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IFAC-PapersOnLine 49-19 (2016) 549–554

A dynamic closed-looped and multidimensional model for Mental Workload evaluation

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Abstract: The interest in mental workload (MWL) has strongly increased over the last 40 years in ergonomics and engineering studies. However, the subject is still very controversial and there is a debate on the dimensions to be considered for representing and estimating the workload. This paper reinvestigates the modeling of the mental workload concept, by combining the model of Hart and Staveland (1988), which considers this concept as a multidimensional construction, and the models of Sperandio (1971) and Leplat (2006), which focus on the regulation of the activity by the operator. This combination reveals new relationships between the different dimensions of MWL, and especially points out a means of measuring and understanding the effect of regulation on the workload. To validate this proposed approach to the modeling of MWL, an experiment is conducted on the dynamic activity of area monitoring based on the management of a swarm of drones.

Keywords: Mental workload; Human-machine cooperation; drone swarm supervision

1. INTRODUCTION

The concept of mental workload (**MWL**) is extensively used, but is also very controversial, giving rise to various theoretical and methodological models (Cegarra and Chevalier, 2008). At present, debate continues on the dimensions to be considered to represent and estimate the MWL, and the way in which these dimensions are connected.

In this paper, we revisit and combine two models: that of Hart and Staveland (1988), which synthetizes and integrates different previous approaches on the MWL, and that of Sperandio (1971) and Leplat (2006), which focuses on the regulation of activity by the operator. This proposal leads (i) to distinguish three classes of MWL variables (i.e. drivers and mediators for cause-based analysis, and indicators for a consequence-based analysis of workload), and (ii) to explore the "perception" black box of Hart and Staveland's model, by integrating different regulation loops and proposing a framework to assess them.

The theoretical model presented in the following section is applied in an experiment focusing on a dynamic activity involving area monitoring by drone swarms. Finally, the results of this experiment are discussed to evaluate the validity and the reliability of the model.

2. LITERATURE REVIEW AND PROPOSAL OF A DYNAMIC MULTI-DIMENSIONAL MWL MODEL

Over the last four decades, the MWL has been modelled and assessed according to different approaches. Firstly, there are exogenous approaches based on the study of activity constraints (Knowles, 1963) and performance (De Waard, 1996). Then, research has also focused on endogenous estimators, which are based on the concepts of operator capacity and mental effort (Sheridan & Stassen, 1979), and new possibilities of measuring physiological activity (Kahneman, 1973). These two approaches are complementary, and grouping them together leads to the emergence of a holistic model, as proposed by Hart and Staveland (1988).

2.1 Model of Hart and Staveland: cognitive multi-dimensional model of MWL

In this model (Fig. 1), the MWL is seen as a multidimensional construction.

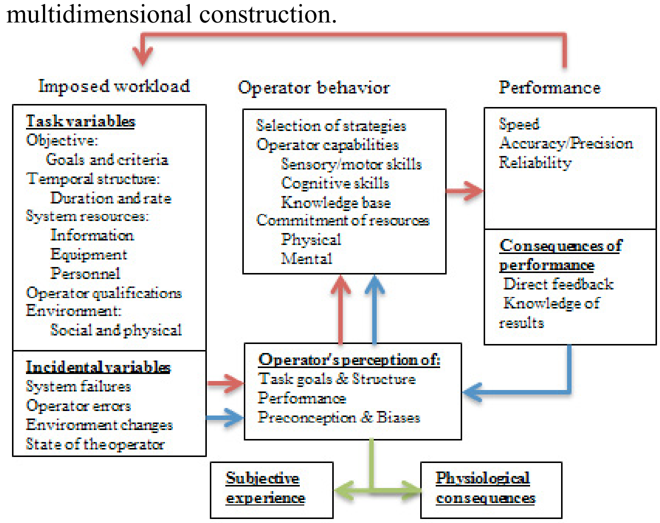

Fig. 1. MWL model of Hart and Staveland (1988)

This model highlights several points:

MWL results primarily from information processing (in red): The constraints (imposed workload) represent the input of the cognitive process. These constraints are thus perceived and

10.1016/j.ifacol.2016.10.621

interpreted by the operator, what guides him/her for choosing and implementing strategies (operator behavior). The output of this process is represented by the results obtained from the actions of the operator (activity performance). It should be noted that the information processing is closed-looped: the achieved performance has an effect on the variation of the constraints (for example, if the operator falls behind, the temporal constraint will increase). Constraints can be considered as “MWL drivers”, and performance as a “MWL indicator”; as proposed by De Waard (1986), an underperformance is related to either an excessively high or an excessively low workload.

