Modeling Human Reliability: the Underlying Cognitive Abilities

Pedro A. Baziuk, Jorge Núñez Mc Leod, Romina Calvo and Selva S. Rivera, *Member, IAENG*

***Abstract*— The innovative inclusion of the Cattell-Horn-Carroll theory on cognitive abilities and Fleishman's premises on social and interpersonal skills simultaneously addresses several problems of existing human reliability models. First, it provides a theoretical basis for causal cognitive models of human error with a strong experimental support specifying their interrelationships and dependencies. Derived from psychometric studies, this quantitative theory facilitates the quantification of the parameters required for a quantitative analysis of human reliability while also reducing the subjectivity in the analysis. Herein, the inclusion of cognitive, social and interpersonal skills puts focus on interpersonal differences and their impact on human performance. In other words, an analysis of operators, a new dimension of analysis in human reliability models, is hereby introduced for the first time.**

***Index Terms*— human reliability analysis; cognitive abilities; human performance; human error; operator analysis; job analysis**

I. Introduction

Risk is currently a subject of significant interest to many areas of high social impact such as healthcare, nuclear power, aviation and military defense. Given that human error and the possibility of an incident are impossible to completely remove from complex technological systems, all potential interventions should be used to ensure that such aspects become, at least, controllable.

Risk management in these sectors represents the set of multiple complex actions which aim to improve the quality and ensure the safety of people and equipment. It is necessary indeed to consider error as an irremovable component of human nature. Therefore, given that it is impossible to completely eliminate human error and the associated risk, it is essential to promote appropriate working conditions. Yet and above all, it becomes crucial to perform a series of actions that make it difficult for humans to make mistakes and, thereafter, to establish defenses to reduce the mistake's consequences. Thus, it is necessary to understand the intrinsic mechanisms of human error in certain circumstances.

Human Reliability studies seek to determine tendencies of persons to make mistakes in their professional performance. According to Kirwan [1] the three principal functions of HRA are "identifying what errors can occur (Human Error Identification), deciding how likely the errors are to occur (Human Error Quantification) and, if appropriate, enhancing human reliability by reducing this error likelihood (Human Error Reduction)".

Human reliability models can be classified into first and second generation. First generation models focus on quantification without taken into consideration the cognitive causes of error. Based on statistical methodologies, these models make strong assumptions about human behavior, e.g. linear cognitive process that can be questioned [2] [3] [4]. Also, statistical methodologies fail to consider qualitative aspects, e.g. language parameters [5]. Complementarily and in order to improve such weaknesses, second generation models focus on human behavior and cognitive causes of human error. An important assumption, which can be strongly questioned, is that cognitive functions (perception, interpretation, planning and action) are separated [2]. In both generations, performance shaping factors (PSFs) are essential for producing quantifications. In first generation, PSFs are drawn from context or the environment while, for second generation, they are obtained from cognitive characteristics considering the aforementioned assumptions and without establishing a clear relationship between environmental and cognitive factors [6].

In this paper, we follow the cyclic cognitive process theory; i.e. acting is not the result of a serial process of perceiving, interpreting, planning and acting but that of a cyclic process of interaction with the environment [7]. In this cycle model of behavior it is important to include the limitation of cognitive resources, supervisory attention systems and problem space in problem solving. At this point, an important contribution is hereby presented for the first time: the inclusion of the Carroll-Horn-Cattell (CHC) [8] theory of cognitive abilities. This insight should later facilitate operator analysis quantification, a novel issue in HRA models, by psychometric tests and PSFs selection.

II. Limitations of HRA models

It was since the year 1960 that HRA methods began to be applied. However, most techniques for assessment of the human factor, in terms of propensity to fail, began to be developed in the mid '80s. HRA techniques or approaches can essentially be divided into two categories: first and second generation. Currently, we have come as far as to HRA dynamics and methods of a third generation, which are understood as an evolution of previous generations [9].

First generation HRA techniques were based on statistical

This work was supported by the National Council of Scientific and Technical Research CONICET Argentina and the National University of Cuyo (Mendoza, Argentina).

