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Towards Human Factor Taxonomy with Cognitive Generic Terms

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Abstract— **In this paper one of the most important issues in human reliability analysis: human error taxonomies will be briefly described divided in two categories: 11 classical and 6 modern taxonomies. Aspects focused on the development of these approaches differ widely among classic and modern taxonomies. The two desirable features sought in newest taxonomies (inter-rater reliability and generality) seem to be contradictory to each other. Also the most important issues will be summarized. The analysis of the review points out that several taxonomies could be applied in some adverse scenario and suggests that possibly the idea of failure taxonomic should be discarded and replaced by human factor taxonomy with cognitive generic terms.**

Index Terms— **human error, human reliability, taxonomy**

I. Introduction

TAXONOMIES or classifications are used in many fields in order to organize knowledge. In human error area, this classification has, initially, practical and theoretical value. Taxonomies of human error that emphasize in observable behaviors have a greater practical value, and they can be used in retrospective analysis (accident/incident investigation) to determine weakness in design, or in prospective analysis to predict possible errors. Taxonomies that emphasize in cognitive aspects have predictive value; i.e. focusing in psychological mechanism and cognitive causes of error, hazard situations can be anticipated.

Human error taxonomy is a system of classification that organizes and cluster error types according to common properties. To describe in depth a phenomenon is necessary to have an unambiguous classification scheme [1]. The application of a theoretical human error classification system to investigate accidents/incidents has a number of potential benefits [2]: provide a consistent and formal structure to accident/incident investigation data collection and analysis; ensure the investigation is systematic and thorough by ensuring that all levels of the system are considered; counteract heuristics and biases that investigators may bring to investigations; enable comparisons of accident/incident contributing factors across industries. According to Itoh et al. [3] the purposes to develop taxonomies are: identify risk factors by retrospective analysis; understand nature and characteristics of errors and associated factor, and assess current levels of risk or safety. One of the most important roles of taxonomies is to provide a meaningful structure for describing, explaining and understanding specific events, and therefore taxonomy shall support a framework for systematic analysis of incident and near-miss reports to support organizational learning [3]. Most taxonomies include the following dimensions or aspects [3]: event type (what happened); domain (characteristics of staff, plant, operator involved, and setting); errors and causes; contributing factors (hazards, root causes, latent conditions, contextual conditions); impact (outcome, consequences, or level of harm); and lessons learned (measures taken or proposed, or prevention and mitigation). One important aspect of human error taxonomies is their capability to standardize the different terminologies in accident/incident reports, allowing comparison and analysis. Also taxonomies make a filter to non-relevant information. Kirwan call these classifications “taxonomic techniques” [4] and they can be generic (like THERP) or specific related to an industry (like SRS-HRA), or specific related to an error type (like INTENT). These techniques are based on experience, therefore have a contextual validity. Senders and Moray [1] and Reason [5] state that there are three main types of mechanism that can be used to classify errors relating to behavioral, contextual and conceptual levels of classification. These mechanisms are:

1) Phenomenological taxonomies (phenotypes). Errors are classified according to how they were observed (such as omissions, intrusions, and unnecessary repetition);
2) Cognitive mechanism taxonomies (genotypes). Errors are classified according to the stages of human information processing at which they occur for example attention failures and memory lapses; and
3) Bias or deep-rooted tendency taxonomy. Errors are classified according to a person’s deep-rooted beliefs and tendency towards 'tunnel vision'. A person may firmly believe that a path is the correct one to take and may ignore all over options.

According to O´Hare [6] there is a lack of “common definitions” and “criteria” for human error classification. In recent years big efforts have been done but there remains a need to integrate the results of accident investigations in various fields [6]. In the same line Gong et al. [7] found some limitations applying taxonomical approaches to aviation accident analysis, and underline the need of “proactive” approaches, i.e. identification of potential

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hazards not only focusing on factors that have been indicated in accidents (“reactive approaches”).

