EXPERIENCE FROM JOINT RESEARCH IN RISK & RELIABILITY WORKSTATION

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ABSTRACT

KAERI (Korea Atomic Energy Research Institute) has been participating in the Risk and Reliability (R&R) Workstation program as a form of joint research since 1993. This paper describes the experience and benefits from this joint research, as well as what KAERI has contributed to the R&R Workstation program. First, the KIRAP code, which is a probabilistic safety assessment tool developed by KAERI to improve quantification speed. Second, KAERI was able to develop its own risk monitor called *Risk Monster*. Third, a fast cutsets generation algorithm for risk monitors, called *McFAR M*, was developed to study on-line maintenance of the Essential Service Water (ESW) pump. Fourth, by participating in the R&R Workstation users' meeting KAERI was able to learn about new issues, and the current situation regarding U.S. nuclear regulations. KAERI's contribution to the R&R Workstation program, was to provide EPRI with the KIRAP code. In addition a localization method for the R&R Workstation software was developed.

INTRODUCTION

For a long time, the nuclear industry has requested the development of a good tool to apply probabilistic safety assessment (PSA) or Individual Plant Examination (IPE) results to plant Operation and Maintenance (O&M). The U.S. NRC's maintenance rule [10 CFR , 1991] and the increasing use of on-line maintenance have accelerated the necessity for such a tool. The U.S.-based EPRI (Electric Power Research Institute) organized an international alliance to develop this tool, called the Risk and Reliability (R&R) Workstation. Based on PSA technology, its purpose is to eventually reduce O&M costs without sacrificing safety.

Currently, 28 U.S. utilities and five international partners from Korea, Spain, France and Mexico are participating in the R&R Workstation project. KAERI has been participating in the program, as a form of joint research, since 1993.

According to the joint research contract between KAERI and EPRI, a representative of KAERI was dispatched to EPRI for one year to develop a fast cutsets generation algorithm, and EPRI provided KAERI with R&R Workstation software (SW) such as CAFTA [CAFTA, 1995], EOOS [EOOS, 1995], etc. KAERI has also participated in the R&R Workstation users' meeting, held semi-annually. During the users' meeting, KAERI was able to access information about new trends and issues, and the current situation regarding U.S. nuclear regulation. The information from the users' meetings sometimes influenced the research direction of the KAERI PSA team. Meanwhile, the KIRAP code [Han, 1990], which is a PSA tool developed by KAERI, was provided to EPRI to be used in the R&R Workstation.

During the three years of joint research, KAERI and EPRI have each benefited considerably from the other. KAERI was able to rapidly access new trends in the U.S.'s nuclear industry and advanced programming technology, and EPRI was able to maintain the R&R Workstation with the improved fast cutsets generation engine provided by KAERI. A detailed outline of the benefits gained from the joint research, as well as the specific contributions of KAERI to the R&R Workstation program, is described as follows.

KIRAP

One of KAERI's main areas of research was to develop a fast cutsets generation engine, or to improve the quantification algorithm of KIRAP which has been developed by KAERI since 1989. The KIRAP algorithm was provided to EPRI when KAERI participated in the joint research of the R&R Workstation. From its valuable discussions with Science Applications International Corporation (SAIC), KAERI improved the KIRAP algorithm, making it several times faster in its cutsets generation speed. Therefore, it is known that the KIRAP algorithm is now much faster than the CAFTA quantification engine. Also, the KIRAP algorithm was selected to be one of the quantification methods in the R&R Workstation SW, such as EOOS, CAFTA, etc. The quantification engine of KIRAP is available to R&R Workstation members.

LOCALIZATION OF RISK AND RELIABILITY WORKSTATION

To become more internationally used, the R&R Workstation should be able to be easily used in foreign countries where English is not mother tongue. Thus, the R&R Workstation should display the local language menu and dialogue instead of English ones, and furthermore, the localization, i.e., the conversion of the English menu and dialogue to local language should be easy and simple. The localization method of R&R Workstation SWs was developed by KAERI with the help of SAIC.

