INL/CON-06-11512
PREPRINT

Culture Representation in Human Reliability Analysis

Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2006

David Gertman
Steven Novack
Julie Marble

December 2006

Idaho National Laboratory

Culture Representation in Human Reliability Analysis[1]

David Gertman, Steven Novack, and Julie Marble
Idaho National Laboratory (INL)
Idaho Falls, Idaho

david.gertman@inl.gov, steven.novack@inl.gov, julie.marble@inl.gov

ABSTRACT

Understanding human-system response is critical to being able to plan and predict mission success in the modern battlespace. Commonly, human reliability analysis has been used to predict failures of human performance in complex, critical systems. However, most human reliability methods fail to take culture into account. This paper takes an easily understood state of the art human reliability analysis method and extends that method to account for the influence of culture, including acceptance of new technology, upon performance. The cultural parameters used to modify the human reliability analysis were determined from two standard industry approaches to cultural assessment: Hofstede's (1991) cultural factors and Davis' (1989) technology acceptance model (TAM). The result is called the *Culture Adjustment Method* (CAM). An example is presented that (1) reviews human reliability assessment with and without cultural attributes for a Supervisory Control and Data Acquisition (SCADA) system attack, (2) demonstrates how country specific information can be used to increase the realism of HRA modeling, and (3) discusses the differences in human error probability estimates arising from cultural differences.

Keywords: *Culture, human reliability analysis, behavior prediction, culture adjustment method*

ABOUT THE AUTHORS

David Gertman, PhD is a human factors and human reliability scientist at the Idaho National Laboratory where he supports work performed for the US Nuclear Regulatory Commission, NASA, the Department of Homeland Defense and various DoD entities**.** He received his PhD in human factors psychology from the Catholic University of America. David is co-author of the *Human Reliability and Safety Analysis Data Handbook* (1994) published by John Wiley.

Steven D Novack, MS received his bachelors in Physics from the University of Washington and MS in Environmental Science from the University of Idaho. He has over 20 years experience in risk analysis for the nuclear and environmental domains and when not supporting data and methods development for risk analysis he manages a number of National Security programs at the Idaho National Laboratory. His research interests include modeling human performance as a component of system reliability.

Julie Marble received her PhD from Purdue University in cognitive science and has supported a number of research efforts for DARPA, NASA and National Security Programs. Her research interests include human robotic interaction, design of equipment for extreme environments, and human reliability.

---

[1] Prepared for the U.S. Department of Energy under DOE Idaho Operations Office, Contract DE AC07 05ID14517

Culture Representation in Human Reliability Analysis

David Gertman, Steven Novack, and Julie Marble
Idaho National Laboratory (INL)
Idaho Falls, Idaho

david.gertman@inl.gov, **steven.novack@inl.gov**, **julie.marble@inl.gov**

INTRODUCTION

Arguably, the best approach for meeting military objectives is to create an integrated strategy. Due to limitations in human factors technology, military planners trying to meet objectives to deny, degrade, destroy, disrupt, or otherwise influence opponents have been forced to treat human-system interaction primarily in a qualitative fashion. This is not to say that logistics, force ratios and equipment survivability have not been treated in a quantitative fashion. Rather, the need for the human to *detect, diagnosis, predict,* and *mitigate* hostile actions has not been treated in a systematic, quantitative fashion. One approach to remedy this situation is to apply quantitative modeling methods. Quantitative modeling is used to interpret and understand sequential events, and predict and calculate the effects of multiple interactions of human and machines across all levels of a system. In part, the current lack of quantification in many approaches to assessing human performance is a result of the lack of underlying data and constrained availability of tools to assess differences in performance. Further, what does exist is not sensitive to important performance distinctions that are a function of culture and organization.

Culture is a universal phenomenon influencing human performance from country to country. Culture influences not only how we perceive the actions of others, but also our response to events. Therefore, when the analyst assesses the behavior of people in a complex, critical system, culture must be accounted for just as internal psychological factors, such as fatigue, workload, and fitness for duty are accounted.

Recent work at the Idaho National Laboratory (INL) provides a unique approach for quantifying human-system interaction and the effect of culture for select scenarios. The model discussed in this article employs probabilistic risk assessment (PRA) and human reliability analysis (HRA) methods to review potential mission success and failures. HRA typically estimates the probability of erroneous (and conversely successful) human action as a function of the task modified by contextual influences called performance shaping factors (PSFs). PSFs are elements of the workers' internal and external environment that affect their cognition; they may include workload, stress, fatigue, training, and fitness for duty.

In previous work, it became apparent that the ability to extrapolate human error probability estimates derived by standard HRA methods to other cultures was limited. Cultural differences limit extrapolation of HRA methods to situations of interest around the world because culture impacts how tasks are designed and performed, as well as influences people's motivation to act. Furthermore, culture combines with situational aspects to affect human decision-making and actions. HRA methods are limited because most data used in HRA was derived from behaviors studies performed in the U.S. on Americans.

Culture, for the purposes of this paper, is defined as the shaping of behavior and expectations that distinguishes the members of one group or category of people from those of another. It can be expressed as a collection of values, norms, traditions, attitudes, beliefs, and institutions that characterize a group [1, 2, 3]. Culture, which includes safety culture and organizational factors, has been shown to significantly affect performance of personnel in many industries. For example, recent events at the Davis Besse nuclear plant indicate that reactor vessel head corrosion was as much due to cultural factors and work process factors as to technical challenges.[4] Culture influences the probability of a person following a specific course of action and thus may affect the probability of actions. Incorporating cultural influences into quantitative, predictive models of human decisions and actions in large complex system operations provides insights into weaknesses and vulnerabilities of human performance. However, the representation and quantification of culture remains a challenge for analysts.

Evidence of Cultural Influences on Human Performance

Human-system performance varies widely for identical equipment because of cultural influences on perception and work processes. We can see this when the safety and performance records for the same aircraft vary dramatically, even when flight profiles and environmental factors are taken into account. On a macro level, organizational factors and workplace safety culture influence performance. Thus, chemical plants designed and built by the same vendor have different performance. On a micro level, psychological studies indicate differences in perception and attribution of cause occur as a function of experience and culture.

