Approach for Integration of Initiating Events into External Event Models

Nicholas Lovelace[a*], Matt Johnson[a], and Michael Lloyd[b]
[a] Hughes Associates, Lincoln, NE, USA
[b] Risk Informed Solutions Consulting Services, Ball Ground, GA, USA
* E-mail: nlovelace@haifire.com

Abstract: Probabilistic Risk Assessments (PRAs) are increasingly being used as a tool to support risk informed applications. As a result, the scope and quality of these PRA models has expanded to account for the risk associated with external events, such as fires, seismic events, external floods, and high winds. Improved methods developed to create a PRA model for one of these external events can often be used to improve the process used to develop PRA models for other external events. This paper explores one such method. It describes an improvement in the method to incorporate fire initiating events into a Fire PRA model. The improved method reduces the potential for mapping external event failures to multiple induced initiating events. Such mapping can have the undesirable effect of generating duplicate cutsets, subsuming issues, etc. during the quantification process. This is especially an issue when the quantification engine applies the "rare event" approximation and cutset basic events probabilities are relatively high (i.e., greater than 0.1). The improved method allows multiple external event induced initiating event mapping, while addressing the limitations of the quantification engine.

Keywords: PRA, PSA, Initiating Event, External Events, Quantification

1. INTRODUCTION

Improved methods have been developed to utilize the existing PRA event trees to model external event initiators without creating quantification and subsuming issues utilizing new programs such as Fire Risk Analysis (FRANX). This methodology has been developed using lessons learned in Fire PRAs and other external event models. This methodology meets the requirements of the American Society of Mechanical Engineers (ASME) PRA Standard [1].

This paper presents the methodology for the approach utilizing Computer Aided Fault Tree Analysis (CAFTA) and FRANX. However, this approach is applicable to any software. Section 2 of this paper provides an overview of the major steps required to implement the methodology. Section 3 provides the conclusion.

2. METHODOLOGY

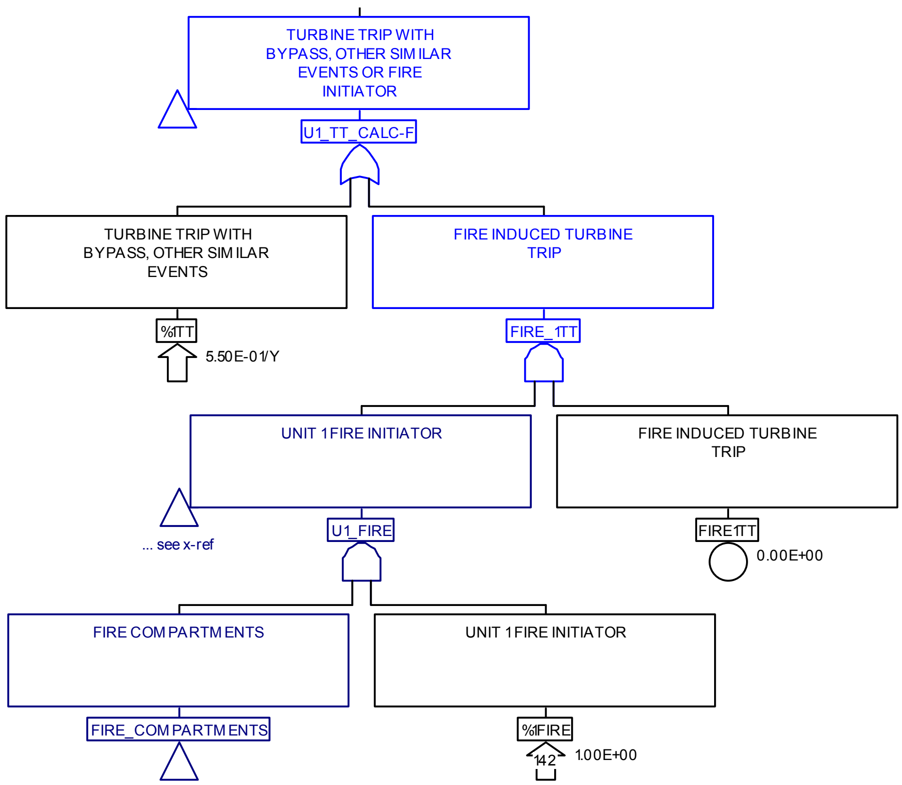
The following approach involves the identification of the external event initiating events. A review needs to be performed of the model to identify the minimum set of induced initiating events (IEs) that can be used to fully represent all accident scenarios applicable for each external event scenario. The example approach shown is from a Fire PRA model but has been successfully utilized in other external event applications such as seismic and high winds.

