

# DEVELOPMENT OF AN INTEGRATED DECISION SUPPORT SYSTEM TO AID COGNITIVE ACTIVITIES OF OPERATORS

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*Received July 16, 2007*

*Accepted for Publication October 10, 2007*

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As digital and computer technologies have grown, human-machine interfaces (HMIs) have evolved. In safety-critical systems, especially in nuclear power plants (NPPs), HMIs are important for reducing operational costs, the number of necessary operators, and the probability of accident occurrence. Efforts have been made to improve main control room (MCR) interface design and to develop automated or decision support systems to ensure convenient operation and maintenance. In this paper, an integrated decision support system to aid operator cognitive processes is proposed for advanced MCRs of future NPPs. This work suggests the design concept of a decision support system which accounts for an operator's cognitive processes. The proposed system supports not only a particular task, but also the entire operation process based on a human cognitive process model. In this paper, the operator's operation processes are analyzed according to a human cognitive process model and appropriate support systems that support each cognitive process activity are suggested.

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**KEYWORDS :** Decision Support System, Operator Support System, Advanced Main Control Room, Operator Cognitive Process

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## 1. INTRODUCTION

### 1.1 Background

The main control room (MCR) operators in a nuclear power plant (NPP) have a supervisory role for information gathering, planning, and decision making. Such operation tasks in MCRs are very complex and mentally taxing activities. In safety-critical systems, especially in NPPs, human error is recognized as a serious cause of accidents. Since the 1980s, human error in NPPs has been a considerable concern. In an analysis of the abstracts from 180 significant events reported to have occurred in the United States, it was found that 48% of the incidents were attributed to human-factor failures [1]. In order to prevent human error, many endeavors have been made to improve MCR interface designs and to develop support systems that allow more convenient MCR operation and maintenance. The design of instrumentation and control (I&C) systems for various plant systems is rapidly moving toward full digitalization, with an increased proportion of automation [2]. In addition, as the processing and information presentation capabilities of modern computers increase, the trend is toward the application of modern computer techniques to the design of advanced MCRs for

NPPs [3]. By adapting modern computer techniques, advanced MCRs (modernized MCRs) have been much simplified, and now use large display panels (LDPs) and LCD displays instead of analogue indicators, hand switches, and alarm tiles. Furthermore, these computerized systems are aimed to improve operator performance by filtering or integrating the raw process data, interpreting the plant state, prioritizing goals, and providing advice. They also help the operator focus attention on the most relevant data and highest priority problems, and they dynamically adapt the proposed response plans to changing situations. Computerized support of operational performance is needed to assist the operator, particularly in coping with plant anomalies, so that any failures of complex dynamic processes can be managed as quickly as possible with minimal adverse consequences [3].

In NPPs, one of the most serious issues when adapting automated or support systems is whether the operator or the system should be the final decision maker. Should an automated system or support system fail to respond correctly, an operator who detects that failure should be able to override the system's decision. Considering the operator's oversight role in such cases, authority for some tasks should be retained by the operator. This problem is called

“out-of-the-loop unfamiliarity” [4], and when it occurs, an automated system or support system that cannot manage a particular problem could degrade a human operator’s performance [5]. According to research from the OECD Halden Reactor Project, as the automation level of an advanced MCR is increased, the concept of human-centered automation should be considered for more efficient automation [6]. In addition, a moderate level of automation that provides decision support while retaining human control of the final decision is optimal for maintaining operator situation awareness [7]. A fully automated system could be more efficient for some tasks, while a support system could be more efficient for others. Simple tasks could be managed more efficiently by automation. In contrast, a support system could be more efficient at managing complex tasks that operators would need to comprehend and analyze, because high levels of automation may reduce operator awareness of system dynamics. MCR operators in particular must be aware of and comprehend a given situation correctly in real time, so they should be the final decision makers. Therefore, support systems may be more appropriate than highly automated systems for operators in MCRs.

## 1.2 Objectives

In advanced MCRs, various kinds of automated systems and support systems can be applied for safer and more stable operation. The roles of a human machine interface (HMI) and decision support systems are briefly shown in Fig. 1: the left diagram shows the independent decision support systems used in conventional MCRs, and the right diagram shows an HMI, including the decision support systems, that performs the role of an agent for advanced MCRs. Because the advanced MCR is a digitalized and computer-based system, the decision support systems can be included as part of an HMI. Such support systems can provide information about the current situation of the NPP, as well as useful information that helps ensure convenient maintenance and operation of the NPP. In an advanced computer-based MCR, it can be more efficient to combine the HMI and support systems into one system.

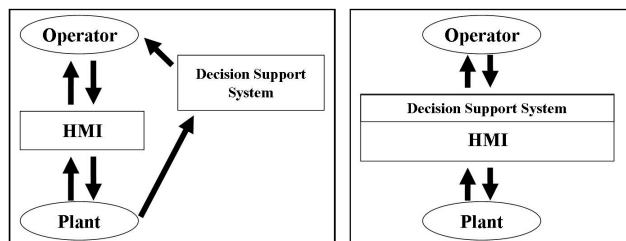


Fig. 1. Independent Support System and Combined Support System

There are various kinds of support systems at work for NPP operators, aiding with surveillance, diagnostics, and the prevention of human error. Some of these, such as early fault detection systems [8], are capable of doing tasks which are difficult for operators; others, such as operation validation systems, are intended to prevent human errors [9]. As MCRs evolve, more support systems will be adapted. However, according to the results of several published support system evaluations, a support system does not guarantee an increase in operator performance [10]. Some support systems could degrade an operator’s situational awareness capability and may increase an operator’s mental workload.

Decision support systems should be designed considering two points. The first is to provide correct information and the second is to provide convenient and easy-to-use information. Most researches, however, focus on only the first point. Even if the information provided by support systems is perfectly correct, it could be useless in some situations. For example, one experiment showed that a fault diagnosis system could have an adverse effect on operator performance [10]. In the experiment, one type of fault diagnosis system provided only possible faults without their expected symptoms or causes. Under those conditions, operators had to infer expected symptoms and compare them to plant parameters in order to confirm the results, resulting in decreased performance. On the other hand, a fault diagnosis system providing expected symptoms showed good performance. In short, performance is improved by provision of not only accurate but easy-to-use support system information.

The system proposed in this paper is focused on provision of information that is easy for operators to use. To generate more convenient information to support operators and to avoid human errors, human aspects are considered in the design of the proposed system. An integrated decision support system to aid the cognitive activities of operators (INDESCO) is proposed as a design concept for efficient decision support systems. The objective of INDESCO is to offer an integrated decision support system for operators of advanced HMIs by suggesting decision support systems based on the human cognitive process.

