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Strategy-Based Evaluation of Information Aids for the Diagnosis of Nuclear Power Plants

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Abstract

While a diagnosis task is concerned with what needs to be done, strategies focus on how to do the task. It can be said that strategies reflect operators' real needs in the diagnosis task. Therefore, Meeting operator strategies is an important requirement for information aiding systems in NPPs. This paper evaluates the effectiveness of four information aiding types based on the operator strategy. The main features of four aiding types were elicited from typical direct operator support systems. An experiment was conducted for 24 graduate students and subject performances were analyzed according to the strategies that subjects used in problem-solving. The result showed that each type of the information aids has a different effect on performance according to subject strategies.

I. Introduction

Diagnosis is an indispensable task for safe and economic operation of nuclear power plants (NPPs). Diagnosis is also necessary for initiating operating procedures, which describe predefined steps and are usually equipped in main control rooms (MCRs) in order to correct the faults. NPP operators' actions on a plant must always be based on an identification of the operational state of the system. To identify the state means to give it a name, to label it in terms which will refer to the functional state of system; to the cause of this functional state; or directly to the related control action [1]. In NPPs, the control actions should follow operating procedures which are initiated by the results of state identification. Therefore, to identify the cause of the state is more emphasized for NPP fault or accident diagnosis than to produce the corrective actions. It was also reported that most of difficulties in NPP operation are the result from inability to identify the nature of the problem, because operators know the appropriate response for a given causality well [2].

Strategies are the generative mechanisms by which diagnosis tasks can be achieved [3]. A strategy can be defined as a category of cognitive task procedures that transforms an initial state of knowledge into a final state of knowledge [1]. He also described two types of search strategies: topographic search and symptomatic search. Yoon and Hammer [13] categorized the search strategies into data-driven search and hypothesis-drive search. They also suggested, as a result of experiments, that the aiding information should be compatible with the human information processing. While a diagnosis task is concerned with what needs to be done, strategies focus on how to do the task. It can be said that strategies reflect operators' real needs in the diagnosis task. Therefore, meeting operator strategies is an important requirement for information aiding systems in NPPs.

As a result of developments in information technology and increased capabilities of modern computers in processing and presentation information, there is an increasing trend toward introducing modern computer techniques into the design of advanced MCRs of NPPs [4]. The advanced MCRs are characterized by a number of new features intended to support operator situation awareness and response execution. These include: 1) compact operator consoles with multiple window, multi-display capabilities, 2) integrated graphic display, 3) soft controls, 4) advanced alarm systems, 5) computer-based procedures, 6) intelligent advisors, 7) a large dynamic overview display, and 8) increased level of automation [5].

Among them, the approaches to improving operator diagnosis and situation awareness can be categorized into two ways. One approach is improving the displays of MCRs, which can be called as "indirect support." This approach includes integrated graphic displays, configural displays [6], and ecological interface design [7],[8],[9],[10]. The other approach is developing decision support system, which can be called as "direct support." This includes intelligent advisors, alarm systems, computer-based procedures, fault diagnostic systems, and computerized operator support systems (COSSs), which are based on expert systems or knowledge-based systems.

This paper evaluates the effectiveness of four information aiding types based on the operator strategy. The main features of four aiding types were elicited from typical direct operator support systems. An experiment was conducted for 24 graduate students and subject performances were analyzed according to the strategies subjects used in problem-solving. The experiment adopted the strategy categorization proposed by Rasmussen. The result showed the different effects of the information aiding types according to subject strategies.

II. Background

II.1 Diagnostic Strategies

From the perspective of cognitive work analysis [3],[11], tasks or control tasks are the goals that need to be achieved, independently of how they are to be achieved or by whom. Strategies are the generative mechanisms by which a particular task can be achieved independently of who is executing them. While the definition of task is concerned with what to do, that of strategy is concerned with how to do. Rasmussen et al [11] defined a strategy as an idealized category of cognitive processes that transforms an initial state of knowledge into a final state of knowledge.