II. TRADITIONAL HUMAN ERROR TAXONOMIES

Taylor-Adams and Kirwan [8] conclude that human error can be classified in four main components: external error mechanisms (EEMs), internal error mechanisms (IEMs), psychological error mechanisms (PEMs) and performance shaping factors (PSFs). Likewise, Reason [5] calls these categories: behavioral (observable features of errors), conceptual (cognitive mechanisms and theoretical concepts to determine the underlying causes of errors) and contextual (conditions under which the errors occurred). Meister [9] classifies errors in following seven categories: design errors, maintenance errors, operator errors, inspection errors, fabrication errors, manipulation errors, and human-machine contributory errors. Fault trees and event trees, often include human error before and after an initiating event. ASME norms [10] use the same classification: pre-initiator errors, post-initiator. Payne and Altman [11] propose a classification schema based on a simplify theory of information processing containing three categories of error: input errors, mediation errors and output errors. Swain and Guttman [12] propose a dichotomous classification: omission errors and commission errors. Rasmussen [13] in the SRK (skill, rules, knowledge) model, classify human behavior according to conscious level or cognitive control used, if conscious level is low (automatize actions) behavior will be based on skills, if conscious level is medium behavior will be based on rules and if conscious level is high behavior will be based on knowledge. Fleishman and Quaintance´s taxonomy of human performance [14] is based on the premise that there is a finite set of human abilities that can be used in the performance of a task. Fleishman has identified, described and isolated a comprehensive set of cognitive abilities that might be thought of as the cognitive resources available to an individual in carrying out any task. Fleishman developed 52 human abilities that range from verbal comprehension to selective attention. The use of these skills has the following disadvantages: users are unfamiliar with the concept of abilities so they tend to choose labels that are longwinded or that vary widely in specificity, redundancy and definition; it is difficult to obtain consistency among analysts (different levels of detail, different word in ability description, etc.); and confusion and subjectivity in the designation of requisite abilities.

SHERPA [15] is based in a five behavior categories: action, checking, retrieval, communication and selection. Error modes are associated to each behavior category, e.g. in action category error modes are: operation too long/ short, operation mistimed, operation in wrong direction; in checking category: check omitted, check incomplete, right check in wrong object or wrong check in right object; in retrieval category: information not obtained, wrong information obtained, information retrieval incomplete; in communication category: information not communicated, wrong information communicated, information communicated incomplete; in selection category: selection omitted, wrong selection made.

Reason [5] classify human error in slips (failure in the execution of a task where the intention is correct), lapses (failure in the cognitive storage of task information where intention is correct), mistakes (failure in the selection of plans conducted for an action where the actions performed are correct) and no detections.

Norman and Shallice [16] contrast slips and mistakes. This classification of error is referred to in much human error research as a way to understand the importance of ‘intention’ in human error but, by itself, is not a useful tool as it fails to distinguish between manifestation and cause [17].

From Wickens’s information processing model [18] errors can be classify in: sensorial errors, pattern recognition, attention errors, decision errors, action execution errors.

Cognitive Reliability and Error Analysis Method (CREAM) [19] take distance from the human error concept thus from a taxonomy, then the probability of incorrect actions is determined rather by conditions under action is done than by human inherent probabilities of error. Performances failing probabilities are described in terms of the “control level” that an operator or crew has of the situation: scrambled, opportunistic, tactic and strategic control.

Traditional human error taxonomies are addressed according to intended/unintended actions (very related to subconscious/conscious actions) and related with the stimulus coming from task or related with the operator response a those stimulus, and associated with the information processing model: sensorial, perceptive and cognitive process. None of the classical taxonomies cover the entire spectrum of possibilities, i.e. CREAM, Rasmussen and Reason focus in operator response; Payne and Altman cover response and stimulus, and the three information processing stages but without distinction about intended or unintended actions; Wickens cover most of possibilities but with narrow limits of errors that make difficult in some cases to address a particular behavior.

SHERPA (don´t included in fig. 1) don´t address sensorial and perceptive errors. Wiegmann and Shappell [20] empirically exposed this problem trying to classify 289 types of pilot-casual factors (contained in the U.S. Naval Safety Center´s database) in to Wickens, Rassmusen and Reason taxonomies. The results were: 19.38% of pilot-casual factors couldn´t be classified according to Wickens taxonomy, 11.57% couldn´t be classified according Rassmusen taxonomy and 15.73% in the case of Reason taxonomy.

