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A data-informed model of performance shaping factors and their interdependencies for use in human reliability analysis

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ABSTRACT: This paper introduces a new hierarchical set of interdependent Performance Shaping Factors (PSFs) and a highlevel model for quantifying the influence of the PSFs on human errors. It is part of a larger project with the goal of developing a Bayesian Belief Network that will improve on current methods for estimating Human Error Probabilities. The model is based on a fusion of HRA models, human performance theories, and data from human error events in nuclear power plants. The data were taken from the Human Events Repository Analysis (HERA) database currently being developed by the US Nuclear Regulatory Commission. The first phase of the research focused on the development of a set of PSFs suitable for use in a causal model. The PSFs to be used in the model must meet several criteria to promote model validity. The PSFs must be orthogonal; that is, the PSFs must be defined such that there is no overlap between the definitions. This ensures that each observation can be consistently linked to a specific definition. The resulting set has 37 PSFs that fall into six categories representing the major aspects of the socio-technical system.

1 INTRODUCTION

In Human Reliability Analysis (HRA), human performance is often represented by a set of Performance Shaping Factors (PSFs). These PSFs can be used in HRA methods to estimate Human Error Probabilities (HEPs). The current HRA methods rely on sets of PSFs that range from a few (e.g. 8 PSFs in SPARH) to over 50 PSFs in IDAC, with varying degrees of overlap between the PSFs. However, very few methods address the overlap or the inherent dependency between the PSFs. The methods that do address dependency among PSFs generally rely on linear or loglinear combinations of PSFs.

These dependencies could be more accurately represented by a causal model that includes relationships among the PSFs. This paper introduces a set of interdependent PSFs and a high-level model for displaying the relationships among them. It is part of a larger project to develop a causal model of PSFs that can be linked to human error. The use of an interdependent model of PSFs is expected to produce more accurate HEPs than current practices.

There are many sets of PSFs available for HEP quantification [see for example (Hollnagel 1998; Gertman *et al*. 2005; Swain and Guttmann 1983; Chang and Mosleh 2007a)]. However current sets of PSFs are not suitable for construction of a causal model because the PSFs overlap within the same set. To build a model of relationships between the PSFs it is necessary to ensure that the PSFs are separately defined entities, i.e. that they are orthogonal. Overlapping PSFs introduce error into the calculations because some elements are double-counted in the data; this skews the relationship among the PSFs and masks the way that elements interact to affect performance.

The concept of orthogonality is central to the development of the model. Elements of the model must be orthogonal to ensure that the model captures how the elements interact instead of how they overlap. The difference between independence and orthogonality is significant. Orthogonality implies that the factors do not overlap in their definitions, and therefore observations can be consistently placed into a single category. However, the categories can still influence each other. Independence implies that the factors do not overlap and also do not interact with each other.

The PSF hierarchy presented herein is based on the major aspects of the socio-technical system. The PSFs at the top layer of the hierarchy are not necessarily independent in behavior, but they are orthogonal. Each aspect can be measured objectively without knowledge of the state of the other system aspects.

2 DATA SOURCES

The primary data source for this research is the Human Events Repository Analysis database, HERA, developed by the US Nuclear Regulatory Commission (NRC) and the Idaho National Laboratory. The HERA database can be accessed online at `https://secure.inl.gov/hera/Login.aspx`. It contains detailed retrospective analyses of human performance in commercial nuclear power. The data are derived from analyst interpretation of Licensee Event Reports (LER) written by utilities and Augmented Inspection Team (AIT) reports written by NRC inspectors (Hallbert *et al*. 2006).

Table 1. Sample event timeline for a HERA analysis. Each table row is a single sub-event. The "code" column refers to the sub-event code; EE refers to an external (off-site) sub-event; XHE and HS refer respectively to human failure and human success sub-events; XEQ and EQA refer respectively to failure or activation or equipment.