The approach of this paper to operator strategies is based on the strategy taxonomy suggested by Rasmussen. The strategies suggested by Rasmussen are characterized by information flow maps. The search strategies can be divided into two types: topographical search and symptomatic search. A search can be performed in the actual, maloperating system with reference to a template representing normal or planned operation. The change will then be found as a mismatch and identified by its location in the template. Consequently, this kind of search strategies is named topographic search. Figure 1 shows the information flow map of the topographic search strategy. Topographic search uses a normal model of the system to select the nest field of attention. Each field is then judged to be good or bad through appropriate observation. The next field of attention can be either a subfield of the current field that was judged to be bad or a field of the same level that is logically or physically adjacent. The advantage of topographic search is its dependence upon a model of normal system operation rather than model of malfunction. Rasmussen pointed out that this advantage make topographic search suitable for novel fault diagnosis. However, the use of available information by topographic search is rather uneconomical because observations are used only for good/bad judgments. Thus, topographic search by itself may not lead to final diagnosis.

On the other hand, a set of observations representing the abnormal state of the system can be sued as a search in a accessing a library of symptoms related to different abnormal system conditions to find a matching. This kind of search will be called symptomatic search. Furthermore, three symptomatic searches are suggested: pattern recognition, decision table, and hypothesis-and-test. Figure 2 shows the information flow maps of the three symptomatic searches. In the pattern recognition strategy, an operator recognizes a pattern of data from the failed equipment as being familiar and attaches a label to that pattern. It can efficiently identify familiar systems and disturbances directly, but it is also used frequently during topographic search to guide the tactical decisions. The decision table strategy relies on a library of state models that associate a particular data pattern with a particular state. The primary difference between pattern recognition and decision table is that the decision table has a larger dependency on experience and long term memory in generating a set of symptoms. The hypothesis-and-test strategy generates the symptom patterns on-line according to hypotheses and then compares them to the observed system behavior, since the symptom patterns are generated via a hypothetical functional model of the system, understanding of the system dynamics and configuration is more important than in other search strategies. This strategy involves the most complicated information processing, with causal reasoning at its center. The main difference of this strategy from other strategies is that it generates hypothesis and a set of symptoms by itself. Thus, it requires high mental load and is relevant to novel fault diagnosis. These three strategies in symptomatic search, that is, pattern recognition, decision table, and hypothesis-and-test are closely related to skill-, rule-, and knowledge-based behavior in Rasmussen's classification [12], respectively.

Yoon and Hammer [13] categorized diagnostic strategy into two types according to directions of information processing: data-driven search and hypothesis-driven search. Data-driven search is triggered by observation of system behavior, takes observations as input and produce hypotheses. In the hypothesis-driven search, when hypotheses are to be evaluated, the operator builds a test plan that may prove one hypothesis and disprove the rest. This type of process tends to be employed more often toward the final stage of diagnosis as the data-driven search loses its efficiency.

II.2 Operator Support Systems for Diagnosis Tasks

As instrument and control systems in NPPs are digitalized and automated due to technology progress, the conventional indicators and control equipment of MCRs were or are going to be replaced by CRTs or computerized control devices such as soft control. In addition, computerized operator support systems such as alarm systems and computerized procedure systems are also installed to help safe and efficient plant operation [14],[15]. The computerized support of operation performance is needed to assist the operator, particularly in coping with plant anomalies so that the failures of complex dynamic processes can be managed as quickly as possible with minimum adverse consequences [4]. The on-line management of process failures may be regarded as having three basic elements: detection, diagnosis and correction. Figure 3 shows the overview of human-machine system for NPPs. Fault diagnostic system should provide timely, accurate, transparent analyses in order to satisfy operator's principal need [16].

Conventional alarm systems, that is, tile-style alarm systems, possess several common problems, including the problem of too many nuisance alarms and that of annunciating too many conditions that should not be part of an integrated warning system. In order to cope with those problems, advanced alarm systems have been developed and they have general functional characteristics of alarm processing such as categorization, filtering, suppression, and prioritization [17].

Various demonstrative diagnostic systems have been also developed, mostly in academic and research institutes, but still remains in the research field not to be applied to real plants, while advanced alarm systems are regarded as a standard system in advanced MCRs. The first reason is that it is difficult to validate the knowledge base and the software of the system completely. Another reason is that advices through providing simply output results are not so effective for operator's diagnosis. For example, Zisner and Henneman [19], and Resnick et al contain examples of laboratory based machine advisors which simple recommended a solution to the human problem solver were ignored. However, the function of fault detection of fault diagnostic systems tends to be implicitly merged into early fault detection of alarm systems and automatic procedure identification of computerized procedure systems.