Safety culture of an organization has been extensively studied in the U.S. and abroad and is known to strongly influence how work is performed. Safety culture encompasses a broad spectrum of characteristics, such as personnel attitudes, the control of work activities, and organizational structures. Safety is affected by how information is communicated and by how peers and supervisors interact. There is evidence that safety attitudes and safety performance are positively correlated [5, 6].

Although safety culture is only a subset of work culture, it highlights the potential influence of culture upon human performance and human systems response. Events at the Tokai Mura Facility in Japan underscore how human factors, management and organization, safety culture and aspects of culture can combine to influence accidents and compromise human response [7, 8]. The Tokai Mura Facility is a uranium reprocessing facility that JCO operated under license agreement with Japanese authorities. At this facility, double batching and failure to use criticality safe geometry led to the deaths of two workers, yielding the worst accident in the history of the Japanese nuclear industry. A key contributor to this event was erosion of the safety culture and safety standards in deference to production.

From this event a number of cultural influence points can be determined. Miscommunication played a key role in this event: a staff member from the fuels division who consulted with the crew performing the ill-fated campaign misunderstood the enrichment concentrations being used and helped support actions leading to the criticality. The miscommunication may have arisen from cultural norms that prescribe interactions between people, due to the hierarchical nature of the culture. Lower ranked workers may have been unlikely to challenge direction from the safety review group or the advice of the fuels department staff engineer. Also there seemed to have been an unwarranted sense of safety by the crew. They mistakenly believed that the technology present in the room were inherently safe and would preclude them from injury.

Examples of culture effects on human performance are found in the work of Nisbett [9], who demonstrated that East Asians and Americans responded in qualitatively different ways to the same information. In one experiment designed to test differences in attention to aspects of an image between East Asians and Westerners, Nisbett found that Japanese attend to the entirety of an image while American are more likely to focus on a particular object within the image. This difference in focus implies that these groups could respond differently to information when faced with complex human-machine interfaces.

Sanchez-Burks, Nisbett, and Ybarra [10] found that Latin Americans focus on socio-emotional considerations resulted in a relatively greater preference for workgroups with a strong interpersonal orientation. Preferred communication style had a far greater impact on preferences for workgroups and judgments about their likely success than did the ethnic composition of the workgroups. Since communication pathways are known to affect group performance [4], these groups may have different rates of success and failure using the same communication system. In still another study, Nisbett and colleagues [Ibid] found that when making predictions about how people could be expected to behave, Koreans were much more likely than Americans to cite situational factors than personality characteristics as reasons for someone's behavior, implying that a worker’s poor fitness for duty may be ignored longer by Koreans than Americans.

In another experiment, Peng and Nisbett [11] argued that the Chinese manner of dealing with contradictions result in compromise, wherein both parties retain elements of their opposing perspectives by seeking a “middle way.” European-American ways result in a differentiation model that polarizes contradictory perspectives in an effort to determine which is ‘correct’. They found that Americans respond to contradiction by polarizing their beliefs whereas Chinese respond by moderating their beliefs. This tendency to moderate beliefs could have a strong impact on performance when workers have differing opinions regarding the correct course of action in a complex situation. A worker who disagreed with the course of action might not suggest what could potentially be a better alternative.

Cultural Factors

In this paper we seek to improve HRA characterization of human performance by broadening the scope of HRA analysis from the traditional, universal set of PSFs to include culture factors. A model of culture and one of technology acceptance are combined with a standard human reliability method: Hofstede’s cultural assessment method [1, 2], the technology acceptance method developed by Davis [12, 13, 14], and SPAR-H [5] by Gertman et al. These approaches complement each other and provide a comprehensive assessment of culture. Where Hofstede's model reviews culture from a national and organizational perspective, Davis relates culture to the assimilation of technology within an organization. The integration of these two approaches provides the basis for the Culture Adjustment Method (CAM). Hofstede's approach is described first and then Davis's method is reviewed. Next, these models are combined with the SPAR-H HRA method to improve estimation of human error probability.

Hofstede's Approach

Hofstede conducted perhaps the most comprehensive study of how culture affects the workplace. From 1967 to 1973 while working at International Business Machines (IBM), he collected and analyzed data from over 100,000 individuals from 50 countries. Subsequent studies validating the results have included commercial airline pilots and students in 23 countries, civil service managers in 14 counties, ‘up-market’ consumers in 15 countries and ‘elites’ in 19 countries. Hofstede identified four primary dimensions to differentiate cultures: Power Distance (PDI); Individualism/Collectivism (IDV); Masculinity (MAS); and Uncertainty Avoidance (UAI).

Power distance indicates how a culture distributes authority (e.g., tall or shallow hierarchies). High power distance yields a strict hierarchy of relations between people such as the relationship between average workers and managers. Subordinates may never be consulted for opinions or ideas in high power distance cultures.

Uncertainty avoidance measures if a culture tolerates situations without well-defined rules. Uncertainty avoidant cultures do not highly tolerate ambiguity. High uncertainty avoidant cultures often have strict ‘rules of etiquette’ that define behavior even in very uncommon situations. In these cultures you may see deeply ingrained rules of etiquette and conduct between people, preferences for tasks with sure outcomes, and a desire to follow instructions. Unsurprisingly, members of uncertainty avoidant cultures are less likely to deviate from rules or procedures. Uncertainty tolerant cultures may expect or even encourage members to extemporize in unusual situations.

Individualistic groups tend to reinforce individual achievement, while collectivist groups reinforce achievement of the group. Collectivist societies are often characterized by close ties between group members, such as families or work groups. These cultures reinforce extended families; everyone takes responsibility for fellow members of their group.

Masculine cultures reinforce and attach importance to individual achievement, control, and power. A high Masculinity ranking indicates the country experiences a high degree of gender role differentiation. A Low Masculinity ranking indicates the country has a low level of differentiation and discrimination between genders. Low Masculinity cultures tend to emphasize the socio-emotional aspects of working together. These include the importance of within group communication, emphasis on family, and individual identities coming not so much from work roles but rather from personal attributes and roles outside of the workplace (e.g., parent, musician, athlete).

Caveats to Hofstede’s Measures

Hofstede’s work generalized about the entire national population in each country solely on the basis a few questionnaire responses. The respondents were employees in the subsidiaries of a single company, IBM, which had many nationally atypical characteristics. These included: the company's selective recruitment only from the 'middle classes'; frequent international training of employees; technologically advanced and unusual characteristics of its products during the survey periods; frequent contacts between subsidiary and international headquarters staff; its tight, internationally centralized control; U.S. ownership when foreign direct investment was new and controversial; and the comparatively young age of its managers.