An operator’s operation processes are analyzed with respect to the human cognitive process, and systems that support each cognitive process activity are suggested. INDESCO performs processes similar to the cognitive processes of operators in order to detect and prevent human errors which can occur during the cognitive process.

## 2. COGNITIVE PROCESS MODEL FOR OPERATORS IN NPPS

### 2.1 Human Cognitive Process Model

In this paper, the primary cognitive activities for NPP operations underlying a technique for human error analysis (ATHEANA) [11],[12] are used. Many attempts have been made to better understand the causes of human errors in NPPs. The key conclusion from these studies is that few human errors represent random events; instead, most errors can be explained based on the methods humans use to process information in complex and demanding situations. Thus, it is important to understand the basic cognitive processes associated with plant monitoring, decision-making and control, as well as how these processes can lead to human error [12]. Through an analysis of the cognitive processes during operations, we can suggest better decision support systems using the human cognitive process model.

The major cognitive activities for NPP operations underlying ATHEANA are: (1) monitoring and detection, (2) situation assessment, (3) response planning, and (4) response implementation. These activities can be further described as follows [12]:

- (1) Monitoring and detection: This refers to the activities involved in extracting information from the environment.
- (2) Situation assessment: When confronted with indications of an abnormal occurrence, humans actively try to construct a coherent, logical explanation to account for their observations. This process is referred to as situation assessment.
- (3) Response planning: This refers to the process of making a decision about which actions to take. For many cases in NPPs, when written procedures are available and deemed appropriate to the current situation, the need to generate a response plan in real time may be essentially eliminated. However, operators still need to (1) identify appropriate goals based on their own situation assessment, (2) select the appropriate procedure, (3) evaluate whether the procedure-defined actions are sufficient to achieve those goals, and (4) adapt the procedure to the current situation as necessary.
- (4) Response implementation: This refers to taking the specific control actions required to perform a task. It may involve taking discrete actions or continuous control actions.

## 2.2 Cognitive Process Model for NPP Operators

As described in the previous section, operators in an MCR monitor and control an NPP according to the human cognitive process. Fig. 2 shows the relation between a human, an HMI, I&C systems, and a plant [13]. All HMIs in MCRs have display and implementation systems for monitoring and controlling the plant. Human operators obtain plant information through the display system in the HMI layer and assess the current situation using the obtained information. In the next step, the human operators select the operations corresponding to the assessed situation. Finally, they implement the operations using the implementation systems. The operators'

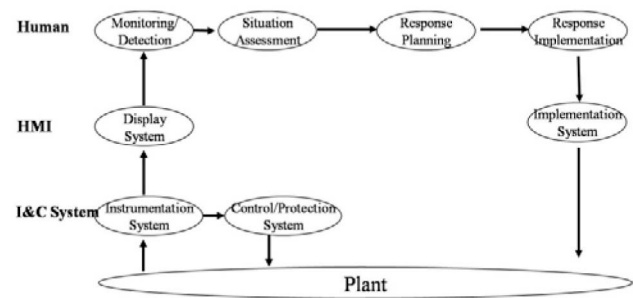


Fig. 2. NPP Operator's Operation Process [13]

operation processes can be represented in this way using the human cognitive process.

Decision support systems to improve operator performance can be categorized into two approaches [14]. One approach is the improvement of MCR displays, which are considered “indirect support”. The indirect support system can be represented using the human cognitive process, as shown in Fig. 3. Improved display systems using integrated graphic displays, configurable displays, and ecological interface designs and information systems, such as an alarm system, are examples of indirect support systems. These systems improve operator perceptual and awareness abilities. If indirect support systems are added, operators can perceive the plant status more easily and quickly using the information provided by the improved display system as well as obtain digested data from the information system. Therefore, indirect support systems can improve the performance of the monitoring and detection activities in the operator's cognitive process.

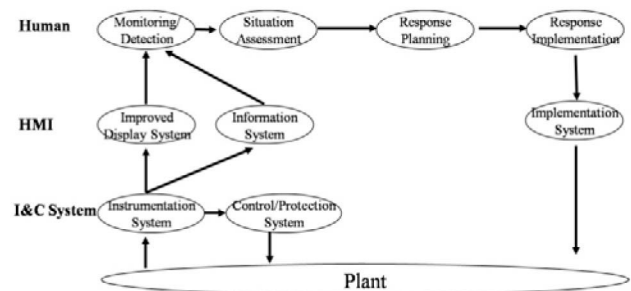


Fig. 3. NPP Operation Process with Indirect Support Systems

The other approach is the development of decision support systems, which are called “direct support”. These

include intelligent advisors, computer-based procedures, fault diagnostic systems, and computerized decision support systems, which are based on expert systems or knowledge-based systems.

The direct support system can be represented using the human cognitive process, as shown in Fig. 4 [15]. For example, several direct support systems, such as a fault diagnosis system and a computerized procedure system, can be added as part of the advanced HMI. The fault diagnosis system assists and supports operator situation assessment tasks, so it can improve the situation assessment activities in the operator's cognitive process. In the same way, response planning activities can be supported by the computerized procedure system.

Even if the design and components of an HMI are changed, the relationship among an operator, an HMI, I&C systems, and a plant can be represented using this model. The model shows which cognitive activity an added support system relates to and supports. As shown in Fig. 4, the indirect support system mainly supports monitoring and detection activities, which is the first of the major cognitive activities, and several kinds of direct support systems support the other cognitive activities. Support systems necessary to support specific cognitive activities can be suggested and selected based on this model.

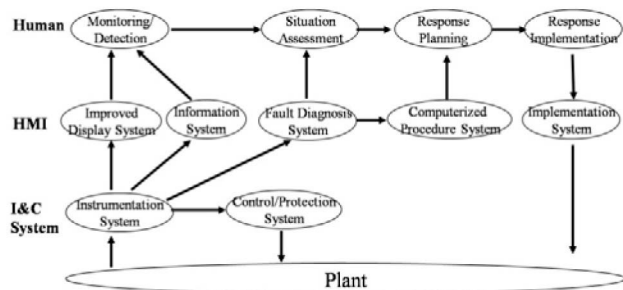


Fig. 4. NPP Operation Process with Indirect and Direct Support Systems [15]

### 3. INTEGRATED DECISION SUPPORT SYSTEM TO AID COGNITIVE ACTIVITIES OF OPERATORS UNDERLYING ATHEANA

#### 3.1 INDESCO Architecture

The central concept of this research is to suggest support systems to aid every activity of the human cognitive process model and to integrate these support systems into one system to maximize efficiency. That is, INDESCO is not a system that helps a task or supports one or two cognitive activities;

rather, it supports every major cognitive activity by integrating the support systems that support each cognitive activity. The simple architecture of INDESCO is shown in Fig. 5. The figure shows the integrated HMI including the decision support systems, and the included decision support systems support four major cognitive activities. The system provides not only plant information, but also other useful information generated from the included support systems.

