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An Information Theory Based Complexity Evaluation Approach and Example for Advanced Alarm Processing System

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Abstract

In this paper, a model-based complexity evaluation approach is addressed in order to apply in early design phase of interface system. An effective model which predicts the complexity of human-computer interface including its contents is expected to provide practical guidance to designers. It is also expected to improve the human performance and to facilitate the system development. In order to overcome the demerits of conventional predictive models, a model which is based on the information theory and has cyclic property is developed. The proposed diagram, cyclic information flow (CIF) diagram, can describe the information flow around human operators, thus represent operator's cognitive workload. It also considers the signal processing and information providing methodology simultaneously. In order to show an application example, the advanced alarm processing system is evaluated using information theory based approach.

1. Introduction

The interface design between human and machine or computer has been considered an increasingly important issue since automatic technology and equipment have been widely used to improve the effectiveness and efficiency of the system ([Vic95], [Hub96], and [Mit95]). Smith and Mosier (1986) pointed out that frequent and serious errors in data handling may result from confusing interface design. Tullis showed that a redesign of faulty screen formats reduced the mean time required by the human operator for data interpretation by 40% [Gro95]. An analysis of computer controlled process systems by Bellamy and Geyer concluded that human errors during operations were associated with almost 60% of the incidents occurred. Bainbridge has also warned of a number of automation problems which relate to deterioration of skills, decrements in vigilance, increased workload in monitoring automated systems and failures of automatic equipment [Kon97].

In a nuclear power plant, which is the typical example of complex and high-risk plant, the human error induced incidents are one of the most significant reasons of degrading plant integrity. Next generation nuclear power plants are designed to be highly computerized and conventional ones are scheduled to be upgraded by computerization [Mei95]. Traditionally, nuclear power plant control room has been designed according to a single-sensor single-indicator (SSSI) philosophy. Each sensor datum is displayed in an independent location on hard-wired panels consisting of a large number of analog meters. This type of control room design is known to be inadequate for the higher-order tasks. That is, it imposes a great cognitive burden on operators. In order to provide more effective and reliable operation condition for the future nuclear power plant, therefore, efforts on developing improved user interface are inevitable.

2. Model-based User Interface Evaluation

2.1 User Interface Evaluation Methods

Numerous investigators in human factors engineering are performing the research that is regard to provide information in more effective and efficient manner for the safety critical application as a nuclear power plant. More credible and easy to use evaluation method will provide great help to design a human-machine interface system. Effective interface evaluation is critical to the eventual success of system because it provides a means of identifying both existing and potential deficiencies in the interface [Mit95]. The complexity of both humans and computing systems makes their interaction less predictable. It is known that even the best intentions can result in system with problems. These problems should be discovered as early as possible so that they can be addressed cost effectively.

Many theories are needed to describe the multiple aspects of interactive systems. Some theories are explanatory and others are predictive. Predictive theories enable interface designers to compare proposed designs for execution time or error rates [Shn92]. Models of user interface performance using these predictive theories can predict the usability of systems based on a design specification. Models can be described as functional/structural (for explaining processes or relations) or as purely predictive (only for predicting, not for diagnostic information). Purely predictive models are usually based on regression analysis, which use weighted averages to make predictions [Per89]. Regression is powerful and easy to use method, but there are some critical limitations of the lack of diagnostic information, the lack of ability to generalize, and hiding of the information in weighted averages. Task Action Grammar (TAG), Goals-Operators-Methods-Selection-Rules (GOMS), and General Transition Network (GTN) are popular predictive models that are used to evaluate cognitive work performance

