Evaluating Operator's Real-Time Mental Workload with Eye Movement Analysis in Nuclear Power Plants Operations

Jinding Xing, S.M. ASCE[1], Zhe Sun, S.M. ASCE[1], Pingbo Tang, Ph.D., P.E., M. ASCE[1], Alper Yilmaz, Ph.D.[2], Ronald Laurids Boring, Ph.D.[3] and G. Edward Gibson, Ph.D., P.E., Dist. M. ASCE [4]

[1]Department of Civil and Environmental Engineering, Carnegie Mellon University, Porter Hall 119, 5000 Forbes Avenue, Pittsburgh, PA 15213; e-mail: jindingx@andrew.cmu.edu, zsun2@andrew.cmu.edu, ptang@andrew.cmu.edu
[2]Department of Civil, Environmental and Geodetic Engineering, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210; e-mail: yilmaz.15@osu.edu
[3]Human Factors and Reliability Department, Idaho National Laboratory, P.O. Box 1625, Idaho Falls, ID 83415; e-mail: ronald.boring@inl.gov
[4]School of Sustainable Engineering and the Built Environment, Arizona State University, 660 S College Avenue, Tempe, AZ 85281; e-mail: GEdwardGibsonJr@asu.edu

ABSTRACT

Nuclear Power Plant (NPP) operators need to have sufficient real-time cognitive ability to ensure their adherence to operational procedures and solve unexpected problems. The heavy cognitive load will degrade such ability and lead to operation errors. Previous studies show that the NPP workflows' (a network of activities) properties, such as workflow structure types, activity types, and recurring activities, can significantly impact the operator's cognitive load. However, which workflow properties could lead to a higher cognitive load are unclear. This study examines what workflow properties pose cognitive challenges to operators and quantitatively evaluates these properties' impact on the operator's cognitive load. The authors designed a simulation experiment on a nuclear reactor operation simulator called "Rancor" and recruited four students as pseudo-operators to perform reactor startup tasks. In the experiment, we collected the students' eye movement data using a mobile eye tracker. Participants' pupil diameter changes and eye movement types can indicate cognitive load and information searching strategies. The correlation analysis results indicate that workflow structure (i.e., sequential and parallel structures) and activity types correlate with participants' pupil diameter changes. Such correlation indicates that parallel structure and recurring activities demand relatively high cognitive efforts. Moreover, eye movement analysis reveals that recurring activities require more fixed attention from operators. Overall, a quantitative evaluation of the relationship between workflow properties and the cognitive process advances understanding about NPP operators' cognitive load and information searching strategies while executing different types of workflows.