The following is the localization steps for SWs written by Microsoft (MS) Visual C++. First, since R&R Workstation SWs use MS Windows, R&R Workstation SWs are installed on a local version of MS Windows (e.g., MS Windows Korean version). Second, local language resource DLL (Dynamic Linking Library) files are put on the same directory as where the R&R Workstation SWs are copied. Only these two steps are required to make and use a local language version of R&R Workstation SWs written by MS Visual C++.

Usually, local language resource DLL files will be supplied together with the original SW. Therefore, general users do not need to worry about how to make the local language resource DLLs. Detailed description of how to prepare local language resource DLLs is discussed in the reference [Kim et al., 1995]. In Figure 1, a localized (i.e., Korean) rather than English menu appears after putting the local language resource DLL on the directory where CAFTA exists.

RISK MONSTER

As a risk monitor for the safe operation of nuclear power plants, a computer code called *Risk Monster* was developed by KAERI [Kim, et al., 1997] using the EOOS methodology and R&R Workstation API (Applications Program Interface) [Riley, 1996]. Risk Monster can update the plant risk continuously according to changes in the system/component configuration. Whenever a plant configuration changes, Risk Monster reevaluates the plant risk based on the PSA results. Risk Monster shows a new plant risk relative to the baseline risk level. In the case of a multiple components outage, Risk Monster could suggest maintenance priorities according to the importance of each component from the viewpoint of plant safety.

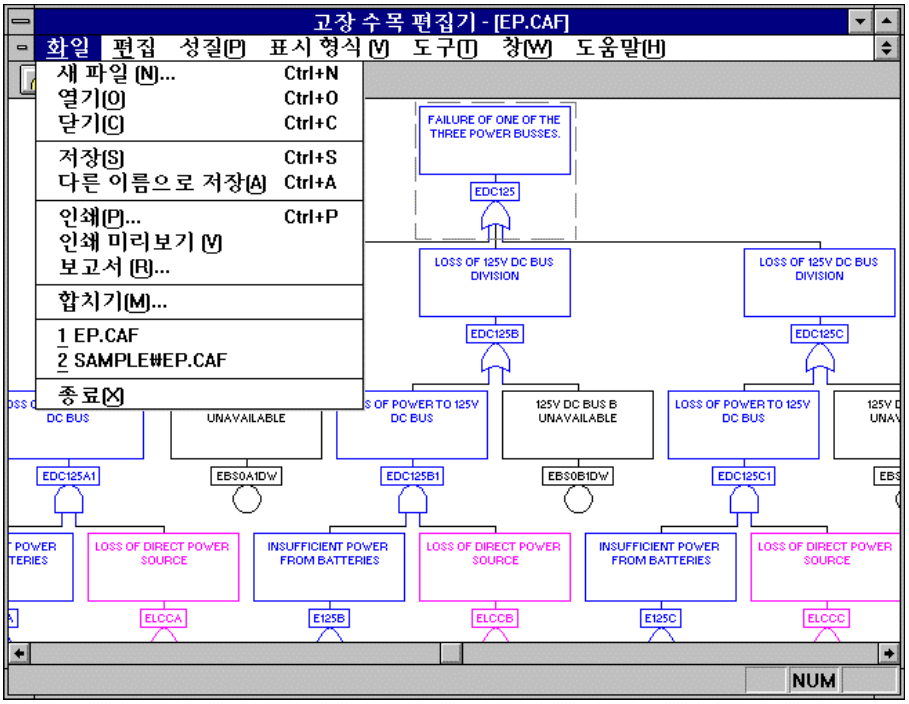

Figure 1. Localized (Korean) Menu in CAFTA

Risk Monster consists of two modules, i.e., operator module and scheduler module. The operator module supports plant operators and the scheduler module supports maintenance schedulers. By using Risk Monster, operators or schedulers can monitor the risk level of plants, and can avoid high peak risks by rearranging the maintenance work schedule during maintenance planning. Later, an economic value/impact analysis module will be added so that Risk Monster can be used as a decision-making tool for maintenance.

There are three ways to calculate the risks associated with plant configurations in Risk Monster: 1) use of pre-solved cutsets; 2) resolving the PSA model; and 3) use of McFARM (Missing Cutsets Finding Algorithm for Risk Monitor). The McFARM algorithm is described in the next section.