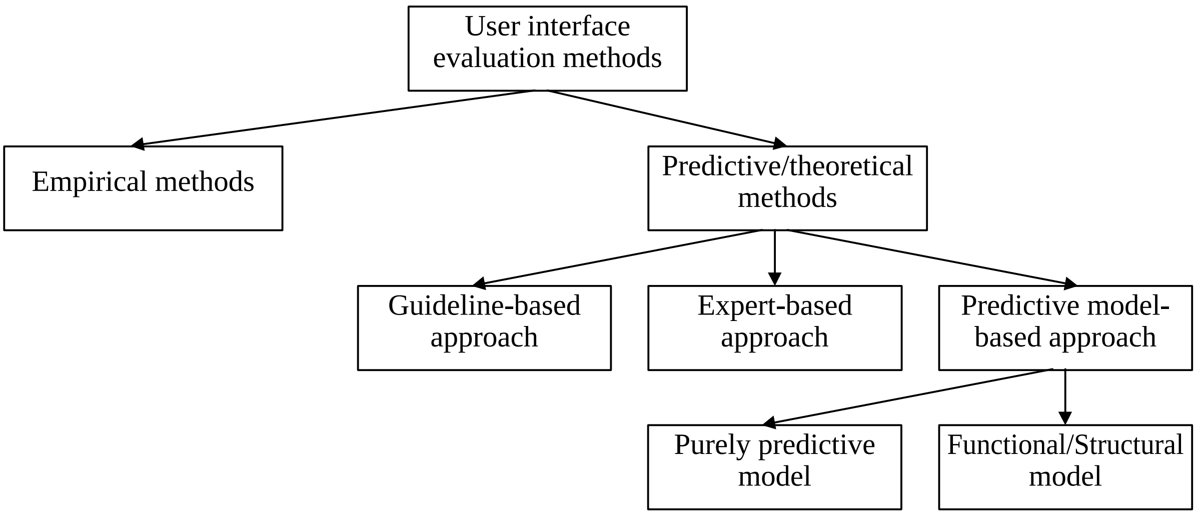

Figure 1. Taxonomy of the user interface evaluation methods

without regression. They provide useful information about interface system design, but specifying data to a predictive model may be as time consuming as an implementation [Cou94]. Predicting performance on complex cognitive tasks is especially difficult because many strategies might be employed. However, they hold the promise of aiding design by predicting evaluation and even by suggesting improvements using diagnostic information [Per89]. If efforts to build model can be effectively reduced, this approach is expected to provide great help to user interface design in early design phase. In conventional predictive model, reducing the efforts for data assignment implies inaccuracy of the performance prediction. In order to develop effective model-based measures for user interface design in early design phase, it is most important to develop a new model which realize the reduction of data assigning efforts with the least loss of prediction accuracy.

2.2 Information Theory Based Model

A considerable portion of human performance theory revolves around the concept of transmitting information [Wic92]. Information theory accomplishes the fundamental goal in engineering psychology which is how to quantify the flow of information in terms allowing the diverse tasks confronting the human operator to be compared. It explains the mechanism by which task difficulty or environmental complexity has an effect on the human being's cognitive behavior as a sequential stimuli-response relation (see Figure 2). The conventional stimuli-response model no more adequately explains the procedure of human information processing because of the high complexity of task. In an unanticipated situation, furthermore, the amount of information that should be processed by human operator in plant control room becomes extremely large.