Date	Time	Code	Sub-event description
08/22/2001	Unknown	XHE	The CTG 11-1 replacement set point card and inverter were incorrectly set to low voltage trip set point of 105 volts (required: 98 volts)
05/30/2003	Unknown	XHE	Maintenance on CTG 11-1 DC fuel oil pump was inadequate: arcing horn clearances were not checked.
05/31/2003	Unknown	XEQ	The CTG 11-1 DC fuel oil pump starter contactor began to stick open against its arcing horn.
08/14/2003	4:05 00 PM	EE	A regional electric grid disturbance occurred that led to blackout conditions in a large portion of NE U.S.
08/14/2003	4:10 00 PM	EQA	Continuing grid instability resulted in an automatic turbine trip.
08/14/2003	4:10 00 PM	EQA	The Reactor Protection System (RPS) initiated a reactor scram as a result of the turbine trip.
08/14/2003	4:11 00 PM	EQA	All MSIVs closed due to the loss of RPS power).
08/14/2003	4:11 00 PM	EQA	EDGs 11, 12 and 14 automatically started from standby.
08/14/2003	4:11 00 PM	HS	Operators transferred EDG 13 from surveillance test mode to emergency mode of operation.

Each HERA analysis consists of a single risksignificant operating event. Each event is broken down into a detailed timeline based on information in the LER or AIT and any additional related reports (e.g. inspection reports) that are publicly available in the United States. The timeline is composed of sub-events; a single sub-event covers either the activation/malfunction of a single piece of equipment or system, or each successful/unsuccessful human action, or external events and plant states. Table 1 contains a portion of an event timeline from HERA analysis 341-2003-002-01, with each table row representing a new sub-event.

After completing the event timeline, the analyst must determine which human failure or success subevents are suitable for further analysis; suitability is based on the quality of available information. The analysis consists of a detailed interpretation of the context of the performance and information on what influenced human behavior and how human behavior contributed to the scenario evolution. A large portion of this analysis is dedicated to determining which PSFs affected the performance. Analysts determine which PSFs contribute to the scenario by using PSF details. The analyst marks each PSF detail that affected the sub-event; the parent PSF is automatically checked when the PSF detail is selected. Table 2 displays a set of PSF details for the Training PSF.

The human errors analyzed in HERA may be committed by individuals or by teams. For this research we have focused on "person errors" committed by single workers who may be part of a time. Team interactions may influence person errors, but the final error of commission or omission can be linked to a single actor. These person errors are different than team errors where the team agrees upon an erroneous conclusion or agrees to follow an incorrect path. The PSF framework presented is suitable for person errors, including errors in single person decision making, but this framework may need additional modification to include team-based human errors.

Table 2. HERA PSF details for the training PSF.

Training (Negative PSF details)
Training incorrect
Training less than adequate (LTA)
Simulator training LTA
Fitness for Duty training missing / LTA
Training process problem
Situation outside the scope of training
Not familiar / well practiced with task
Not familiar with tools

The HERA database is currently being populated with data. As of March 2009, HERA contains 25 fully coded events. While the 25 events provide a wealth of information about human performance, the number of events is not sufficient to provide conclusive evidence about any relationships among PSFs. Among the 25 events there are 168 human failure sub-events with detailed human error analyses. Several of the human error analyses belong to the same HERA event, so there are only 25 truly independent data points. With 25, or even 168, data points there is not sufficient data to ensure that each PSF is represented in proportional to its impact on human performance.

In the remainder of this paper the authors discuss indications of correlation, not necessarily firm correlation. Given the data limitations we are unable to definitively say that the PSFs correlate, only that they correlate based on the available data. As events are added to the HERA database over the coming years it will become possible to announce more statistically significant conclusions.

3 DATA ANALYSIS

To create the base structure of a model it is necessary to finalize a set of orthogonal PSFs that can be used as the nodes of the model. It is also necessary to determine how the PSFs relate to each other. We used correlation results to garner an initial understanding of these relationships.

Correlation gives a quantitative measure of the relationship between two variables – the amount of variance from the common area between them. For data that are normally distributed, the Pearson product-moment correlation coefficient can be calculated by many commercial analysis packages (e.g. SAS, SPSS, MS Excel). The degree of correlation is indicated by a number between −1 and 1. A correlation of 0 indicates complete independence between the variables, and a correlation of 1 indicates a perfect increasing linear relationship.

