  - Metrics
  - Valuation
  - Aggregation
- Concluding Remarks

Background

- The United Nations Office for Disaster Risk Reduction (2011)
  - 302 natural disasters worldwide including the earthquake and tsunami that struck Japan
  - US$366 billion in direct damages
  - 29,782 fatalities
  - Storms and floods accounted for 70%
  - Earthquakes producing the greatest number of fatalities
- Average annual losses in the US amount to about $55 billion (2011)

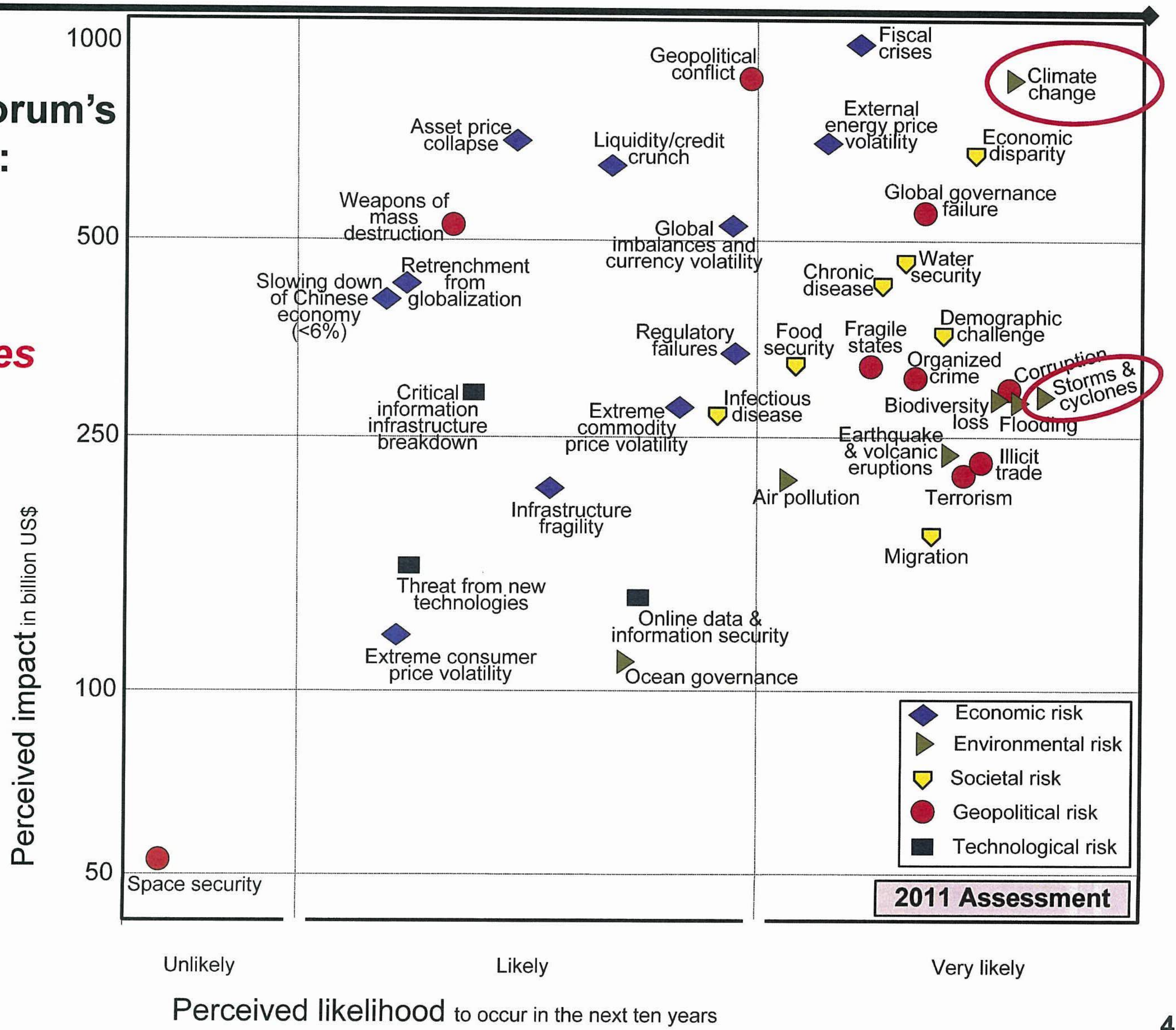
Background: Global Risk Landscape

World Economic Forum's Global Risk Survey:

Climate change

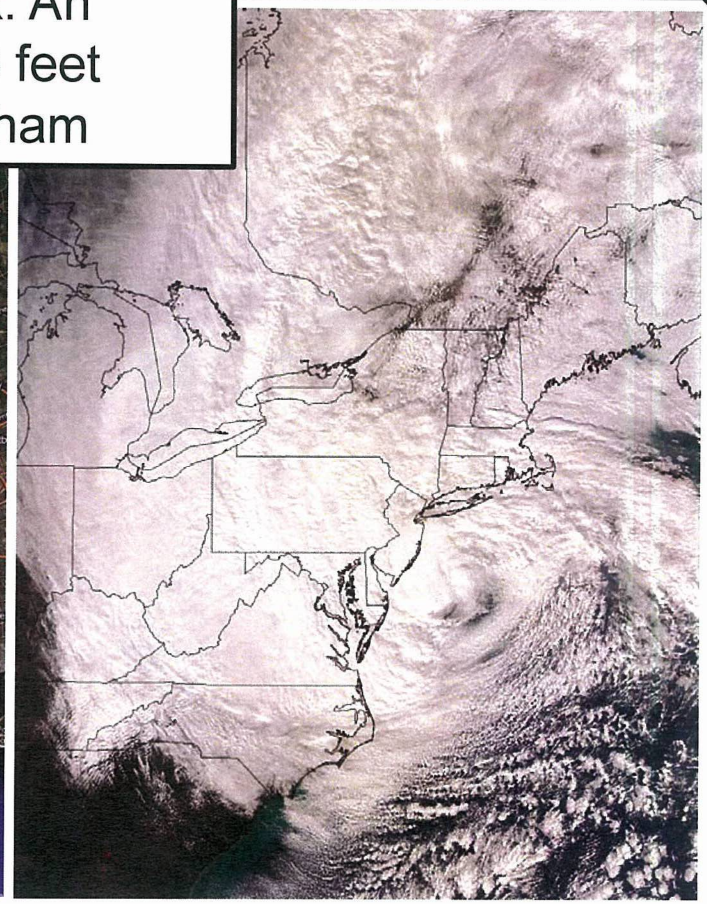
Storms and cyclones

Interconnection
Interdependence



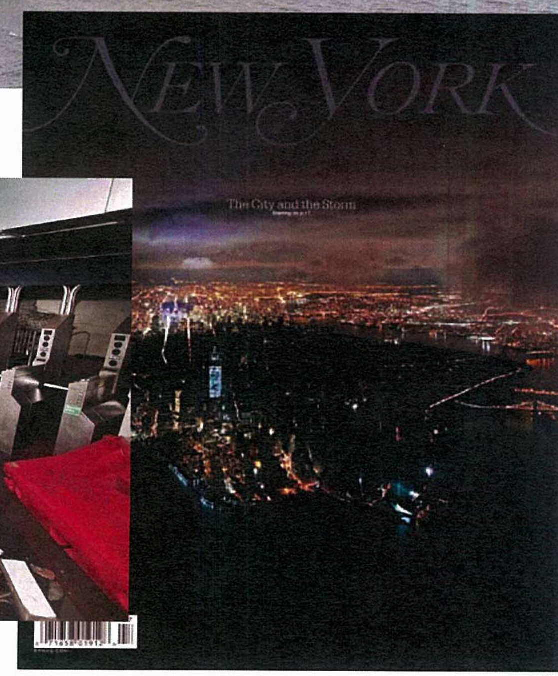
Background: Sandy Super Storm

Highlighted areas show flooding in New York. An unprecedented 13-foot surge of seawater - 3 feet above the previous record - gushed into Gotham



NASA's Aqua satellite captured a visible image Sandy's massive circulation on Oct. 29 at 18:20 UTC (2:20 p.m. EDT). Sandy covered 1.8 million square miles, from the Mid-Atlantic to the Ohio Valley, into Canada and New England

Background: Losses



Background: Nuclear Power Plans

- **Indian Point** – Automatic shutdown of a reactor unit due damage to electrical connection
- **Oyster Creek** – Issuance of an alert since water level were higher then usual for the intake. it also lost power
- **Limerick** – Reduction of power to 91% since the storm damaged a condenser
- **Salem** – Shutdown, when 4 out of 6 pumps stops working
- **Nine Mile Point** – Automatic shutdown of a reactor unit and another lost power when there was an electrical fault, unclear if storm related

Background: Nuclear Safety

- Factors of safety and allowable stresses
  - Acceptable safety margin
- Reliability-based design
  - Acceptable (average safety margin)/(standard deviation of the safety margin)
- Risk-informed design
  - Safety acceptance by also considering failure consequences
- What is next?
  - Designing for recovery? Designing for resilience?