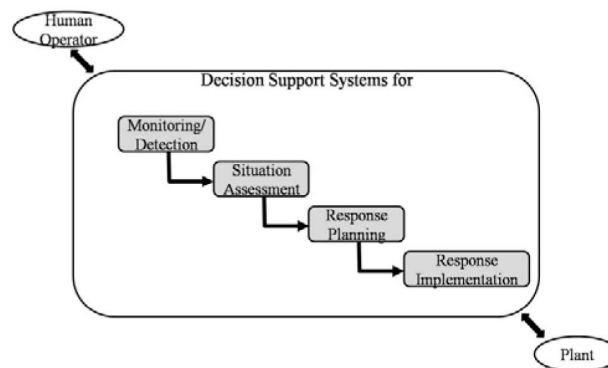


Fig. 5. The Architecture of INDESCO

#### 3.2 Decision Support Systems for Cognitive Processes

Various indirect or direct support systems can be added to the HMIs to support cognitive process activities. Among these many systems, the most appropriate support systems can be selected based on the cognitive process, thus enhancing operational efficiency. For example, several kinds of support systems are selected and their related cognitive activities are shown in Fig. 6. A display system, which is an indirect system, supports the monitoring and detection activities. A fault diagnosis system, a computerized procedure system, and an operation validation system are types of direct systems supporting three other cognitive activities. In addition, there are an alarm prioritization system, an alarm analysis system, a corresponding procedure suggestion system, and an adequate operation suggestion system. Since the latter four systems can be implemented as sub-systems of the former four systems, the former four systems can be classified as main support systems.

##### 3.2.1 Support Systems for the Monitoring/Detection Activity

Monitoring/detection activities access a high volume of NPP information in order to detect abnormal situations.

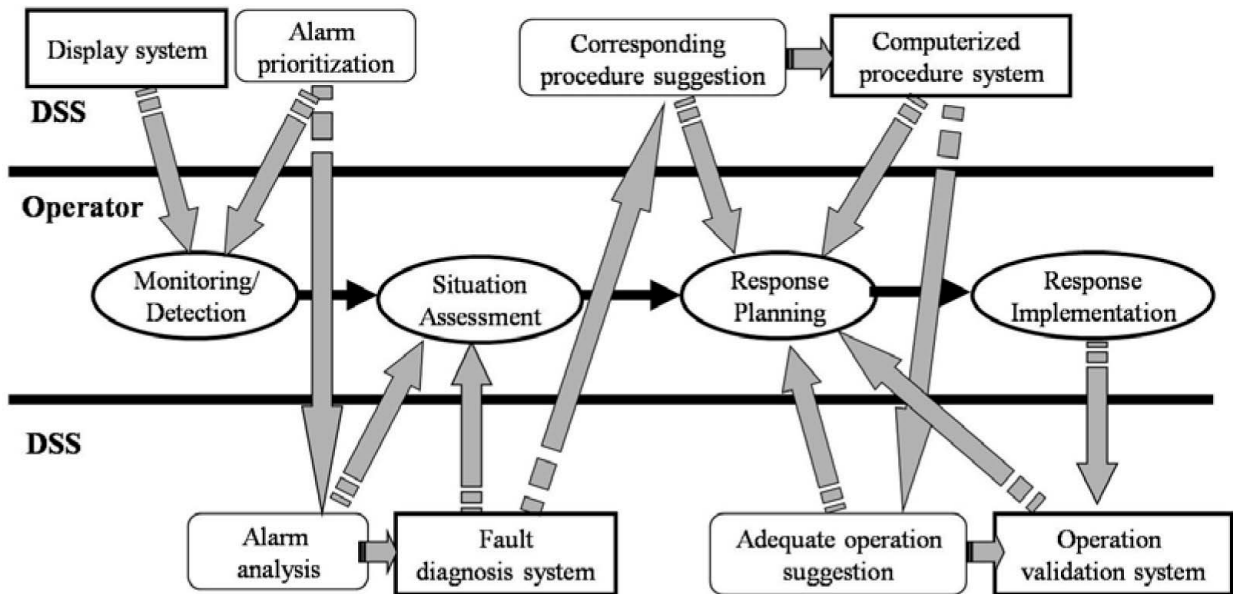


Fig. 6. Decision Support Systems Based on the Human Cognitive Process Model

This activity is performed by instruments and alarms in MCRs. Operators always monitor the instruments and alarms in order to detect variation of instrument values or changes of color or the sounding of alarms. Upon detecting an abnormal situation, operators proceed to situation assessment. In an NPP, there are many instruments that indicate the status of the plant. While an analysis of all instruments is the best way to ensure a correct detection and diagnosis, the sheer number of instruments makes it impossible for operators to examine each individually. If there is no alarm that serves as major information source for detecting process deviations, operators have to consider too many instruments and an operation will take too long. A slow reaction on the part of the operator could result in accidents with serious consequences. Alarms help operators to make quick detections by reducing the number of instruments that must be considered. Though alarms are helpful in this way, there are too many of them; a typical MCR in an NPP has more than a thousand alarms. In emergency situations such as a loss of coolant accident (LOCA) or a steam generator tube rupture (SGTR), hundreds of lights turn on or off within the first minute and having many alarms that repeatedly turn on and off may cause operator confusion.

There are two approaches to support monitoring/detection activities. The first approach is to improve the interface of an MCR, and the second approach is the development of an advanced alarm system.

Advanced MCRs have been designed as fully digitalized

and computer-based systems with LDP and LCD displays. These display devices are used for more efficient display, but they have disadvantages. Using the LDP and computerized display system, more flexible information display is possible, so an operator can select and monitor only necessary information. However, even LDP display space is limited and operators must navigate screens in order to find information that they want to see. Excess NPP information increases the number of the necessary navigations. If too many navigations are required to manipulate a device or to read an indicator, the system becomes inefficient. Therefore, a key support for monitoring and detection activities is the efficient display of information.