P. A. Baziuk is with CONICET and National University of Cuyo, Mendoza, Mendoza 5500 Argentina (+542614135000; fax: +542614380120; e-mail: pbaziuk@cediac.uncu.edu.ar).

R. Calvo is with CONICET and National University of Cuyo (e-mail: rcalvo@cediac.uncu.edu.ar)

S. S. Rivera is with National University of Cuyo, Mendoza (e-mail: srivera@cediac.uncu.edu.ar).

J. NuñezMcLeod is with CONICET and National University of Cuyo (e-mail: jnmcleod@cediac.uncu.edu.ar).

ISBN: 978-988-14048-0-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

techniques. A lot of methods and models in classical reliability theory assume that all probabilities are precise [10]; that is, that every probability involved is perfectly determinable. Human error probability can be assigned based on the characteristics of the operator's task and then modified by performance shaping factors (PSFs). This generation focuses on quantification in terms of success/failure of the action and is less concerned with the depth of the causes and reasons of human behavior, matters borrowed from the behavioral sciences.

Modeling human errors through probabilistic approaches has presented a limitation on quantification of qualitative aspects of human errors and complexity of attributes given the circumstances involved [5]. Mosleh & Chang indicated what the limitation of the first generational methods of human reliability analysis is while listing some expectations about how methods should be and demonstrating that methods must be human behavior model-based [3].

In second generation HRA methods (as CREAM or ATHEANA), the focus shifted to the cognitive aspects of humans, the causes of errors rather than their frequency, the study of the interaction of the factors that increase the probability of error and the interdependencies of the PSFs. This generation of methods emphasizes on qualitative characterizations of human error while describing the cognitive roots and the human cognitive functions involved. Human behavior, according to both these methods, is assumed to be governed by two basic principles: the cyclical nature of human cognition and the dependence of cognitive processes on context and working environment. Within the scope of these models, cognitive functions (perception, interpretation, planning and action) are separately considered and individual differences are modeled as PSFs.

The use and choice of PSF is different in both generation models. In the first generation model, PSF mainly represents task environment [11] and some operator characteristics (in recent updates) without thorough explanations of PSF and performance relations. Moreover, a large group of PSFs are not adequately treated in these models [9]. Conversely, PSFs in second generation focus on operator characteristics and how task environment impacts on the operator's cognition.

None of the second generation models have been generally accepted or proved sufficiently comprehensive [12]. The limitations of present HRA models can be enumerated as follows:

1) Many proposed second generation models still lack sufficient theoretical or experimental bases for their key ingredients [13] [9].

2) Both models lack a fully implemented representation of the underlying causal cognitive mechanisms, linking measurable PSFs and their interdependence, or other characteristics of the operator and their context such as, particularly, a measurement of the cognitive and physical abilities or person to person differences. [9], [14], [15].

3) Most second generation models do not produce quantifications per se. Instead, developers of the models or other authors make adjustments for such quantifications.

4) The majority of the proposed approaches still rely on implicit functions relating PSFs to probabilities without providing correct uncertainty treatments. [3], [14].

5) Another limitation of current HRA models is the strong dependence on expert opinion to assign values to the PSFs: "during this assignment process, subjectivity plays an important role, causing difficulties in assuring consistency" [9].

A lot of work has been done to make progress on the matter of the gap between cognitive psychology (human brain and human behavior knowledge and theories) and human reliability analysis (for exemplification, see [16]). It is since such efforts that researchers have found an important relation between human error rate and reaction time [17] [18] and stress [19] [20], the concept and theory of situation awareness [21], workload and multiple resources in simultaneous tasks [22] and the concept and theory of mental models [23][24]. Dekker and Hollnagel [13] carried out a strong critique to these models by establishing that these "folk" models are more descriptive than explicative and that the measures obtained from them reflect important aspects of operator situation but related with "intermediate cognitive states" rather than with real performance. The aforementioned authors proposed focusing on real performance instead of inferring uncertain states of mind.