Data that is not normally distributed, regardless of the distribution of the process creating the data, violates the assumptions underlying product-moment correlation. For discrete data, polychoric correlation provides a more accurate measure of relationship than does product-moment correlation (Drasgow 1988; Olsson 1979). Tetrachoric correlation is polychoric correlation applied specifically to binary sets. It assumes that the binary data is representative of an underlying normally distributed model and the maximum value of the normal distribution is a threshold where the variable becomes either 1 or 0. This is not a valid assumption for some binary data sets. One example is gender; gender is not normally distributed, a person is either male or female, and therefore tetrachoric correlation cannot be used on such data. However, most human behavior is not truly discrete, so tetrachoric correlation is particularly useful for human behavior modeling.

Determining tetrachoric correlation is a very computationally intensive task. We used SAS version 9.1 (SAS Institute Inc.) to perform all analyses discussed in this page. We determined tetrachoric correlations using the % polychor macro available online at `http://support.sas.com/kb/25/010.html`.

4 PSF MAPPING

The proposed set of PSFs is based on a fusion of current HRA models, relevant theories, and data from human error events. The new set of PSFs is modeled after the IDAC framework (Chang and Mosleh 2007a). The IDAC model combines HRA and psychological theories with information from operating experience in nuclear operations. It offers a hierarchical structure and an orthogonal set of PSFs. IDAC also includes qualitative links between PSFs that can be used as to form the initial structure of a directed model (Chang and Mosleh 2007b).

The human error data used came from the HERA database, which includes information about influencing factors in both operations and maintenance tasks. The HERA PSF details can be used to extend the IDAC framework to situations beyond operating crews. By expanding the IDAC structure and combining it with the PSF details from HERA we can maximize the use of the data. HERA provides informative data about human performance plant-wide, but is largely limited to observable PSFs available in documentation. The HERA data can be used to validate sections of the IDAC model, and the expanded IDAC structure can be used to hypothesize influences that are not captured in the HERA data.

Our goal was to develop a hierarchical set of PSFs that consider the HERA PSFs and the IDAC Performance Influencing Factors (PIFs). Before mapping any PSFs onto the IDAC framework we ran tetrachoric correlation and iterative Principal Factor Analysis (PFA) on the data grouped by the 11 HERA PSFs. Due to the amount of overlap among the HERA PSFs, we found correlations above $|0:9|$ between several PSF groups. We were unable to obtain valid PFA results due to Heywood cases, wherein the correlations exceed $|1|$ (Van Driel 1978). Heywood cases can be eliminated by adding data or by adjusting the factor model and eliminating outlying variables.

We approached the mapping with the intention of dividing the PSFs in a way that linked each PSF with a single aspect of the socio-technical system. The new set placed each of the PSFs into one of six categories: machine (hardware and software) based, situation (task) based, stressor (load) based, person (internal) based, team based, and organization based. This ensured that each PSF was defined orthogonally and is particularly critical in differentiating between inadequate personnel performance and inadequate organizational performance.

The mapping procedure entailed sorting the HERA PSF details into new PSF groups, running quantitative analysis to determine the suitability of the grouping, and redistributing the outlying variables. To determine which PSFs were producing Heywood cases, we permitted correlations to exceed 1 in the PFA. For the first round of mapping we assigned each HERA PSF detail to one of the 50+ IDAC PIFs. We ran correlation and PFA analyses on this data and again received invalid results due to Heywood cases. We identified the PIF with the greatest invalid correlation and either merged it with another PIF or redistributed the HERA details to other PIFs. We continued to run PFA analysis and adjust the PSF mapping based on the results until we produced a set of results without any Heywood cases.We then identified the IDAC PIFs that are unobservable based on current data collection techniques. We combined the unobservable IDAC PIFs with the PSFs retained in the factor analysis to develop a set of 37 PSFs corresponding to the six PSF categories previously identified. These results were used to develop a high-level model with the 6 orthogonal PSF groups (Fig. 1) and a more detailed model of the 37 PSFs (Groth and Mosleh 2009).