An advanced alarm system also supports monitoring and detection activities. Conventional hardwired alarm systems, characterized by one sensor-one indication, may confuse operators with avalanching alarms during plant transients. Conventional alarm systems possess several common problems, including the issues of too many nuisance alarms and that of annunciating too many conditions [16]. Advanced alarm systems feature general alarm processing functions such as categorization, filtering, suppression, and prioritization. Such systems also use different colors and sounds to represent alarm characteristics. These functions allow operators to focus on the most important alarms.

### 3.2.2 Support Systems for the Situation Assessment Activity

During situation assessment activities, operators analyze

the situation at hand, make a situation model, and generate appropriate explanations for the situation. Systems which analyze the information representing that situation and generate estimated faults and expected symptoms could be useful for supporting situation assessment activities; fault diagnosis systems and alarm analysis systems are two examples. An alarm analysis system could be regarded as either a kind of fault diagnosis system or as a part of one, because they have equivalent objectives.

Operators make operation plans based on operating procedures which are categorized into two types: event-based procedures and symptom-based procedures. Different support systems should be assigned to situation assessment activities on the basis of these procedure types. In case of event-based procedures, operators start to execute procedural operations after identifying a situation, so fault diagnosis systems offering expected faults would be useful for quick and easy situation assessment. However, operators using a symptom-based procedure do not begin by diagnosing a situation. Instead, they determine the appropriate procedure by comparing the procedure entry conditions with the current parameters, and then act according to the selected procedure. For operators using such a method, a system to suggest the appropriate procedure for a given situation would be more useful than a fault diagnosis system.

A critical issue for situation assessment activity support is the reliability of the support system, because, without a high degree of reliability, operators will distrust the support system. If operators must always consider the possibility of incorrect results, the support system will be rendered ineffective. Therefore, there have been researches using knowledge bases, neural networks, genetic algorithms, and other means to develop more reliable fault diagnosis systems [17, 18, 19].

### **3.2.3 Support Systems for the Response Planning Activity**

In general, response planning activities involve the operator's situation model of the plant state to identify goals, generate alternative response plans, evaluate response plans, and select the most appropriate response plan relevant to the situation model. However, one or more of these steps may be skipped or modified in a particular situation [12]. As mentioned previously, when written operating procedures are available and judged appropriate to the situation, operators can handle the situation according to those procedures. In such cases, errors arising from omission of a step or selection of a wrong step are of particular concern. Written operating procedures are designed to avoid such errors, and procedures intended to avert emergent situations are designed with more strict and formal linguistic formats. For example, NPP emergency operating procedures (EOPs) intended to handle most serious accidents mainly consists of IF-THEN-ELSE statements.

Though operators may be provided with well-written procedures, there is still the potential for human error.

Since the content of the paper-based operating procedure is written in a fixed format in natural language, the information can sometimes be overwhelming, making it difficult to continuously manage the requisite steps. Due to the deficiencies of paper-based operating procedures, computerized procedure systems have been being developed and implemented since the 1980s [20],[21]. In a computerized procedure system, information about procedures and steps, relations between the procedures and steps, and the parameters needed to operate the plant are displayed. Such systems also provide functions to prevent operator errors such as omitting a step or selecting a wrong step (e.g., a function of checkoff provisions). Moreover, system functions such as provision of a list of candidate operations may help an operator determine which operation should be performed next.

### **3.2.4 Support Systems for the Response Implementation Activity**

Response implementation activities are those activities which execute the selected operation after planning a response (e.g., flipping a switch or closing a valve). In this step, simple errors rather than decision-making errors are the concern. Operators can still commit an unsuitable operation despite correctly assessing a situation and making an appropriate plan. Accidents caused by such commission errors have in fact been reported.

Response implementation supports such as an operation validation system have been proposed to prevent such commission errors. The objective of an operation validation system is to detect inadequate operations and to warn operators about them in order to allow a chance to double-check operations which offer the possibility of commission errors. One of the most important considerations in the design of an operation validation system is to optimize the system-initiated interruptions. Provided that operators follow operation rules and procedures, such a system should allow operators to do as they prefer [9]. Although a validation system should interrupt all operations which may go wrong, too many interruptions result in excessive operation validation time. Moreover, operators become accustomed to repeated interruptions, resulting in their becoming insensible to them. If operators are always or very frequently required to double-check their operations, then the double check loses its original significance. On the other hand, if a validation system has too liberal a validation filter, then it may also fail to accomplish its objective. Therefore, it is necessary to have an optimized and efficient filtering algorithm to validate operations.

## **3.3 INDESCO Prototype**

As one application of the proposed system, a prototype was implemented including four support systems: a display system, a fault diagnosis system, a computerized procedure system, and an operation validation system. As explained in the previous section, each main system supports each

major cognitive activity for NPP operations based on ATHEANA. In the prototype, several decision support systems were selected and integrated, which were developed by the authors and showed good and highly reliable results. The systems cooperate, sharing a database and other information. The prototype is insufficient for adaptation to an actual NPP because specific situations and parameters were considered and a compact simulator was used. However, the architecture of INDESCO could be roughly constructed, and a simple evaluation of the system could be performed using the prototype. As shown in Fig. 7, the prototype has four main systems, two sub-systems, and four databases.

The prototype was implemented by connecting it to the compact nuclear simulator (CNS), which was originally developed by the Korea Atomic Energy Research Institute (KAERI) and Studsvik Inc. in 1986 and has been recently updated by KAERI [22]. The reference plants of the CNS are Kori 3&4 NPPs which are Westinghouse 900MWe 3-loop pressurized water reactors (PRWs) and their operating procedures are symptom-based.

### 3.3.1 Display System

The display system of the prototype is a simple system that displays information about plant parameters and decision support systems. As explained in the previous section, various design methodologies can be used for more efficient interfaces but, in the prototype, a simple information display system was implemented. The interface of the prototype is shown in Fig. 8.