Computerized procedure systems (CPSs) are also regarded as a main system in advanced MCRs [20],[21]. CPSs were developed to assist personnel by computerizing paper-based procedures. Their purpose is to guide operators' actions in performing their tasks in order to increase the likelihood that the goals of the tasks would be safely achieved [17]. CPSs were originally designed to support response planning. CPSs, on the other hand, may support the cognitive functions such as monitoring and detection, and situation assessment according to the level of automation of CPSs.

III. Experiment

III.1 Overview of Experimental Design

An experiment was designed to evaluate the effectiveness of information aiding types for diagnosis tasks of NPPs, based on diagnostic strategies. Four types of information aid approaches were used in the experiment: no aid, alarm, hypothesis, and hypothesis and expected symptoms of the hypothesis. The features were basically derived from those of operator support systems for operator diagnosis. Figure 4 shows the displays of three types of information aids.

Alarm information is provided with occurrence time, as shown in Figure 4 (a). Nineteen alarms are available in the display and currently activated alarms are highlighted with red color. Figure 4 (b) shows the display of hypothesis aiding type. This type of aiding provides the hypotheses about possible faults of the current state with certainty factor. The certainty factor is calculated through the algorithm used in MYCIN system [22]. The knowledge base of this type of information aid was constructed by using emergency and abnormal operating procedure of Yonggwang unit 3 & 4. The third type of information aid is hypothesis and expected symptoms of the hypothesis. In this aid, if a subject clicks one hypothesis, he/she can get the expected symptoms of the fault which were elicited from operating procedures. This aid added symptom sets to the hypothesis aid.

III.2 Experimental Tasks and Procedure

Subjects were randomly divided into four groups according to information aiding types. Subjects were asked to identify eight events: Loss of Coolant Accident (LOCA), Steam Generator Tube Rupture (SGTR), Feed Line Break (FLB), Steam Line Break (SLB), Pzr Spray Valve Fail Close + Pzr Heater Fail On, Main Stem Isolation Valve Fail Close, Reactor Coolant Pump Trip, Pzr Spray Valve Fail Open.

The experiment was conducted in six sessions. Firstly, participants learned NPP systems using system manuals and the simulator which is used in the experiment. Then, they learned the displays or usage of the simulator and the information aids. Then, they practiced with the simulator. Next, they took a written test of three problems. They then also solved two diagnostic problems as exercise with the simulator, which was the same situation as the actual experiment. Finally, in the main experiment, the participants were asked to diagnose eight events that are common to all four groups. The experiment took 1h 40m to 2h 20m, including training sessions.

III.3 Participants and Apparatus

The subjects were 24 graduate students (20 males and 4 females) of department of nuclear and quantum engineering at KAIST, who ranged in age from 22 to 29 yrs, having normal or corrected-to-normal vision. They all had more than three years of nuclear engineering experience.

This experiment used FISA2/PC real time microsimulator, which was developed at KAIST and Chosun university. Figure 5 shows the view of nuclear steam supply system (NSSS) of the simulator. The simulator contains six windows for mimic diagrams of NPP systems, three tables for plant status, and six windows for trend graphs of important variables. Video and audio recording systems were also equipped in the experiment.

III.4 Performance Measures

Three performance measures were used for evaluating the diagnostic performance. Time was measured for primary task performance. The number of navigated windows was also measured for secondary task performance. The strategy that subjects used was obtained through short interview with subjects after each identification activity. Strategies were categorized into three groups: hypothesis-and-test strategy, decision table search strategy, and pattern recognition and topographic search. If a subject used two or more strategies in the problem solving, his/her strategy was assigned to the strategy which is the most memory-demanding and requires the most complex cognitive process. The subject's strategy was also analyzed through verbal protocol. Subjects were asked to tell the hypothesis when they entertained a hypothesis during the experiment. Subjects were asked to verbalize only the hypotheses since the mental workload for verbalizing their thought may affect the problem solving activity.

III.5 Result

A. Hypothesis-and-Test Strategy

Figure 6 shows the experimental result about hypothesis-and-test strategy. The analysis of variance showed that both time (p=0.000802) and # of navigated windows (0.000787) were significantly affected by the types of aiding. Through a pairwise comparison of the four aiding types, "hypothesis and expected symptoms of the hypothesis" aid showed better performance in two measures than the other three types.