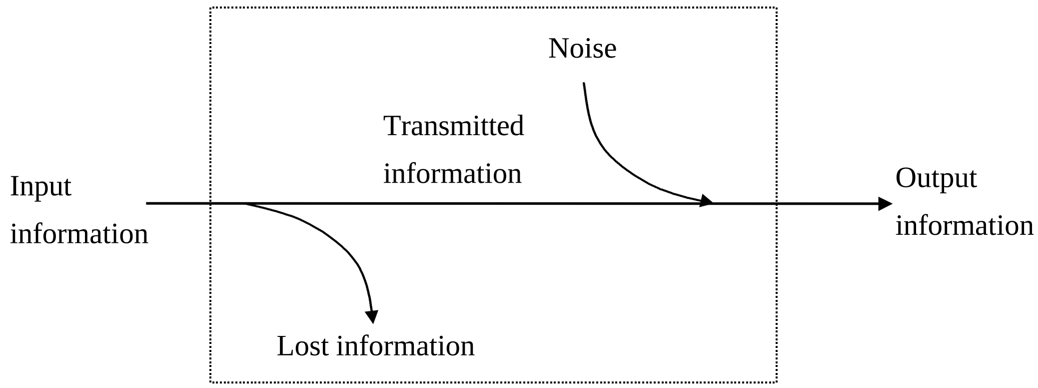

Figure 2. Information channel model for stimuli-response task

Thanks to sophisticated user interface of visual display unit (VDU), however, the amount of information and workload on a human operator can be effectively reduced. In this case, an information-searching manner is completely different from that of conventional stimuli-response task. Well-designed user interface of VDU will restructure the information content and provide easy and simple way to find required information. The conventional model, furthermore, has some limitations that are pointed out by Bainbridge [Bai97] because of its sequential properties. In order to develop more effective task-performing model of operators, the properties of sophisticated models (e.g., cyclic contextual property) should be added. Most important characteristic of sophisticated models is the cyclic processing of information opposed to the sequential processing.

In this study, the information display system in a nuclear power plant is selected for the target application system. Models should also reflect the dynamic nature of the system and environment as perceived by operators given the current system state and current system goals [Mit97]. That is, models should represent not only physical activities but also cognitive activities of operator, which include monitoring, situation assessment, planning, and diagnosis. When sequential modes are used, some crucial feature of human behavior in complex tasks tend to be forgotten. It may induce serious consequences for the design of systems to support human behavior.

The external factors that may affect operator behavior depend on many elements of the working environment [Cac97]. Representation for complex relations surrounding human operators must be achievable in performance prediction model, such as the collaboration between operators acting in the same control room or in different places aiming at achieving the same goals. New robust modeling methodology of human-machine interaction including user interface is required.

Figure 3 shows examples of describing the human activities. Figure 3(a) can be expanded to Figure 3(c) through Figure 3(b). We call this the cyclic information flow (CIF) diagram. It is constructed based on the information flow concept. Rectangle in Figure 3 implies the sender or the destination of information. Circle implies the mean of communication. There exists, however, neither start-point nor end-point in this model to the contrary of sequential form of the conventional models based on information flow. No constriction on the order of task performing or number of repeating exits. This flexibility is due to the cyclic property.

3. Example for Advanced Alarm System

Dynamic alarm console (DAC) is an advanced alarm processing system which was developed in NUSCOL Lab. at KAIST. It processes and presents multiple activated alarms and also provides the alarm-related information and the historical record of alarms. DAC has special function of reducing the number of alarms by prioritization. Because of this function, operators will be less embarrassing when alarm avalanche happened. DAC, however, cannot consider the increase of the number of irrelevant alarms. It may make operator have more difficulty on understanding the plant status. Jin-Kyun Park [Par97] resolved this problem by introducing the concept of signal detection theory (A' score for evaluating informativeness).