O’Hare [6] notices the overlapping of taxonomies. Reason’s taxonomy is encompassed in Rasmussen classification: mistakes and violations are either rule-based (normal violations) or knowledge-based (exceptional violations), slips and lapses are invariable skill-based actions (coding errors according Rasmussen taxonomy “provides more detail than simply coding as slips or violations” [6]). However, classical taxonomies only describe operator actions, proving information as to “what happened” not “why happened”: “to deal with this question, contributing influences at both the local and global levels need to be described” [6].

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III. TAXONOMIES DEVELOPMENT

Post-accident investigation is probably the most important utilization of human error taxonomies. In this application, the major criticism to traditional taxonomies is the gap between human error framework theory and practical application in post-accident investigation. Generally, accident reports are designed and used by engineers without background in human factors, so are not based in any theory of human error. As a result, these systems are very efficient detecting machine and engineering fails, and in better cases, when address a human fail, they focused on external mode of human fail without regarding the cognitive subjacent causes. [21]

The current approaches to human error taxonomies and its critiques are briefly reviewed below. Two desirable features are sought in these new contributions: inter-rater reliability and generality.

The most general approach in human factor research is Svedung and Rasmussen´s Accimap model [22] not included in this review because it hasn't taxonomy of human failures [23]. Results of Accimap depend on analyst subjectivity [23] and the reliability of this method is very limited. Continuing this work Gong et al. [7] is developing an integrated graphic-taxonomic-associative approach (AcciTree). This approach provides a new conception and.

Without taxonomy, generality seems to be more easily achieved.

A. The taxonomy of unsafe operations

Working in this problem Shapell and Wiegmann developed "The Taxonomy of Unsafe Operations" (HFACS) based on SHEL (software-hardware-enviromental conditions-liveware) model of Edwards and Bird´s domino model [21]. This taxonomy describes three levels of failure: (1) unsafe acts, (2) unsafe conditions of operators, and (3) unsafe supervisory practice. First level incorporates Reason´s classification of unsafe actions, considering the intentionality of actions. Second level addresses substandard conditions of operators (e.g. adverse psychological states) and substandard practices of the operator (including mistakes-misjudgments, crew resource mismanagement and readiness violations). Third level is, according Shapell and Wiegmann, an expansion of Reason and Bird theories, presenting a framework for classify supervisory failures (divided in unforeseen and known unsafe supervision). Later publications of HFACS [24] add a fourth level: organizational influences, which include resource management, organizational climate and organizational process.

The taxonomy of unsafe operations was developed in aviation field (has been successfully applied from 2001 to several aviation accidents [25]), but according to its authors is a generic human error accident investigation schema. Indeed it has been successfully applied in conduct train and railway accident [2] [26]. However, according to Salmon et al. [23] analyzing the Mangatepopo canyon incident, various failures could not be classified using HFACS due to its constrained terms taxonomy from a completely different area. They recommend using HFACS in multiple accident cases analysis and strongly recommend the use of the fourth level of HFACS taxonomy. O'Hare [6] noticed, due to the large number of categories in HFACS that eventual number of classificatory categories will become too unwieldy for practical use. In this work was criticized that isn't clear what criteria govern the allocation of factors in second level and he characterized `loss of supervisory situational awareness' (in third level) as a "nebulous" category. Another interesting critic of HFACS [27] highlight as a result of being based on a theoretical model of human behavior is possible to adapt this taxonomy for use in a variety of fields. The taxonomy is organized in an efficient and hierarchical structure that reduce de cognitive demands on the user; regarding the weaknesses of taxonomy: poor suggestions for remedial action, difficult to collect latent failures, and does not identify the chain of events. Beaubien and Baker suggest adding "reason codes", i.e. supplemental information that would be used to identify relevant information and organize information into one or more generic list of exemplars. Even if Beaubien and Baker´s ideas have an interesting direction, they haven´t yet developed human error taxonomy.

O´Connor et al. [28] applied HFACS to categorize 69 human factors for accident causation identified from 60 diving mishaps: only 38 (55.1%) could be classifying into the four categories and subcategories of HFACS. Human causes of accidents are most commonly attributed to unspecified human factors, and in cases were the human factor is classified it is most commonly attributed to inadequate supervision and an adverse physiological state [28].