MWL can be estimated by its psychophysiological consequences (in green). The information processing does not only result in the performance of an activity. The operator behavior also generates effects on the operator himself/herself, which can be measured by objective physiological variations or subjective feelings. These two kinds of variables, introduced by the energetic approach and the concept of mental effort *(Kahneman, 1973)*, can be therefore considered as “MWL indicators”.

The central place of perception explains the dynamics of MWL (in blue). Based on a perception of the situation and of his/her own activity (evaluation of constraints and performance), the operator interprets and anticipates the evolution of the situation. This understanding influences the choice of the strategies implemented. This continuous and reflexive assessment of the activity can therefore generate MWL variations, and can be regarded as another class of MWL drivers, that we refer to here as “MWL mediators”.

The MWL can be seen as a multidimensional construction, since some variables are drivers, while others are mediators (cause-based analysis) or indicators (consequence-based analysis). The perception process is central in the model; it guides the behavior of the operator. However, this dynamic and reflexive evaluation of the situation is complex and very difficult to measure. To improve our understanding of this black box "perception", we investigate the regulation loops.

2.2 Model of Sperandio (1971) and Leplat (2006): a closed-looped dynamics of MWL

In his studies on air traffic control, Sperandio (1971) identified two regulation loops.

Loop 1: the feedback of the MWL, resulting from the implemented strategy, has a regulating effect on the future strategy. Indeed, if the implemented strategy imposes a high cognitive level, the operator could change strategy to obtain a lower cognitive level.

Loop 2: the strategy implemented in response to the perception of constraint allows a regulation of the future level of constraint.

To these two loops, we can add a third regulation loop, presented by Leplat (2006):

Loop 3: The difference between the actual and the expected level of performance will have an incidence on the selection of future strategies.

Hence, the dynamic behaviour of an operator is guided by the perception of the situation that can be modelled by the three different loops proposed by Sperandio and Leplat. These regulation loops depend on the assessment of variables already existing in the multi-dimensional model of Hart and Staveland. The following section presents the articulation of both these approaches, so as to propose a comprehensive methodological and practical framework for understanding and assessing MWL.

2.3 Articulation of both models: towards a dynamic multi-dimensional MWL model

According to the model of Hart and Staveland, the operator performs the information processing, and then chooses and implements a strategy primarily in response to the perceived constraints. Moreover, according to the models of Sperandio and Leplat, the perceived operator behaviour, task constraints, and performance have an influence on the choice of strategy, in a dynamic and reflexive assessment of the situation. The choice of strategy is therefore based on the perception of three criteria: the constraint, the behaviour and the performance. It can be assumed that the pairwise comparison of these three criteria would allow the operator to select a strategy and regulate his or her activity. From this comparison, we can identify and integrate the three regulation loops into the model of Hart and Staveland:

- The effectiveness loop (Performance-Based Regulation: **PBR**). This loop corresponds to the comparison between the prescribed objectives (task variables partially defining the constraints) and the performance. If there is a great difference between the actual and the expected performance, this means that the behaviour is not effective. In such a case, the operator should implement more effective strategies.
- The pertinence loops, corresponds to the comparison between the constraint and the behavior. We can identify two comparisons: the prescribed strategies vs. the implemented strategies, and the dynamic constraint vs. the cognitive cost induced by the complexity of implemented strategies.
  - Compliance-based regulation (**CBR**): in the first case, the operator is aware that the implemented strategies do not comply with the strategies prescribed for a targeted better performance (which form part of the constraints as variables characterizing how the tasks must be performed). The operator will regulate his/her activity by adopting a more pertinent behaviour, and by implementing the prescribed strategies.
  - Priority-based regulation (**PRBR**): in the second case, if the dynamic constraints are high and the strategies implemented are the most costly, the behaviour can be also irrelevant. The operator should regulate his/her activity by defining priorities and implementing some of the less costly strategies. For instance, in studies of air traffic control, Sperandio (1988) observed that, when there are a large number of airplanes, the controller focuses only on safety, and no longer takes account of fuel economy or time of transit, etc.