A Consideration to Display Operator Support Information to Human Operators under High Mental Pressure

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Abstract. Operator support systems are extensively studied and developed to support human operators for their activities in especially an abnormal condition of a nuclear power plant. By the advancement of computer technology and artificial intelligence, an operator support system can provide detailed support information based on detailed models and utilizing detailed simulation of plant dynamics and/or complicated inference algorithms. However, human operators may not understand the detailed support information under high mental pressure in an abnormal plant condition. In such a case, it is important how to provide essential and understandable support information. This paper deals with a technique to simplify functional models in order to display operator support information that is generated based on detailed functional models. This paper defines eight cognitive states of human operators from the viewpoint of cognitive abilities of human. In addition, three ways to simplify functional models are identified.

Keywords. operator support system, information display, model simplification, cognitive state

INTRODUCTION

Operator support systems that computer systems support human operators, especially in the cases of abnormal plant situations are important to increase the safety of nuclear power plants. Up to now, extensive studies were made to support the activities of human operators. The studies cover detection and identification of a small disturbance [Nagamatsu 2014], estimation and display of internal plant states [Furusawa, 2013], generation and display additional information desirable for a computer-based operation procedure [Suryono, 2018], generation of plausible counter operation procedures [Gofuku, 2017, Song, 2018], and so on.

By the recent advancement of computer technologies and software engineering, especially, artificial intelligence, an operator support system becomes to use huge data and apply complicated calculation/reasoning techniques. By the usage of complicated data and base models and application of sophisticated calculation/reasoning processes, the accuracy and resolution of generated information will increase. However, from the viewpoint of human-machine interface, this means that the generated information will be too many and detailed resulting in becoming hard to understand for human operators under high mental pressure in an abnormal plant condition. Therefore, it is important for an operator support system to display operator support information by considering the cognitive state of human operators.

This paper discusses the necessity of information display that is suitable for the cognitive state of human operators, classification of cognitive states of human operators, and ways of simplification of a base model for generating understandable support information in the case of using a functional model as a base model for generating operator support information.

METHODOLOGY

When an anomaly happens in a nuclear power plant, human operators in the main control room will have high mental pressure because they should take suitable counter actions without human errors to prevent an accident and

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to decrease environmental impact by the anomaly. The high mental pressure will deteriorate cognitive abilities of human operators and increase the possibility of human errors.

This paper first surveys some literatures related with classification of cognitive states of plant operators and information display technique even in a degraded cognitive state of operators. Then, a new classification of cognitive states of operators is proposed from the viewpoint of degrading major abilities that are necessary for making actions: information perception, understanding information, judgment, and action execution. Then, this paper points out the advantages and disadvantages of the usage of a detailed base model. It also discusses how to display necessary information considering cognitive states of operators. Finally, this paper points out three ways of simplifying functional model that will be important to explain the purpose of necessary counter actions in an emergency situation of nuclear power plants.

RESULTS AND DISCUSSIONS

Cognitive States of Human Operators

Hollnagel [Hollnagel 2002] classified cognitive states of human operators into four modes from the viewpoint of control actions to manage plant conditions: strategic control, tactical control, opportunistic control, and scrambled control. The strategic control mode is the ordinal cognition state. Operators can predict the next event and plan a sequence of counter actions. In the tactical control mode, operators can apply the counter actions and theories prepared in advance. In the opportunistic control mode, the decision of next action is made only based on the salient features of the situation. In the scramble control mode, operators cannot consider previous events and predict the next event. They act in panic typically.

Niwa, et al. [Niwa 2001] pointed out that the support to human operators should be changed depending on their cognitive states and proposed a concept of direct support and indirect support. In the direct support, an operator support system provides the information about the actions that human operator should take. On the other hand, if the cognitive state of human operators is in almost normal, the support information necessary for planning counter actions is mainly provided in the indirect support not to make human operators blindly follow the action proposal by the support system.

The authors are studying a technique to display operator support information by considering the cognitive state of human operators. In our study, eight cognitive states of human operators are identified depending on their cognitive performance in the abilities of information perception, understanding information, judgment, and action as shown in Table 1. In the consideration of the cognitive states, we assume that the ability of judgment needs highest cognitive resources. The ability of understanding information is the second. And, the information perception needs least cognitive resources.

Table 1 Cognitive states of human operators

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">State description</th><th colspan="4">Ability</th></tr>
<tr><th>Information perception</th><th>Understanding information</th><th>Judgment</th><th>Action execution</th></tr>
<tr><td>1</td><td>Able to make long-term planning</td><td rowspan="7">Normal</td><td rowspan="3">Normal</td><td rowspan="2">Normal</td><td rowspan="6">Normal</td></tr>
<tr><td>2</td><td>Able to plan counter actions by combining rules and based on information</td></tr>
<tr><td>3</td><td>Able to consider actions by combining some given counter actions</td><td rowspan="2">Partially degraded</td></tr>
<tr><td>4</td><td>Able to retrieve predefined counter actions and evaluate their validities</td><td rowspan="2">Partially degraded</td></tr>
<tr><td>5</td><td>Able to retrieve predefined counter actions</td><td rowspan="4">Degraded</td></tr>
<tr><td>6</td><td>Able to take actions based on instructions or experiences</td><td rowspan="3">Degraded</td></tr>
<tr><td>7</td><td>Able to percept information</td><td rowspan="2">Degraded</td></tr>
<tr><td>8</td><td>Confusing</td><td>Degraded</td></tr>
</table>