The starting point in implementing the methodology is to review the current set of event trees in the model to ensure they bound the hazards, failures, and plant response to the external event. Generally, the internal events model event trees in the PRA model will bound the external event initiators. Once this has been determined it's simply a matter of mapping the external event initiators to the internal event initiators that result in the same plant response to the event.

For simplicity, it's initially assumed that any fire will cause a plant turbine trip. If this assumption leads to unnecessary conservatism in the analysis, the assumption should be revisited, as necessary, for the affected fire compartments in order to avoid potentially inappropriate conclusions in future Fire PRA applications.

The simplest way to set the turbine trip Initiating Event (IE) to TRUE for a Fire PRA is to set the internal IE to TRUE. However, to avoid quantification problems (i.e., automatic exclusion of valid cutsets by the quantifier when multiple initiators occur in the same cutset), each of these turbine trip IEs should be "generically" applied in the model by replacing each by an OR gate with two contributors: (1) the random turbine trip IE and (2) a gate representing the fire initiated turbine trip. An example of this logic is shown in Figure 1, below. The fire induced IE (%1FIRE) is set to TRUE for all fire scenarios and, consistent with the assumption that any fire in any compartment will induce a turbine trip, the fire induced turbine trip flag basic event (FIRE1TT) is generically set to TRUE for all scenarios. Gate FIRE_COMPARTMENTS is an OR gate of basic events (BEs) each representing each and every fire compartment. This gate was AND'd with %1FIRE to indicate the compartment associated with each fire quantification cutset.

Figure 1: Gate Representing Fire Initiated Turbine Trip



Even though all components damaged by the fire are failed, use of the turbine trip (TT) as the sole generic fire induced IE is not expected to fully account for all effects of a fire, since this initiator only applies the general transient event tree accident sequence fault tree logic. Some fires should invoke other accident sequences. For example, use of the TT as the sole fire induced IE will not fully account for fires that induce LOCAs due to pressure boundary equipment impacts and need to be modelled using the applicable internal model LOCA event tree.

To ensure that every IE that could be caused by a fire is incorporated into the quantification results, each of the candidate fire induced IEs should be reviewed for unique model impact. This review involves two steps. The first step is to find the minimum set of internal events initiating events that are needed in the fire model and the second step is to identify which of these minimal IEs should be set to TRUE for each fire scenario. These two steps are described below.

Step 1: Identify Minimal Set of Internal Event IEs Needed in the Fire PRA
In this first step, every gate that each internal event IE reports to in the Fire PRA model was traced upwards (towards the top event) in the fault tree. A candidate fire induced IE can be eliminated, if every gate to which the IE reports are also failed by either one or a combination of the following criteria:

Criterion 1: a generically applied fire induced IE fails the gate or
Criterion 2: component failures associated with the IE that are failed by the same fire fail the gate.

As noted above, initially, the only "generic" fire induced IE was the turbine trip IE.

The search for which of the candidate fire induced IEs are "subsumed" by generically assumed IEs involves a CAFTA fault tree review for each candidate IE. The process involves the creation of a special unit specific Core Damage Frequency CDF top gate extracted from the internal events PRA fault tree model, excluding mutually exclusive logic. This logic contains all of the candidate fire induced IEs uncomplicated by the presence of Large Early Release Frequency (LERF), Equipment Out Of Service (EOOS), and event tree success and mutually exclusive logic. The basis for this approach is that a large early release requires core damage, that not all EOOS logic reports to the CDF top gate, and that removal of success and mutually exclusive logic only maximizes the potential for a fault tree Basic Event (BE) to result in core damage.

Using the applicable unit specific fault tree, the gates to which each candidate fire induced IE reports were identified, and gates to which these gates report are identified, etc. The resulting "IE impact" table is a combination of the CAFTA BE and gate cross reference reports extending to multiple gate levels. This table is used to assess the impact of each candidate IE and to determine whether this impact is addressed by either assumed by generic fire induced IEs, by fire induced system failures, or by a combination of these.

