A Practical Review of Studies on Operator's Supervisory Monitoring Behavior

Jun Su Ha and Poong Hyun Seong
Department of Nuclear and Quantum Engineering, KAIST
373-1, Guseong-Dong, Yuseong-Gu, Daejeon, South Korea, 305-701

1. Introduction

Correct situation awareness (SA) has been considered a crucial key to improving performance and reducing error in NPPs [1]. There are a lot of information sources that should be monitored in NPPs, but operators have only limited capacity of attention and memory. Operators in NPPs selectively attend to important information sources to effectively develop SA when an abnormal or accidental situation occurs. Selective attention to important information sources is continued while maintaining SA as well. In this work, various models of operator's visual sampling behavior are reviewed for the use in human factors studies in NPPs.

2. Models of the Visual Sampling Behavior

Attention is typically driven by four factors: expectancy, value, salience, and effort [2]. Expectancy shifts attention to specific sources which are most likely to provide information. Frequency of looking at or attending to an information source is modified by how valuable it is to look at. Salience refers to stimulus in the environment such as alarms, alerts, or some remarkable indication representing deviation from the normal situation. Attention may be inhibited if it is effortful compared to its value.

The first studies on information searching (or visual sampling) behavior have been done for flight maneuver tasks by Jones, Milton, and Fitts [3-5]. They suggested that dwell time was a function of the difficulty of reading an instrument and of interpreting the data from it. The difference in the relative fixation frequencies was more than ten to one, and it was concluded that this was due to their relative importance [5]. The first theoretical model of the visual sampling was made by Senders [6]. Senders focused on the optimum sampling of dynamic instruments as a function of the bandwidth (event rate) of signals, employing optimal sampling theory. Senders's original scanning model was subsequently elaborated by others [7-11] to account for value in addition to the bandwidth (event rate). Wickens et al. have developed two models such as a descriptive model and an optimal prescriptive model which extend previous models [12]. The descriptive model identifies the role of event salience, effort, expectancy, and value in influencing where and when people look at different channels to sample information in dynamic environments. The optimal prescriptive model accounts for the role of expectancy and value, as these characterize the properties of channels necessary to serve tasks that may differ in their importance. While previous models have defined properties of each AOI (area of interest) or channel, purely in terms of the bandwidth and value of events along that channel, the optimal prescriptive model includes another factor "task significance". This model defines task significance and importance of AOIs for each task.

3. Application to Human Factors Studies in NPPs

The bandwidth obviously plays an important role in the monitoring behavior in NPPs. It permits operators not only to expect the location of valuable information sources (expectancy) but also to diagnose the state in more detail, if an abnormal situation occurs. In the example of a loss of coolant accident (LOCA), if an operator sees a set of symptoms such as the decreases of pressurizer pressure, temperature, and level and the increase of containment radiation, the operator is supposed to assess the abnormal situation as a LOCA. The operator may want to know further into the LOCA such as the location of the leakage, the leakage amount (or diameter of leakage breach), and so on, which can be assessed with a set of change rates of the indicators. The expectancy played the most significant role in the basis of the models for situation assessment based on Bayesian inference [13, 14]. The two models were all based on the behavioral rules of a NPP in either a probabilistic or a deterministic form. The mental model in which the rules are established generates expectancy, when a deviation (or some deviations) from a normal state is (are) observed. Usually there is a set of symptoms given an accident or a transient in NPPs (i.e, situation-events relations). Symptoms generally have diagnostic attributes. It should be noted that there can be two kinds of symptom: a symptom representing changed part (e.g., onset of alarm or deviation in a process variable) and a symptom of stationary part (e.g., a process variable in normal state). In the LOCA example, if pressurizer pressure, temperature, and level decrease, then a LOCA and a steam generator tube rupture (SGTR) can be competing hypotheses. If the containment radiation has no change, it will be a SGTR not a LOCA. In this case, the containment radiation is a stationary symptom which has the ability to be diagnostic between a LOCA and a SGTR. Selective attention should be paid to stationary symptoms in order for operators to understand the situation correctly in NPPs, even though they are not changed. Hence, a set of symptomatic information sources including both changed and unchanged symptoms and the bandwidth should be considered as determining factors governing the visual sampling behavior in NPPs.

Considering the above-mentioned factors, measures of attentional-resource effectiveness such as FIR (fixation to importance ratio) and SAE (selective attention effectiveness) have been proposed by the authors, which quantitatively describe operator's information searching behavior in NPPs [15]. The underlying principle of the measures is that information sources should be selectively attended according to their informational importance. In this model, the informational importance is quantified with respect to "informative expectancy" (i.e., symptom sets) and "informative value" including the change rate.