The Australian Defence Force (ADF) developed a variant of The Taxonomy of Unsafe Operations (HFACS-ADF), adding a set of specific 'descriptors' based on Fleishman´s abilities. Olsen and Shorrock [29] evaluate this adaptation: results suggest an unacceptable level of inter-coder consensus and intra-coder consistency for the use of HFACS-ADF. This evaluation pointed out the following weakness in both traditional and adapted taxonomy: (1) often user had difficult to determine a taxonomy level of casual factor (especially at the level of 'Unsafe act and condition' or a 'Precondition for unsafe acts'), (2) generally were a lack of information determining the category level (especially when reliable information about operator intention is needed), (3) is difficult to assess if coders or user can reliably code information processing concepts (categories and descriptors) and distinguish these from contextual concepts. These results create doubt about the initially good results of HFACs, especially because this initially evaluation were performed with own developers as participants. Particularly in adapted HFACs-ADF, at the descriptor level this evaluation found: a tendency to use "favourite" descriptors many times selected for its "face value"; overlapping descriptors; questionable validity and usefulness of many descriptors; and a large number of descriptors (155) can contribute to reduced mutual exclusivity and consensus and their specifity result in a difficult description of events. Authors of this evaluation indicate that it is possible to improve HFACS-ADF, and recommend four principal strategies of improvement [29]. Nevertheless they also propose moving away from the HFACS-based approach, creating a new taxonomy more operationally and contextually oriented.

B. Technique for the Retrospective and predictive Analysis of Cognitive Errors

Similar to HFACS there is other technique: TRACEr (technique for the retrospective and predictive analysis of cognitive errors in air traffic control) [30]. TRACEr has a modular structure (author compare with Rasmussen classification). Taxonomy is divided initially in three main groups: context (task error taxonomy, information taxonomy and performance shaping factors taxonomy), error production (External Error Modes: selection and quality, timing and sequence and communication; Internal Error Modes: 34 types of internal error modes, divided in 14 cognitive function belonging to 4 cognitive domains; Psychological Error Mechanisms: are associated with IEMs if there is the information necessary) and recovery (analyzed through an error detection and a recovery error questionnaire). TRACEr has a different procedure for retrospective and predictive procedure. Author of TRACEr have validate their method obtaining a "reasonable level of agreement", the "strongest areas of the technique were comprehensiveness, structure, acceptability of results, and usability" and some confusion in the use of the categories. Author indicates that this method is in "prototype" stage, and they indicate some areas of improvement.

TRACEr has been applied in air traffic (e.g. HERA-JANUS developed by EATMP Human Resources Team cited in [25]) and air traffic control (Shorrock 2003, 2005, 2007); and adjust for other areas (e.g. tool for train driving created by the Rail Safety and Standards Board –RSSB– in 2005 cited in [25]). RSSB's tool has a lite version with eight taxonomies or classification schemes (task errors, cognitive domains, internal error modes, psychological error mechanisms, information, error detection, error recovery, performance factors; for a brief review see table 1 from [25]).

Baysari et al. [25] have done an excellent comparison between HFACS and TRACEr in rail incident characterization and classification. They analyzed 19 investigation reported of railway accidents.

As a conclusion of these results, Baysari et al. [25] remark the importance of organizational influences identified emerging from HFACS, in contrast TRACEr allow to classify cases of driver detection and recovery. In application of TRACEr the analyst must firstly identify that an error has occurred, in contrast HFACS simply map each contributing factor, this leads in a greater number of error detected by HFACS. Performance shaping factor list from TRACEr isn´t comprehensive and some obvious additional categories are needed [25]. It was found that HFACS performed well at categorizing the "organizational context" of errors while TRACEr-rail performed well at categorizing the "immediate context surrounding errors". Finally, none of the two techniques was able to sufficiently identify and classify the whole range of factors and errors contributing to incident or accident.