For each IE, the fire impact review on a gate path can be terminated if the gate is TRUE'd by a generic fire induced IE (Criterion 1) or if the gate is TRUE'd by BEs that are failed by the same fire (Criterion 2). To apply Criterion 1, each unit's generic IE (e.g., %1TT) is set to TRUE. As can be seen in Figure 1, this is equivalent to setting the following unit specific BEs and gates to TRUE: (1) the generic fire induced IE flags (e.g., FIRE1TT), (2) the fire initiator (e.g., %1FIRE),), and (3) gate FIRE_COMPARTMENTS.

This type of review, looking upwards into the fault tree from the IE, should be performed on all candidate fire induced IEs. The results of these reviews should be documented. As noted above, initially, only one generically applied fire induced IE flag FIRE1TT is set to TRUE for all fire scenarios. This event should be found to subsume a number of other candidate fire induced IEs. During this review you may find that setting a second fire induced IE flag such as the Main Steam Isolation Valve (MSIV) closure flags to TRUE for all fire scenarios could cause additional IEs to be subsumed. Setting multiple "generic" fire induced IE to TRUE for all scenarios eliminates the need to include many additional candidate fire induced IEs in the model.

If there are candidate fire-induced IEs that have pre-initiator support system fault trees (SSFTs) in the PRA model, they can be explicitly addressed via minor model revisions. Essentially, the revision is to replace the existing IE flag event with an OR gate with two contributors: the IE flag and the existing gate U1_FIRE. Figures 2 and 3 provide an example of this revision. These revisions ensure that the effects of the initiator propagate into the model if a fire causes a component contributing to the initiator in its SSFT to fail. Thus, these IEs need not be explicitly addressed in the Fire PRA model.

In addition, because many cutsets that come out of the SSFTs will have a 1 year, 1.5 year, or a 2 year exposure interval, these terms must be divided by 1/365, 1/(1.5*365), and 1/(2*365), respectively to convert to a 24 hour exposure. These corrections are BE specific and convert these BE "frequency" events to "probability" events, i.e., probability of failure during the 24 hour mission time. The subject BEs can be identified via review of the SSFTs contributing to each of the SSFT initiating events.

Figure 2: %1VI Logic before SSFT Logic Revision

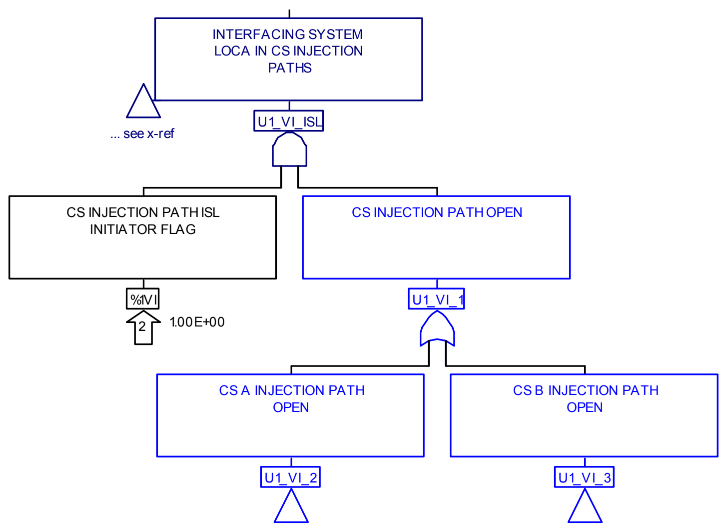
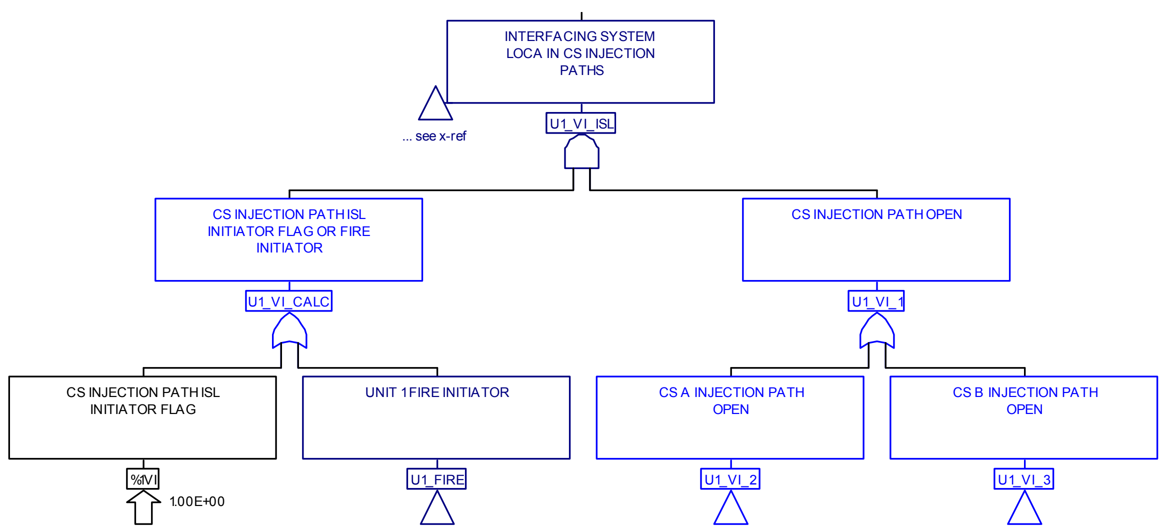