MCFARM

The motive to develop McFARM was given by SAIC during the joint research. KAERI developed the theory and programmed McFARM [Kim & Han, 1996]. McFARM can be summarized as follows:

The McFARM algorithm consists of the following three steps:

- Simplifying Step
- This step simplifies and restructures a fault tree logic in order to quickly find minimal cutsets containing out of service (OOS) equipment.
- Comparing Step
- This step compares the minimal cutsets containing OOS equipment, found in the previous step, with the original pre-solved cutsets.
- Adding Step
- If new cutsets containing OOS equipment are identified in the above Comparing Step, this step adds the new cutsets (which are actually missing cutsets) to the original pre-solved cutsets.

After the three steps are completed in McFARM, core damage frequency (CDF) is calculated with the original presolved cutsets plus the missing cutsets found through McFARM. If a fault tree can be significantly simplified in the Simplifying Step, then total calculation time to find a new CDF can be significantly reduced since it takes only several seconds in the Comparing Step and Adding Step in McFARM. The Simplifying Step, which is the most important and time-consuming step in McFARM, is introduced in detail in the reference [Kim & Han, 1996].

Figure 2 show an example fault tree before applying the Simplifying Step. In Figure 2, the “i” component is OOS and the f(J), f(K), and f(L) subtrees do not have events related to “i” component. In Figure 2, if the Simplifying Step is applied as indicated (i.e., “yes” means “can be deleted” and “no” means “cannot be deleted”), then the example fault tree can be simplified, as shown in Figure 3.

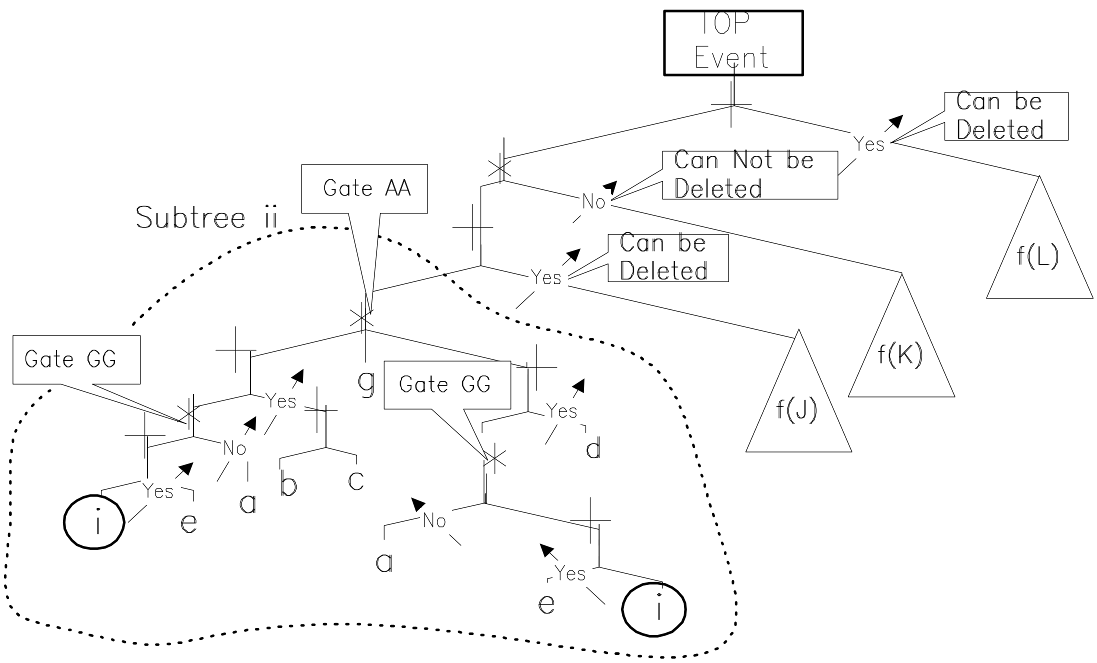

Figure 2. An Example Fault Tree Being Simplified In McFARM

McFARM was tested by using two actual risk monitor models for Korean nuclear power plants (i.e., one is for YGN 3,4 and the other is for UCN 3,4). The test result shows that McFARM can significantly improve the CDF calculation speed for the OOS of non-safety system and supporting systems. For example, when a charging pump is OOS, McFARM calculates CDF and minimal cutsets 6.4 ~ 7.8 times faster than the normal method does. Generally, if McFARM is used, minimal cutsets can be generated 2 ~ 6 times faster without losing accuracy in the risk monitor [Kim & Han, 1996].