Following this line, we propose the inclusion of CHC cognitive abilities theory [8] in order to sort out some of the limitations described above. Cognitive abilities taxonomy is a strong theoretical and experimental based model of human differences that favors objective quantification of such differences by means of psychometric tests. Measuring cognitive abilities is closer to measuring real performance than abstract constructions such as situation awareness or stress. Also, the later comparison between operator cognitive abilities and task demands results in human error possibility, which is in itself explanatory of underlying cognitive causes.

III. Human Cognitive Abilities

For several authors, CHC theory, which gets its name from Raymond Cattell, John Horn and John Carroll, is the most comprehensive and empirically based psychometric theory [25] [8]. It is the conjunction of two theories; namely, Gf-Gc theory, proposed by Cattell in 1963 and expanded by John Horn in 1965 [25], and Carroll´s three-stratum theory [26].

According to Carroll´s three-stratum theory, relationships among individual differences can be classified into three different strata; that is, stratum 1 "narrow" abilities, stratum 2 "broad abilities" and stratum 3 "general abilities" or "g" factors. This theory is based on factor analysis. Stratum 1 is composed of first–order factors among tests and often referred to as primary mental abilities including nearly 80 abilities [27]. Meanwhile, stratum 2 or second-order factors include 16 abilities [8] while stratum 3 or third-order factors comprise general abilities or "g" factors (in spite of proving mathematically valid, no correlation with psychology constructs has been established and its validity has been questioned). There is structural evidence (differing in gender, level of education, ethnicity, nationality, language and historical period) confirming that primary abilities are part of second-factor high-order abilities positively correlated but independent (independence is demonstrated by way of structural evidence and distinct construct validity)

ISBN: 978-988-14048-0-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

[27]. Carroll (1993) argued that these strata are more than mathematical entities as they can explain neurocognitive differences, i.e. broad abilities representing behavioral organizations founded in neural structures and functions [27]. Furthermore, these factor scores are effective when accounting for behavioral differences.

Second-order abilities, or broad abilities, reflect most knowledge of the nature of human intelligence and initially were [27] crystallized intelligence or acculturation knowledge (breadth and depth of knowledge of the language, concepts and information of the dominant culture), fluid reasoning or fluid intelligence (capacity to identify relationships, implication comprehension and inference drawing in novel or familiar situations), short-term apprehension and retrieval (also referring to short-term memory and working memory), fluency of retrieval from long-term memory, processing speed (rapid scanning and comparison of situations), visual processing (visual closure and constancy, object and pattern recognition), auditory processing (perception of sound patterns under distraction or distortion circumstances), quantitative knowledge (understanding and application of quantitative and numerical concepts, mathematical rules, numerical symbols) and reading and writing ability (includes basic reading and writing skills). A tenth ability, which is not currently assessed by tests drawn from a psychometric framework but can be interesting in terms of HRA domain, involves decision/reaction time/speed (reflecting the immediacy with which an individual can react to stimuli or a task). McGrew [8] included six additional broad abilities: general or domain specific knowledge (breadth, depth and mastery of knowledge in specialized subject matters or discipline domains that typically do not represent the general universal experiences of individuals in a culture and are developed through intensive systematic practice and training), tactile abilities, kinesthetic abilities, olfactory abilities, psychomotor abilities and psychomotor speed.

Interrelations among broad abilities do not point toward a single factor (factor g) [27]. Focusing on their interrelations, second factor abilities can be classified as follows: (1) vulnerable abilities which include fluid reasoning, processing speed and short-term memory (these abilities are likewise related to variables indicating neurological, genetic and aging effects), (2) expertise abilities which comprise crystallized intelligence, long-term memory and quantitative knowledge (these abilities are related to learning and socialization; McGrew's domain specific knowledge ability should be included in this cluster), (3) sensory-perceptual abilities, closely linked to strengths and weakness of sensory modalities, that present characteristics from both previous groups but do not clearly fit within any of them, (4) psychomotor-physical abilities which were embraced by McGrew [8] and exhibit different characteristics and evaluation tests drawn from the others abilities. This classification should be relevant for HRA in terms of several aspects; namely, analyst training, initial human error possibility screening, task analysis, etc. Clusters 1 and 2 are usually grouped together into a more general "cognitive abilities" set.