Resilience Definitions

- **Psychology** – Resilience is an individual's tendency to cope with stress and adversity
- **Material science** – It is the capacity of material to absorb energy when it is elastically deformed
- **Engineering** – Many definitions exist and a succinct definition is the ability of the system to return to a stable state after a perturbation
- **Systems science** – A resilient system returns to an equilibrium state after perturbation, with more resilient systems having multiple equilibrium points
- **Other uses** – Ecological, infrastructure, neuroscience, economic and community systems

Resilience Definitions

- Presidential Policy Directive (PPD-21, 2013) on Critical Infrastructure Security and Resilience
  - The "term resilience means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."

Resilience Definitions

- National Research Council (2013)
  - Resilience is the ability to prepare and plan for, absorb, recover from or more successfully adapt to actual or potential adverse events (consistent with U. S. governmental agency definitions SDR 2005, DHS 2008 and PPD-8 2011, and NRC 2011)
- National Infrastructure Advisory Council
  - Infrastructure resilience is the ability to reduce the magnitude and/or duration of disruptive events
  - The effectiveness of a resilient system depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event

Resilience Definitions

- A Summary by Attoh-Okine (2009)
  - Holling (1973 in ecology)
    Resilience determines the persistence of relationships within a system, and is a measure of the ability of these systems to absorb change state variable, driving variables, and parameters and still persist
  - Lebel (2001)
    Resilience is the potential of a particular configuration of a system to maintain its structure/function in the face of disturbance, and the ability of the system to re-organize following disturbance-driven change

Definition Requirements

- Requirements for an operational definition that lends itself to measurement or metrics:
  - Considering initial capacity or strength, and residual capacity or strength after a disturbance, i.e., robustness
  - Accounting for abilities to prepare and plan for, absorb, recover from or more successfully adapt to adverse events as provided in the NRC (2013) definition
  - Treating disturbances as events with occurrence rates and demand intensity, i.e., modeling them as stochastic processes
  - Treating different performances based on corresponding failure modes for various things at risk, such as people, physical infrastructure, economy, key government services, social networks and systems, and environment

Definition Requirements

- Requirements for an operational definition to support metrics(cont.):
  - Accounting for systems changes over time, in some cases being improved, in other cases growing more fragile or aging
  - Considering full or partial recovery and times to recovery
  - Considering potential enhancements to system performance after recovery
  - Relatable to other familiar notions such as reliability and risk, i.e., building on the relevant metrics of reliability and risk
  - Enabling the development of resilience metrics with meaningful units

Proposed Definition

Notional Definition (Builds on the PPD-21 2013):
Resilience notionally means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from disturbances of the deliberate attack types, accidents, or naturally occurring threats or incidents.

Measurement

The resilience of a system's function can be measured based on the persistence of a corresponding functional performance under uncertainty in the face of disturbances

Proposed Definition

Measurement

The resilience of a system's function can be measured based on the persistence of a corresponding functional performance under uncertainty in the face of disturbances