Davis: Technology Acceptance

The Technology Acceptance Model (TAM) developed by Davis and Bagozzi [12; 13; 14] relates perceived ease of use and perceived usefulness of technology and technological solutions to the user's intention to use the technology. Ease of use is the degree to which use of a technology is free from effort, and includes how transparent rules for use are to the user, how easily the system state is understood, ease of navigation or manipulation of data items, and whether the technology provides sufficient information to complete the task. Perceived usefulness is the degree a user believes that the technology will improve his or her work performance beyond that of alternate methods. It is influenced by the reliability of the software and the amount of trust between the user and the system. Davis's work has been replicated numerous times.

Innovation, or the degree to which a technology affords the user additional or enhanced capabilities, also moderates technology acceptance. Although a technology may be highly innovative, intended users may not accept it. Tornatzky and Klien [16] found that compatibility, relative advantage, and complexity had the most significant relationships with technology adoption across a broad range of innovation types.

HUMAN RELIABILITY ANALYSIS (HRA)

HRA is used to estimate the probability of a system-required human action, task, or job being completed successfully within the mission time with no extraneous human actions detrimental to system performance. Results of HRAs are often used as inputs to PRA or event sequence diagrams (ESDs), which decompose the system into its constituent components, including hardware, software, and actions performed by human operators. An overview of HRA and HRA methods can be found in Gertman and Blackman (1994). [17]

The goals of HRA are to determine whether human errors will have serious consequences and to identify how likely these errors are to occur. Most, if not all HRA methods, do not consider the influence of culture upon human performance beyond safety culture. Therefore it is an open challenge to integrate the factors identified by Hofstede and Davis into the HRA quantification process. HRA methods may be either qualitative or quantitative. Qualitative HRA methods identify decision points, failure mechanisms, and error pathways. Once vulnerabilities are identified qualitatively, the results are used to inform analysts and support modeling in the form of ESDs and other systems analysis tools.

Introduction to HRA Methods

The HRA method used in the Culture Adjustment Method (CAM) is built on an explicit information-processing model of human performance derived from the behavioral sciences literature [4, 16, 5,17]. In traditional HRA, base human error probabilities are estimated and then modified by PSFs. CAM identifies eight standard PSFs capable of influencing human performance; see Gertman et al. [5] for detailed information regarding these PSFs.

Incorporation of Cultural Influence

After research and review of cultural influences and the factors identified by Hofstede, Power Distance and Uncertainty Avoidance were selected as the two factors that account for the greatest variance in technology use across infrastructures. Further, these factors appear to be the least subsumed by Hofstede's other factors or by Davis' TAM.

Determine and Apply the Culture Modifier

The analyst obtains an estimate of the effect of each of the three cultural factors identified by answering the questions provided in Tables II –

IV (below) regarding the group of interest. Tables II – IV include in parentheses answers used in the later example. These questions were based upon questions used by Hofstede in his cultural assessments at IBM and on Davis' questionnaires for TAM. Answers to the questions lead to a high, moderate or low rating of the group on each of the three cultural characteristics. Cultural scores are required on all three dimensions; the 27 possible combinations are listed in Table V, which includes the modifier for each factor combination.

Table 1. Eight 'Traditional' PSFs used in CAM and general description.

PSF	Description
Available Time	The amount of time that an operator or a crew has to diagnose and act upon an abnormal event. *Barely adequate*—less than 2/3 the nominal required time is available. *Extra time*—time available is one to two times greater than the nominal time required. *Expansive time*—time available greater than two times the nominal time required; there is an inordinate amount of time to diagnose the problem.
Stress	The level of undesirable conditions and circumstances that impede the operator from easily completing a task.
Complexity	How difficult the task is to perform in the context, considers both the task and the environment in which it is to be performed. *Highly complex*—very difficult to perform, high ambiguity in what needs to be diagnosed or executed. *Moderately complex*—somewhat difficult to perform, some ambiguity in what needs to be diagnosed or executed, perhaps with some concurrent diagnoses or actions. *Nominal*—not difficult to perform, little ambiguity. *Obvious diagnosis*—diagnosis greatly simplified. Validating and/or convergent information available, such as additional sensory information including sounds or vibrations.
Experience/ Training	Includes years of experience of the individual or crew, whether or not the operator/crew has been trained on the scenario, the amount of time passed since training, whether training occurred in-house or if operators had to travel to another country to receive training, and the systems involved in the task and scenario. *Low*—Experience/training does not provide the level of knowledge required to adequately perform the required tasks; does not provide adequate practice in those tasks; or does not expose individuals to various abnormal conditions. *Nominal*—An adequate amount of instruction, individuals are proficient in day-to-day operations and have been exposed to abnormal conditions. *High*—extensive experience; demonstrated mastery.
Procedures	The existence and use of formal operating procedures for the tasks under consideration. *Not available*—the procedure needed for a particular task is not available. *Incomplete*—information is needed that is not contained in the procedure. *Available, but poor*—a procedure is available, but it contains wrong, inadequate, ambiguous, or other poor information. *Nominal*—procedures are available and enhance performance. .
Ergonomics	Quality of equipment, displays and controls, workplace layout, quality of information available from instrumentation. Includes the human-machine interface quality. *Missing/Misleading*—Required information is not available from any source or the information that is present is inaccurate. *Poor*—the design of the system negatively impacts task performance. *Nominal*—the design of the system supports correct performance, but does not enhance performance or make tasks easier to carry out than typically expected *Good*—the design of the system provides needed information and the ability to carry out tasks to

	lessens the opportunities for error.
Fitness for duty	The ability of the individual to physically and mentally perform the task at the time required. *Unfit*—the individual is unable to carry out the required tasks, due to illness or other physical or mental incapacitation. *Degraded fitness*—the individual is able to carry out the tasks, although performance is negatively affected, e.g., illness, fever, fatigue from long duty hours, or distraction, or inappropriate overconfidence in abilities. *Nominal*—no known performance degradation is observed, the individual or crew is able to carry out tasks.
Work processes	Aspects of doing work, including inter-organizational, safety culture, work planning, communication, and management support and policies, and coordination, command, and control. Also includes management, organizational, or supervisory factors, such as shift turnover, or communication with maintenance crews and auxiliary operators. Does not include culture. Three levels of work processes are identified: poor, nominal, and good.

