Development and Evaluation of Automatic Tools of Fault Tree Creation Using Artificial Intelligence Technology with the Ability to Integrate Fault Tree Created from Multiple Design Documents to assist Probabilistic Risk Assessment Engineers

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ABSTRACT

In recent years, utilization field of probabilistic risk assessment (PRA) has been widened. On the other hand, PRA engineers have been needing to endure the laborious task to read and understand a huge amount of design documents and utilize the information obtained. One of key methods for solving these issues is to use AI technology. Therefore, the authors have been developing an automatic fault tree (FT) creation tool using AI technology for the aim of enabling any engineer to easily perform PRA with the same quality as a conventional approach. This paper describes the updates of the automatic FT creation method as the progress of the final step under our three-year program. There are two updates. One is that AI technologies such as image recognition can be used to extract information necessary to create FT not only from design documents for piping and power supply systems but also from design documents for signal systems. And the function has been expanded so that a signal FT can be generated from a multi-page design document. The other one is the newly added function to integrate FT, considering the functional dependencies between the frontline system and the support system. The effectiveness of the AI tool was evaluated by comparison between the time required to create an FT using the tool and the time required to create an FT without using the tool, confirming that the enhanced automatic FT creation tool significantly reduced work time for PRA engineers.

Keywords: Artificial Intelligence, AI, Probabilistic Risk Assessment, PRA, Fault Tree

1. INTRODUCTION

In recent years, power plants have been implementing risk informed decision making (RIDM) for improved safety, and PRA is used to quantify those risks [1]. To implement PRA, engineers have been needing to endure the laborious tasks to read and understand a huge amount of design documents. One of key methods to reduce the laborious tasks is to automate FT creation [2, 3]. However, this method had room for improvement such as the information extraction process from design documents. The authors have been trying to assist PRA engineers using AI and developing an automatic FT creation tool using AI technology [4]. The AI tools are intended to enable any users to easily perform PRA with the same quality less depending on user's PRA skill. From this background, the authors have conducted a three-year program. In the first step, the prototype tool with a FT creation function of component level piping systems was developed [5]. In the second step, the tool was updated to create more detailed failure mode level FT. And, the image recognition process in the FT creation from the design documents was improved to consider power supply systems [6]. Automatic FT creation tool using AI technology is basically designed to include two key functions. One is the information extraction function from paper design documents. And, the other is FT data creation function form extracted design information. In the information extraction process, template matching and object detection are used for image-based information such as component and piping. And, optical character recognition is used for character-based information such as name of component and piping. Because of the errors come from low resolution of design document and AI technology origin, some of extracted information are practically needed to check and correct by PRA engineers. Automatic FT creation tool is also designed to include annotation function. Because of the less annotation work is the better for PRA engineers, automatic FT creation tool can easily switch future AI technology updates such as improvement of AI technology origin errors.

In this paper, the updates of the automatic FT creation method are described, as the final step progress.

2. UPDATES OF AUTOMATIC FT CREATION METHOD

Automatic FT creation process from the design documents was improved to expand two functions. One is that AI technologies such as image recognition can be used to extract information necessary to create FT not only from design documents for piping and power supply systems but also from design documents for signal systems. This function expansion also enables to generate signal system FT from a multi-page design document. The other one is the logical data construction function to integrate FT, considering the functional dependencies between the frontline system and the support system.

2.1. Function expansion for FT creation of signal system

Figure 1 shows an example of signal system components and signal paths identified from multiple design documents of the experimental fast reactor "Joyo". This is the temperature control system of the secondary sodium system by using air cooler inlet vane/damper. To create an FT from design documents of the signal system, PRA engineers will manually conduct several tasks as follows.

① Select the target component and determine its failure mode from the design document.

② Identify the signal system components and signal path that constitute to the failure mode analyzed from multiple design documents such as interlock circuit diagram, control circuit diagram and sequence diagram.

③ Identify the basic events of each component or failure mode.