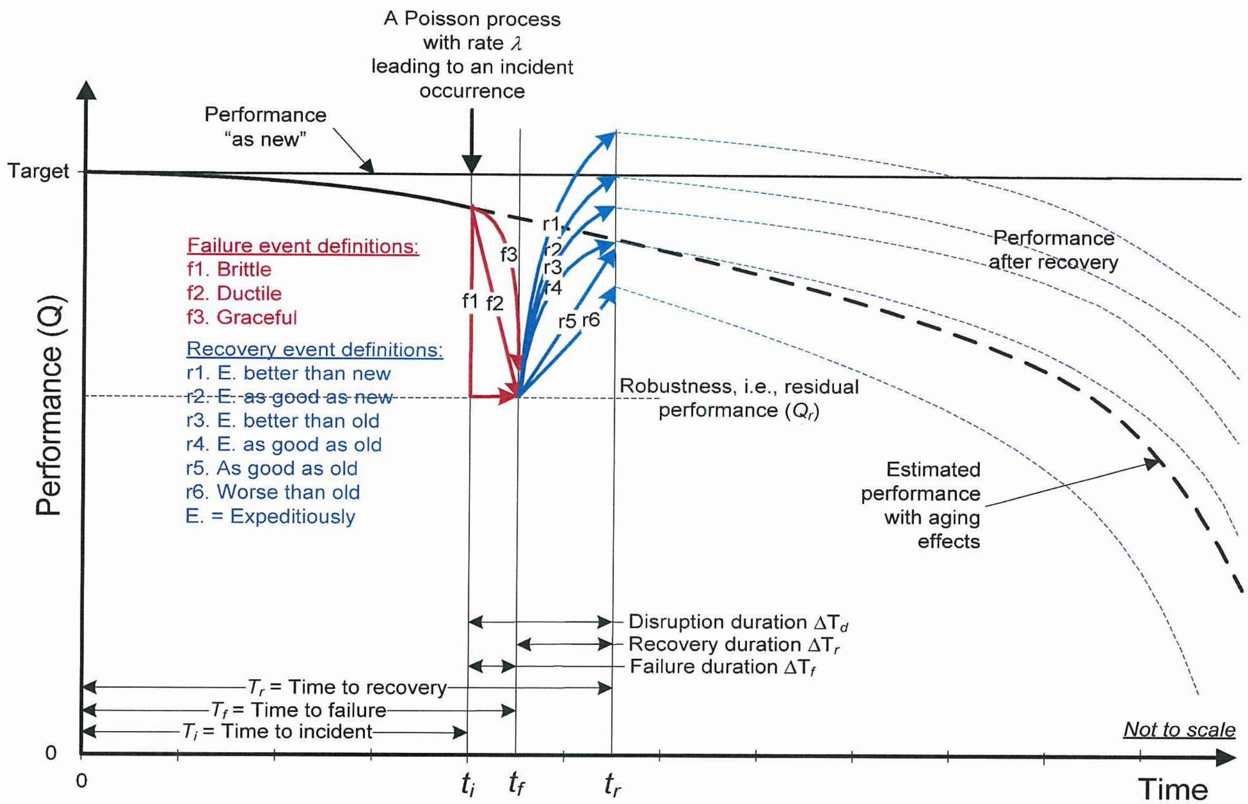
ISO (2009) Risk Definition

Risk is the effect of uncertainty on objectives

Steps Towards Quantification

- **The key words in the definition are listed in a suggested order for their analysis as follows:**
  - System's performance defined in terms of requirements or objectives, and examined in the form of functions: output, throughput, structural integrity, lifecycle cost, etc.
  - Uncertainty relating to events such as storms, disturbance, conditions, system states, etc.
  - Persistence examined in terms of enduring the events, recovery, continuance and/or resumption of functional performance

Measuring Resilience (Persistence)



$$\text{Failure}(F) = \frac{\int_{t_i}^{t_f} f\,dt}{\int_{t_i}^{t_f} Q\,dt}$$

$$\text{Recovery}(R) = \frac{\int_{t_f}^{t_r} r\,dt}{\int_{t_f}^{t_r} Q\,dt}$$

$$\text{Resilience}(R_e) = \frac{T_i + F\Delta T_f + R\Delta T_r}{T_i + \Delta T_f + \Delta T_r}$$

$$R_e \geq 0$$

Measuring Resilience

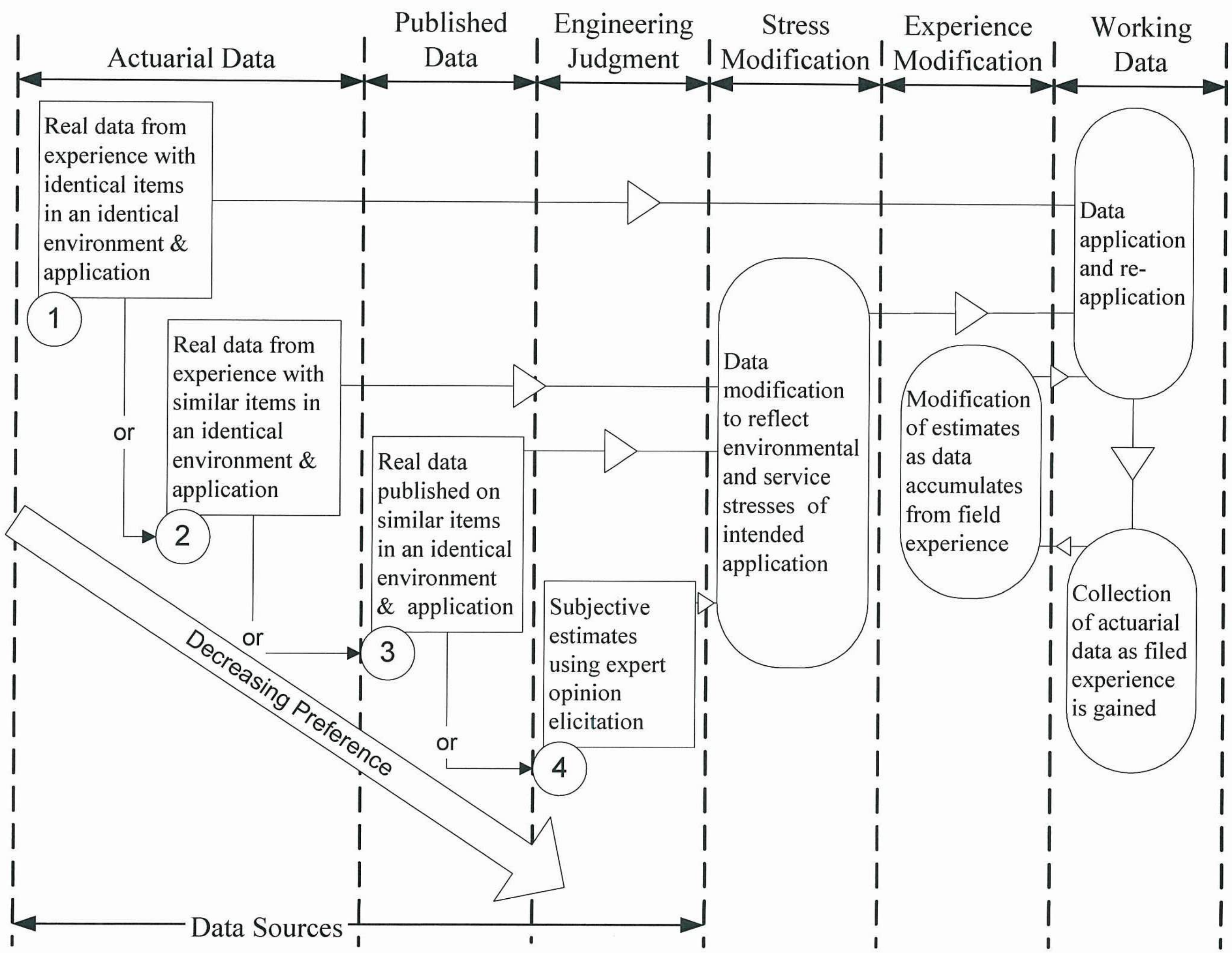
$$\text{Resilience}(R_e) = \frac{T_i + F\Delta T_f + R\Delta T_r}{T_i + \Delta T_f + \Delta T_r} \qquad R_e \leq 1$$