The culture modifier is used to update the HEP that already accounts for traditional PSFs influences for action or diagnosis. For sake of simplicity and consistency, higher culture scores increase base failure rates. The range of effect for culture varies from 0.8 (positive cultural influence) to 5 (strongly negative cultural influence). This range of values for culture is consistent with the range of effects associated with traditional PSF included in SPAR-H. However, the CAM modifiers are preliminary estimates based upon expert judgment.

Table 2. Power Distance

1. Degree of inequality among people	Low/little 1	2	3	4	High [✓ 5]
2. Salary range between the highest and lowest paid in organizations	Small 1	2	3	4	Large [✓ 5]
3. Importance of social status symbols	Small 1	2	3	[✓ 4]	Large 5
4. Importance of equality before the law	Low 5	[✓ 4]	3	2	High 1
5. Importance of loyalty to close groups (i.e., family and friends)	Low 1	2	3	[✓ 4]	High 5
6. Importance of good / agreeable interpersonal relationships	Lesser 1	2	[✓ 3]	4	Higher 5
7. Recognition of a right to privacy	Low 5	4	[✓ 3]	2	High 1
8. Freedom of the press	Low 5	[✓ 4]	3	2	High 1
9. Respect for individual freedom	Low [✓ 5]	4	3	2	High 1
10. Importance of consensus in society	Lesser 1	2	3	[✓ 4]	Higher 5

Scoring:

10 – 23	Low
24-37	Moderate
38 – 50	[✓ High] (41)

Table 3. Uncertainty Avoidance

1. Openness to change and innovation	Low 5	[✓ 4]	3	2	High 1
2. Faith in young people	Low 1	2	[✓ 3]	4	High 5
3. Tolerance of differences (i.e., religious, political and ideological)	Low 5	[✓ 4]	3	2	High 1
4. Reliance on rules to govern behavior	Low 1	2	3	4	High [✓ 5]
5. Degree to which uncertainty is accepted as a normal feature of life	Low 5	[✓ 4]	3	2	High 1
6. Acceptability of displaying emotions	Low 1	2	3	4	High [✓ 5]

Scoring

5 – 13	Low
14 – 21	Moderate
22-30	[✓ High] (25)

Table 4. Technology Acceptance

1. What the use of the technology stands for is important to the operators.	7 (SA)	6	5	[✓ 4]	3	2	1 (SD)
2. Operators prefer use of the technology is because of the underlying organizational values.	7 (SA)	6	5	4	3	[✓ 2]	1 (SD)
3. Operators like using the technology primarily based on the similarity of their values and the organizational values underlying its use.	7 (SA)	6	5	4	[✓ 3]	2	1 (SD)
4. Operators feel a sense of personal ownership about the use of the technology.	7 (SA)	6	[✓ 5]	4	3	2	1 (SD)
5. Operators talk up the use of the technology to colleagues as a great asset.	7 (SA)	6	5	4	[✓ 3]	2	1 (SD)
6. Operators are proud of using the technology.	7 (SA)	6	5	4	[✓ 3]	2	1 (SD)
7. Operators' private views about use of the technology are different than those they express publicly.	7 (SA)	6	5	4	3	[✓ 2]	1 (SD)
8. Unless operators are rewarded for using the technology in some way, they see no reason to spend extra effort in using it.	7 (SA)	6	5	4	3	2	[✓ 1] (SD)
9. Operators must use the technology in order to get rewarded in their jobs.	7 (SA)	6	5	[✓ 4]	3	2	1 (SD)

10. How hard operators work on using the technology is directly linked to how much they are rewarded.	7 (SA) 6 5 ④ 3 2 1 (SD)

Scoring

10 – 30	Low	
31 – 50	[✓ Moderate]	(41)
51-70	High	
51-71		

Table 5. Cultural Factors Rating and Modifier.

Power distance	**Uncertainty avoidance**	**Technology acceptance**	**Modifier**
High	Low	Low	5
High	Low	Moderate	
High	Moderate	Low	
Moderate	Low	Low	
High	Low	High	2
Low	Low	Low	
High	High	Low	
High	Moderate	Moderate	
Moderate	Low	Moderate	
Moderate	Moderate	Low	
High	Moderate	High	
High	High	Moderate	
Moderate	High	Low	
Moderate	Low	High	
Low	Moderate	Low	
Low	Low	Moderate	
Moderate	Moderate	Moderate	
High	High	High	1
Low	High	Low	
Low	Low	High	
Moderate	Moderate	High	
Moderate	High	Moderate	
Low	Moderate	Moderate	
Low	High	Moderate	0.8
Moderate	High	High	
Low	Moderate	High	
Low	High	High	

CAM APPROACH

The CAM approach ties together assumptions for human performance modeling, performance shaping factors assessment, cultural influence determination, and system response requirements and places them within the context of a probabilistic modeling framework.

CAM Theoretical Basis

The theory behind CAM is straightforward. As in standard HRA, a base HEP is presented that represents a distribution of values describing a human action. It is assumed that the base HEP mean for a specific human action is the most likely estimate of the population in question and that the most likely specific human action for any culture can be derived from the base HEP distribution. The base HEP is then influenced by a set of PSFs by multiplying the cumulative PSF modifiers by the base HEP mean and converting the result into a ratio of failures per demand. The values are used as input to a Bayesian update method that results in a posterior distribution that reflects the modifications of the PSF. The resulting distribution reflects PSF impact to the base HEP. This follows the logic that the PSFs act on the base HEP, are contained within the base HEP, and are independent.

The concept of a weight of knowledge factor to aid in quantifying uncertainty is introduced here for the CAM approach. The weight of knowledge qualitatively describes the strength of information behind the cumulative PSFs. It is measured as a weak, moderate, or strong data inference (w-weak, m-moderate, s-strong) on the PSF and is determined by the analyst. A weak weight of knowledge suggests that the expert opinion or data are weakly tied to the PSF cumulative factor. It implies that there is uncertain knowledge to support the modifier associated with a given PSF. Similarly, a moderate or strong weight of knowledge suggests that there is sufficient evidence to support the attribution of the PSF.