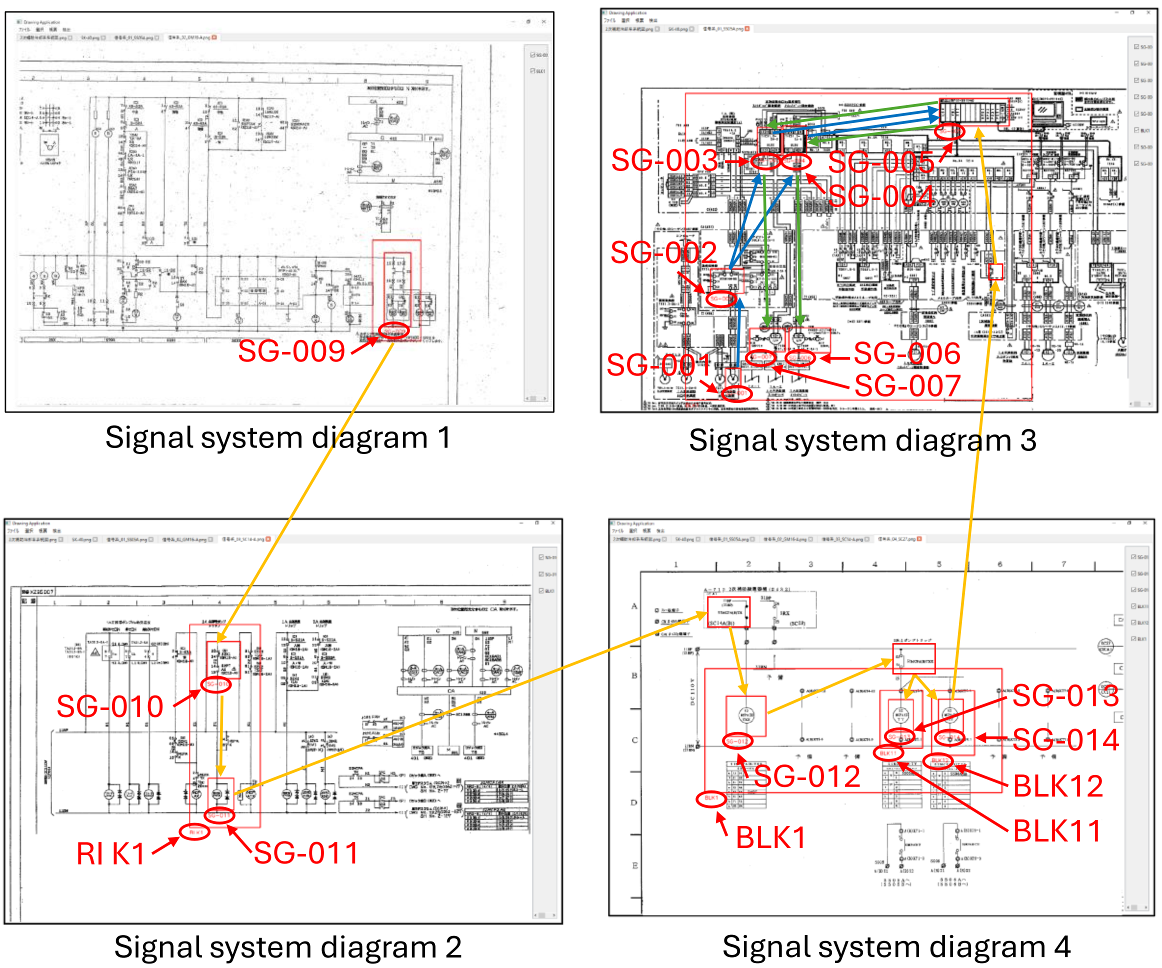

FIGURE 1. Example of signal system components and signal paths identified from multiple design documents

Based on the understanding of manual FT creation tasks mentioned above, function expansion of automatic FT creation method was designed to conduct 4 steps.

Step 1: Extraction of signal system components from design documents

In this process, the signal components of the design documents are extracted by the AI tool. The AI tool can assist human work, such as Graphical User Interface (GUI) function that displays design data on the screen and a function that makes it easy to detect and specify the target with a mouse. Extraction of signal system components from design documents was assisted by AI technology such as template matching and object detection. In this process, extracted components are specified as shown in the red frame of Figure 1, and are recorded in the list file (Excel format).