Figure 3: %1VI Logic after SSFT Logic Revision



Since they are not subsumed by other internal event IEs that are assumed to be TRUE in the Fire PRA model (i.e., TT) and are not explicitly modelled as SSFTs, the remaining candidate fire IEs that are considered a set of minimal IEs should be explicitly accounted in the Fire PRA model. Additional insights and assumptions must be made to determine which fire scenarios that would result in each of these IEs. This determination is part of Step 2 in this assessment.

Step 2: Identify Scenarios in which Minimal IEs Should be TRUE in the Fire PRA

It is reasonable to assume that only certain fires cause certain effects. For example, it is reasonable to assume that a fire in the plant switchyard will result in a loss of off-site power IE. Thus, the corresponding loss of off-site power fire initiator flag event will be set to TRUE for all fire scenarios in the switchyard. Similarly, since off-site power cables are routed from the switchyard to the plant's electrical buses through the Turbine Building, it may be assumed that a fire in either the switchyard or the Turbine Building will result in a loss of off-site power IE. Thus, the loss of off-site power fire initiator flag will be set to TRUE for all fire scenarios in both the switchyard and in the Turbine Building.

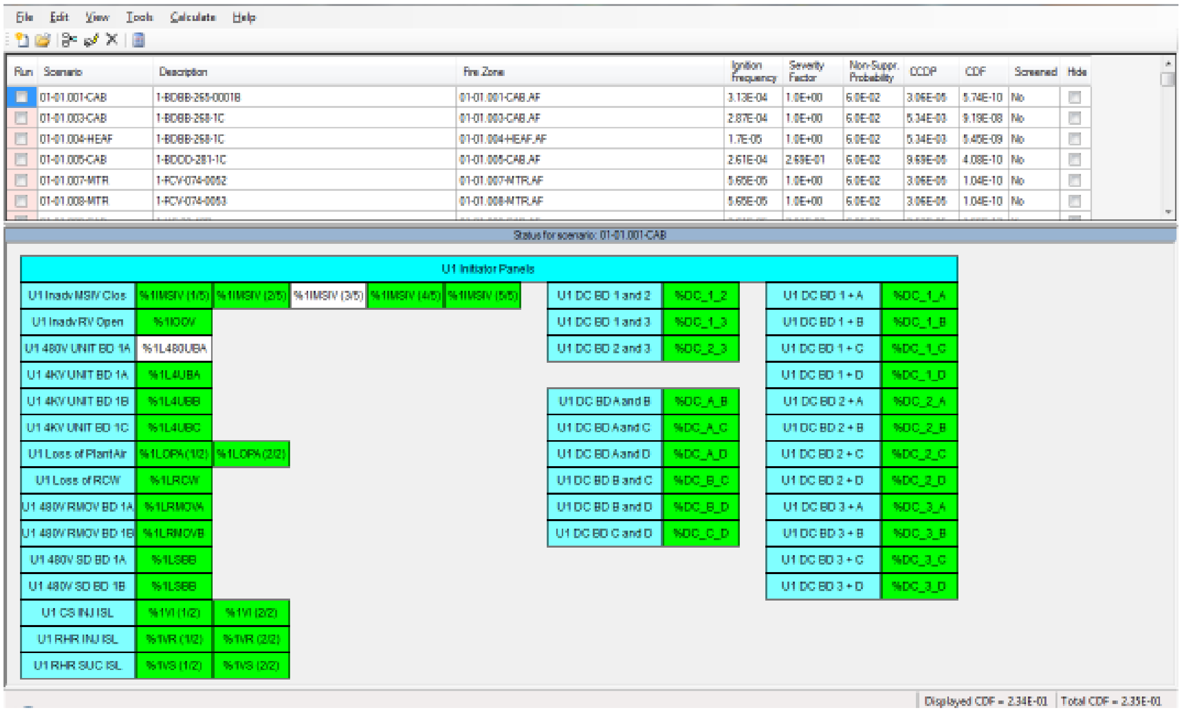
The remaining candidate fire induced IEs that are not subsumed by a "generically" applied IE and also are not subsumed by their post-initiator support logic failures must be taken into account. However, unlike the loss of off-site power IEs, these IE may not be easily correlated with any single plant physical location. Determining the list of applicable fire scenarios for which they apply requires special consideration.