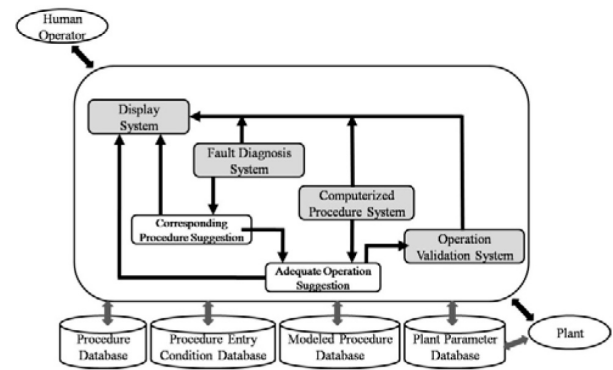


Fig. 7. The Architecture of the INDESCO Prototype

In Fig. 8, the interface of the CNS is on the left side and that of the decision support system is on the right. The CNS interface displays plant parameters and allows manipulation of devices such as pumps and valves. The main window of the prototype is shown in Fig. 9, and this window is primarily used to display information about the computerized procedure system. Users can select the operating procedure type using touch buttons on the upper right side, and choose a procedure or step in the 'tree view' on the left side. In the upper left box, four

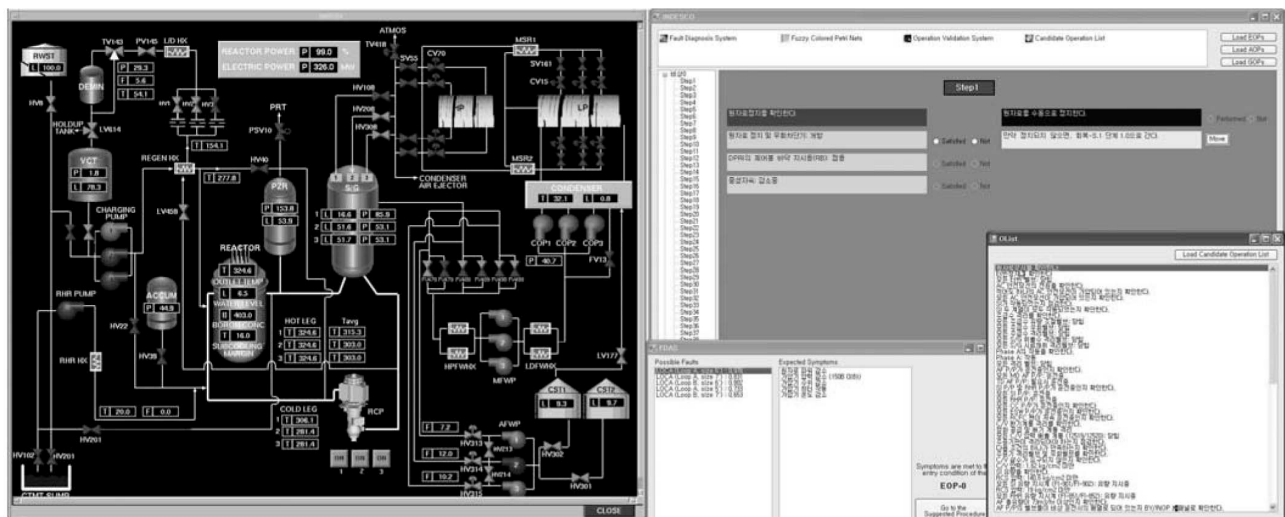


Fig. 8. The Interface of the Prototype

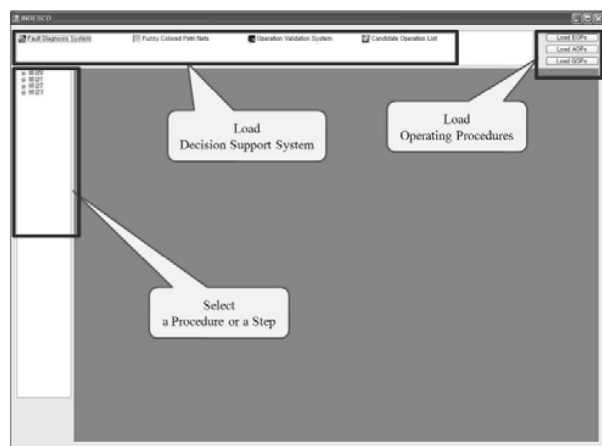


Fig. 9. The Interface of the Main Window

types of windows can be selected: windows for the fault diagnosis system, fuzzy colored Petri nets (FCPNs), operation validation system, and candidate operation list. The fault diagnosis system window shows the diagnosis results for the current situation, and the operation validation system window shows the validation results against the executed operation. In the prototype, the operating procedures were modeled using the FCPN, and the modeled procedures are shown in the FCPN window. Lastly, the candidate operation list window shows a list of operations that should be performed.

### 3.3.2 Fault Diagnosis System

The fault diagnosis system of the prototype lists the possible faults and their expected symptoms, and was implemented using dynamic neural networks. The diagnosis algorithm suggested by Lee and Seong [18] was used, and a brief diagnosis process is shown in Fig. 10.

The fault diagnosis system has two main objectives. The first objective is to analyze the plant status and show a possible fault list in realtime. Reasonable results are generated using realtime information through analysis of dynamic trends. In order to achieve this objective, dynamic neural networks are used. The second objective is to generate more reliable diagnosis results. A critical issue for diagnosis systems is their level of reliability because, without a high level of reliability, operators will not trust the diagnosis system. If operators must always consider the possibility of misdiagnoses, the diagnosis system becomes ineffective. This system increases the reliability of the diagnosis results by using two independent dynamic neural networks: the modified dynamic neural network (MDNN) and the dynamic neuro-fuzzy network (DNFN).

As shown in Fig. 10, alarms and trip parameters are

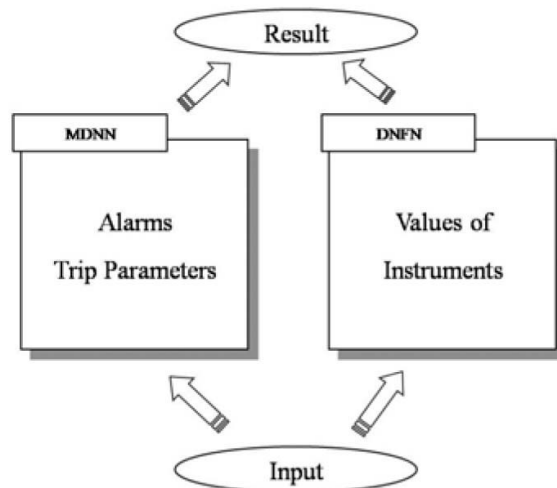


Fig. 10. Diagnosis Process of the Fault Diagnosis System [18]

used as the inputs of the MDNN and values of instruments are used as the inputs of the DNFN. Two networks perform calculations and generate expected faults independently, and the final result is obtained based on the results of both. Although a diagnosis process using two networks duplicates efforts, more certain results are attainable this way as the two networks can complement each other. When the results of the MDNN and DNFN differ, operators can see the discrepancy and double-check the results. However, if the results of both neural networks are very close, then the operators can be confident that the results are accurate and reliable.