The only antecedent relating human error to cognitive abilities was described by Buffardi et al [28]. Their approach was based on Fleishman´s cognitive abilities taxonomy [29] derived from a correlation study of different jobs [30]. We assume that the Cattell-Horn-Carroll classification theory is more appropriate due to the large extension and validation of their work, the fact that it is based on individual differences rather than differences between jobs and for being closely related to psychometric test that facilitate quantification [8]. This last aspect, which is essential throughout this work, involves the fact that the problem in defining non-observable constructs for human reliability analysis is their subsequent measurement. The Cattell-Horn-Carroll theory tackles this issue.

IV. Teamwork: Social and Interpersonal Abilities

Several authors have agreed on the importance of social and interpersonal abilities (e.g. [31] [32] [33] [34]). The analysis proposed focuses on the individual in team circumstances rather than on team level as a whole [35]. The abilities required to properly perform in a team may not be the same that are required for traditional individually oriented jobs [31]. Thereby, a fifth category of human abilities, or "social-interpersonal abilities", should be drawn upon in order to address human performance in teamwork. The level of social abilities relates to better adopting social roles required for managing conflict and handling work coordination [31].

LePine and Van Dyne [36] followed the distinction regarding performance proposed by Borman and Motowidlo in 1993. Such notion indicates that there are two types of performances; that is, task performance (focused on activities that directly contribute to or support the transformation of inputs into outputs; i.e. operating machinery in a factory) and contextual performance (indirectly contributing with organizational success by maintaining or improving the organizational, social or psychological environment necessary for the technical core to function effectively and efficiently; i.e. helping and cooperating with others). LePine and Van Dyne studied 276 individuals and subsequently demonstrated that personality characteristics proved to relate more compellingly to contextual performance than to task performance.

Schumacher et al [37] used a set of 19 social and interpersonal abilities extracted from F-JAS taxonomy [38]: achievement striving, agreeableness, assertiveness, behavior flexibility, coaching, coordination, dependability, negotiation, openness to experience, oral defense, oral fact finding, perseverance, resilience, resistance to premature judgment, self-control, sociability, social confidence, social conformity and social sensitivity.

Stevens and Campion [35] classified social and interpersonal abilities into two broad groups: interpersonal abilities and self-management abilities. Interpersonal abilities are then subdivided into three narrower categories: conflict resolution (manage conflict, air and relieve interpersonal friction, recognize types of conflicts and match a correct resolution strategy, negotiation or bargaining), collaborative problem solving (utilize the proper degree and type of participation, recognize obstacles and implement appropriate corrective actions) and communication (understand and utilize communication networks, communicate openly and supportively, listen non-evaluatively and appropriately use active listening techniques, maximize consonance between nonverbal and verbal messages, recognize and interpret the nonverbal messages). Self-management (of the team) abilities are divided into two categories: 1) goal setting and performance management (which help establish specific, challenging and accepted team goals as well as monitor, evaluate and provide feedback on both overall team performance and individual team member performance) and 2) planning and task coordination (plan and coordinate activities, information and task interdependencies among team members together with helping establish task and role expectations of individual team members and ensuring proper balancing of workload amongst the team).

As mentioned above, the problem in defining a set of abilities is their later measurement. Individual performance that facilitates effective team functioning is more related to contextual performance than to task performance [31] [36]. Then, personality characteristics are likely to be good predictors of contextual performance which, in addition, is positively related to social skills [31]. Therefore, it is possible to infer measurements of certain personality characteristics, contextual performances or social skills.

Burch and Anderson [39] indicated that personality should be a predictor of human performance and drew on the Five Factor Model personality taxonomy which classifies personalities into five groups: neuroticism, extraversion, openness to experience, agreeableness and conscientiousness. The most important factor included in this analysis is, in all probability, the relation that can be established between human performance and emotions such as anxiety, irritability, optimism or sense of responsibility. Results drawn from Barrick and Mount studies [40] revealed that one particular dimension of personality, conscientiousness, proves consistently correlated to all job performance criteria for all occupational groups.