It is assumed that a Strong (s) Weight of Knowledge has 3x the level of knowledge of a Weak (w) Weight of Knowledge and a Moderate Weight of Knowledge is 2x the Weak (w) Weight of Knowledge for any given PSF. Therefore, the Weight of Knowledge qualifying factors results in: (w) = a factor of 1; (m) = a factor of 2; and (s) = a factor of 3. These factors are based upon the concept of influence to the prior distribution and are the product of observation. If little information is known about the assignment of the PSF modifier to the base HEP then an assignment of a (w) to the cumulative PSF modifier will not modify the uncertainty of the prior substantially and will be at the same order of magnitude to the mean value in the base HEP. This assumption places the burden of uncertainty about the mean on the prior distribution. For example, if the mean is on the order of 1E-5 then this infers some information about the dataset and the number of samples or initial evidence applied for the base HEP dataset to estimate a mean of 1E-5. This is demonstrated in the example below.

Determining the Cultural PSF

The analyst determines the PSF culture rating in the following manner: Using the questionnaires in Tables II through IV, a gross score across for the 3 culture factors is determined. Guidance is provided on taking the gross score and assigning either a low, medium or high range of influence. The basis for answering these culture questions is the analysts understanding, familiarity, and supporting information related to the scenario(s) under evaluation. There are twenty- seven combinations (high/high/high, high/high/medium, etc) possible, shown in Table V. The complete CAM process is shown in Figure 1.

Example 1

Terrorists from a religious Middle Eastern country have attacked a more secular country on their northern border. The attackers are trying to launch a denial of service (DOS) attack on one of the host country's control centers for the Energy Management System (EMS) controlling transmission and distribution across the national electric grid. They have done so at the end of swing shift. The terrorists are exploiting an internet connection from the host facility to an international vendor who has an on-site service contract with them. The link to the vendor is suspended and the facility personnel will have to respond on their own. In this scenario, the terrorist gains access to the internal EMS network which will permit a DOS attack against the host system. Additionally the terrorist may be able to corrupt the system and cause an extended outage period, i.e., blackout. The situation is compounded because the terrorists have exploited a vulnerability that has corrupted the system status information available to the host country operators. The three HEPs being considered as part of hypothetical risk analysis for this exploit is the operators' 1) failure to detect system anomalies and 2) failure to isolate the system and shut down and 3) failure to restore to a safe/known state.

Assumptions

1) Modeling of the attacker is not part of this exercise, the attacker is assumed to have complete knowledge of the EMS, the vendor connection, and have infinite preparation time prior to the attack. Also, there is no advance warning that the attack might occur.
2) The operators, dispatch, supervision,

and Information Technology (IT) at the host country facility have the following characteristics:

   a. Hierarchical culture;
   b. Higher level of training on computer systems, have home systems;
   c. Have procedures available to them that they have been trained on, they have moderate trust in these procedures;
   d. Current reliability of the equipment is perceived to be high;
   e. They trust their equipment and there is little reliance on face-to-face communications;
   f. The culture supports uncertainty and ambiguity;
   g. Ergonomics are not thought to detract from the defender, i.e., host country operators' response.

3) Supervisors and management are not as computer literate as the workers.

HRA with cultural overlay

Cultural values were determined from two sources: Hofstede's country-by-country evaluation [16] and analysts' review of the scenario and personnel culture and experience factors presented in the section above served as a basis to respond to the cultural characteristic matrix questions (see Tables II-IV). The conventional PSF assignment for each of the three HEPs is in Appendix A.
The PSF assignment for the 3 HEPs was as follows:

HEP_1 (Detect System Anomalies) represents a strong cognitive demand and the base HEP is 1.0E-2, training = .8, complexity = 2, fitness for duty = 2, stress = 2; the remaining PSFs are rated nominal. The cultural modifier was estimated at 2. In the analysts' judgment, the cumulative PSF applied to the base HEP has a strong Weight of Knowledge (s) associated with it.

HEP_2 (Isolate and Shutdown) is action oriented and the base HEP is 1.0E-3; complexity is =5, stress = 2, fitness for duty =2, training is = 2 (loss of vendor link and complications have not been trained to) ergonomics and remainder of PSFs are nominal. PSFs were determined to have a rating of 2. The cumulative PSF has a moderate weight of knowledge (m) applied to it.

HEP_3, restore system to safe state is action oriented. Stress is now nominal because of analyst assumptions that personnel have properly isolated systems, fitness for duty is not an issue because additional personnel or the next shift have been involved in assisting with the situation, training is nominal because restoration is trained to complexity is there because of communication and reporting requirements. Procedures and work practices are assumed to be nominal because of the relatively disciplined and educated work force. The cumulative PSF has a strong weight of knowledge (s) applied to it.

Note that for the 3 examples above, the Cultural PSF assignment for the 3 factors is determined to be High/High/Moderate meaning the PDI and UAI indices were judged to be high for this culture and Technology Acceptance was judged to be moderate. This culture rating is applied to all 3 HEPs in the current example. It is possible that different culture ratings could exist for singular HEPs, such as when different work groups or organizations within the same scenario would be involved.

The calculations for the 3 HEPs are presented below:

***(1) HEP_1 Detect system anomalies calculation**:* The base HEP is represented by a beta distribution, where the mean is μ =1.0 E-2, α = .4966, β = 49.16.

HEP_C = base HEP * (PSF_1 (.8x) * PSF_2 (2x) * PSF_3 (2x) * PSF_4 (2x) * PSF_c (2x)) (s)

= 1.0E-2 * 12.8, = 12.8E-2 or 12.8 failures/100 demands

Since a strong weight of knowledge is associated with the cumulative PSF the final failure/demand ratio is 12.8/100 * 3/3 = 38.4/300. The result is:

$HEP_{culture}$ is represented by a beta distribution, where the mean is μ =6.42E-2, α = 160.497, β = 2339.16 and σ = 4.9E-3.

***(2) HEP_2 Isolate and Shutdown calculation**:* The base HEP is represented by a beta distribution, where the mean is $\mu = 1.0$ E-3, $\alpha = .497$, $\beta = 499.2$.