Many instruments and faults must be considered, so it is not easy to make a neural network which can cover all the instruments and possible faults. The fault diagnosis process is therefore divided into two levels; the first-level diagnosis is for identifying the fault and the second-level diagnosis is for generating detailed information about the fault. At the first level, key parameters are used to identify the fault type, and then more parameters representing the identified fault are used for the second-level diagnosis. A more detailed explanation of this diagnosis method is described in Lee and Seong's paper [18] and also in Mo, Lee, and Seong's paper [23].

The fault diagnosis system window is shown in Fig. 11. The two lists on the left show possible faults and their expected symptoms. Every possible fault has its probabilistic value, and this is shown after the fault description in the leftmost list. When a user selects a fault from the list, the expected symptoms of the selected fault are displayed in the right list. The user can compare the symptoms to the actual current plant parameters so that misdiagnosis or misjudgment can be detected.



The corresponding procedure suggestion sub-system, was implemented and the output of this sub-system is displayed in the lower right side of the fault diagnosis system window, as shown in Fig. 11. When operators handle a fault using symptom-based procedures, they should select a corresponding procedure for the fault by comparing the entry conditions of procedures to instrument values. This task is time-consuming and tends to raise the potential for operator error. The corresponding procedure suggestion sub-system performs this task instead of human operators. It searches for the procedure that should be performed to handle the current situation by comparing the current plant parameters to the diagnosis results and procedure entry conditions. If a user pushes the button labeled 'Go to the Suggested Procedure', the suggested procedure is displayed automatically.

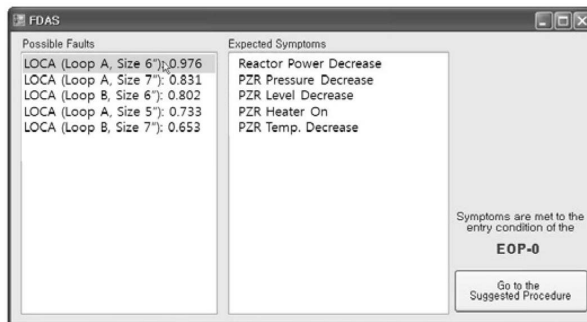


Fig. 11. The Fault Diagnosis System

### 3.3.3 Computerized Procedure System

In the computerized procedure system, the relationships between the steps and the procedures were represented by the FCPN method proposed by Lee and Seong [24].

The operating procedures in NPPs consist of "IF-THEN-ELSE" statements, so they could be easily converted into the FCPNs. Another advantage of the FCPN is that it is well-suited to represent not only a sequential process but also parallel processes, so that simultaneously executed steps can be modeled using the FCPN. In the prototype, the target procedures were the EOPs, which were modeled using an FCPN. An example is shown in Fig. 12. In the FCPN, the steps are categorized into five types and represented by different symbols as follows:

- Comment type : Instruction to provide a comment or caution
- ⊙ Confirm type : Instruction to check a device or situation

(e.g. check that a parameter value is over setpoint)

- Action type : Instruction to perform an action (e.g. open/close a valve)
- ⇒ Goto type : Instruction to move to a step in the same procedure
- ⊗ Jump type : Instruction to move to a step in other procedure

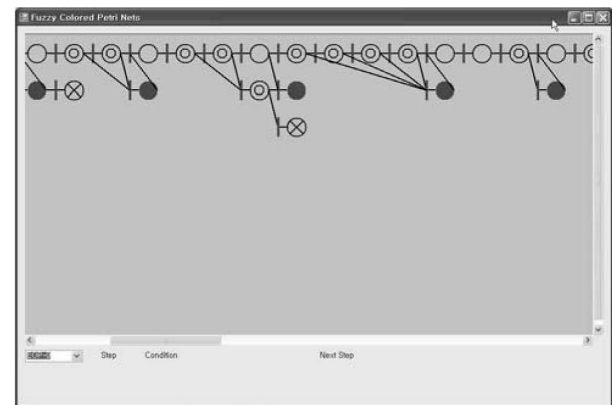
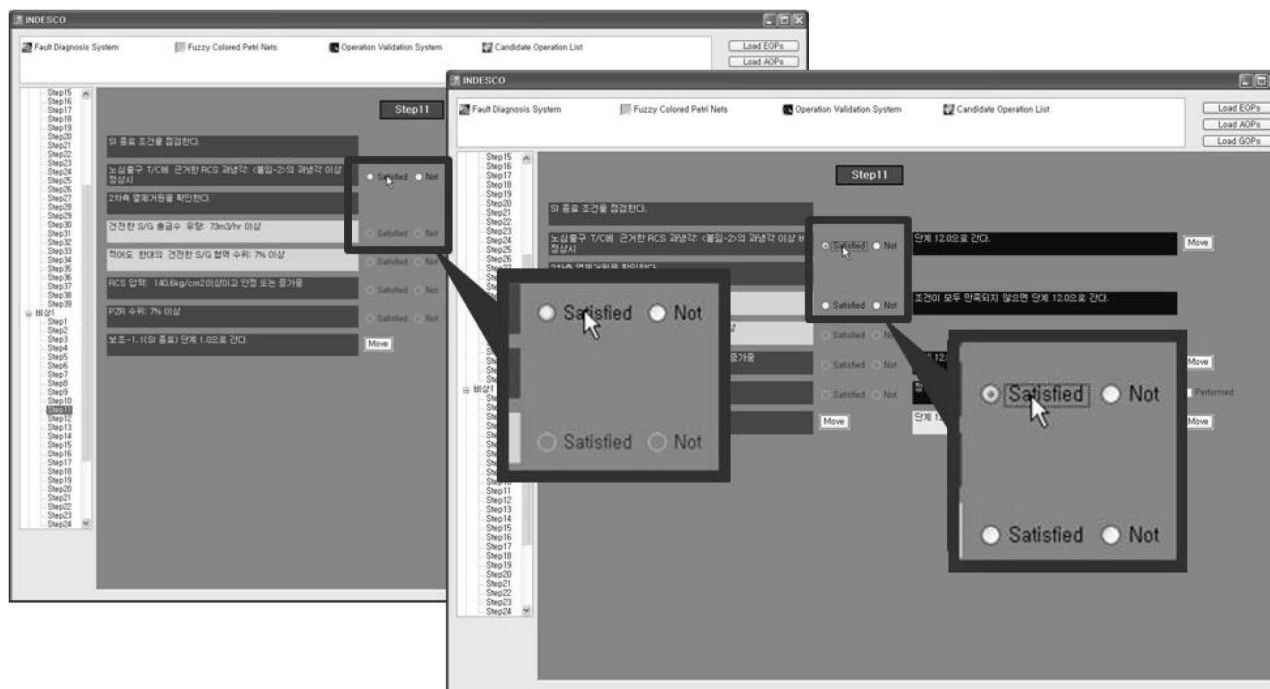