Personality characteristics to be measured are conscientiousness, extraversion, agreeableness, emotional stability and openness to experience [41]. Such measurement entails the usage of the Personal Characteristics Inventory (PCI) method [42].

V. Cognitive abilities: Predictors, Correlations and Falsability

Dekker and Hollnagel (2004) implied that phenomenon or construct explanations should be decomposed or reduced into fundamental elements that suggest possible measures favoring the corroboration of the given explication. That is, falsifiability, an important principle in science.

Carroll´s three-stratum theory provides a framework in which comparisons and correlations between psychometric variables and information processing variables can be made [27]. Also, correlations between human reliability constructs and cognitive abilities can be evaluated and would therefore prove the validity of measuring cognitive abilities instead of situation awareness, stress, complacency, workload, etc.

Some of these correlations have already been explored. For instance, a significant correlation between situation awareness and cognitive abilities was performed amongst military aviation pilots [43]. The prior example suggests that such type of correlation should be found in others cases and that, moreover, some other human reliability constructs should be equally supported by way of these means.

The validation (as opposite of falsifiability) criterion applied for the inclusion of cognitive abilities in human reliability analyses entails answering the question "are cognitive abilities predictors of human reliability?" to then perform evaluations on the bases of correlations.

McKenna, Duncan and Brown [44] observed a substantial correlation between typical intelligence tests and accident rates for bus drivers. Buffardi et al [28] also perceived correlations between error rates and ability requirements for tasks in nuclear power plants.

Different abilities are required for different jobs and correlations between cognitive abilities and jobs should benefit task analysis, job redesign and operator recruitment and training. For example, Schumacher et al [37] detected that 63 % of the cognitive abilities present significant differences in requirement levels between analyzed jobs. Additionally, relevant divergences can also be established when examining social/interpersonal abilities.

The validity of personality characteristics as human performance predictors has also been assessed. While the highest validity is established for conscientiousness, there seems to be a "more complex pattern of relationships between personality and performance in jobs that involve interpersonal interactions than is captured solely by assessing Conscientiousness" [41]. Conscientiousness and emotional stability are positively correlated with job performance in the case of virtually all jobs [40]. These personality dimensions prove more stable in terms of validity for jobs requiring interpersonal components or teamwork organization (e.g. interactions with coworkers and customers). For example, sales and customer services exhibit the highest relations to conscientiousness of all while sales and managerial jobs also present such relations but in a lower degree with emotional stability and extraversion standing out. Another example involves customer services and how they are related to (in order of importance) conscientiousness, agreeableness, openness to experience and emotional stability [41].

Another important issue concerning predictions of performance is the notion of incremental prediction. If the measurement of any given construct does not increment prediction accuracy or happens to reflect aspects that are related to other measurements, there is unnecessary redundancy. In other words, it is important that no construct measures can be inferred by means of other construct measures. In terms of Fleishman: "the fewest independent ability categories which might be most useful and meaningful in describing performance in a wide variety of tasks" [30]. In the case of cognitive abilities, there is an experimental correlation between them that has led to the groundwork for the notion of general ability or "g" factor. There are two reasons for disregarding the usage of the "g" factor. Firstly and primarily, it is of dubious validity and, secondly, the use of different abilities facilitates task analysis for different jobs that may require different sets of abilities. In the case of social/interpersonal abilities, personality characteristics have been consistently found to be unrelated to cognitively oriented measures [31].

ISBN: 978-988-14048-0-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

VI. CONCLUSION AND DISCUSSION

The inclusion of underlying cognitive abilities in human reliability analyses involves relying on a theoretical base and, specifically, the Cattell-Horn-Carroll theory, which is largely experimental-based. This latter theory also facilitates consequent quantification since it is based on psychometric tests. Concurrently, the theory in question addresses the problem of strong dependence on expert judgment by drawing on these tests which are expressly developed to function as objective measurements.

