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H.P. Alesso, T. Altenbach, D. Lappa, C. Kimura
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# DIGRAPH MATRIX ANALYSIS APPLICATIONS TO SYSTEMS INTERACTIONS *

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Complex events such as Three Mile Island-2, Brown's Ferry-3 and Crystal River-3 have demonstrated that previously unidentified system interdependencies can be important to safety.[1] A major aspect of these events was dependent faults (common cause/mode failures). The term "systems interactions" has been introduced by the Nuclear Regulatory Commission (NRC) to identify the concepts of spatial and functional coupling of systems which can lead to system interdependencies. Spatial coupling refers to dependencies resulting from a shared environmental condition; functional coupling refers to both dependencies resulting from components shared between safety and/or support systems, and to dependencies involving human actions. The NRC is currently developing guidelines[2] to search for and evaluate adverse systems interactions at light water reactors. The assessment of systems interactions is being addressed from several approaches, the most conventional being the enhancement of existing fault tree methodology used in Probabilistic Risk Assessment (PRA). This is generally accomplished by expanding the scope and boundary conditions of the fault tree model giving added emphasis to dependency analysis by conducting a failure model and effect analysis on the cut sets. A second approach utilizes graph theoretical methods and is called digraph matrix analysis (DMA). This methodology has been specifically tuned to the systems interaction problem.

A preliminary description of DMA was presented in Reference 3. The objective of this paper is to present results from two DMA applications and to contrast them with the results from more traditional fault tree approaches.

DMA differs from traditional fault tree techniques in four major ways:

1. Construction of the directed-graph logic (digraph) model is performed directly from plant drawings (piping and instrumentation diagrams, electrical schematics, safety logic). The resulting logic model corresponds directly to the individual components of the plant drawings. Thus, the model can be readily understood, reviewed and corrected.

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2. The resulting digraph (directed graph with logic connectives) is not restricted to a "tree" structure and hence can represent physical situations which may include cycles.

3. The digraph model is processed through graph theoretical DMA computer codes based on a conditioned reachability calculation. These codes determine low order cut sets such as single component failures (singletons) and pairs of component failures (doubletons) which would cause system(s) failure.

4. DMA computer codes can process very large models. Presently, an entire accident sequence, consisting of several front line systems, their support systems, and human actions, can be modeled as a single digraph. The ability of the DMA codes to process such large models is based on its graph theoretical approach as opposed to the approach taken in Boolean equation substitution codes (e.g., SETS or FTAP) currently used to find fault tree cut-sets.

The DMA technique is now being applied to systems interaction analysis at two Westinghouse pressurized water reactors. At one of these reactors (Watts Bar), singletons and doubletons which could cause the failure of the safety injection system in response to an (S-1) LOCA have been studied. Table 1 summarizes the quantitative results of this DMA assessment showing unavailability in comparison to WASH 1400 and BNL[5]. The results suggest that a very strong dependency between the Watts Bar High Pressure Safety injection systems and their support systems exists.

Table 1

Watts Bar Loss of High Pressure Safety Injection Systems
(System Unavailability)

| DMA[4] | WASH 1400 | BNL[5] |
|---|---|---|
| $4 \times 10^{-2}$ | $8.6 \times 10^{-3}$ | $3.1 \times 10^{-3}$ ($\beta$* = 0) |
| | | $1.8 \times 10^{-2}$ ($\beta$ = 0.3) |

At the other reactor (Indian Point-3) the ongoing systems interaction study is focusing on failure modes of several dominant accident sequences. Brookhaven National Laboratory is performing a fault tree analysis on the same systems and a direct comparison of results will be made by the NRC.

DMA has been found to be highly capable of modeling and evaluating accident sequences (including front line systems, support systems, and human actions) as a continuous, well-integrated logic model in order to identify and evaluate systems interactions.[6] Numerous non-intuitive and, potentially risk significant systems interactions have been found between front-line and support systems.[4] As an example, it was found that a Unit 1 powered component cooling pump significantly effected Unit 2 component cooling for high pressure safety injection pumps.

Additional results of the DMA assessments for both reactor studies will be presented and compared with results obtained through application of a traditional fault tree safety study.

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*$\beta$ denotes statistical dependency factor. For ($\beta$ = 0) no dependency between basic events is assumed. For ($\beta$ = 0.3) a very strong dependency is assumed.

## REFERENCES


[1] G. E. Cummings, "Operator/Instrument Interactions during the Three Mile Island Incident," IEEE Symp. Nucl. Power Sys. (October 19, 1979).

[2] F. D. Coffman, "Initial Guidance for the Performance of Systems Interaction Reviews at Selected LWRs", U. S. Nuclear Regulatory Commission (Draft) (October 1, 1981).

[3] H. P. Alesso, I. J. Sacks, and C. F. Smith, "Initial Guidance on Digraph Matrix Analysis for Systems Interaction Studies at Selected LWR's," Lawrence Livermore National Laboratory UCID 19457, (October 1982).

[4] I. J. Sacks, B. Ashmore, and H. P. Alesso, "Systems Interaction Results from the Digraph Matrix Analysis of the Watts Bar Nuclear Power High Pressure Safety Injection Systems", (Draft), Lawrence Livermore National Laboratory, UCRL-53467, (July 1983).

[5] Y. H. Sun, A. Fresco, I. A. Papazoglou, "Availability of High-Pressure Safety Injection in PWR's," Brookhaven National Laboratory, American Nuclear Society Winter Meeting, San Francisco, (Nov 1-3, 1983).

[6] I. J. Sacks, "Digraph Matrix Analysis", Submitted to IEEE Transactions on Reliability, to be published Nov. 1984. (Submitted April 12, 1983).