B. Decision Table Search Strategy

Figure 7 shows the result for decision table search. The analysis of variance showed that both time (p=0.012128) and # of navigated windows (0.010907) were significantly different according to the types of aiding. Through a pairwise comparison of the four aiding types, 'hypothesis and expected symptoms of the hypothesis' aid showed better performance in time measure than 'hypothesis' and 'no aid' types. The aiding type of 'alarm' differed from 'no aid' type in time. For the # of navigated windows, 'hypothesis and expected symptoms of the hypothesis' and 'alarm' aids showed better performance than "no aid'.

C. Pattern Recognition and Topographic Search Strategy

Figure 8 shows the result for pattern recognition and topographic search. The result showed that the difference between aiding types was not significant in both time and # of navigated windows. However, the # of navigated windows was almost significant (p=0.0745).

VI. Conclusion

This paper performed the strategy-based evaluation of information aids for NPP diagnosis. The experimental result showed that 'hypothesis and expected symptom of the hypothesis' aid is a useful aiding type in hypothesis-and-test and decision table search strategies. It seems that this aiding approach can help subjects to generate hypotheses and symptom sets corresponding to a hypothesis in hypothesis-and-test strategy. It is also useful in decision table search because it can help subjects compare their own hypotheses and validate them. The 'alarm" type aid had been supposed to be helpful in the hypothesis-and-test strategy since it can support subjects' information gathering activities. Since generating hypotheses and symptoms takes more time in that strategy than gathering information, there was no difference between the 'alarm' type aid and 'no aid'. However, the 'alarm' aid was helpful in decision table search strategy.

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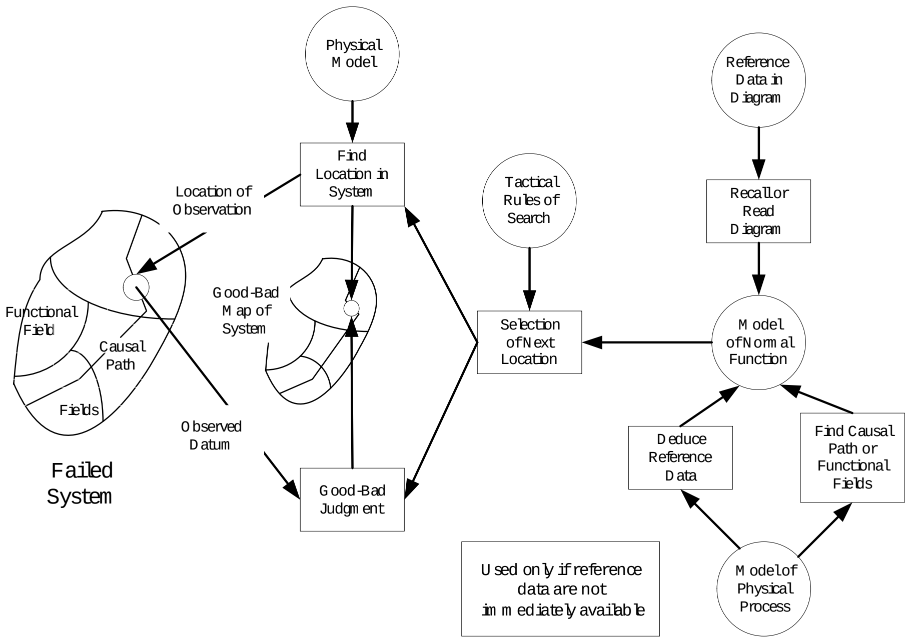
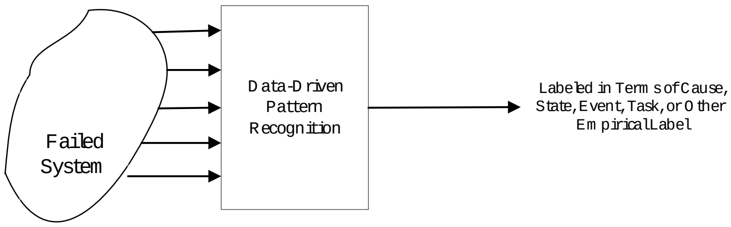
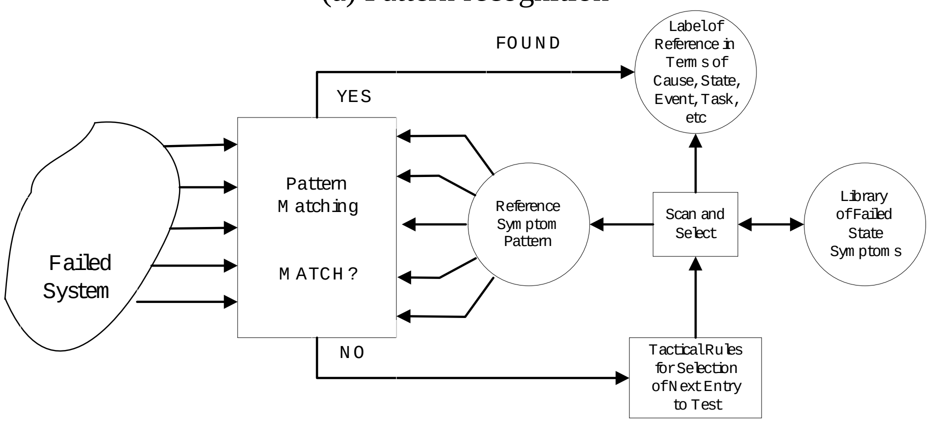


