Safety Science 48 (2010) 914–920

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Assessing team workload under automation based on a subjective performance measure

Chih-Wei Yang [a,*], Tzu-Chung Yenn [a], Chiuhsiang Joe Lin [b]

[a] Institute of Nuclear Energy Research, 1000, Wenhua Rd., Jiaan Village, Longtan Township, Lungtan, Taoyuan County 32546, Taiwan, ROC
[b] Department of Industrial Engineering, Chung-Yuan Christian University, 200, Chung Pei Rd., Chung-Li 32023, Taiwan, ROC

ARTICLE INFO

Article history:
Received 3 August 2009
Received in revised form 12 January 2010
Accepted 23 March 2010

Keywords:
Team workload
Communication
Coordination
Cooperation
Subjective measure

ABSTRACT

This study presents a subjective measure approach to assess how automation impacts teamwork. Hart and Staveland (1988) indicated that the subjective measure approach is the conventional most commonly used workload assessment method that represents the criteria against which other measures are evaluated. The subjective experience of an operating crew regarding workload normally involves the influence of many factors in addition to the objective demands imposed by a particular task. Therefore, this study first assumes that team workload is a hypothetical construct that represents the cost incurred by a specific crew to achieve a particular level of team performance. The concept of team workload is developed by applying individual workload concepts, principles, and relations to a team environment. Although teams are increasingly important in the workplace, team workload has seldom been evaluated in literature. Therefore, this study develops a subjective performance measure approach to optimize team workload. An illustrative example demonstrates the effectiveness of the proposed approach. Results of this study significantly contribute to research efforts in the field of workload measurement under automation.

1. Introduction

Teamwork refers to how individuals interact with each other in order to exchange information, develop and maintain communication patterns, coordinate actions, and maintaining social order (Bowers et al., 1997). As communication is essential to teamwork, coordination reflects how team activities are executed so that members respond as a function on the behalf of others. Additionally, team orientation includes attitudes that team members have towards each another, the team task, their team leadership, and self-awareness as a team member. Monitoring team performance involves observing and remaining aware of the activities of other team members. Moreover, teams must adapt and learn from their performance to ensure success, which requires giving, seeking, and receiving feedback among team members. Furthermore, backup behavior implies a degree of task interchangeability among members and a willingness to provide and seek assistance.

The team workload concept derives from the application of individual workload concepts, and relationships to the team environment (Bowers et al., 1997). Several variables related to the team and the task at hand likely to contribute to team workload. Coordination refers to several individuals acting simultaneously to perform certain complex tasks. Communication and team operations are inseparable. The extent to which experience affects team workload must be investigated. Above systematic changes in mutual knowledge and communication behaviors reflect a team development process during which a series of transformations in teams might influence their experience of workload. Additional measures must also be derived directly from models of team workload. For instance, global measures of team workload may simply be insensitive to all demands imposed on teams.

Extensively adopted in various domains, team workload measures are negatively related to measures of team performance. The NASA Task Load Index (NASA-TLX) (Hart and Staveland, 1988) assesses the workload of individual team members. TLX can be extended to a team as well as individual workload (Entin et al., 1998). Entin et al. (1998) used a revised workload measure. First, participants described their workload in terms of the conventional items comprising the TLX. Second, each participant estimates the overall workload experienced by other team members. Finally, each participant responds to the TLX items, but this time, as a whole team.

The workload is determined in a new cockpit by adopting a novel team concept approach (Bohnen, 2003). In this case, NASA-TLX and Cooper–Harper ratings are combined for use. According to this approach, the workload of a team member consists of four components, i.e. mental effort, time constraint, stress and physiological

* Corresponding author. Tel.: +886 920613125.
E-mail addresses: yangcw@iner.gov.tw, wayne383@ms23.hinet.net (C.-W. Yang).

0925-7535/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ssci.2010.03.011

effort. Following a simulated scenario segment, ratings and scores are obtained in three steps:

(1) Each team member rates, i.e. from low to high workload, each component, using TLX and the adapted Cooper–Harper Test.
(2) Each team member assigns a unique weight, i.e. one to six, to each of the possible six combinations of two components, based on the weight experienced by this combination of components.
(3) Each team member assigns four uncertainty scores to the rating for each component. Each uncertainty score is related to an uncertainty source, e.g., an uncertainty in the workload rating due to a non-representative scenario. The four uncertainty sources are scenario, simulator, knowledge/training and system functions. The team member determines whether he possibly made a rating error in the workload component owing to an uncertainty source. Hence, four qualitative uncertainty scores per component are obtained.

