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**ISSUES FOR RESOLVING ADVERSE EFFECTS ON THE SAFETY  
CULTURE OF HUMAN WORK UNDERLOAD AND WORKLOAD  
TRANSITIONS IN COMPLEX HUMAN-MACHINE SYSTEMS**

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## ABSTRACT

A workshop was conducted whose specific purpose was to build on earlier work of the United States National Research Council, United States Federal government agencies, and the larger human factors community to: (1) clarify human factors issues pertaining to degraded safety performance in advanced human-machine systems (e.g., nuclear production, transportation, aerospace) due to human work underload and workload transition, and (2) develop strategies for resolving these issues. The workshop affirmed that: (1) work underload and workload transition are issues that will have to be addressed by designers of advanced human-machine systems, especially those relying on automation, if cost, performance, safety, and operator acceptability are to be optimized, (2) human machine allocation models, standards, and guidelines which go beyond simple capability approaches will be needed to preclude or seriously diminish the work underload and workload transition problems, and (3) the 16 workload definition, measurement, situational awareness, and trust issues identified during the workshop, need resolution if these models, standards, and guidelines are to be achieved.

## I. INTRODUCTION

Organization culture, including the priority given to safety, is an amalgamation of a number of factors including the larger society, business community, organizational structure, management policies and oversight, work content within the organization, and the people who make up the organizational work force. In complex high reliability system settings such as the nuclear industry, a high priority is given to safety.

While the social, business, structural, and management factors are determinants of safety performance, the work content and the work force are the primary determinants. A myriad of laboratory and field studies of the past 50 years have demonstrated that work content leading to job satisfaction is a major determinant of performance including work that could have safety consequences.

Attitudes toward the work environment itself have changed dramatically over the past 30 years. Thirty years ago, for the majority of workers their allegiance was primarily to the organization for which he or she worked. Today, that allegiance is primarily to one's own discipline rather than the work organization. The forming of conglomerates, downsizing, and the shrinking of organizational benefits have depersonalized the working environment causing this shift in allegiance. Of far greater impact on this shift has been the creep of automation. The majority of today's workers entered the work force prior to automation. In many instances automation has replaced their jobs. From a safety culture perspective, however, a greater concern is organizations which have partially replaced workers with automation. Their work content involves humans interacting with automated technologies creating job sharing. Work content may even place a higher priority on the automated technology over the human, relegating the human to a back-up role.

Research on issues unique to human workload allocation, particularly with regard to advanced technologies is currently in its infancy. Historically, human factors designers have employed straight-forward capability models to allocate tasks between

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humans and machines. With the introduction of automation, this approach has led to a steadily diminishing human role. Recent history also demonstrates that: (1) humans often react adversely to their the diminishing roles, and therefore (2) new allocation models and strategies are required if humans are to be willing and able to assume the diminishing and shifting roles assigned to them in these new systems, and are to accept the new technologies making up these systems. Problems associated with these diminishing and shifting human roles are characterized as work underload and workload transition.

In 1988, in response to a request from the United States Army Human Engineering Laboratory, the Committee on Human Factors of the United States National Research Council, undertook a study to provide advice and guidance on the effects of prolonged work underload on the subsequent performance of critical tasks under abnormal or emergency conditions, and on approaches that might be employed to off-set or compensate for decrements in safety performance which may otherwise occur. Concern for this issue, in part, grew out of transportation-related events in nuclear energy production (nuclear power generation, waste transportation), commercial aviation, rail, shipping, and emergency medial service, that have occurred in the recent past in system settings where automation and related technologies have made ambiguous the role of the human-in-the-loop. The United States National Research Council findings published in early 1993, under the title Workload Transition: Implications for Individual and Team Performance, were the main inputs to the Idaho Falls workshop for developing a workload solution statement (Huey and Wickens 1993).

## II. PURPOSE

This paper presents the findings of a two-day workshop conducted in Idaho Falls, Idaho, United States, among 20 experts in the areas of human factors and advanced human-machine systems (e.g., nuclear operations, transportation, military). The Idaho Falls workshop built on earlier work conducted by the United States National Research Council, United States federal government agencies, and the larger human factors community. Its purpose was to: (1) identify and refine human factors issues pertaining to degraded safety performance in advanced human-machine systems due to human work underload and workload transition; and (2) develop general technical approaches for resolving the issues. (Ryan, et. al

1994)<sup>[1]</sup> (Ryan, 1994)<sup>[2]</sup>

The workshop affirmed that; (1) work underload and workload transition are problems that will have to be addressed by designers of human-automation operating configurations, if cost, performance, safety, and user acceptability are to be optimized, (2) human function allocation models, standards, and guidelines, which go beyond simple capability approaches, will be needed to preclude or seriously diminish the work underload and workload transition problems, and (3) the 16 issues identified during the Idaho Falls workshop, need resolution if these models, standards, and guidelines are to be achieved.