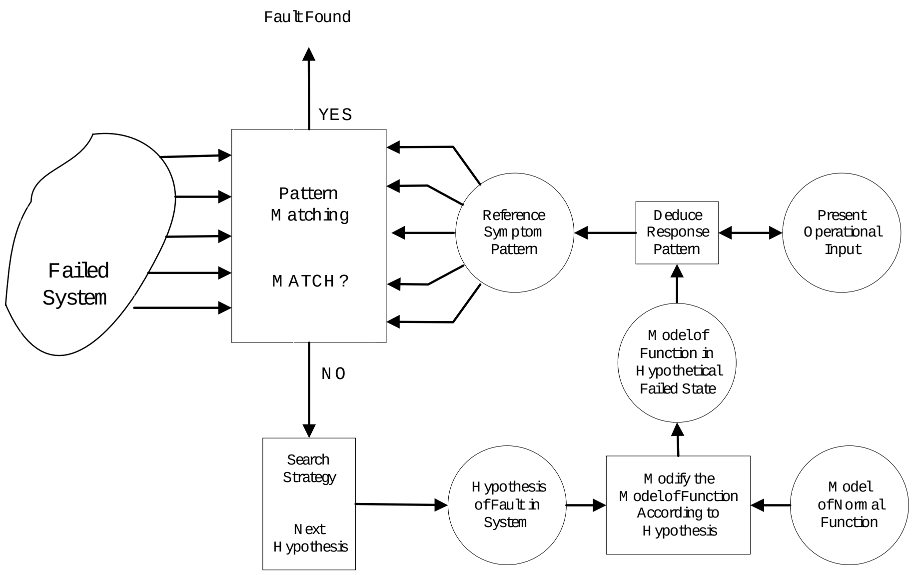
Figure 1. Information flow map for topographic search strategy