McFARM can be applied to multiple OOS events, as well as to a single OOS event. In addition, it can generate minimal cutsets as accurately as the normal method used to resolve the PSA model can do.

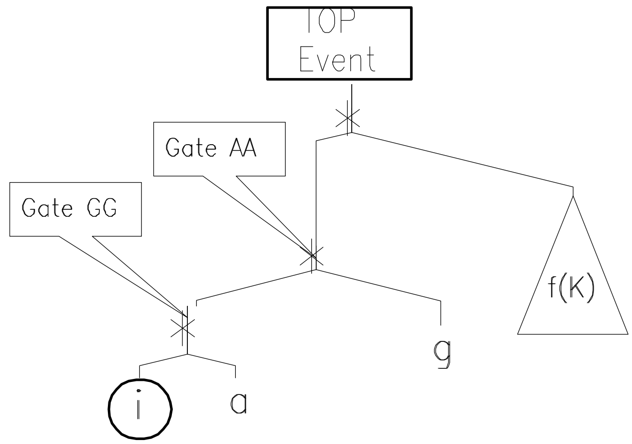

Figure 3. The Final Fault Tree Simplified In McFARM

ON-LINE MAINTENANCE

In Korea, on-line maintenance of safety systems is a rare event, although on-line maintenance for non-safety systems has often been performed. However, some safety systems having redundancy and diversity could allow the plant manager to perform on-line maintenance. A feasibility study of on-line maintenance of safety systems was performed with Risk Monster model converted from the UCN 3,4 PSA model. An essential service water (ESW) pump was selected to be a good candidate for on-line maintenance since the ESW system has two trains, each with two pumps, and since ESW pumps are often out of order due to intaken silt.

The quantitative screening criteria for safety used in the feasibility study of on-line maintenance was adopted from the PSA Application Guide [EPRI, 1995] developed by the U.S. EPRI. According to the PSA Application Guide, for temporary risk-increasing cases, if the change in mean core damage probability (CDP) is below 10^{-6}, then the temporary risk increases are regarded as non-risk significant changes. Also, configuration-specific risk levels in excess of 10^{-3} /yr. should be avoided.

The feasibility of on-line maintenance was studied from a safety and economic point of view, respectively.

Safety Point of View

If one ESW pump is out-of-service for on-line maintenance, then temporary CDF will increase, and temporary risk increase criteria will be used to check whether the on-line maintenance is acceptably safe. If ΔCDF is the increased CDF due to one out-of-service ESW pump, then ΔCDF is 2.5 x10^{-7} /yr [Kim, et al., COPSA, 1997]. If ΔCDP is the increased CDP during the maintenance period of the ESW pump, then,

ΔCDP = ΔCDF x maintenance period = (2.5 x10^{-7} /yr.) x maintenance period << 1 x 10^{-6} where maintenance period is usually below 14 days.

Since the maintenance period can not be longer than 1 year, ΔCDP is much smaller than $1x10^{-6}$ which is the screening criteria for a temporary risk increase. Thus, on-line maintenance of one ESW pump is acceptably safe.

Economic Point of View

If on-line maintenance of one ESW pump is performed, the reactor trip frequency caused by the loss of component cooling water (LOCCW) increases by 0.28/yr (from 0.153/yr to 0.432/yr). Even though 72 hours are allowed for an unavailable ESW train, it is assumed that the loss of an ESW train induces the reactor trip because its loss causes the loss of the reactor coolant pump seal. However, the increased reactor trip frequency, 0.28/yr, was calculated using the assumption that an ESW pump is out-of-service for 1 year. However, since the preventive maintenance of an ESW pump has been performed during the refueling period and the maintenance period usually does not exceed 14 days, it can be assumed that on-line maintenance of the ESW pump is performed only once a year and the maintenance period is below 14 days. Since the failure rate of an ESW pump is 0.280 per year, the assumption that on-line maintenance of an ESW pump can be performed one time in any given year instead of during the refueling period is reasonable. Thus, *the number of reactor trip per year due to D LOCCW = 0.28/yr x 14 days = 0.011*

That is, a reactor trip would occur 0.011 times per year due to on-line maintenance of an ESW pump. However, the increased trip number seems negligible since a nuclear power plant experiences usually one or more unplanned trips every one or two years.