> HEP_C = base HEP * (PSF_1 (5x) * PSF_2 (2x) * PSF_3 (2x) * PSF_4 (2x) * PSF_c (2x)) (m)
>
> = 1.0E-3 * 80, = 80E-3 or 80 failures/1000 demands

Since a moderate weight of knowledge is associated with the cumulative PSF the final failure/demand ratio is 80/1000 * 2/2 = 160/2000. The result is:

> **$HEP_{culture}$** is represented by a beta distribution, where the mean is $\mu = 1.1$ E-1, $\alpha = 38.497$, $\beta = 311.16$ and $\sigma = 1.67$E-2.

In HEP2, culture combined with complexity, stress, and deficiencies in fitness for duty and training lead to a higher failure rate. The human action response is complicated by the stress of the situation, the complexity of competing or misleading systems feedback and insufficiencies in training (it is assumed that personnel did not receive training on the sequence and timing of failures present during the attack). Since the operator culture believes their computer-based systems to be moderately reliable, it takes them a while to realize that some systems must be over ridden. Again there are delays waiting for approval by superiors before action is taken, this reflects the cultural Power Distance norms for inequality among people and the importance of social status. The culture is not open to truly assimilating innovation and change and thus, operators will not, unlike American operators, take the initiative to take innovative means to restore or isolate systems.

(3) HEP3 Restore to Safe State calculation:
The base HEP is represented by a beta distribution, where the mean is $\mu = 1.0$ E-3, $\alpha = .497$, $\beta = 499.2$.

> HEP_C = base HEP * (* PSF_c (2x)) (s)
>
> = 1.0E-3 * 2, = 2E-3 or 2 failures/1000 demands

Since a strong Weight of Knowledge is associated with the cumulative PSF the final failure/demand ratio is 2/1000 * 3/3 = 6/3000. The result is:

> **$HEP_{culture}$** is represented by a beta distribution, where the mean is $\mu = 1.86$ E-3, $\alpha = 6.497$, $\beta = 3393.2$ and $\sigma = 7.28$E-4

In HEP3, culture contributes to increased failures for this phase of the loss of service scenario. Human performance requirements for restoring systems to a safe state occur in the latter stages of the scenario and PSFs normally considered in HRA are considered to be nominal. Isolation has been performed and some sense of control has been returned to the operators and work force. Positive restoration requires understanding of what went wrong and system status. It requires a depth of knowledge of dependencies between systems. It may require sending linemen out to the field to correct problems. Culture operates within this scenario to cause an increased failure rate in the following manner. In this particular culture, there is not a large incentive to investigate what went wrong. Thus, an accurate understanding of root or proximate causes of system failure may not be obtained leading to increased errors in restoration. A reluctance to take responsibility will delay or defer sending individuals out into the field, thus causing an error of omission.

– Table 6. HEP with the influence of culture considered.

-

	Base HEP	HEP_{PSF1-8}	$HEP_{Culture}$
Detect system anomalies	1.0E-2	5.58E-2	1.1E-1
Isolate and Shutdown	1.0E-3	3.2E-2	6.4E-2
Restore to safe state	1.0E-3	1.0E-3	1.86E-3

The questionnaires in Tables 2-4 provide scoring mechanisms for the various culture inventory items. The use of the cultural overlay suggests the failure rate for detecting system anomalies is greater when cultural assessment is applied to base HEPs that have been adjusted for the traditional PSFs described earlier in this paper. The failure to isolate and shutdown is higher when the influence of culture is accounted for when determining the failure rate. The HEP associated with restoring systems to a safe state is also higher when culture is considered. This is because this hypothetical culture fails to reward individuals for taking initiative or for using technology to solve problems when other means are available. Thus, we can expect personnel to take greater time to respond and have higher failure rates when correcting problems. From a planning perspective reducing alternative means of solving problems in this particular population can force personnel to use technology with which they are not comfortable and potentially make the cyber attack even more effective.

Example 2

The example below presents one of the ways that we are using the CAM method to modify estimations of system response that involve human interactions. Unlike the previous example, wherein CAM was used to answer the question, "Will this system function as required?" This example, shows how CAM may be used in a model to answer the question "Given an initiating event, when will the system be back to normal?".

INL has done extensive work analyzing weaknesses and vulnerabilities of complex systems focusing on system response to abnormal events and the associated duration for systems to return to a nominal functioning state after such an event. The human element often plays an integral role in estimating the extent and duration of an abnormal event.

Event Sequence Diagrams (ESDs) are often used in PRA to provide an overview of system safety barriers and establish the sequential logic for developing event trees and binning consequences for different initiating events. Critical component response is not typically captured, but can be in the ESD framework. ESDs consist of an initiator and a set of sequential actions or decision blocks. The result provides the analyst with sets of system response pathways prioritized by likelihood. INL has enhanced standard ESDs to include the timing of an abnormal event to establish the probability the system is restored to a nominal state within a period of time.

One of the important aspects uncovered from developing an ESD is the identification of influence points that are significant contributors to pathway probability. These influence points can provide a more surgical approach to defending systems and minimizing event durations and consequences. Figure 1 is a representative ESD for an INL SCADA controlled electrical power grid.

Adjusting for cultural perspectives provides a more accurate estimate of system response. ESDs are a natural environment to apply and test CAM. The probability graphs below the action blocks in Figure 1 show the likelihood that an action is completed within a period of time with the median value shown directly above the graph. The timing probability curves for these events were based on procedures, historical logs, and discussions with system experts.

This ESD presents system response logic for a loss of power event affecting several facilities. Although the timing of actions will be determined by environmental and cultural factors, the emphasis of this example is on the decision blocks. Cultural dependencies may modify the probabilities of decisions, thus directing the event down certain pathways.