(a) Pattern recognition



(b) Decision table search



(c) Hypothesis-and-test

Figure 2. Information maps for symptomatic search strategy

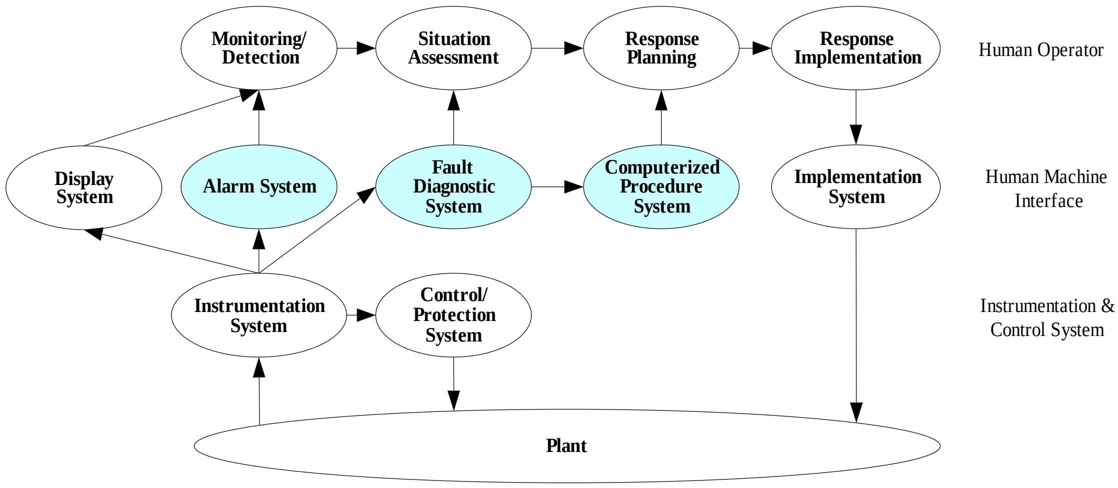
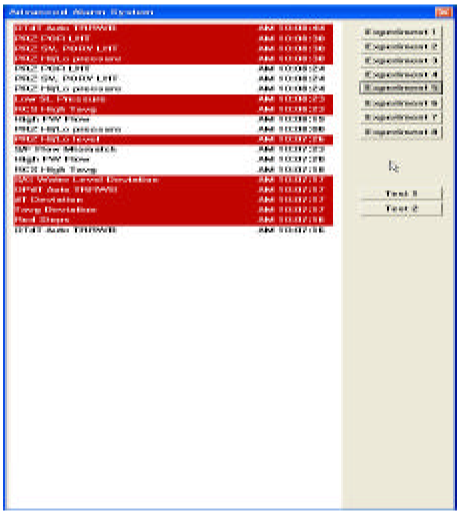
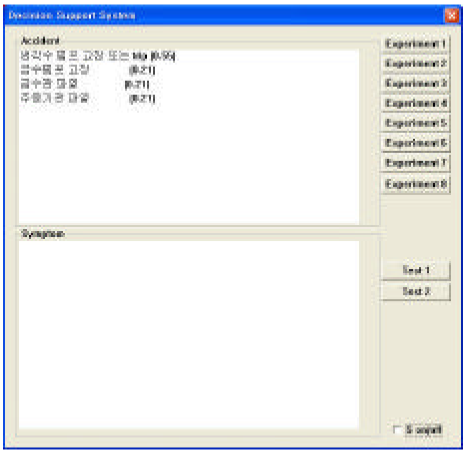


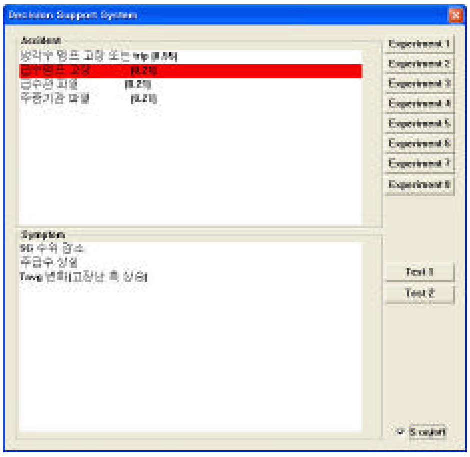
Figure 3. Overview of human-machine system for NPPs