Phillips (1986) proposed a multi-criteria decision analysis (MCDA) framework, which utilizing multi-attribute decision theory (MADT) to provide a quantitative theory that derives object preferences from utility values assigned to outcomes. These outcomes are derived from numeric weights associated with properties or attributes of objects. Phillips (1986) found differences among best strategies in one of three scenarios (high, medium and low based on one key uncertainty) and find ways of managing them through further analysis or information. Multi-attribute decision theory (MADT) provides an easily understood, yet comprehensive set of quantitative and qualitative approaches to justify a decision between alternatives (Canada and Sullivan, 1989).

Multi-criteria decision analysis (MCDA) provides a suitable framework to deal with complex decision making problems with multiple attributes and alternatives. It helps to clarify the objectives and to identify the attributes that can be used to measure the success of a strategy in achieving the objectives. The aim is to enhance understanding of the problem, to communicate preferences, values and objectives, and to guide the decision makers or stakeholders in their choice of the most preferred action. The approach provides a set of techniques to model the decision makers' preferences.

An experimental approach, i.e. Team Performance Assessment Battery (TPAB), as proposed by Bowers et al. (1992) uses synthetic work, i.e. the monitoring and prosecuting of incoming targets on a radar screen, to approximate a command, control, and communication environment. Straightforwardly designing synthetic work allows for an inexpensive price, ease of measurement, and maximum experimental control, while still replicating realistic amounts of cognitive demand and workload requires that TPAB is equivalent to that of actual tasks.

The primary dependent measure is reaction time, as state changes within the monitoring component necessitate certain responses. A coordination component is also provided, as resources and actions must be synchronized properly to withstand incoming targets; this must be done concurrently with the monitoring task. Task characteristics, e.g., workload and time pressure, and situational characteristics, e.g., uncertainty, can also be examined within TPAB. Finally, a further development has extended the original configuration to allow team size to vary.

Above approaches are widely known, practical and feasible. Notably, workload refers to information processing demands placed on an individual or a team by a task (Davis and Kuang, 2000). In the human information processing (HIP) model proposed by Wickens and Hollands (2000), a simple four-stage view is adopted (Parasuraman et al., 2000). The first stage involves acquiring and registering multiple sources of information. This stage includes the positioning and orientation of sensory receptors, sensory processing, pre-processing of data prior to full perception, and selective attention. The second stage involves conscious perception, manipulation of processed and information retrieval in working memory. Although this stage also includes cognitive operations, e.g., rehearsal, integration and inference, such operations occur before the point of decision. The third stage involves reaching decisions based on cognitive processing, whereas the fourth stage involves implementing a response or action consistent with the decision choice.

The model outlined by Parasuraman et al. (2000) provides a framework for addressing automation design issues for specific systems. In their model, the four stage of HIP has its equivalent in system functions, including information acquisition, information analysis, decision and action selection, as well as action implementation. Information acquisition involves sensing and registering input data. Information analysis involves cognitive functions, including working memory and inferential process. Decision and action selection involves selecting from among decision alternatives, whereas action implementation refers to executing the action choice.

While previous studies assumed that workload decreases when introducing automation, this advantage has been only partially realized. Automation replaces human activities with machine activities in combination with new human activities, while not lowering workload levels. Additionally, situation awareness (SA) may decline owing to monitoring demands and subsequent vigilance decrements, complacency due to over-reliance on automation, system complexity, inferior interface design, inadequate training or lack of trust in automation (Endsley, 1997; Paris et al., 2000).

Although team workload has received considerable attention in recent years, human information processing and system functions executed by automation have seldom been addressed. Therefore, this study develops a subjective performance measure approach to optimize team workload. An illustrative example demonstrates the effectiveness of the proposed approach. Results of this study significantly contribute to research efforts in the field of workload measurement under automation.

2. Constructing a subjective performance measure in assessing team workload

Team attitudes are assumed here to be as important as their activities. Thus, workload is defined in this study as task-centered rather than human-centered. Team attitudes are gauged by developing a systematic questionnaire approach. This section introduces a 'C3 + C2' approach, i.e. Communication, Coordination, Cooperation plus Command and Control, to evaluate the team workload. Furthermore, the four stages of HIP and system functions are incorporated in the multi-dimensional rating scale, as shown in Fig. 1. The multi-dimensional rating scale can be used to evaluate the subjective team workload of the following four system functions:

(1) *Communication*: Adequate opportunities to exchange information vertically and horizontally in order to achieve the team objectives.
(2) *Coordination*: Standardization and documentation of tasks and procedures to match the team in reaching a shared objective.
(3) *Cooperation*: Willingness to share ideas and views, as well as collaborate to build a cohesive team.
(4) *Coommand*: Determination of required information to gain knowledge for a particular situation, implementation of the decisions, and coordination of forces to achieve a shared objective.