5 SUGGESTED PSF HIERARCHY

The 6 PSF groups in Fig. 1 are the top level of the hierarchical PSF model. The second layer of the model

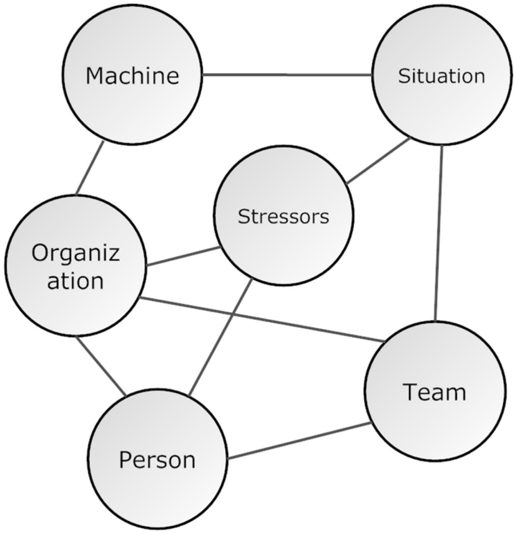

Figure 1. The "6 Bubble Model," a high-level representation of the relationships among major aspects of a socio-technical system.

is a set of 37 PSFs, and under several second layer PSFs there is a third PSF layer. The complete first and second layers of the hierarchy are illustrated in Fig. 2. The top level of the hierarchy is represented by the six boxes, one for each aspect of the socio-technical system. The second level of the hierarchy contains the 37 PSFs within the six boxes. These 37 PSFs comprise the complete PSF set that will be used in the final model. The PSFs in the third level of the hierarchy are indented below the associated second level PSFs. This level is only partially displayed due to space constraints; elements that are not displayed are still captured by the second level PSFs.

Some elements in the third level of the hierarchy are not PSFs, rather they are *behaviors* that can be associated with a specific PSF. These behaviors have been italicized in Fig. 2 to differentiate them from third level PSFs. While the associated behaviors are not influencing factors, it is necessary to retain them as part of the hierarchy because they provide essential information about largely unobservable internal factors. The inclusion of these behaviors helps clarify vague terms like work conduct; work conduct itself cannot be directly observed, but compliance behavior can be observed.

The hierarchical arrangement of the PSFs is intended to reflect the way that retrospective data is collected and not necessarily how the information is expected to be used by analysts. In organizing the PSFs we considered the final impact on worker behavior. Both tools and procedures are sub-categories for the resources PSF because the end effect is the same: the worker does not have all of the necessary resources to complete the task, regardless of what the resources are. In this version of the hierarchy we have also lumped together the adequacy of the resources and the availability of the resources because they have a similar effect on performance.

The multiple layers of PSFs in the hierarchy offer increasing amounts of detail for analysis. The structure is designed to maximize data collection by allowing analysts to address PSFs at several levels of detail. Analysts may collect very detailed data when it is available and high level data when detailed data is not available. The flexibility of the hierarchical structure enables us to combine the detailed and high-level data into one framework.

The 6 major PSF groups are largely orthogonal by definition, but are not independent. It will never be possible to create completely independent categories as long as humans belong to teams and organizations. However, by linking the major PSF categories to the aspects of a socio-technical system it is possible to maintain separation by definition.

Within the 6 PSF groups the definitions are not fully orthogonal or independent. Due to space constraints we are unable to fully discuss the 37 suggested PSFs. The reader is referred to (Groth and Mosleh 2009) for complete definitions of the PSFs and examples from the HERA database. This reference also contains a draft version of the causal model expanded to include PSFs from the second and third levels of the hierarchy.

5.1 *Machine (design)-based*

Machine-based PSFs refer to the system as designed by the manufacturer. All of the mechanical and electrical components of the system are part of the machine, but the building is also included in the "machine" because it is designed along with the mechanical system. The machine-based PSFs consider the entire system as purchased, which generally cannot be modified without significant cost and effort.

The machine-based PSFs include characteristics of the human-system interface and the responses that the machine is designed to provide. Malfunctioning indicators are not a machine-based PSF, they are a situation-based PSF. However, poorly designed indicators are a machine-based PSF. In this PSF framework, HSI includes control panels and other traditional HSI elements, but it also includes the accessibility (as designed) of machine components and plant areas. This expanded definition of HSI covers humans obtaining output from displays and charts, and it also covers humans providing input to the machine through software, buttons and dials, mechanical tools, or other contact.