For purposes of discussions we have chosen the decision block where linemen decide to first check the substation versus a particular facility. In this hypothetical example, three cultures have been analyzed. The probability for each is as follows. The probability for INL SCADA linemen is $p = 0.7$, that is, there is a 70% chance that they will check the substation first. There is a complementary probability of 30% that they will go directly to a facility that has reported an outage to investigate. The cultural influence is from a number of factors; their trust that the SCADA is providing dependable information; their assessment of the distance and travel time to the substation versus the distance and travel time to the facility, the perceived importance of the facility, deference to what their supervisor would have them do, their tendency to think and act independently, and their understanding of and respect for procedures

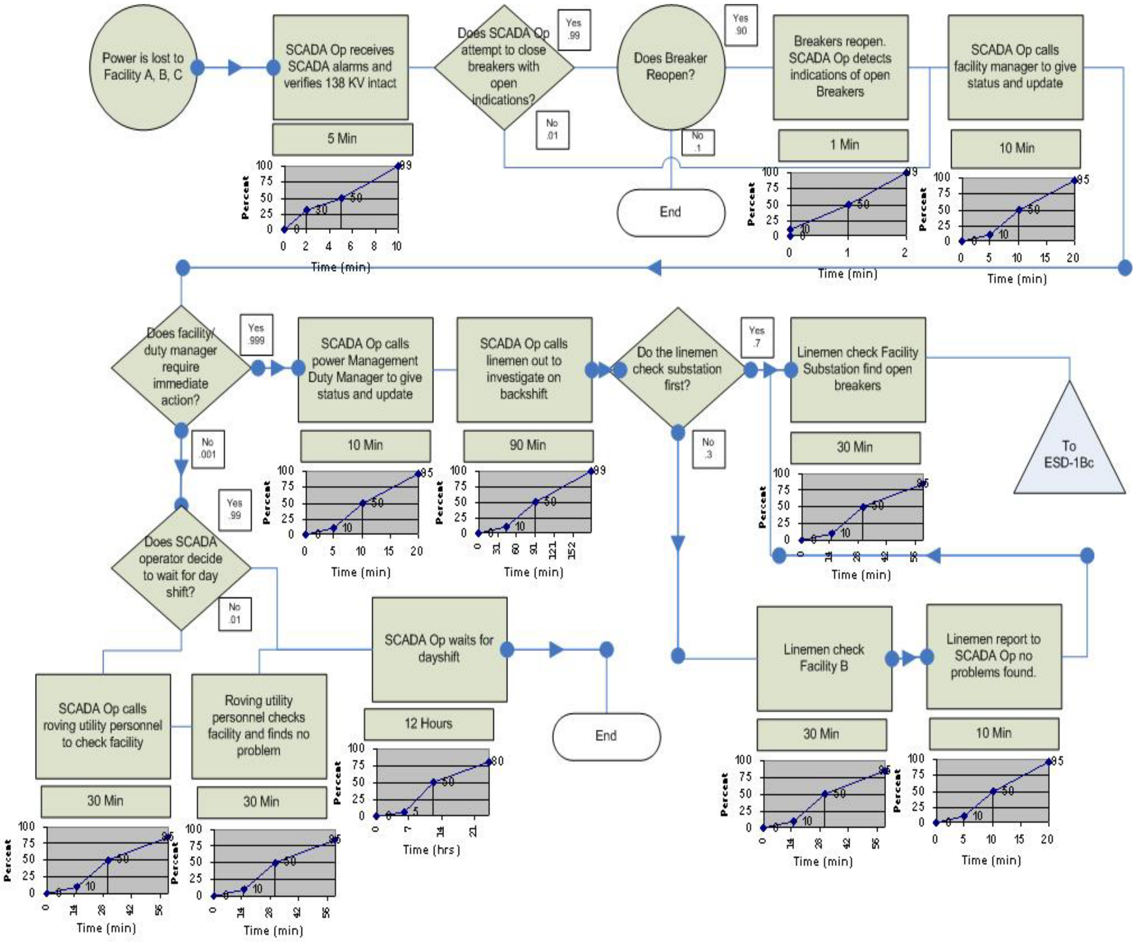

Figure 1. Event Sequence Diagram for INL SCADA response

Culture #2 is evaluated on the same factors, but have procedures in place that make them slightly more disposed to check the facility first. There is a 60% chance for linemen from culture #2 to check the substation first. For the third culture, their trust in SCADA when directing them to the substation is not strong, the status of the facility manager is relatively high, and their procedures are vague. Thus, culture #3 is less likely than the INL culture or culture #2 to go to the substation first to verify breaker conditions and take action. There is a 45% chance that linemen from culture #3 will go to the substation prior to the facility. In a full-blown example, the analyst would apply the CAM method shown in the previous sections to determine weights that modify the baseline probabilities