Fig. 12. The Fuzzy Colored Petri Nets (FCPN)

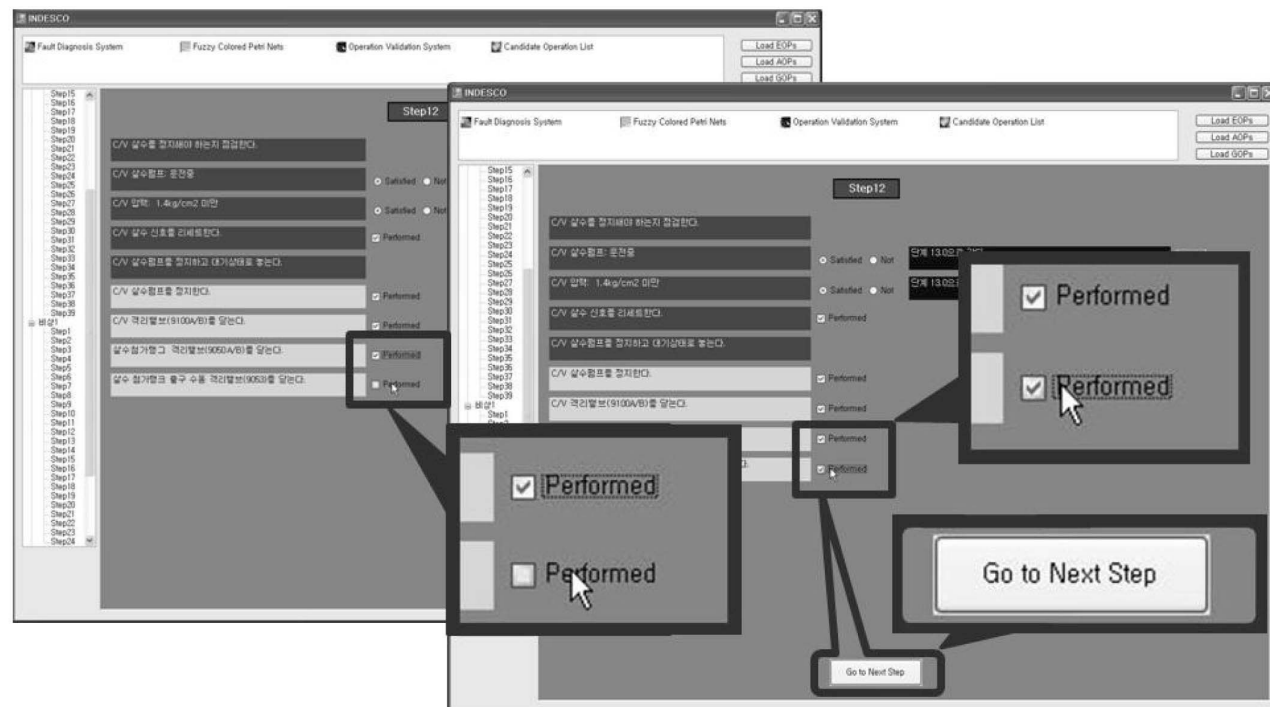
The interface in Fig. 12 displays the FCPN of the currently executed procedure, though operators mainly use the computerized procedure system interface shown in Fig. 13 rather than this one. However, if an operator should want to know additional display information not represented in the computerized procedure system interface, such as what steps are connected to the current step, or additional future steps, and so on, then they can get that information from the FCPN interface.

Based on the FCPN, functions for the computerized procedure system were implemented as follows:

- a. When a step is selected in the tree view on the left side of the window shown in Fig. 9, detailed step instructions are displayed in the right panel.
- b. According to the instruction type, the appropriate 'check box' is inserted. For confirm instructions, a check box that marks if the condition is satisfied or not is inserted. A check box that marks if the instruction is performed or not is inserted for action instructions and a 'move' button that can move to the target step is inserted for goto and jump instructions.
- c. When a confirm instruction is performed, the appropriate step is automatically activated in both cases regardless of whether the condition is satisfied or not, as shown Fig. 13(a).



(a)



(b)

Fig. 13. The Computerized Procedure System

- d. If all instructions in a step are performed, then a button to move to next step appears as shown in Fig. 13(b).

As a function of the computerized procedure system, an adequate operation suggestion system was implemented. The adequate operation suggestion system suggests operations that should be performed next in a given situation as shown in Fig. 14. This system issues the operations based on the corresponding procedure suggestion system and computerized procedure system. Operations in the selected procedure are listed and operations that have already been performed are removed from the list. If the target operating procedure changes, then the operation list is updated. Operators may then recognize which of the remaining instructions should be executed, and human error through omitting a step or an instruction may thereby be reduced.

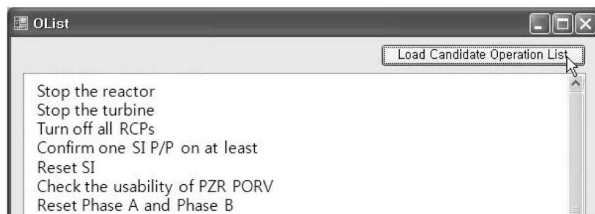


Fig. 14. The Adequate Operation Suggestion System

### 3.3.4 Operation Validation System

The operation validation system validates an operator's action and shows the qualitative and quantitative effects of that action. The system was implemented using the algorithm proposed by Mo, Lee, and Seong [25]. The basic logic of the operation validation system is shown in Fig. 15.

All operator actions are classified into three levels according to their different potential threat as follows [25]:

- Level 1 – Operations not permitted by the plant's safety system: The operations are considered to have strong potential threats to the safety of NPPs and must be directly denied.
- Level 2 – Operations not included in the EOP: The operations are considered to be inappropriate for the current situations, therefore requiring corresponding confirmations from the operators. Operators can choose to confirm or cancel the operations according to the possible results of the operation simulated by the operation validation system.

- Level 3 – Necessary operations included in the EOP: The operations are considered to be currently needed and directly permitted. Nevertheless, operators can still choose to validate the operation to check the possible influences of the operation.