### A. Statement of the Problem

The Human Workload Allocation Problem, derived during the Idaho Falls workshop, states that..." advanced technologies are increasingly assuming primary roles in complex high reliability systems, roles formerly occupied by human beings. Humans all too often experience chronic under-utilization (Work Underload) or a shifting between and coping with under- to over-utilization (Workload Transition). This transfer of roles may be accompanied by measurable declines in human and overall system performance. Socio-technological systems, such as those anticipated in advanced nuclear production settings, are not adequate for ensuring high levels of human acceptance and performance, or for ensuring good cost benefit ratios."

### B. Statement of the Solution

The Human Workload Allocation Solution derived during the Idaho Falls workshop states that..."models, strategies, standardized criteria, and guidelines which go beyond simple considerations of human versus mechanical capabilities and which are based on empirical data, are required for static and dynamic allocation of functions and roles of hardware, computer software, and humans in systems involving advanced human-machine technologies. More specifically, they need to be directed toward counteracting negative motivational, attitudinal, and performance effects of Work Underload and Workload Transition."

## III. IDAHO FALLS WORKSHOP PARTICIPANTS

The 20 participants in the workshop represented the interdisciplinary safety practitioner community which included: consultant research, academia, United

States National Research Council (NRC), United States Department of Transportation, Idaho National Engineering Laboratory (INEL), Battelle Human Affairs Research Centers (HARC), and Idaho Department of Transportation (IDOT).

#### IV. WORKSHOP METHODOLOGY

The Idaho Falls workshop built, in part, on the results of the recent study on workload transition conducted by the National Research Council cited above (Wickens and Huey, 1993)<sup>[1]</sup>. The workshop also built on recent workload research sponsored by the United States Department of Transportation, other Government agencies, and academia (e.g., Dingus and Hulse, 1993<sup>[4]</sup>; Hill et al., 1992<sup>[5]</sup>; Kantowitz et al., 1993<sup>[6]</sup>; and Ng and Barfield, 1993<sup>[7]</sup>). Their work focuses on information requirements and acceptability of new technologies by humans in advanced human-machine system settings. The latter acceptability of new technologies can be expected to be a major issue in workload determination.

The workshop followed a presentation-discussion-presentation format in order to achieve a final list of work underload and workload transition issues capable of being studied/resolved using human factors state-of-knowledge research and development approaches and techniques. The workshop was divided into three sessions.

#### V. WORKLOAD DEFINITIONS

During the first session, workshop participants developed the following working definitions of work underload and workload transition.

"Work Underload is a task characteristic in which substantially more human resources are available to perform the task than the task requires."

"Workload Transition is a marked shift in task demand, or an abrupt increase or decrease in workload."

#### VI. IDENTIFICATION OF TECHNICAL ISSUES

During the second session of the workshop participants identified the following 16 workload issues needing resolution for advanced human-machine systems.

[1] Operational definition of workload

distinguishing between workload and task load.

- [2] Models of system operator attention, vigilance and monitoring.
- [3] Factors influencing operator trust.
- [4] Factors and measures affecting situational awareness.
- [5] Factors affecting operator situational comprehension.
- [6] Operator strategies for monitoring and changing his own workload.
- [7] Levels and types of automation available.
- [8] Influences of stress, fatigue, alcohol, drugs, and other fitness for control factors.
- [9] Physical mechanisms (e.g., touch, voice).
- [10] Factors affecting the mental models under differing operating configurations.
- [11] Generalizability of the current state of knowledge concerning human-machine interactions.
- [12] Other human performance data required for fully exploiting human-machine technologies in advanced human-machine systems.
- [13] Cost trade-offs between safety and performance under differing human-automation operating configurations.
- [14] Safety and performance under differing human-automation operating configurations brought about by display transparency.
- [15] Factors distinguishing proximal, distal, and extraneous tasks.
- [16] Effects of social factors, on human performance in differing human-automation operating configurations.

## VII. RESOLUTION STRATEGIES

During the third session of the workshop, participants further refined the issues and reach a consensus judgement on the their impacts on safety performance.

- [1] All work underload and workload transition issues are expected to significantly impact the practicality, acceptability and usefulness of any advanced human-machine technology.
- [2] Operator characteristics, including disabilities and other demographics, such as age and experience, along with situational factors, such as work setting and language, all mediators of workload, will impact system success.
- [3] Workload guidelines and standards emerging from research and development can be expected to generalize to other complex high reliability system settings involving multifaceted human-machine interactions.

Also during the third session, the participants developed a series of potential resolution strategies for resolving the issues. These strategies included state-of-knowledge literature reviews, laboratory studies, field demonstration studies, in situ validation and verification, surveys, interviews, observations, and reviews of operating experience and event reporting data bases. The participants reach a consensus on the following

- [1] Considerable credit is given to the existing state-of-knowledge as an important source of data for resolving many of the work underload and workload transition issues identified during the workshop.
- [2] Workshop participants were ambivalent about inclusion of incident reports as a source of information. In Table 11 it was only selected as a potential data gathering setting, by the situational awareness group. Later in Tables 12 and 13, however, the trust group also selected incident reports as a source of data for analysis.
- [3] A second dimension to the issue resolution strategy, that must be considered, is the role of the system operator on the one hand, and

the role of the system designer on the other hand. Workload allocation guidelines and standards perceived as practical, acceptable, and useful to the operator may not be to the designer.

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