The insight presented herein improves theoretical and empirical contrastability; incorporates deeper knowledge of cognitive sciences; sorts out the problem of lack of specificity in terminology and constructs in traditional models; reduces the structural model uncertainty, especially concerning the randomness of cognitive resources among individuals; and allows quantification by psychometric tests therefore decreasing bias introduced by expert judgment.

The innovation herein introduced would bring about the development of a model for which plausibility is based on the reviewed correlations. These correlations illustrate theoretical and conceptual contrastability and, thus, concluding that human abilities are a good predictor of human reliability and validating the use of human abilities over traditional model constructs (situational awareness, stress, complacency, workload, etc.).

The main contribution of this paper has to do with the inclusion of human abilities as the heart of reliability analyses and, consequently, the modeling of operator´s individual specific abilities (including cognitive, physical and social ones) as a fundamental component of the system.

This contribution should also be utilized in human resources administration for tasks involving personnel selection, operators evaluation, training programs and training requirements (for exemplification, see abilities required for acquisition of necessary skills [45]) and so on [46].

A usual factor was omitted from this analysis: operating conditions. In unusual or, moreover, emergency situations, the human factor plays an important role as well. These types of operating conditions may increase task ability requirements while also modifying the ways in which people respond to stimulus. Emergency situations seem to encourage demand of social/interpersonal and sensory/perceptual abilities without modifying that of other cognitive abilities. Shumacher et al [37] found that a small number of abilities, only 5 of 51, significantly differed regarding demand for normal and emergency situations: "three were from social/interpersonal domain (Behavior Flexibility, Self-Control and Oral Defense), and two were from the sensory/perceptual domain (Speech Recognition and Auditory Attention)" [37]. These results suggest that such factor does not introduce significant changes in human reliability analyses modeled by means of cognitive abilities measurements.