Fortunately, there are generally specific gates in the model which, should it occur, can be used to identify whether a fire in a given scenario could result in each of these initiators. Initiator Inadvertent Open Relief Valve (IOOV) will be used to demonstrate this process. The effect of all of these initiators is addressed in a like manner.

Although in this case, only one gate is of particular interest, in the general case, as many panels as gates of interest can be used in this process. Once the gates of interest are identified, the FRANX model, specifically the FRANX Status Panel feature, can be used to determine which fire scenarios TRUE which initiating event related gates of interest.

The effort involves creating a new status panel configuration file (*.cfg) containing a panel for each of the gates of interest. The easiest way to create the new FRANX status panel configuration file is to edit the existing panel configuration file for the Fire PRA model, replacing the existing model gate associated with each panel with an initiating event gate of interest and renaming the panel title to the initiating event gate name or description. The editing can be performed in FRANX by viewing an existing status panel file (via FRANX command: View, Show Status Panel, and selecting the panel configuration file), revising it (via FRANX command: Edit, Configure, Edit Status Panel), saving the new panel configuration file, and then creating a status grid for each fire scenario (via FRANX command: Tools, Show Status Grid). Figure 4, below, provides an example of a status panel developed to show the status of initiating event gates, including a panel labelled %1IOOV, which represents the status of the spurious opening of a relief valve.

Figure 4: Example Status Panel for a Set of Gates of Interest



Depending on the number of fire scenarios, the complexity of the PRA model logic, and the number of gates of interest, it may take several hours to create the new status panel grid. The grid is stored in FRANX table SystemStatus. It can be copied to a MS EXCEL file by opening the FRANX model using MS ACCESS. Note that attempting to open this table within FRANX (via FRANX command: Edit, Configure, Edit Database in MS Access) can result in the deletion of all records in this table. Further processing can be performed using the MS EXCEL file to identify which fire scenarios fail which gates of interest.

As a result of running the FRANX status panel for %1IOOV, the list of fire scenarios can be provided that are identified to cause the spurious relief valve opening gate to be TRUE. The FRANX Zone_to_Raceway table can be used to set event FIRE1IOOS in the model to TRUE for the scenarios identified.

A similar process using the FRANX status panel can be performed for the other initiators to identify which scenarios their corresponding FIRE1* events should be set to TRUE.

3. CONCLUSION

As discussed, this proposed methodology can be utilized to identify which internal model initiating events and event trees should be utilized in modeling the various external event scenarios in the PRA model. This approach limits quantification issues and avoids the need to create additional external event specific event trees with accurate results. This example presented is for a Fire PRA, however, the methodology has been applied to other external events applications successfully.

References

[1] ASME/ANS RA-Sa-2009 Addenda to ASME/ANS RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, February, 2009.