Information Display Using Simplified Model

Operator support systems can provide detailed support information because recent computer systems have enough computation power and resources (memories and data storages) to precisely simulate dynamic behavior of a nuclear power plant and to make inference based on a detailed model and using complicated algorithms. However, human operators may not understand detailed support information because their cognitive abilities decline due to high mental pressure in an abnormal plant condition. They can understand and use detailed support information in the cognitive states 1 and 2 in Table 1. However, because the cognitive capability of a human under a high mental pressure deteriorates, simple and essential support information will be effective in the cognitive states under the state 3 and/or in the plant situation of requiring immediate counter actions.

Simple and understandable information will be informative for human operators under high mental pressure. A display system of operator support information should have an ability to change the complexity of the information to be displayed. There are two ways to change the complexity of information. The one is to generate information based on a simplified model. The other is to simplify the generated information considering a simplified model of the base model of information generation. The usage of simple base models and/or simple calculation/inference algorithms will decrease the accuracy and resolution of support information generated. Therefore, a strategy that an operator support system generates support information based on detailed models and using complicated calculation and/or inference procedures and then displays support information using simplified models will be feasible. For this strategy of information display, an important technical topic is how to simplify a model that is consistent with the original detailed model and preserves essential information of the model.

Ways of Simplification of a Functional Model

A functional model of a system expresses the information related with its purpose, goal, and how to achieve the goal. Multilevel Flow Modeling (MFM) [Lind, 1990, Lind, 2011] is one of popular functional modeling methodologies. The characteristic features of MFM are the usage of primitive function concept and graphical modeling of a system from two directions of means-end and whole-part. Recently, it is extensively applied to diagnostic systems and operator support systems of engineering plants [Lind, 2014] as well as theoretical studies to improve its modeling capabilities. The group of the author studies operator support systems based on MFM models of engineering plants. We have proposed techniques of generating plausible operation procedures in an emergency situation of an engineering plant [Gofuku, 2017, Song, 2018] and generating additional information that is desirable to include in computer-based operation procedures [Suryono, 2018]. We are also studying a technique how to display the operator support information that is generated based on an MFM model to an operator under a high mental pressure.

This section discusses the simplification of an MFM model. An MFM model is composed of objectives/threads, function flows that are composed of function primitives, and relations among them and forms a network-like graphical model [Lind, 1990, Lind, 2011]. In addition, components that realize function primitives are assigned although they are not explicitly represented. Considering this model formation, there are several viewpoints for the simplification of an MFM model.

The first type of simplification is to delete objectives/threads and the function flows that achieve the objectives/threads because they are not relevant with the purpose of problem solving and/or displaying information. In this simplification, the recognition of the relevance is critical to what extent of simplification is suitable. For example, the objective of circulating lubrication oil and its relevant function flow of a pump can be omitted if an anomaly in a system including the pump does not originate the pump. Some cases may need an objective/thread but can omit the achieving function flows if a function flow is easy to understand from the content of the objective/thread. A simple mass flow structure that represents the supply and circulation of lubrication oil for lubricating a pump is an example.

The second type is to simplify a function flow [Zheng, 2005]. For this simplification, a formal technique called function flow simplification was proposed. The essential idea of the function flow simplification is to simplify a function flow by changing the abstraction level of MFM model from a microscopic level to a macroscopic one. In this type of simplification, the recognition of major functions of a function flow is important. Major functions depend on the purpose of a system, that is, the top objective/thread of an MFM model. In the popular example of a central heating system to demonstrate representational capability of MFM, the most simplified function flow could be composed of energy source, energy transport, and energy sink functions. In this model, the central heating system as a whole is regarded to an energy source although this simplified model has little sense as a base model for problem solving and/or displaying information. Usual MFM models include the objectives and functions of boiler, radiator, circulation pump, expansion tank, pipes, and so on that are composed of a central heating system.

The third type is to first simplify a structural model of a system by applying part-of relations in the system and then simplify the corresponding MFM model according to the simplification results of the structural model. For example, a central heating system is composed of several components but we can recognize them as a system "central heating system." Then, we can model the system to play the role of energy source function. The recognition of main parts of a system is important. This simplification is identical to create an MFM model from a macroscopic structural model of a system.

CONCLUDING REMARKS

This paper pointed out the importance of considering cognitive state of operators in the display of operator support information. Eight cognitive states of human operators are defined from the viewpoint of cognitive abilities of human. This paper also deals with a technique to simplify functional models in order to display operator support information that is generated based on detailed functional models. Three ways are identified to simplify MFM models.

Future works include the following topics. Because MFM has the capability to change abstraction level of modeling, it is necessary to improve the modeling framework to include the information of major functions of a function flow and main components/parts of a system in an MFM model. In addition, a technique is necessary to be developed for changing flexibly the explanation level of details of generated information.

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