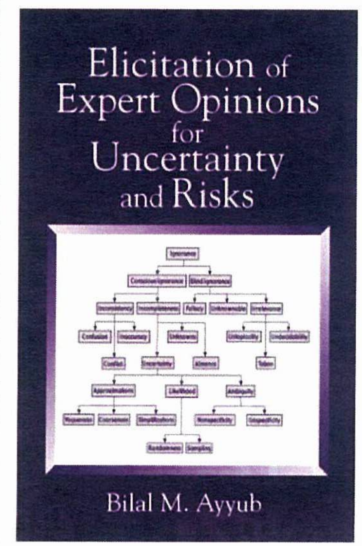
Time to failure (T_f) has the following density function:

$$-\frac{d}{dt}\int_{c=0}^{\infty} \exp\left[-\lambda t\left(1-\frac{1}{t}\int_{\tau=0}^{t} F_L(\alpha(\tau)s)d\tau\right)\right] f_{S_0}(s)ds$$

S = strength, L = load or demand by a disturbance,
α = degradation, λ = rate or generally hazard function

Data Sources for Quantitative Analysis





Considerations in Decision Making

- What are the alternatives?
- Is an alternative cost effective?
- Does an alternative make it meet resiliency objectives?
- Is it affordable?
- Does it limit future options?
- Are there other considerations, political, legal, etc.?

Valuation of Resilience

- Anthropocentric in nature based on utilitarian principles
- Consideration of all instrumental values, including existence value
- Permitting the potential for substitution among different sources of value for human welfare
- Individual's preferences or marginal willingness to trade one good or service for another that can be influenced by culture, income level and information making it time- and context-specific
- Societal values as the aggregation of values by individual