On the other hand, there are two major benefits of the on-line maintenance of an ESW pump: it can reduce the refueling period and can effectively allocate resources such as maintenance man-power, equipment, etc., avoiding peak resources usage during the refueling period. Therefore, even though further research is required, on-line maintenance of an ESW pump seems to be desirable also from an economic point of view.

CONCLUSIONS

With joint research in the R&R Workstation, the cutsets generation module of KIRAP was improved in speed by as much as several times, and the R&R Workstation SWs, such as CAFTA and EOOS, use the cutsets generation module of KIRAP for their fast cutsets generation. Also, a fast cutsets generation algorithm for risk monitor, called McFARM, was developed. Using McFARM in the risk monitor, minimal cutsets can be generated 2 ~ 6 times faster without losing accuracy. In addition, a localization method of the R&R Workstation was also developed so that R&R Workstation SWs could be easily used in non-English speaking countries.

The most important benefit of participating in the R&R Workstation program is that KAERI can develop its own risk monitor called Risk Monster. With the Risk Monster model, the on-line maintenance of UCN 3,4 ESW (Essential Service Water System) pump was studied. In the study, the on-line maintenance of the UCN 3,4 ESW pump is acceptable from both a safety and economic point of view.

From the joint research, KAERI and EPRI have both benefited considerably. KAERI could rapidly access the new trends of the US nuclear industry and advanced programming technology, and EPRI could maintain the R&R Workstation with improved fast cutsets generation program provided by KAERI.

REFERENCES

10 CFR Part 50.65, “Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants”, Federal Register, Washington, DC, 1991

“CAFTA- Fault Tree Analysis System”, Version 3.1, User’s manual, EPRI & SAIC, July 1995

"EOOS Monitor", Version 2.4, User's manual, SAIC, August 1995

EPRI " *PSA Applications Guide*" EPRI-TR-105396, Aug. 1995

Han S.H., K.S. Chung, and K.J. Ryu. "PC-Workstation Based Level 1 PRA Code Package-KIRAP", *Reliability Engineering and System Safety*, Vol. 30, pp.313-322, 1990

Kim, K.Y, F. Rahn, J. Riley, and B. Putney, "Localization of Risk and Reliability Workstation": PSA '95, *Proceedings of the International Conference on Probabilistic Safety Assessment Methodology and Applications*, Seoul Korea, Nov. 26-30, 1995, pp890-892, Korea Atomic Energy Research Institute, 1995

Kim, K.Y., M.J. Hwang, S.C. Jang, S.H. Han, and T.W. Kim, "Development of Computerized Risk Management Tool": NUTHOS-5, *Proceedings of the Fifth International Topical Meeting on Nuclear Thermal Hydraulics, Operations and Safety,* Beijing China, Apr. 14-18, 1997, ppN2-1~ 6, Chinese Nuclear Society, 1997.

Kim K.Y. and S.H. Han, "A Missing Cutsets Finding Algorithm for Risk Monitor (McFARM)", PSA '96, *Proceedings of the International Topical Meeting on Probabilistic Safety Assessment*, Park City, Utah, Sept. 29- Oct 3, 1996, pp190-194, American Nuclear Society, 1996.

Kim, K.Y., S.H. Han, and T.W. Kim. " Risk Monitor Application for UCN 3,4 NPP of Korea" : COPSA '97, Proceedings of the International Conference on the Commercial & Operational Benefits of Probabilistic Safety Assessments, Edinburgh, Scotland, Oct 7 -9, 1997

Riley, J, "R&R Workstation Applications Program Interface(API) ", Version 1.2, Functional Specifications manual, SAIC RR9501, February 1996

KEYWORDS

Risk, Reliability, Technology Transfer, Risk Monitor