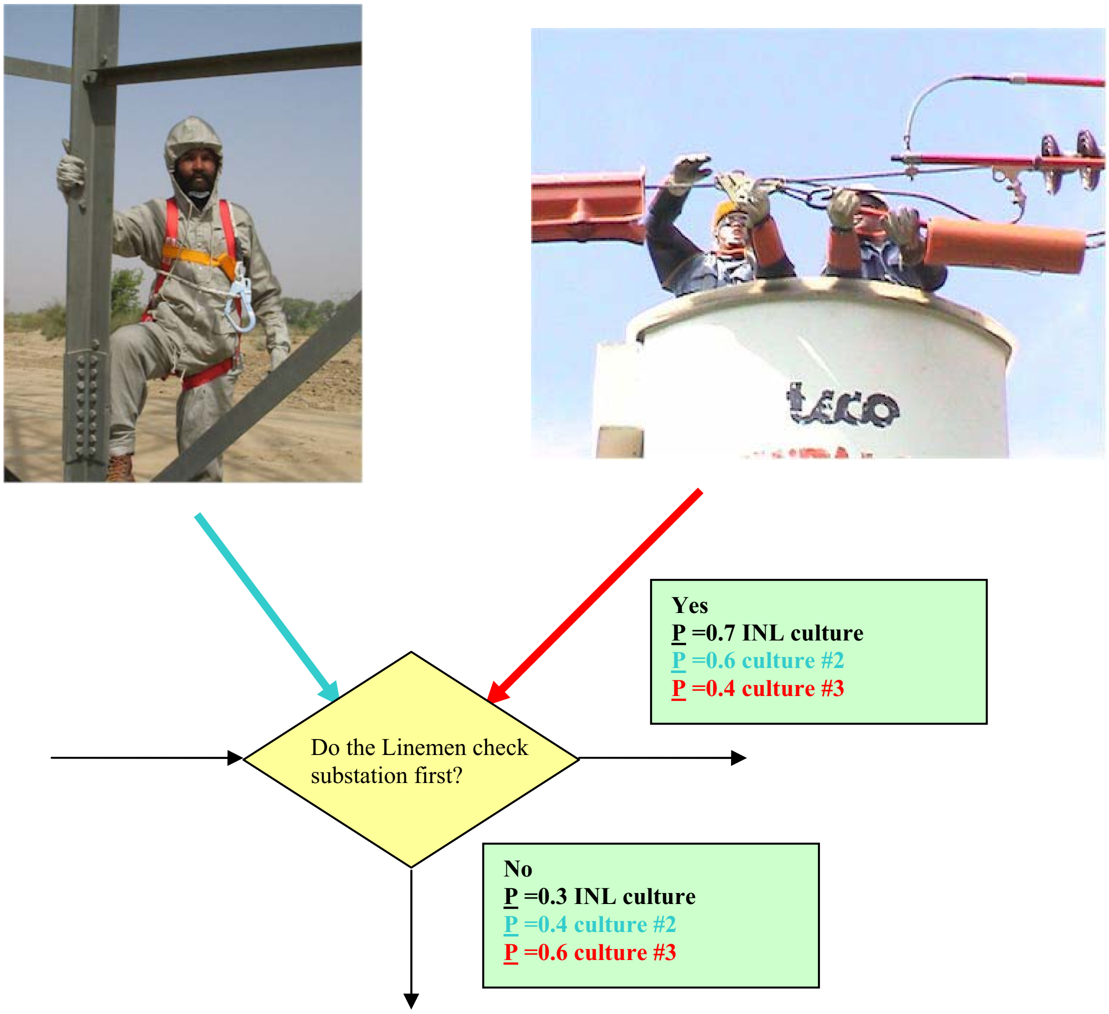

Figure 2: An Example of CAM Application for Event Sequence Diagrams

CONCLUSIONS

Incorporation of the CAM approach to cultural factors into the SPAR-H HRA method gives analysts new insights into potential sources of error to more accurately represent critical situations. These sources of error may not immediately be apparent when only viewed from the perspective of performance by U.S. operators. In addition, the basic HRA method presented in this paper has been vetted for predicting human performance; its extension to include cultural factors has been consistently applied. However, the CAM method needs validation.

Aside from the insights gained from modeling human response including understanding and predicting the immediate consequence(s) of human error, changes in the enemies' *time to respond* that are due to cultural factors can provide information useful to the combatant commander's planning process. The CAM has not been applied to performance times. However, the cultural composite matrix and analysis presented above can be extrapolated from human error probability to include duration metrics. This could be done by assessing the base time required in minutes for similar facilities in the U.S. and using the cultural score to compute the increase or decrease in expected response time. This can be performed for each sub event modeled and quantified in the event sequence diagram or fault tree. The multipliers for this application will be derived and validated in future work.

Future work will be performed in four areas: 1) to assess the relative effect and independence of the proposed cultural factors presented here; 2) to extend the capability of CAM to include expected changes in “time to perform” as a function of culture; 3) to provide guidance to the analyst regarding the determination of weights associated with importance and degree of knowledge; and 4) to assess the extent to which CAM can be applied in other scenarios involving critical infrastructure protection (CIP). These future efforts should be supported through the use of focused studies that can be used to validate the values, i.e., relative range of effect, used in CAM. In the absence of an empirically-based data set, simulation methods in conjunction with structured expert estimation may be a logical and desirable near term alternative.

REFERENCES

Augmented Inspection Team Report for Davis Besse, US Nuclear Regulatory Commission, April 2005.

Bagozzi, R. P., Davis, F. D., & Warshaw, P. R. (1992). Development and test of a theory of technological learning and usage. *Human Relations*, 45(7), 660-686.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319-340.

Furuta, K., Sasou, K., Kubota, R., Ujita, H., Shuto, & Yagi, E. (2000). Human factor analysis of JCO criticality accident. *Cognition, Technology & Work, 2*, 182-203.

Gertman, D. I., and Blackman, H.S. (2000). *Human Reliabilty and Tokai Mura, Cognition, Technology and Work, 2.*

Gertman, D. I. and Blackman, H. S. (1994). *Human Reliability and Safety Analysis Data Handbook*, New York; John Wiley.

Gertman, D. I., Blackman, H., Marble, J., Byers, J., and Smith, C. (2005) The SPAR-H Human Reliability Analysis Method, NUREG/CR-6883, U.S. Nuclear Regulatory Commission, Washington DC, (October 2005).

Hofstede, G. (1991). *Cultures and organizations: Software of the mind.* London: McGraw-Hill.

Hofstede, G. (1980). *Culture's consequences: International differences in work-related values.* Newbury Park, CA: Sage.

IAEA (2002). *Safety Culture in Nuclear Installations: Guidance for Use in the Enhancement of Safety Culture*. IAEA TECDOC Series No. 1329.

Malhotra, Y. & Galletta, D. (1999). Extending the technology acceptance model to account for social influence: Theoretical bases and empirical validation. *Proceedings of the 32nd Hawaii International Conference on System Sciences (HICSS).* Available at: http://www.brint.org/technology acceptance.pdf.

McSweeney, B. (2002). Hofstede’s ‘Model of National Cultural Differences and Consequences’: A Triumph of Faith – A Failure of Analysis, *Human Relations*, *55*, 89-118.

Nisbett, R.E. (2003). *The geography of thought: How Asians and Westerners think differently ... and why.* New York: Free Press.

NUREG/CR-1278, Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications (THERP) Final Report, (1983). Sandia National Laboratories.

Peng, K., and Nisbett, R. E. (1999). Culture, dialecticism, and reasoning about contradiction. *American Psychologist, 54*, 741-754.

Sanchez-Burks, J., Nisbett, R. E., & Ybarra, O. (2000). Cultural styles, relationship schemas, and prejudice against outgroups. *Journal of Personality and Social Psychology, 79*, 174-189.

Tornatzky, L. G., & Klein, R. J. (1982). Innovation characteristics and innovation adoption-implementation: A meta-analysis of findings. *IEEE Transactions on Engineering Management*, EM-29, 28-45.

U.S. Nuclear Regulatory Commission, NUREG-1756, Safety Culture: A Survey of the State of the Art, Prepared by Advisory Committee on Reactor Safeguards, J. N. Sorensen, Senior Fellow, ACRS (see also Reliability Engineering & System Safety, vol. 76, pp. 189-204, 2002).

DISCLAIMER