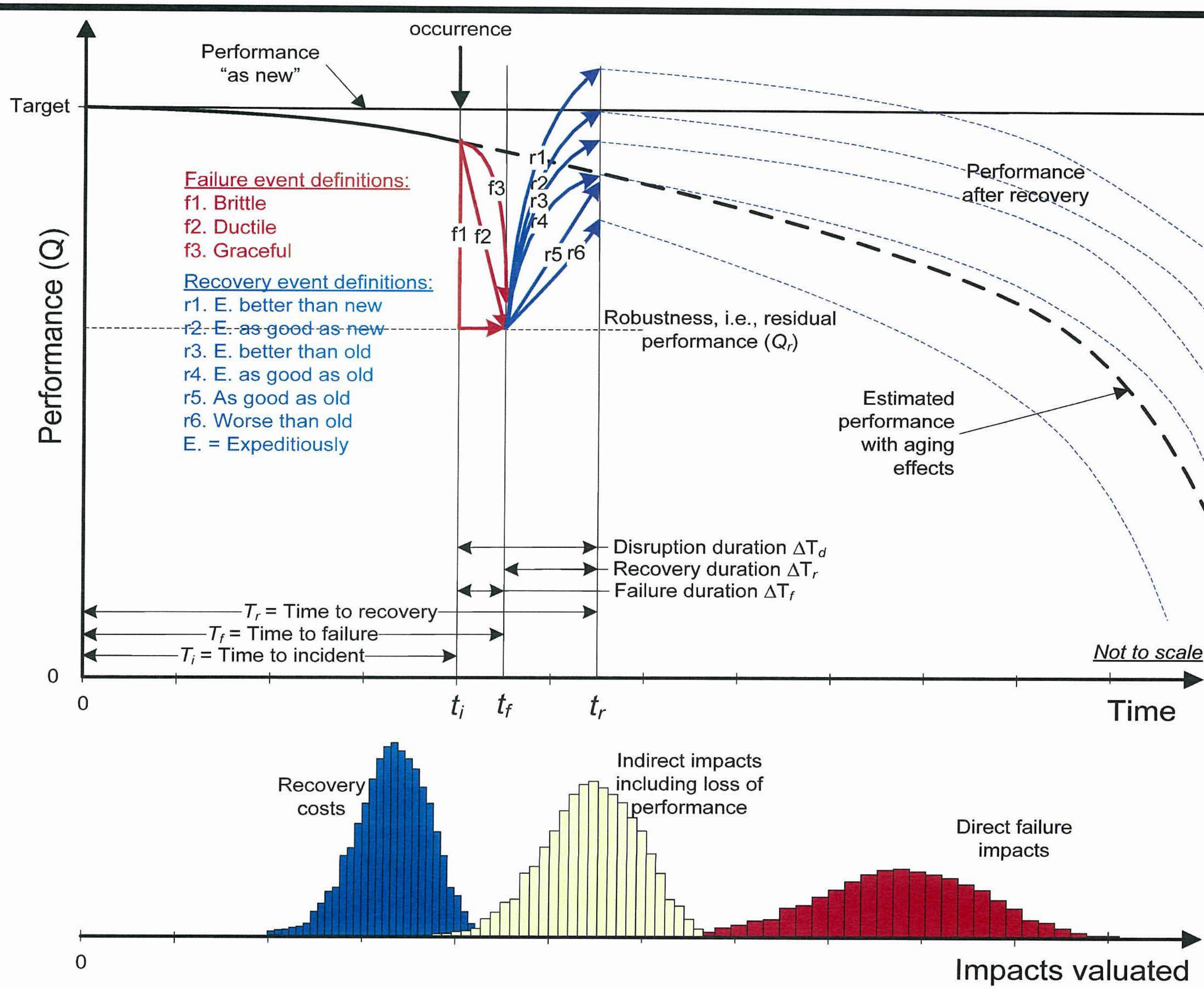
Economic Valuation of Resilience

- Labor theory of value
- Affected populations
- Willingness to accept
- Willingness to pay

Measuring Performance

Systems	Performance	Units
Buildings	Space availability	Area per day
Other structures: Highway bridges	Throughput traffic	Count per day
Facilities: Water treatment plants	Water production capacity	Volume per day
Infrastructure: Water delivery	Water available for consumption	Volume
Network: Electric power distribution	Power delivered	Power per day
Communities	Economic output Quality of life (consumption)	Dollars Dollars

Economic Valuation of Resilience



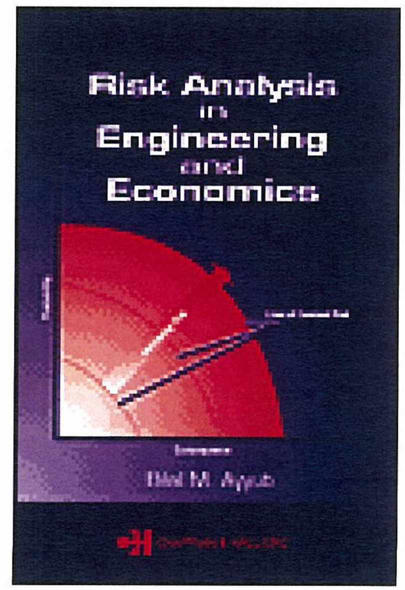
Decision Analysis

- Identify alternatives (strategies)
- Assess benefits and costs of each
- Assess impacts of strategy on future options

Benefit = Valuation Differential due to an Action

$$\text{B/C Ratio} = \frac{\text{Benefit}}{\text{Cost}} \qquad \beta_{B/C} = \frac{\mu_B - \mu_C}{\sqrt{\sigma_B^2 + \sigma_C^2}}$$

$$P\left(\frac{\text{Benefit}}{\text{Cost}} \geq 1\right) = 1 - P(\text{Benefit} - \text{Cost} \leq 0)$$