(a) Alarm



(b) Hypothesis



(c) Hypothesis and expected symptoms of hypothesis

Figure 4. Three types of information aids

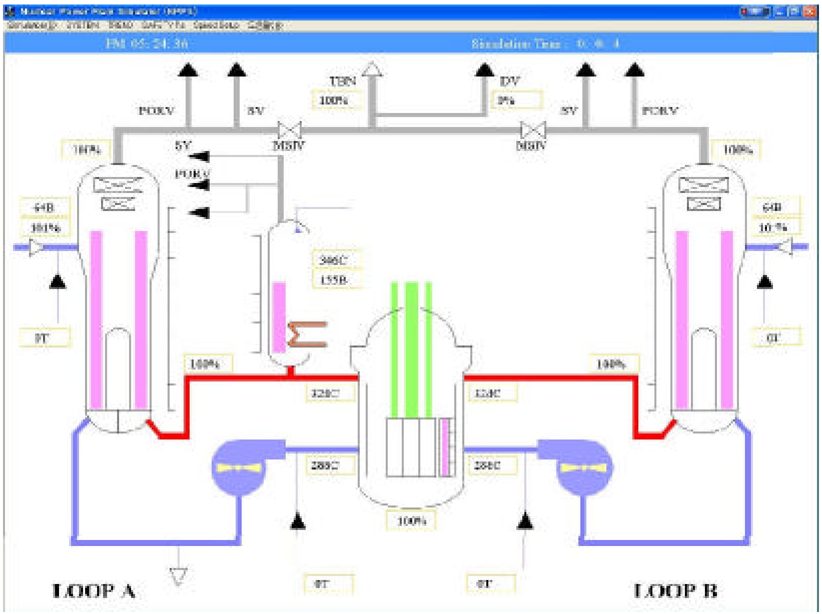
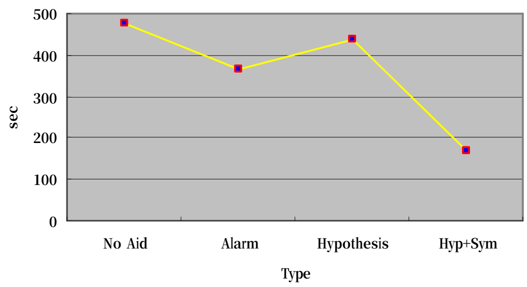
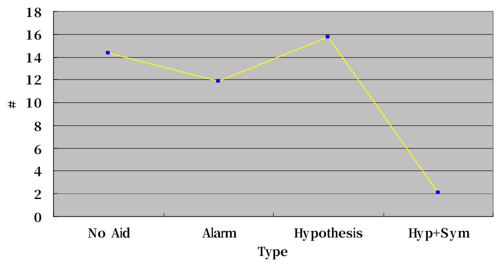


Figure 5. NSSS view of the test simulator

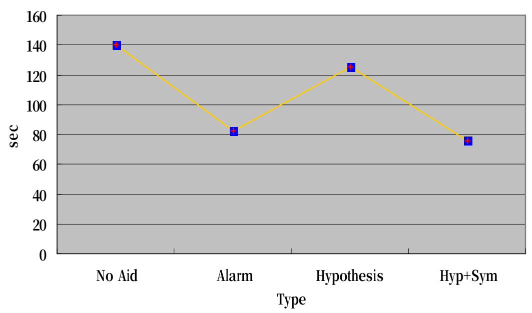


(a) time

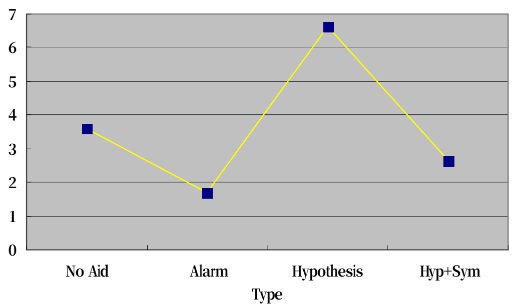


(b) # of navigated windows

Figure 6. Experimental result for hypothesis-and-test strategy

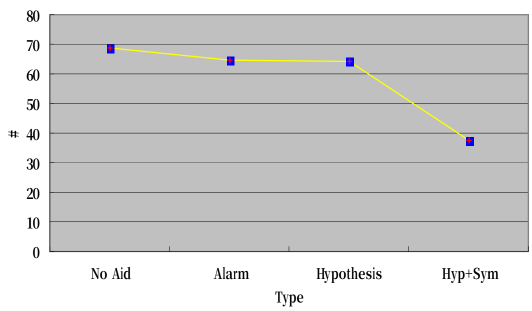


(a) time

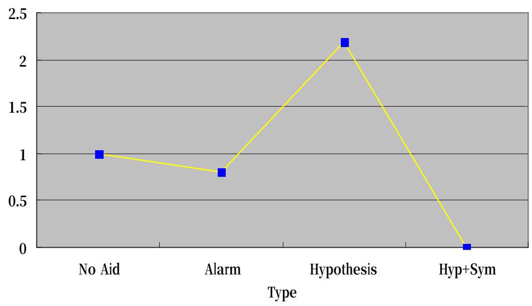


(b) # of navigated windows

Figure 7. Experimental result for decision table search strategy



(a) time



(b) # of navigated windows

Figure 8. Experimental result for topographic search and pattern recognition strategy