Machine-based PSFs can be distinguished from situation-based PSFs because machine-based PSFs are the static physical (and software) parts of the system that are generally unchanging over the course of an event. This also differentiates machine-based PSFs from organizational PSFs by defining who has control over the part. The design of the containment building is something that the utility cannot change because it was designed and constructed by a different organization. If the control room does not have enough lights

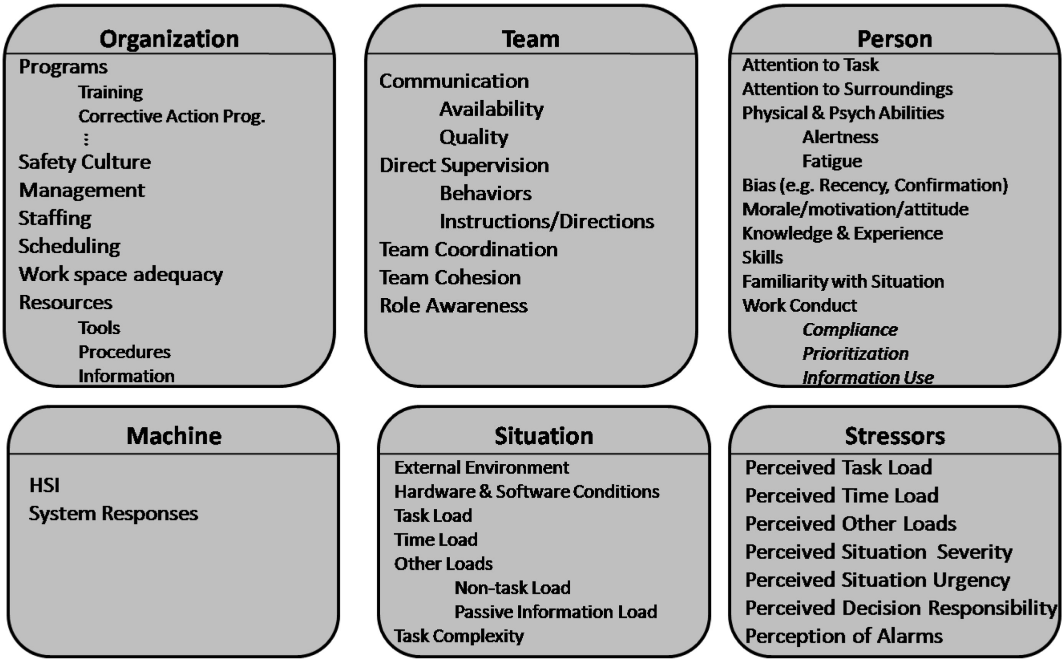

Figure 2. Proposed PSF grouping. The highest level of the hierarchy is represented by the 6 shaded bubbles. The second and third levels of the hierarchy are contained within the bubbles. Italicized aspects of the hierarchy are behavioral indicators of certain unobservable PSFs.

by design, it is a machine-based problem. However broken light bulbs are organization-based issues since the organization, not the designer, is responsible for changing light bulbs.

5.2 *Organization-based*

The organization-based PSFs refer to the factors that are defined by or are under the control of the organization. The organization-based PSFs include the organization's attitudes and certain organizational behaviors that influence the performance of workers. Safety culture and management have a wide impact on all plant personnel. Management behaviors such as scheduling and staffing shape personnel performance because they are directly related to the number and type of tasks assigned to workers, the composition of work teams and the qualifications of personnel. The organization-based PSFs differ from the machine-based PSFs because the organization has primary responsibility for these factors. HSI is machinebased because it is a largely static system that is designed and constructed once and is unlikely to change. In contrast, procedures can be updated relatively easily and frequently by the organization.

The resources PSF includes the procedures and tools provided by the organization. It also includes other information resources that should be provided to personnel. This can include maintenance records and databases, log books, etc. While the specific part of the organization that is responsible for the various resources may change, the impact on behavior is that the necessary tools and information are not provided to the worker. On a broad level, the organizational programs can also be seen as organizational resources. The programs-based PSFs include the non-physical resources provided through training programs in addition to other plant programs not listed in Fig. 2.

5.3 *Team-based*

A team can be described as any group of people expected to work together to complete a task or achieve a common goal. In the plant context, team members are expected to interact directly either in person or in writing. Members of the same operating crew or the same maintenance shift are certainly a team, but members of different operating crews can also be considered a team because the off-going crew is expected to pass certain information to the oncoming crew.

Team-based PSFs include the way the team members interact and communicate. While communication style and role awareness are unique to each individual, these PSFs are not person-based because communication requires at least two participants. Likewise, role awareness only emerges as an influencing factor when there are multiple roles available.