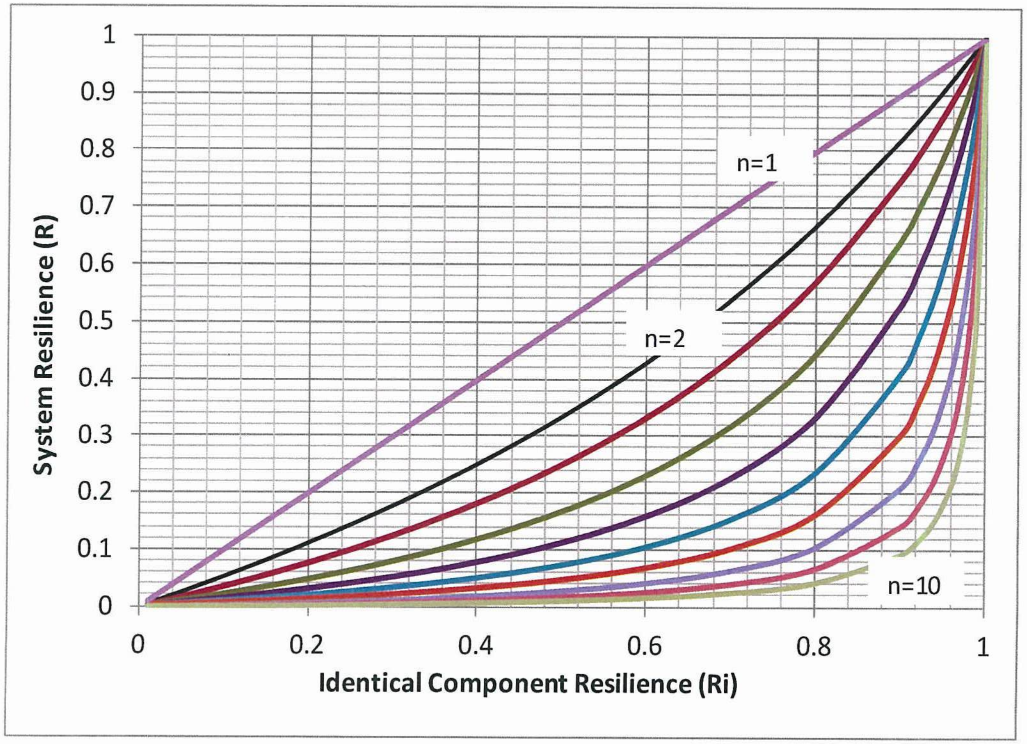


Resilience Segregation & Aggregation

For $0 \leq R_i \leq 1$, (MCEER 2010) defines

$$\text{Resilience}(R_{12}) = \frac{R_1.R_2}{R_1 + R_2 - R_1.R_2}$$

For identical components using the independence assumption



Resilience Aggregation

- Measuring the resilience of a network based on its components
- Measuring the resilience of a community based on underlying networks, and socio-economic components
- Limitations of scorecards
  - Units of measurement
  - Axiomatic and mathematical considerations
  - Suitability for cost-benefit and tradeoff analysis

Concluding Remarks

- Resilience metrics
- System analysis (interdependence)
- Resilience aggregation

- <u>Announcement</u>
  ASCE-ASME Journal of Risk and Uncertainty Analysis (forthcoming)

Thank you

Instructions for the WG Chair

The IEEE-SA strongly recommends that at each WG meeting the chair or a designee:

- **Show slides #1 through #4 of this presentation**
- **Advise the WG attendees that:**
  - The IEEE's patent policy is described in Clause 6 of the *IEEE-SA Standards Board Bylaws*;
  - Early identification of patent claims which may be essential for the use of standards under development is strongly encouraged;
  - There may be Essential Patent Claims of which the IEEE is not aware. Additionally, neither the IEEE, the WG, nor the WG chair can ensure the accuracy or completeness of any assurance or whether any such assurance is, in fact, of a Patent Claim that is essential for the use of the standard under development.
- **Instruct the WG Secretary to record in the minutes of the relevant WG meeting:**
  - That the foregoing information was provided and that slides 1 through 4 (and this slide 0, if applicable) were shown;
  - That the chair or designee provided an opportunity for participants to identify patent claim(s)/patent application claim(s) and/or the holder of patent claim(s)/patent application claim(s) of which the participant is personally aware and that may be essential for the use of that standard
  - Any responses that were given, specifically the patent claim(s)/patent application claim(s) and/or the holder of the patent claim(s)/patent application claim(s) that were identified (if any) and by whom.
- The WG Chair shall ensure that a request is made to any identified holders of potential essential patent claim(s) to complete and submit a Letter of Assurance.
- It is recommended that the WG chair review the guidance in *IEEE-SA Standards Board Operations Manual* 6.3.5 and in FAQs 12 and 12a on inclusion of potential Essential Patent Claims by incorporation or by reference.