Step 2: Setting basic events IDs of component level and failure mode level

Signal system component names and images cropped from design documents are included in the list file. In this process, basic events of component level and failure mode level are set to list files based on component names and images.

Step 3: FT data creation

In this process, FT data is created from the list file by the AI tool. The FT data is generated to be a textual input to PRA analysis software such as SAPHIRE [7].

Step 4: FT drawing

In this process, FT diagram can be drawn using FT drawing function provided in the PRA analysis software SAPHIRE etc.

The authors demonstrated to confirm the function of the AI Tool for FT creation with comparing conventional manual FT creation method. Figure 2 shows the example of signal system FT created using the AI Tool combined with the FT drawing software provided in SAPHIRE in step 4. From the demonstration results, the authors confirmed that the expanded function of the AI tool is consistent with conventional manual method.

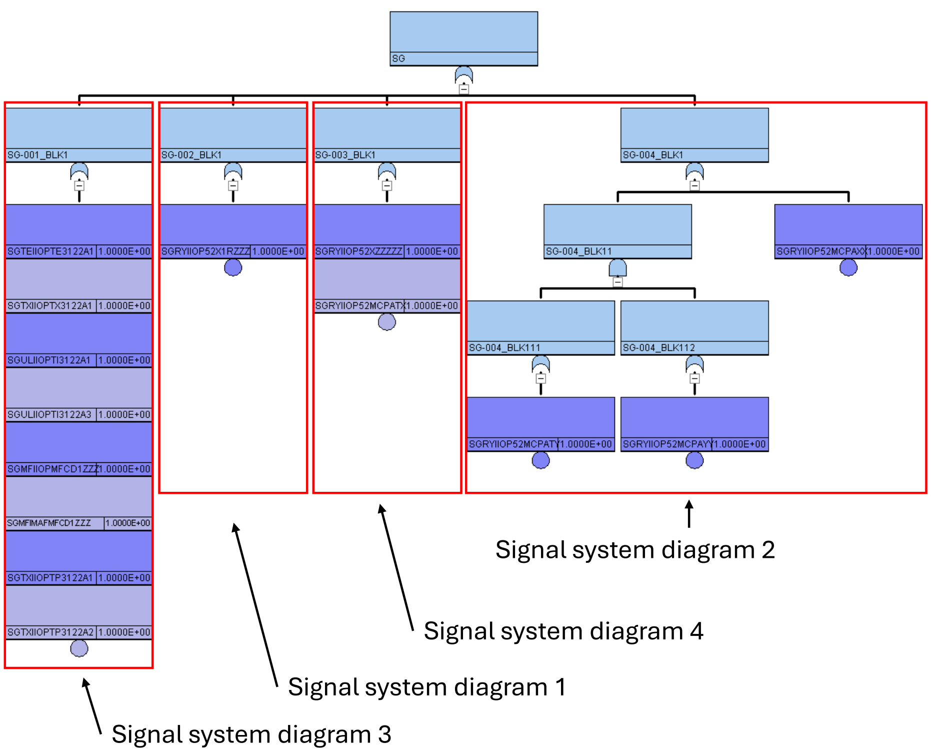

FIGURE 2. Example of the signal system FT

2.2. Function expansion for FT creation considering the functional dependencies between a frontline system and its support systems.

To consider the functional dependencies between a frontline system and its support systems, function was expanded to link support systems to the frontline system via the transfer gates. For the topical example of linking these systems, experimental fast reactor "Joyo" was considered to demonstrate how to link the secondary cooling system, which is a frontline system for decay heat removal, with its support systems, i.e., the secondary sodium purification system, the power supply system, and the signal system. The secondary cooling system is connected to the secondary sodium purification system for sodium purification through piping. Active components in the secondary cooling system are also connected to the power supply system and the signal system through electrical wiring. Based on these connections, linking points in the secondary cooling system is indicated on the display of the AI tool by the PRA engineer as shown in Figure 3. In this example, an FT top event of the secondary sodium purification system was named "SP", a top event of the signal system was determined to "SG", and a top event of the power supply system was determined to "EPS_6C", and then the support system FTs are automatically created using the AI tool. The AI tool identifies these top events in the support system FTs as linking points with the frontline components or area and the tool connects the frontline system FT and its support system FTs via the transfer gates. The transfer gates linking to the support system FTs mentioned above were named "SP", "SG", and "EPS_6C" by the AI tool, respectively.