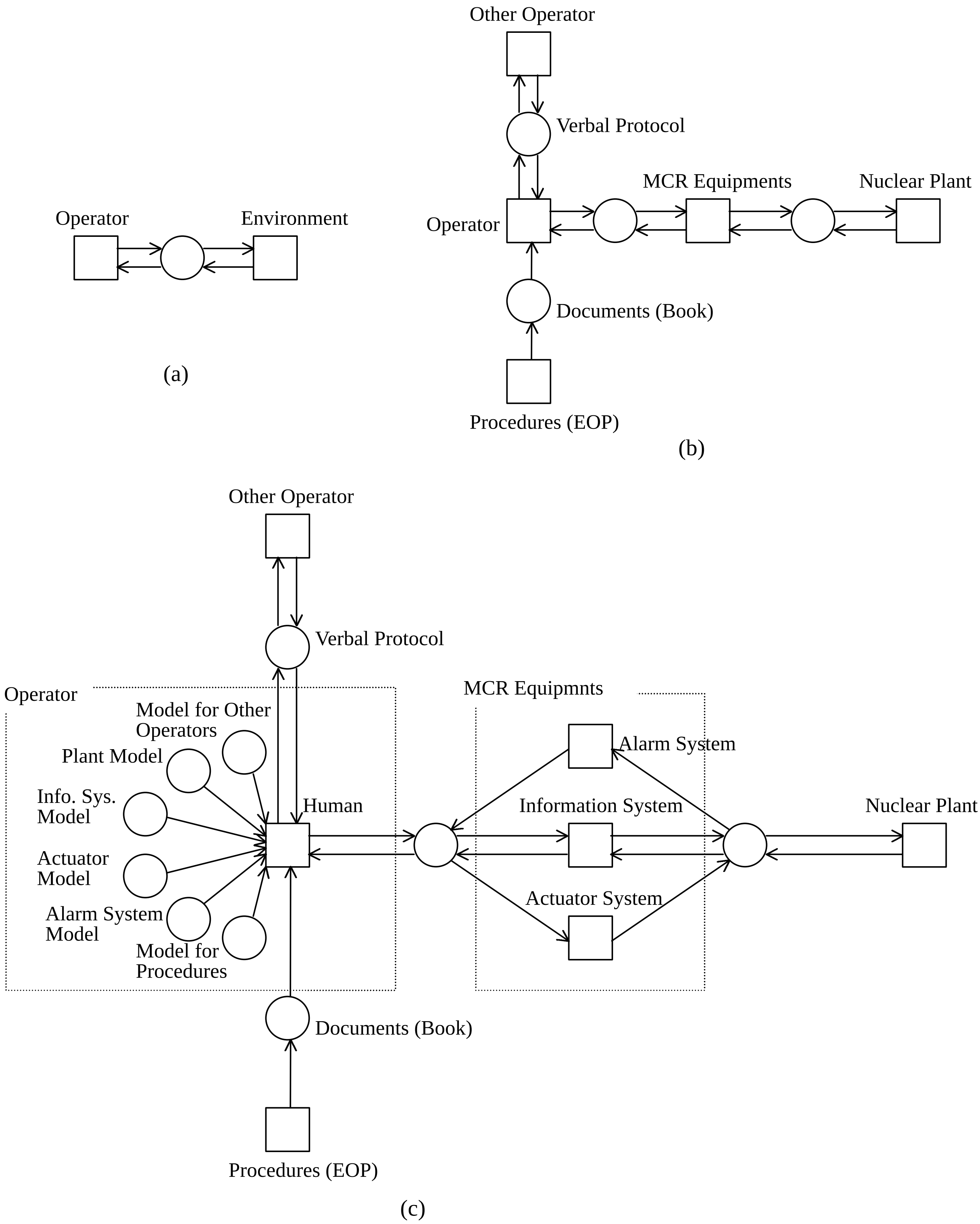

Figure 3. Example CIF diagrams for nuclear power plant operator

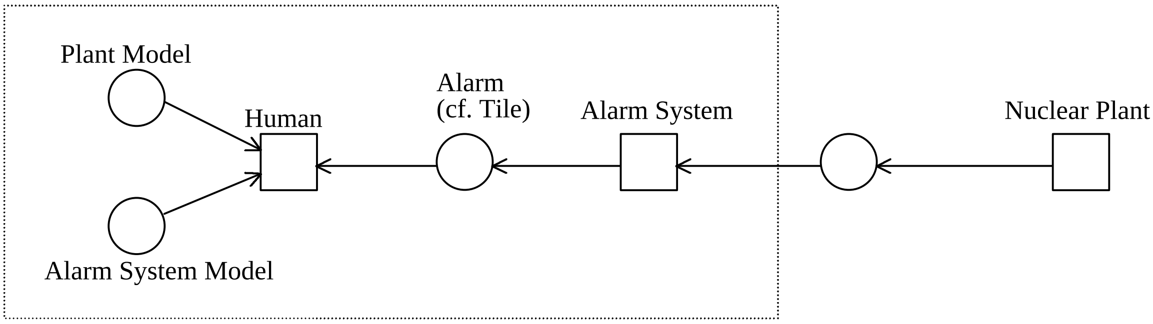

Figure 4. CIF diagram for Alarm Processing System

Figure 4 shows that Human processor will receive the information from the alarm system and his/her mental model for plant and alarm system simultaneously. In the case of well trained operator, the alarm system model can be ignored. Whether the information from the alarm system is proper or not can be evaluated using the measure based on information theory by considering two factors: 1) The plant model in well trained operator might provides the alarms related to the expected plant status. The coincident information part of two independent source (alarm system and mental model) will decrease the difficulty of accepting this expected status. 2) The number of alarms presented to operators will increase the difficulty. These quantities cannot be algebraically summed. For the purpose of convenience, however, we define $h_{decision}$ by adding these two quantities as follows:

$$h_{decision} = h_{difficult} + h_{confuse}$$

$$h_{difficult} = \log_2 \frac{1}{P_{difficult}} \qquad \left(P_{difficult} = \frac{\textit{number of coincident alarms}}{\textit{total number of alarms}} \right)$$

$$h_{confuse} = n \frac{1}{n} \log_2 \frac{1}{1/n} \qquad \text{(n = \# of non-coincident alarms)}$$

Calculation results are compared to Dr. Park's and the results from operator questionnaire. Table 1 shows the comparison results for the case of LOCA.

Table 1. Result of evaluation for LOCA (A', Experiment and *h* values)

Criteria	A'	R	E = R*A'	Questionnaire	$h_{difficult}$	$h_{confuse}$	$h_{decision}$
18	0.3972	0.899	0.357	0 %	3.3923	4.248	7.640
16	0.7189	0.760	0.546	57 %	1.4150	4.322	5.737
14	0.6450	0.608	0.395	0 %	1.6521	4.907	6.559
12	0.8713	0.544	0.473	44 %	1.0297	4.644	5.674
9	0.8470	0.481	0.407	0 %	1.1699	4.907	6.077
8	0.8485	0.329	0.280	0 %	1.3440	5.322	6.666

4. Conclusion

CIF diagram which can describe the information flow around human operators, thus represents operator's cognitive workload is proposed. It considers the signal processing and information providing methodology simultaneously. In order to show an application example, the advanced alarm processing system is evaluated using information theory based approach.

References

[Bai97] C. L. Bainbridge, The Change in Concepts Needed to Account for Human Behavior in Complex Dynamic Tasks, IEEE Transactions on Systems, Man, and Cybernetics –PART A Systems and Humans, Vol. 27, No.3, 1997.

[Cac97] P. C. Cacciabue, A Methodology of Human Factors Analysis for Systems Engineering: Theory and Applications, IEEE Transactions on Systems, Man, and Cybernetics –PART A Systems and Humans, Vol. 27, No.3, 1997.

[Gro95] J. Grobelny, W. Karwowski and J. Zurada, Application of fuzzy-based linguistic patterns for the assessment of computer screen design quality, International Journal of Human-Computer Interaction, Vol. 7, no. 3, pp. 193-212, 1995.

[Hub96] G. S. Hubona and J. E. Blanton, Evaluating system design features, International Journal of Human-Computer Studies, Vol. 44, 1996.

[Kon97] T. Kontogiannis and D. Embrey, A User-centred Design Approach for Introducing Computer-based Process Information Systems, Applied Ergonomics, Vol. 28, No. 2, 1997.

[Mei95] D. Meister, Cognitive Behavior of Nuclear Reactor Operators, International Journal of Industrial Ergonomics, Vol. 15, pp. 109-122, 1995.

[Mit95] D. A. Mitta, Selecting system functionalities for interface evaluation, Human factors, Vol. 37, No. 4, 1995.

[Per89] G. Perlman, User Interface Development (SEI Curriculum Module; SEI-CM-17-1.1), Software Engineering Institute, Carnegie Mellon University, 1989

[Shn92] B. Shneiderman, Designing the user interface: strategies for effective human--computer interaction (2nd ed.), Addison-Wesley, 1992.

[Vic95] K. J. Vicente, K. Christoffersen and A. Pereklita, Supporting operator problem solving through ecological interface design, IEEE Transactions on Systems, Man, and Cybernetics, Vol. 25, No.4, 1995.

[Par97] J.K. Park, S. S. Choi, J. H. Hong and S. H. Chang, Development of the effectiveness measure for an advanced alarm system using signal detection theory, IEEE Transactions on NS, Vol. 44, No.2, April 1997