Direct supervision is a team-based factor, whereas management is an organization-based factor. On most teams the direct supervisor plays an active role as a member of the team, albeit a member with increased authority and responsibility. The behavior of the direct supervisor is not a PSF for the supervisor performance, rather it is a PSF for other team members and the team as a whole.

5.4 *Situation-based*

Situation-based PSFs are characteristics of the situation that are likely to affect human performance. These characteristics are external to the human and to the design of the machine. Situation-based factors differ from machine-based components because the situation factors can change during the scenario. These changes can be due to natural causes, e.g. weather, or can be due to actions executed earlier in the scenario. A non-working piece of hardware is a situationbased conditioning event, but a poorly designed piece of equipment is a machine-based problem. Failures that occur during scenario evolution and latent failures that are discovered during the scenario evolution are both conditioning events. Situational factors include the characteristics of the situation such as complexity, the number of simultaneous tasks, the status of the machine and the work environment.

Many of the situation-based PSFs are closely related to the stressor PSFs. Human perception is the dividing line between situational and stressor PSFs. While task complexity is subjective depending on the worker, it is still possible to estimate the relative complexity of a situation from the perspective of the "average" worker; there are scenarios which can be clearly labeled more complex. An SGTR event may seem simple to very experienced personnel and complex to less experienced workers, but an SGTR event coupled with broken SG level indicators will always be more complex than an SGTR event with properly functioning indicators. It is this objective complexity that is captured by situation-based PSFs.

5.5 *Stressors*

Stressor PSFs are the demands of the situation as perceived by the person. The external loads manifest in the person as stress. It is important to emphasize the role of perception in this category – the loads are objective characteristics of the situation, but the perception of the loads is what makes them a stressor. Individual perception serves as the filter that turns situational characteristics into an internalized load. The subjective loads can increase based on the perception of the objective difficulty of diagnosing and executing work, the amount of knowledge required, the number of steps required, and the ambiguity of the situation.

The number of alarms flashing is objective, but the perception of the alarms is what imposes stress. The perception of the alarms can vary between personnel and can also vary within the same person depending on the state of other PSFs. Each person performs an individual situational assessment and forms individual perceptions of situational severity and urgency.

The inclusion of perception as a major aspect of the stressor PSFs limits the orthogonality of the this PSF group. Personal characteristics covered in the person-based PSFs will always have some amount of influence over how a person perceived situational demands. Likewise, the perception of the situation cannot be completely independent of objective situationbased factors.

Table 3. Correlations among the high-level PSFs. The results suggest that the groups are largely independent, with some exceptions discussed below. PSF group names are abbreviated due to space constraints.

	Mach.	Team	Org.	Situ.	Str.	Pers.
M	1					
T	−0.06	1				
O	−0.06	−0.21	1			
Si	0.35	0.47	0.06	1		
St	−0.15	0.42	−0.13	0.19	1	
P	−0.10	0.31	0.07	0.10	0.32	1

5.6 *Person-based*

Person-based PSFs are internal factors that affect each individual. People may act as a member of a team and an organization, but every individual has a unique working style and unique perception of a situation.

Organizational culture cannot fully account for the behavior of every member of the organization because each person has unique internal factors.

The person-based PSFs include the person's physical and mental fitness and suitability for the task. Physical and psychological fitness have been treated as a single PSF because it is very difficult to separate one's physical abilities from one's psychological state, both in practice and by definition.

Psychological and physical abilities should not be confused with knowledge and experience. Experience relates to the knowledge possessed by the worker, whereas the PPA refer to the readiness of the worker to *use* that knowledge. Cognitive biases and abilities, including knowledge, are also unique personal factors. Unlike the organization-based training PSF, which is generally uniform for personnel throughout a department, knowledge and experience are unique to every person and are therefore a person-based factor. Information from training is converted into knowledge, but different people will always retain different information from training. The retention of knowledge could also be related to other person-based factors including attitude and morale.

Many of the person-based PSFs are unobservable because they cover internal states. Because of the difficulty of observing a person's internal characteristics, it is necessary to include behavioral indicators in lieu of actual PSFs. The way the person prioritizes information may affect the state of the situation, but it is not an influencing factor on that person's current performance. However, the way the person prioritizes information is an indicator of aspects of the personal work conduct. In the current model, work conduct is the only PSF with explicitly associated behaviors, but future versions of the model may include behaviors for other unobservable PSFs.