The authors demonstrated to confirm the function of the AI Tool for FT creation with comparing conventional manual FT creation method. An example of the frontline system FT including the transfer gates is shown in Figure 4, and examples of the support system FTs are shown in Figure 5. From the demonstration results, the authors confirmed that the expanded function of the AI tool is consistent with conventional manual method.

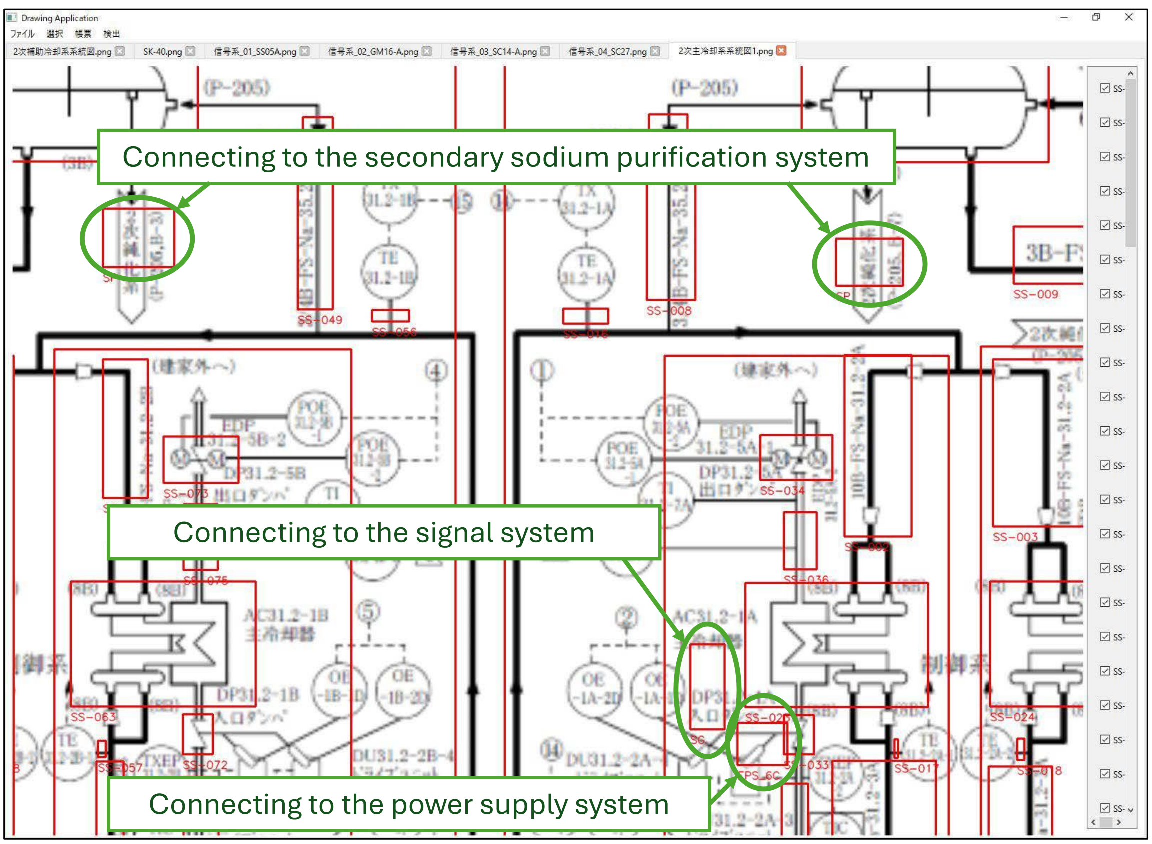

FIGURE 3. Linking points in the secondary cooling system

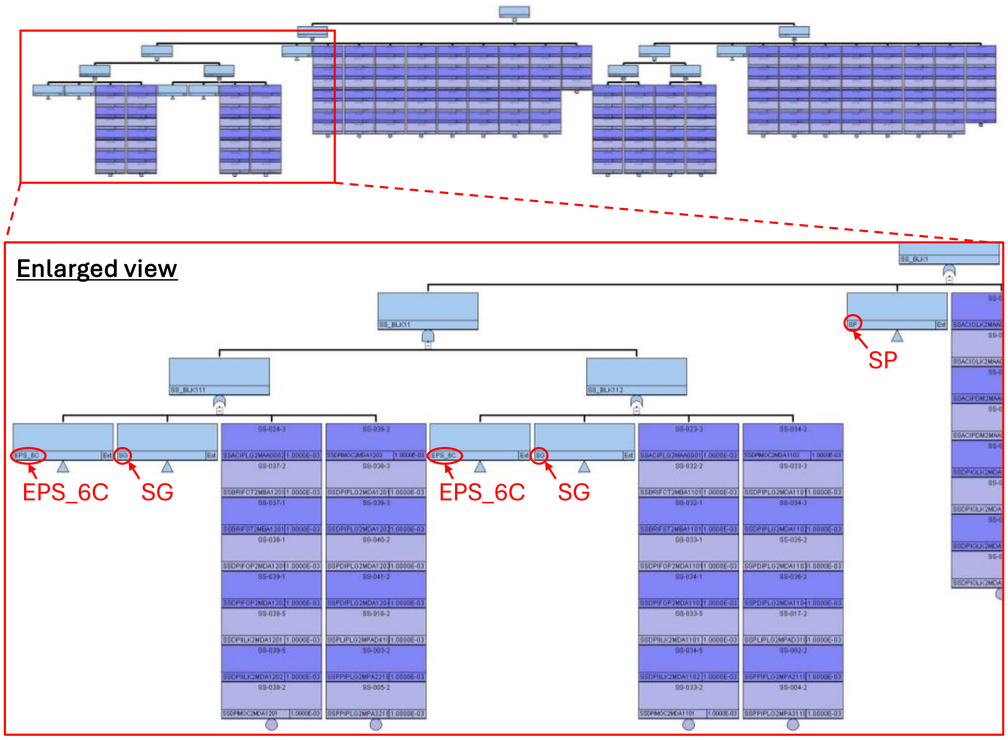

FIGURE 4. Example of the frontline system FT including the transfer gates

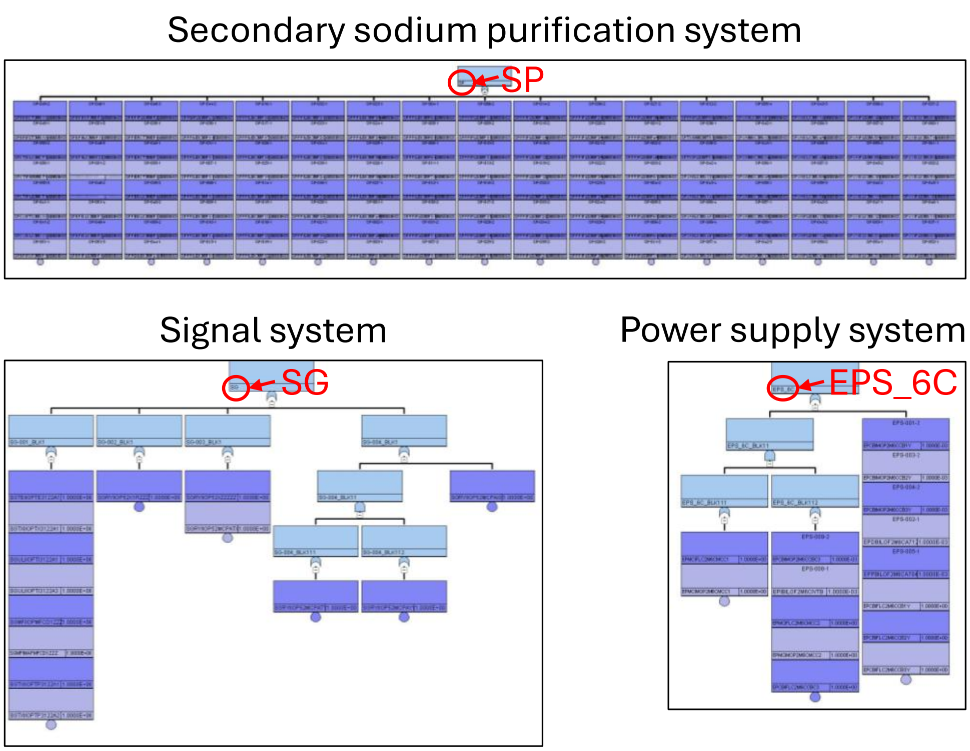

FIGURE 5. Examples of the support system FTs

3. QUANTITATIVE EVALUATION OF FT CREATION TIME THROUGH TRIAL HUMAN WORK

