Framework, Approach and System of Intelligent Fault Tree Analysis for Nuclear Safety Assessment

A Thesis Submitted for the Degree of
Doctor of Philosophy
By

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Certificate Of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literatures used are indicated in the thesis.

Sydney, 1 July 2013

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Julwan Hendry PURBA

DEDICATION

To my amazing wife, Rita, for sharing the pain, sorrow and depression during the hard time and above all for her unconditional love, patience and encouragement.

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“My help comes from the LORD, the Maker of heaven and earth.” Psalm 121:2.

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ABSTRACT

Probabilistic safety assessment by fault tree analysis has been considered as an important tool to evaluate safety systems of nuclear power plants in the last two decades. However, since the estimation of failure probabilities of rare events with high consequences is the focus of this assessment, it is often very difficult to obtain component failure rates, which are specific to the nuclear power plant under evaluation. The motivation of this study is how to obtain basic event failure rates when basic events do not have historical failure data and expert subjective justifications, which are expressed in qualitative failure possibilities, are the only means to evaluate basic event failures.

This thesis describes a new intelligent hybrid fault tree analysis framework to overcome the weaknesses of conventional fault tree analysis, qualitative failure possibilities and their corresponding mathematical representations to articulate nuclear event failure likelihoods, an area defuzzification technique to decode the membership functions of fuzzy sets representing nuclear event failure possibilities into nuclear event reliability scores, and a fuzzy reliability approach to generate nuclear event quantitative fuzzy failure rates from the corresponding qualitative failure possibilities subjectively evaluated by experts. Seven qualitative linguistic terms have been defined to represent nuclear event failure possibilities, i.e. *very low*, *low*, *reasonably low*, *moderate*, *reasonably high*, *high*, and *very high* and the corresponding mathematical forms are represented by triangular fuzzy numbers, which are defined in the [0, 1] universe of discourse based on nuclear event failure data documented in literatures using inductive reasoning. Finally, an intelligent software system called InFaTAS-NuSA, which has been developed to realize the new intelligence hybrid fault tree analysis framework to overcome the limitations of the existing fault tree analysis software systems by accepting both quantitative failure probabilities and qualitative failure possibilities, is also described in this thesis.

The results of the InFaTAS-NuSA evaluation using a real world application confirm that InFaTAS-NuSA has yielded similar outputs as the outputs generated by a

well-known fault tree analysis software system, i.e. SAPHIRE, and therefore it can overcome the limitation of the existing fault tree analysis software system, which can accept only quantitative failure probabilities. The experiment results also show that the fuzzy reliability approach seems to be a sound alternative for conventional reliability approach to deal with basic events which do not have historical failure data and expert subjective opinions are the only means to obtain their failure information.