6 DISCUSSION

Table 3 displays the tetrachoric correlation coefficients among the 6 PSF groups. Correlation values below $|0 : 25|$ suggest that the PSFs tend to be independent in the data. Orthogonality is one of the necessary aspects that defines independence, so the number of low correlations observed suggest that the 6 group PSF model is orthogonal for the majority of the categories. Five of the correlation values are large enough to merit further discussion: Machine – Situation, Team – Situation, Team – Stressors, Team – Person, and Stressors – Person.

The stressor PSFs are largely based on personal perception, and the person-based PSFs play a significant role in the way that individuals perceive loads. This close relationship ensures correlation between the two PSF categories. However, the stressor and person categories can still meet the condition for orthogonality; the PSFs in the categories may interact, but they are distinctly defined entities.

The team-based PSF category has a non-trivial correlation with several other PSF categories. There are multiple explanations for this behavior. Team factors are likely to be correlated with the person-based factors because a team is composed of individuals, and therefore the individual characteristics of the team members affect the team. For example while communication is categorized as team-based, each member has a unique inherent personal communication style, and these styles combine together to form the team-based communication. However, we can state that by definition the communication must occur between two or more people, so while the inherent characteristics of each person do play a role, there cannot be communication without multiple individuals, i.e. a team. It follows logically that there is a correlation between team-based and stressor factors because personal characteristics influence both elements.

The high correlations between team-based factors and other PSF categories may also be an indicator of the strong role that teams play in commercial nuclear power. For most operations and maintenance tasks there is either direct teamwork or some level of review to ensure that tasks are completed correctly. The team has a significant role in almost every aspect of commercial power and it is natural that the team would correlate with many aspects of the sociotechnical system.

The highest correlation observed is between team-based factors and situation-based factors. It is important to note that the data included only human error events that had an impact on the plant, i.e. the correlation between human error and the values in Table 3 is 1.0. During normal operating conditions the operating crew plays a generally passive role monitoring indicators of the system state. However during abnormal situations the crew shifts to an active role controlling the plant. The data suggest that poor teamwork alone is not sufficient to produce an error, because humans do not have the opportunity to make an error that impacts the plant if they are not affecting the state of the plant. Team-based factors may have a significant influence on human performance, but they do not become important to the plant until the team is asked to interact with the plant. The high correlation between the machine-based factors and situation-based factors can be explained in a similar way. The machine design does not become salient until a situation requires personnel to interact with the machine.

7 CONCLUSIONS

The combination of the IDAC structure with the HERA PSFs details has allowed us to produce a datainformed structured set of PSFs for use in HRA. The set reflects the orthogonal structure of PSFs in IDAC, which reduces overlap between the PSFs while still permitting natural dependencies to exist. While the 6 major PSF groups may not be completely orthogonal, there is a significantly higher amount of orthogonality between the groups than within the groups.

During analysis of the data it became apparent that team and organizational factors were at the root of many of the human errors. However, not all human errors were organizationally based. For this reason certain PSFs have been broken down into organizational and personal components. One of the shortcomings of some HRA methods is the blurring of the line between individual and organization. The new set of PSFs contains Work Practice/Work Conduct elements that parallel each other in the organizational and human sections. Both humans and organizations can display poor work behaviors. In most cases safety culture will influence both sets of work processes, but in the end the human and the organization must each take responsibility for their behaviors. Differentiating between organization and personnel work conduct will allow HRA analysts to better address the source of problems.

Specific behaviors associated with work conduct have been added to the set of PSFs. The behaviors themselves are not PSFs; they are visible manifestations of an invisible PSF. Some HRA methods do not differentiate between improper work conduct and the behaviors that demonstrate improper work conduct.

The next phase of this work will focus on expanding the 6 bubble model into a full model that uses the 37 second-level PSFs that are encompassed by the 6 bubbles. The model will include causal connections between the 37 PSFs based on the HERA data and on expert elicitation. It will contain quantified links among the PSFs from all three layers of the hierarchy. The final model will also include relationships between specific PSFs and several error forcing contexts.

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