There are two other important factors that also influence the visual sampling behavior such as effort and salience. Effort and salience may exert a greater or lesser influence on scanning to the extent that designers have adhered to good human factors practice in display layout, by correlating effort and salience with expectancy and value. Hence, effort and salience are matters to be considered during designing a HMI. The effect of effort and salience were studied with a human factors evaluation tool called DEMIS (difficulty evaluation method in information searching) which is based on the effectiveness measures, the FIR and the SAE [15].

4. Recommendations and Further Study

In this work, significant factors governing operator's information searching behavior are identified for the use in human factors studies in NPPs. The authors' attentional-resource effectiveness (ARE) model is the-state-of-the-art model which can quantitatively describe the NPP operator's information searching behavior in monitoring task. However, if a factor of task management is included, the ARE model can be used for not only the monitoring task but also other cognitive tasks in NPPs.

References

[1] M.J. Adams, Y.J. Tenney, and P.W. Pew, "Situation Awareness and Cognitive Management of Complex System," Human Factors, 37(1), 85-104, 1995.

[2] C.D. Wickens and J.G. Hollands, Engineering Psychology and Human Performance, 3rd edition, Prentice Hall, 2000.

[3] R.E. Jones, J.L. Milton, and P.M. Fitts, Eye Movements of Aircraft Pilots: I. A Review of Prior Eye Movement Studies and a Description of Eye Movements during Instrument Flight, USAF Tech.Rep. No. 5837, Dayton, Ohio: Wright-Patterson Air Force Base, 1949.

[4] J.L. Milton, R.E. Jones, and P.M. Fitts, Eye Movements of Aircraft Pilots: II. Frequency, Duration, and Sequence of Fixation When Flying the USAF Instrument Low Approach System (ILAS), USAF Tech.Rep. No. 5839, Dayton, Ohio: Wright-Patterson Air Force Base, 1949.

[5] P.M. Fitts, R.E. Jones, and J.L. Milton, "Eye Movements of Aircraft Pilots during Instrument Landing Approaches," Aeronautical Engineering Review, Vol. 9, pp. 1-5, 1950.

[6] J.W. Senders, J.E. Elkind, M.C. Grignetti, and R.P. Smallwood, An Investigation of the Visual Sampling Behavior of Human Observers, NASA-CR-434, Cambridge, Mass.: Bolt, Beranek, and Newman, 1964.

[7] J.R. Carbonell, "A Queueing Model for Many-instrument Visual Sampling," IEEE Transactions on Human Factors in Electronics, Vol. HFE-7, pp. 157-164, 1966.

[8] J.R. Carbonell, J.L. Ward, and J.W. Senders, "A Queueing Model of Visual Sampling: Experimental Validation," IEEE Transactions on Man-Machine Systems, Vol. MMS-9, pp. 82-87, 1968.

[9] R.D. Smallwood, "Internal Models of the Human Instrument Monitor," IEEE Transactions on Human Factors in Electronics, Vol. HFE-8, pp. 181-187, 1967.

[10] T. B. Sheridan, "On How Often the Supervisor Should Sample," IEEE Transactions on System, Science, and Cybernetics, Vol. SSC-6, pp. 140-145, 1970.

[11] N. Moray, "Human Information Processing and Supervisory Control," Tech. Rep., Cambridge, Mass.: M.I.T., Man-Machine Systems Laboratory, 1980.

[12] C.D. Wickens, J. Helleberg, J. Goh, X. Xu, and W.J. Horrey, Pilot Task Management: Testing an Attentional Expected Value Model of Visual Scanning, Tech. Rep. ARL-01-14/NASA-01-7, NASA Ames Research Center, Moffett Field: CA, 2001.

[13] A.X. Miao, G.L. Zacharias, and S.P. Kao, "A Computational Situation Assessment Model for Nuclear Power Plant Operations, IEEE Transactions on Systems, Man, and Cybernetics-PART A, Vol. 27, No. 6, pp. 728-742, 1997.

[14] M.C. Kim and P.H. Seong, "An Analytic Model for Situation Assessment of Nuclear Power Plant Operators Based on Bayesian Inference," Reliability Engineering and System Safety, Vol. 91, pp. 270-282, 2006.

[15] J.S. Ha and P.H. Seong, "A Human-machine Interface Evaluation Method: A Difficulty Evaluation Method in Information Searching (DEMIS)," Reliability Engineering and System Safety, (In press), 2009.