In order to confirm the effectiveness of the AI tool, comparisons were made between the time required to create an FT using the tool and the time required to create an FT without using the tool. In these comparison, 2 cases of FT creation time were measured. One case is a case for signal system FT creation. The other case is a case for FT creation considering support systems. These comparison results are shown in Figure 6. For the signal system creation, the work time was reduced to 29%. In the other case, the work time was reduced to 22%. The AI tool contributed to reduce the work time in both cases.

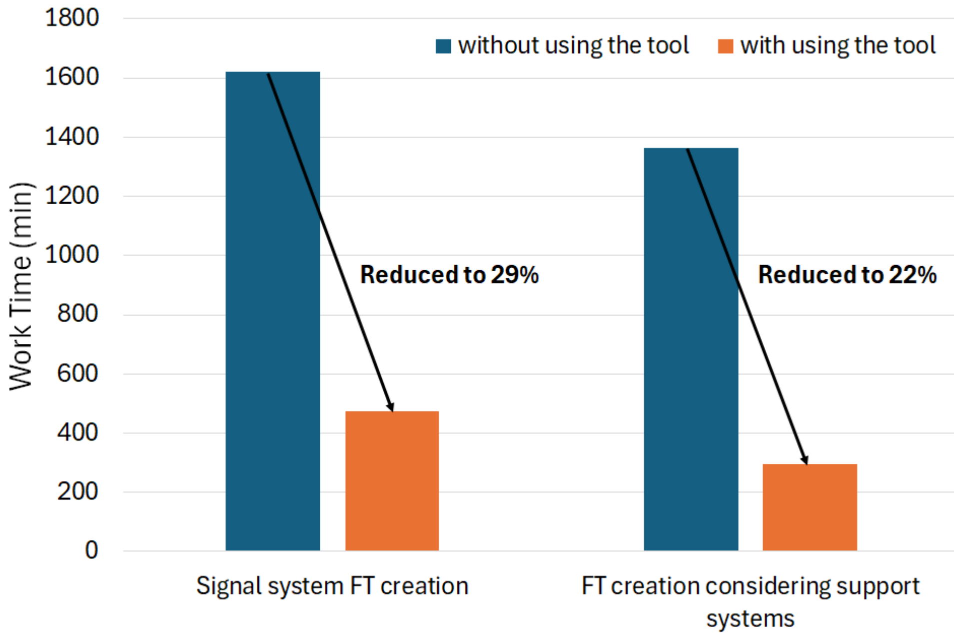

FIGURE 6. Comparison results of work time

4. CONCLUSIONS

The authors have been conducting a three-year program including development of the AI tool for automatic FT creation. The AI tool is intended to enable any users to easily perform PRA with the same quality without user effect. As the final step of the three-year program, the AI tool was expanded the functions to create FT of signal system and to create FT considering support systems. The demonstration results showed that the expanded functions of the AI tool are consistent with conventional manual method. The quantitative evaluation of work time indicated that the AI tool contributed to reduce work time. This three-year program was finished for now. Demonstration results of the three-year program provide a basic outlook for social implementation as an early stage of development. The authors will prepare to download this tool to applicant users.

ACKNOWLEDGMENTS

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