Note: **WG** includes Working Groups, Task Groups, and other standards-developing committees with a PAR approved by the IEEE-SA Standards Board.

(Optional to be shown)

Participants, Patents, and Duty to Inform

All participants in this meeting have certain obligations under the IEEE-SA Patent Policy.

- **Participants [Note: Quoted text excerpted from IEEE-SA Standards Board Bylaws subclause 6.2]:**
  - **"Shall inform the IEEE (or cause the IEEE to be informed)" of the identity of each "holder of any potential Essential Patent Claims of which they are personally aware" if the claims are owned or controlled by the participant or the entity the participant is from, employed by, or otherwise represents**
    - **"Personal awareness" means that the participant "is personally aware that the holder may have a potential Essential Patent Claim," even if the participant is not personally aware of the specific patents or patent claims**
  - **"Should inform the IEEE (or cause the IEEE to be informed)" of the identity of "any other holders of such potential Essential Patent Claims" (that is, third parties that are not affiliated with the participant, with the participant's employer, or with anyone else that the participant is from or otherwise represents)**
- **The above does not apply if the patent claim is already the subject of an Accepted Letter of Assurance that applies to the proposed standard(s) under consideration by this group**
- **Early identification of holders of potential Essential Patent Claims is strongly encouraged**
- **No duty to perform a patent search**

Patent Related Links

All participants should be familiar with their obligations under the IEEE-SA Policies & Procedures for standards development.

Patent Policy is stated in these sources:

IEEE-SA Standards Boards Bylaws

http://standards.ieee.org/develop/policies/bylaws/sect6-7.html#6

IEEE-SA Standards Board Operations Manual

http://standards.ieee.org/develop/policies/opman/sect6.html#6.3

Material about the patent policy is available at

http://standards.ieee.org/about/sasb/patcom/materials.html

If you have questions, contact the IEEE-SA Standards Board Patent Committee Administrator at patcom@ieee.org or visit http://standards.ieee.org/about/sasb/patcom/index.html

This slide set is available at https://development.standards.ieee.org/myproject/Public/mytools/mob/slideset.ppt

Call for Potentially Essential Patents

- If anyone in this meeting is personally aware of the holder of any patent claims that are potentially essential to implementation of the proposed standard(s) under consideration by this group and that are not already the subject of an Accepted Letter of Assurance:
  - Either speak up now or
  - Provide the chair of this group with the identity of the holder(s) of any and all such claims as soon as possible or
  - Cause an LOA to be submitted

Other Guidelines for IEEE WG Meetings

- **All IEEE-SA standards meetings shall be conducted in compliance with all applicable laws, including antitrust and competition laws.**
  - **Don't discuss the interpretation, validity, or essentiality of patents/patent claims.**
  - **Don't discuss specific license rates, terms, or conditions.**
    - Relative costs, including licensing costs of essential patent claims, of different technical approaches may be discussed in standards development meetings.
      - Technical considerations remain primary focus
  - **Don't discuss or engage in the fixing of product prices, allocation of customers, or division of sales markets.**
  - **Don't discuss the status or substance of ongoing or threatened litigation.**
  - **Don't be silent if inappropriate topics are discussed … do formally object.**

See *IEEE-SA Standards Board Operations Manual*, clause 5.3.10 and "Promoting Competition and Innovation: What You Need to Know about the IEEE Standards Association's Antitrust and Competition Policy" for more details.

Subcommittee 3.0 Draft Schedule

	WG 3.1	WG 3.2	WG 3.3	WG 3.4
2014-1	1819		352	1205
2014-2	1819		352	1205
2015-1	1819		577	
2015-2	1819		577	
2016-1	1819		577	
2016-2	1819		577	
2017-1	336		577	
2017-2	336		933	
2018-1	336		933	
2018-2	336		933	
2019-1	336		933	
2019-2	338		933	
2020-1	338	692		
2020-2	338	692		
2021-1	338	692		1205
2021-2	338	692		1205
2022-1	338	692		1205
2022-2	338	692		1205
2023-1	1819	692		1205
2023-2	1819		352	
2024-1	1819		352	
2024-2	1819		352	
2025-1	1819		352	
2025-2	1819		352	
2026-1	1819		352	
2026-2				

STD	Issued
336	2010
338	2012
352	Working
577	2012
692	2013
933	2013
1205	Working
1819	Working