REFERENCES

[1] B. Kirwan, A guide to practical human reliability assessment, London: Taylor&Francis, 1994.
[2] W. J. Clancey, «Situated Cognition: Stepping out of Representational Flatland,» AI Communications, vol. 4, nº 2, pp. 109-112, 1991.
[3] A. Mosleh y Y. H. Chang, «Model-based human reliability analysis: prospects and requirements,» Reliability Engineering and System Safety, vol. 83, nº 2, pp. 241-253, 2004.
[4] E. Hollnagel, «Human Reliability Assesment in Context,» Nuclear Engineering and Technology, vol. 37, nº 2, pp. 159-166, 2005.
[5] L. V. Utkin y F. P. A. Coolen, «Imprecise Reliability: an introductory overview,» Computational Intelligence in Reliability Engineering, vol. 40, pp. 261-306, 2007.
[6] P. Baziuk, S. Rivera y J. McLeod, «Cognitive task analysis and Human Performance Shaping Factors. A reassessment from a second generation model,» American Society of Civil Engineers. ISBN: 978-0-7844-1303-6, pp. 1275-1281, 2013.
[7] S. Franklin, «The role of consciousness in memory,» Barins, Minds and Media, vol. 1, nº 1, pp. 1-38, 2005.
[8] K. S. McGrew, «CHC theory and the human cognitive abilities project: Standing on the shoulders of the giants of psychometric intelligence research,» Intelligence, vol. 37, nº 1, pp. 1-10, 2009.
[9] V. Di Pasquale, R. Iannone, S. Miranda y S. Riemma, «An Overview of Human Reliability Analysis Techniques in Manufacturing Operations,» de Operations Management, ISBN 978-953-51-1013-2, 2013, p. Chapter 9.
[10] B. Kim y R. Bishu, «Uncertainty of human error and fuzzy approach to human reliability analysis,» International Journal of Uncertainty, fuzziness and Knowledge-Based Systems, vol. 14, pp. 111-129, 2006.
[11] S. W. Lee, R. Kim, J. S. Ha y P. H. Seong, «Development of a qualitative evaluation framework for performance shaping factors (PSFs) in advanced MCR HRA,» Annals of Nuclear Energy, vol. 38, nº 8, pp. 1751-1759, 2011.
[12] E. Lois, V. Dang, J. Forester, H. Broberg, S. Massaiu, M. Hildebrandt, P. Braarud, G. Parry, J. Julius, R. Boring, I. Männistö and A. Bye, "Description off Overall Approach and Pilot Phase Results from Comparing HRA Methods to simulator Performance Data," NUREG/IA, 2009.
[13] S. Dekker y E. Hollnagel, «Human factors and folk models,» Cogn Tech Work, pp. 79-86, 2004.
[14] S. S. Rivera, P. A. Baziuk y J. E. NuñezMcLeod, «Fuzzi Uncertainties in Human Reliability Analysis,» Lecture Notes in Engineering and Computer Science, pp. 970-975, 2011.
[15] P. A. Baziuk, S. S. Rivera y J. E. NuñezMcLeod, «Towards a unified human reliability model,» Advances in Safety, Reliability and Risk Management, pp. 746-753, 2011.
[16] A. M. Whaley, S. M. Hendrickson, R. L. Boring y J. Xing, «Bridging Human Reliability Analysis and Psychology, Part 2: A Cognitive Framework to Support HRA,» (No. INL/CON-12-24797), Idaho National Laboratory (INL), 2012.
[17] G. Hannaman, A. Spurgin y Y. Lukic, « Human cognitive reliability model for PRA analysis,» Draft Report NUS-4531, EPRI Project RP2170-3, Electric Power and Research Institute: Palo Alto, CA., 1984.
[18] K. Kirytopoulos, M. Konstandinidou, Z. Nivolianitou y K. Kazaras, «Embedding the human factor in road tunnel risk analysis,» Process Safety and Environment Protection, p. http://dx.doi.org/10.1016/j.psep.2014.03.006, 2014.
[19] E. Hagen, «Human Reliability Analysis,» Nuclear Safety, pp. 315-326, 1976.
[20] H. Beech, L. Burns y B. Sheffield, «A Behavioral Approach to the Management of Stress,» New York, John Wiley and Sons, 1982.
[21] M. R. Endsley, «Situation awareness global assessment technique (SAGAT),» de National Aerospace and Electronic Conference (NAECON), Dayton, OH., 1988.
[22] M. R. Endsley, «Towards a Theory of Situation Awarness in Dynamic Systems,» Human Factors, pp. 32-64, 1995.
[23] M. R. Endsley, «Theoretical underpinnings of situation awarness: a critical review,» de Situation Awarness Analysis and Measurements, Mahwah, NJ, Lawrence Erlbaum Associates, 2000.
[24] C. D. Wickens, «Multiple Resources and Mental Workload,» Human Factors, pp. 449-455, 2008.
[25] C. D. Wickens, «Multiple resources and performance prediction,» Theoretical issues in ergonomics science, pp. 159-177, 2002.
[26] C. D. Wickens, «Workload and situation awareness: An analogy of history and implications,» Insight: The Visual Performance Technical group Newsletter, pp. 1-3, 1992.
[27] A. Mosleh y Y. H. Chang, «Cognitive modelling and dynamic probabilistic simulation of operating crew response to complex system accidents - Part 1,» Reliability Engineering and System Safety, pp. 997-1013, 2007.