C. Crew Resource Management (CRM)

O´Connor and Flin [31] develop a human factor based training management with the objective to improve safety in offshore oil production. The importance of their work to this article is the non-technical skill framework formed the basis of the skills to be trained in the CRM course. They classify skills in six categories: Situation Awareness (plant status awareness, environmental awareness, anticipation, concentration/avoiding distraction, shared mental models), Decision Making (problem definition/diagnosis, risk and time assessment, recognition primed, decision making/procedures/ analytical, option generation/choice, outcome review), Communication (assertiveness/speaking up, asking questions, listening, giving appropriate feedback, attending to non-verbal signals), Team Working (maintaining team focus, considering others, supporting others, team decision making, conflict solving), Supervision/Leadership (use of authority/assertiveness, maintaining standards, planning and co-ordination, workload management) and Personal Resources (identifying and managing stress, reducing/coping with fatigue, physical and mental fitness).

This classification of skills was used as error taxonomy for address human errors from fatality reports in US Navy diving accidents [28]. The conclusion of this work is a large number of recommendations to human error researchers: caution in applying error taxonomy from one industry to another (subcategories specific to the industry are needed); examine characteristics of accident reports; often industry specific language is used in error taxonomies; taxonomy selected must be not so small that it provides insufficient information, and not so big that it is unwieldy and has low levels of inter-rater reliability; to improve inter-rater reliability utilize a bottom-up approach to error classification by starting the classification at the subcategory level.

D. System Theoretic Accident Modelling and Processes model

Other similar taxonomic technique is STAMP: System Theoretic Accident Modelling and Processes model [32]. STAMP proposes control failures taxonomy: inadequate control of actions, inadequate execution of control actions, and inadequate or missing feedback. According to Salmon et al. [23] there is an extra requirement using STAMP: before accident analysis is performed, a control structure diagram is needed representing the safety control loops, so this technique require more information about the domain in question (Government policy and legislation, regulatory bodies, rules and regulations, company procedures and training programs). STAMP taxonomy is generic by nature and less restrictive than HFACS [23]. Three difficulties were found in application of STAMP [23]: difficult to classify some human and organizational failures, difficult to discriminate between control failures types and difficult in taking account the whole environmental and contextual conditions. STAMP is very comprehensive in terms of coverage of the overall sociotechnical system and more suitable for identifying and classifying technical control failures instead to complex human decisions and organizational failures [23].

E. The "Wheel of Misfortune"

O´Hare [6] propose a "revised theoretical model and associated classificatory framework" based on Helmreich's concentric spheres: the first internal sphere represents the action of operators (classify behavior according a six step model of cognition: information, diagnosis, goal setting, strategy selection, choice of procedure, action), the middle sphere represents context local conditions (task will be successfully performed if operator resources are at least equal to demands on the task), and the last external sphere represents the global conditions (organization' s philosophy, policies and procedures). The action of operator will be conscious depending if control is skill-, rule-, or knowledge-based (as Rassmusen´s model), e.g. for very training operator in a very familiar task the operator moves directly between information and action. The context local conditions are classified according the "cognitive triad" proposed by Roth and Woods (cited by O´Hare 2000): inherent demands of the task environment (complexity, dynamism, tight coupling, uncertainty and risk), resources supplied by operator (physical and psychological capacities and skills) and "representation of the task environment through which the operators act on the world" [6].

O´Hare call the taxonomy of operator action (first sphere) "revised internal malfunction taxonomy" applied successfully in New Zealand aviation accidents and he cited the Wiegmann and Shapell´s comparison work [20] were they found that internal malfunction taxonomy account for a slightly greater percentage of the reports (88.4%) than either the Reason model (84.3%) or the traditional information-processing model (80.6%). O´Hare highlights three advantages of his framework [6]: as a heuristic model: the concentric spheres-within-spheres representation is a better approximation of the reality of accident, as a practical investigation tool: directs the attention of the investigator to specific questions within the three layers of concern causation than any linear sequence of factors, and as an over-arching framework: is expressed in terms of general processes that are quite independent of functioning within any specific domain. Other approach is the "generic driver error taxonomy" developed by Stanton and Salmon [33]. They attempt to unify Norman´s, Reason´s and Rasmussen´s classical theories and include specific driver taxonomies from several authors and post-accident analysis. The result is a taxonomic that classifies errors in five categories of 26 external error modes. There are no publications of its validity.