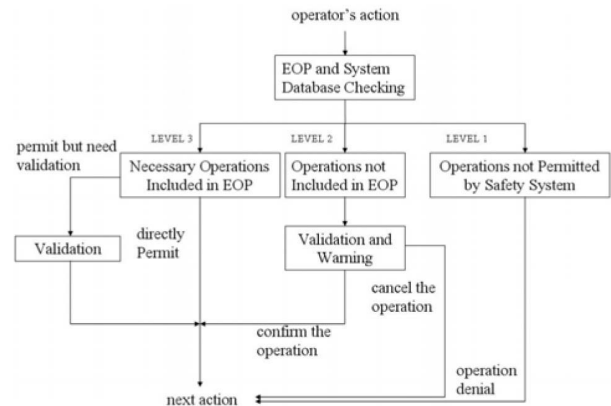


Fig. 15. The Logic of the Operation Validation System [25]

The operation validation system provides both qualitative and quantitative effects analysis of operator actions. The qualitative evaluation is shown to operators at the same time as the quantitative evaluation. The operators can examine the possible results of their expected operations and confirm or cancel accordingly. The quantitative evaluation provides more detailed information to operators than the qualitative evaluation. The trend of some key plant parameters affected by the operator's action is generated. The evaluations are performed based on the trained neural network of the fault diagnosis system as shown in Fig. 16. Based on the results of the fault diagnosis system, appropriate trained neural networks are selected, which were previously trained using training cases similar to the emergent situation. The trends of key parameters are then generated in a range from 1 to 200 seconds for quantitative evaluation and statuses of the parameters are analyzed in the relatively long range of from 1 to 5 minutes for qualitative evaluation.

The results of the operation validation system from the prototype system are displayed as shown in Fig. 17. The qualitative effect estimation results are shown by a list of symptoms on the left side of the window, and the quantitative results are shown by graphs on the right side. The validation results for the executed operation are shown below the qualitative and quantitative effect estimations.

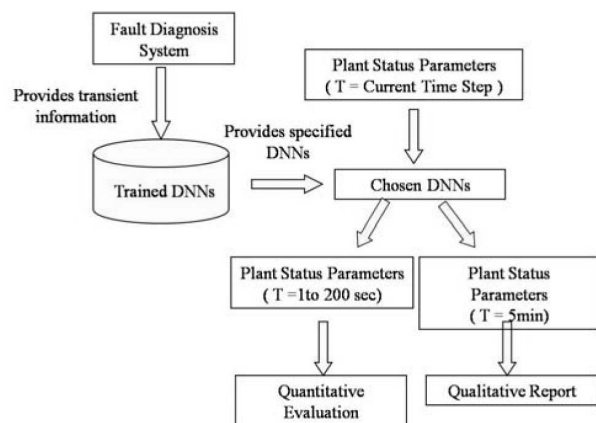


Fig. 16. The Process of the Qualitative and Quantitative Effect Estimation [25]

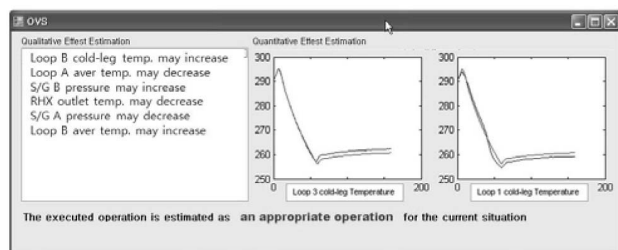


Fig. 17. The Operation Validation System

This prototype is just one application of INDESCO. The primary concept of INDESCO suggests support systems to support every activity of the cognitive process and to integrate these systems into one system. Therefore, if more efficient and useful support systems are developed, INDESCO can be redesigned to adopt such systems.

#### 4. DISCUSSION

The main purpose of decision support systems is to provide useful and convenient operational information in order to reduce and optimize the workload and the stress of operators. Such information is not basic information but supplemental information. That is, although operators can operate an NPP without the information provided by decision support systems, using that additional

information may reduce their potential for human error. Various decision support systems for NPPs have already been developed or are developing. Some of them may generate helpful information for operators. Using these systems, operators could identify and comprehend the plant conditions more easily and may be able to recognize potential errors before they make a mistake. Operator performance can thus be enhanced using such well-designed decision support systems. However, some of these systems may generate unnecessary information. Operators seldom use or want to use overly-informative systems because they do not seem to be useful. Information overload can result from the unnecessary information, so such systems could have adverse effects on operator performance. Moreover, even if a decision support system was proved to be generally efficient, the efficiency of the system could vary according to the specific situational or environmental factors.

Therefore, decision support systems must be evaluated to prove their efficiency. The evaluation of decision support systems is as important as designing good decision support systems. Evaluation can be performed using various theoretical and experimental methods. An evaluation method to estimate the effect of support systems using a Bayesian belief network (BBN) was proposed by Lee, Kim, and Seong [26]. The method constructs an evaluation model including operators, decision support systems, I&C systems, and an NPP. The effect of INDESCO could be evaluated by that method. The results of such a theoretical evaluation tend to be considerably affected by the assumptions and the data used. It is very hard to obtain precise data, particularly data about human aspects of a system. Therefore, in order to compensate for weakness in the theoretical evaluation, experimental evaluations are also necessary. Many researches have been performed to develop reliable operator performance estimation methods [27]. INDESCO must be evaluated for effect and efficiency, and these evaluations should be performed using both theoretical and experimental methods in further study.

#### 5. SUMMARY AND CONCLUSION

Operational tasks in MCRs are mentally taxing activities, and human error has been identified as the most serious cause of accidents in NPPs. For advanced MCRs, which have fully digitalized and computerized systems, improving HMIs and developing a decision support system can help prevent human errors. In this paper, an integrated decision support system to aid the operator cognitive activities underlying ATHEANA has been suggested as a design basis for the support systems of advanced MCRs. The primary concept of our research is to suggest appropriate support systems that aid every activity of the human cognitive process and to integrate

these support systems into one system to obtain better performance. INDESCO supports not only a particular task, but also the entire operation process based on a human cognitive process model. Operator operation processes are analyzed based on the human cognitive process model. Operator operation processes are analyzed based on the human cognitive process model, and optimum support systems to support each activity of the human cognitive process are suggested. All of the suggested systems are integrated into one system and work together to facilitate the operator's entire operation process: monitoring plant parameters, diagnosing the current situation, selecting corresponding actions for the identified situation, and performing those actions. A prototype of INDESCO has been suggested in this paper. It has four main systems: a display system, a fault diagnosis system, a computerized procedure system, and an operation validation system. Each main system supports each activity in the cognitive process. The prototype is only one application of INDESCO. If a more efficient and useful support system is developed, INDESCO can be redesigned to adopt the new system.

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