[28] O. Sträter, V. Dang, B. Kaufer y A. Daniels, «On the way to assess errors of commission,» Reliability Engineering and System Safety, pp. 129-138, 2004.
[29] V. C. Alfonso, D. P. Flanagan y S. Radwan, «The impact of the Cattell-Horn-Carroll theory on test development and interpretation of cognitive and academic abilities,» de Contemporary intellectual assessment: Theories, tests and issues, 2005, pp. 41-68.
[30] J. B. Carroll, Human cognitive abilities: A survey of factor-analytic studies, New York: Cambridge University Press, 1993.
[31] D. P. Flanagan y P. L. Harrison, Contemporary Intellectual Assessment: Theories, Tests, and Issues, Guilford Press, 2012.
[32] L. C. Buffardi, E. A. Fleishman, R. A. Morath y P. M. McCarthy, «Relationships between ability requirements and human errors in job tasks,» Journal of Applied Psychology, pp. 551-564, 2000.
[33] E. A. Fleishman y M. K. Quaintance, Taxonomies of human performance: The description of human tasks, Orlando, FL: Academic Press, 1984.
[34] E. A. Fleishman, R. G. Kinkade y A. N. Chambers, «Development of a taxonomy of human performance: A review of the first year's progress (No. AIR-726-11/68-TPRI),» American Institutes for Research, Pittsburgh, 1968.
[35] F. P. Morgeson, M. H. Reider y M. A. Campion, «Selecting individual in team settings: the importance of social skills, personality characteristics, and teamwork knowledge,» Personnel Psychology, pp. 583-611, 2005.
[36] K. M. Goeters, P. Maschke y H. Eissfeldt, «Ability requirements in core aviation profession: job analyses of airline pilots and air traffic controllers,» de Aviation Psychology: Practice and Research, Ashgate, Aldershot, UK, Goeters, 2004, p. 99–119.
[37] J. Cannon-Bowers y E. Salas, Making Decisions Under Stress: Implications for Individual and Team Training, Washington, DC: American Psychological Association, 1998.
[38] K. E. Weick, «The vulnerable system: an analysis of the Tenerife air disaster,» Journal of Management, pp. 571-593, 1990.
[39] M. J. Stevens y M. A. Campion, «The knowledge, skill, and ability requirements for teamwork: Implications for human resource management,» Journal of management, pp. 503-530, 1994.
[40] J. A. LePine y L. Van Dyne, «Voice and cooperative behavior as contrasting forms of contextual performance: evidence of differential relationships with big five personality characteristics and cognitive ability,» Journal of Applied Psychology, p. 326, 2001.
[41] S. Schumacher, M. Kleinmann y K. G. Melchers, «Job requirements for control room jobs in nuclear power plants,» Safety science, pp. 394-405, 2011.
[42] E. Fleishman y M. Railly, «Fleishman job analysis survey (F-JAS) Administrator's guide,» Management Research Institute, Potomac, MD, 1995.
[43] G. J. Burch y N. Anderson, «Personality as a Predictor of Work-Related Behavior and Performance: Recent Advances and Directions for Future Research,» de International review of industrial and organizational psychology, John Wiley & Sons, 2008, p. 261.
[44] M. R. Barrick y M. K. Mount, «The big five personality dimensions and job performance: a meta-analysis,» Personnel psychology, pp. 1-26, 1991.
[45] G. M. Hurtz y J. J. Donovan, «Personality and job performance: the Big Five revisited,» Journal of applied psychology, pp. 869-879, 2000.
[46] M. K. Mount, M. R. Barrick, L. J. Laffitte y M. C. Callans, Administrator's guide for the Personal Characteristics Inventory, Libertyville, IL: Wonderlic, 1999.
[47] K. Sulistyawati, C. D. Wickens y Y. Ping Chui, «Prediction in Situation Awareness: Confidence Bias and Underlying Cognitive Abilities,» The International Journal of Aviation Psychology, pp. 153-174, 2011.
[48] F. P. McKenna, J. Duncan y I. D. Brown, «Cognitive abilities and safety on the road: a re-examination of individual differences in dichotic listening and search for embedded figures,» Ergonomics, pp. 649-663, 1986.
[49] G. Cuschieri, N. Hanna y A. Francis, «Psychomotor ability testing and human reliability analysis (HRA) in surgical practice,» Minimally Invasive Therapy & Allied Technologies, pp. 181-195, 2001.
[50] N. Petterson, M. Mumford, W. Borman, P. Jeanneret y E. Fleishman, «Understanding work using the Occupational Information Network (O* NET): Implications for practice and research,» Personnel Psychology, pp. 451-492, 2001.
[51] L. M. Hough, «The'Big Five'personality variables--construct confusion: Description versus prediction,» Human performance, pp. 139-155, 1992.

ISBN: 978-988-14048-0-0
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)