F. Healthcare human error taxonomies

Other area were human error taxonomies are important is healthcare [34]. Taib et al. identify 26 different medical error taxonomies. They compared and analyzed all 26 taxonomies and found: medical error taxonomies that used theoretical error concepts were more likely to be generic than domain-specific and also to classify PSF and PEM. However, taxonomies with theoretical error concepts require some knowledge of cognitive processes or psychology training to be applied. They also highlight the importance of adopting "system approach" instead of "person approach", i.e. system approach address error to work condition, environment and organizational issues. Granularity, other comparison criteria, is the taxonomy's capability to deepen categories of error.

One of the most recent taxonomies in healthcare was developed by Itoh et al [3]. They partially adapted the HERA (Human Error in Air Traffic Management) taxonomy [30] adding specific healthcare setting. This taxonomy is dived in six sections: event outline (problem type, action failed and information/equipment), error recurrence (error type and violation), contextual conditions (communication factors, staff human factors, patient human factors, task factors, equipment/material factors, organizational factors, environmental factors), outcome and recovery (outcome severity, error capture cue, error recovery), preventive mechanisms and maturity of reporting (timing reporting, reported content, time-band of description, descriptive level). They applied the approach to 3749 incident reports. Qualitatively they found a gradually improvement in reporting culture over the period analyzed, they analyzed the differences in severity across the five hospital departments, near-miss detection by safety procedures continuously increased in each department for every half-year period and positive reporting culture contributes to higher level of safety performance in healthcare. In terms of error, they found that most common error type was errors of omission (41%), in more than 60% of cases were involved staff human factors (the most important: lack of knowledge (34%), wrong assumption or preconception (29%) and psychological factors (9%)). In terms of inter-rater reliability: "there were moderate and high chance-corrected agreements between the two judges for three dimensions, near-moderate for two others, and just fair agreement for one dimension, according to Landis and Koch's criteria" [3]. Specifically: category assignment within outcome severity was performed perfectly, but only moderately within error capture and the descriptive level. The remaining dimensions achieved only fair agreement: time of reporting, reported content, and time-band of description. [3]

G. Human error taxonomies evaluation

Following the Fleishman and Mumford's criteria [35] for evaluating taxonomies of human performance, Beaubien and Baker [27] review and evaluate 8 accident/incident reporting systems and its taxonomies. Briefly Fleishman and Mumford [35] criteria include 3 items: internal validity (if taxonomy is logically organized: the reliability of descriptors used to classify an event, reliability of classification as a whole, descriptors must be mutually exclusive and exhaustive), external validity (generalizability or robustness, capacity to help researchers plan programmatic lines of research, predictive validity) and utilitarian criteria (communication among different user groups, solve applied problems, use of resources). As seen before, recent researches focus on two evaluation aspects:

1) Inter-rater reliability: the degree to which different evaluators agree on the classification of errors
2) Generality: be sufficiently comprehensive, regardless of where it was developed.

Also some authors highlight "granularity", defined as the

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ability of a taxonomy subcategories and deepen accessing psychological causes of the error.

IV. CONCLUSION AND FUTURE WORK

The two desirable features sought in newest taxonomies (inter-rater reliability and generality) seem to be contradictory to each other, i.e. when generality is achieved then inter-rater reliability decrease. Models that have no taxonomy or have a lax one, more easily reach the goal of generality. Strict taxonomy approaches, like HFACS, seems to be the most inter-rater reliable current techniques, however its application in other areas shows difficulties.

One evident conclusion of this review is that different taxonomies can provide different analysis information. So, more than one technique should be applied in some adverse scenario of analysis, i.e. complicated area like health care or complex accidents (e.g. Mangatepopo canyon walking accident). It is desirable to continue working in a generic taxonomy, being flexible as much as possible without losing inter-rater reliability. Intuitively, this objective will be achieved by incorporating newest cognitive frameworks, falling in a theoretical error concepts based model. Possibly, the idea of failure taxonomic should be discarding and replaced by human factor taxonomy with cognitive generic terms, allowing an inter-rater reliability at once from sufficient flexibility to be applied in many areas. The cognitive specific terminology used in this theoretical "generic taxonomy" may require more specialized analysts and more resources for its application.

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