Improving the Understanding of Complex Nuclear Accidents: A Network Visualization Accident Modeling Approach

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With advancements in accident investigation models, we now have the means to capture rich and complex accident information. Sophisticated analysis of accidents using systematic frameworks (Leveson et al., 2003; 2009; Sklet, 2004) have shown promise in providing tools to conduct systematic in-depth analysis of multiple socio-technical layers involved in accidents, however these methods are sometimes very large in size or exacerbate the perceived complexity of the accident. In addition, a lack of coding standards, inconsistencies in accident database designs and the sheer amount of data generated has made understanding of this rich set of information a time-consuming and intimidating endeavor for even a well-versed scholar. The goal of this research is to establish the efficacy of network visualization of complex nuclear accident information. A four-phased sequential methodology was developed to create the network representation of incidents. First phase is to generate a list of known and potential sources contributing to accidents using a triangulation of sources and methods including the review of literature, ethnographic observations, expert opinion solicitation, and analysis of previous incidents. Using a systems-theoretic model, the identified sources can be organized into environmental, organizational, instrumentation, and cognitive sources to facilitate the investigation of sources at different systems levels in isolation. Phase two involves mining the existing incident databases for evidence to support the identified sources as well as to identify new accident-specific sources. The output of this phase is an evidence database that holds identifiers that relate to different sources. Several incident databases in the nuclear industry use coding mechanisms where human faults and success, as well as equipment fault are coded separately to facilitate human reliability analysis (HRA) methods. After detailed content analysis, the relevant subcodes could be used as evidence to support the identified sources contributing to accidents. Phase three involves the analysis of actual and potential interactions between sources. Systems-theoretic methods such as STAMP (system-theoretic accident modeling and prevention) (Leveson, 1995, 2009), HAZOP (hazard and operability study) (Kletz, 1983), SAfER and FRAM (Functional Resonance Analysis Method) (Hollnagel, 2012), that use systematic retrospective analyses of accident have shown promise in unveiling complex interactions between sources. Another approach is a simplified method that utilizes the wealth of information coded into accident databases to infer potential interaction between sources. The last phase involves visualizing the accidents as networks where nodes represent sources contributing to the accident and links between nodes represent actual or potential interactions (Sasangohar, Thornburg, Cummings & D'Agostino, 2010). Network representation of accidents enables the measurement and evaluation of characteristics of networks such as connectivity and creates an emergent visual property that facilitates the identification of major sources and interactions. Understanding connectivity and modularity of accident networks can provide insight into the interrelation between sources of failure in an accident. Using accident networks as an analytical approach in identifying the potential interactions between the sources, retrospective and preventative efforts can be made to mitigate the propagation effect of potential interactions between the sources of failures and reducing the connectivity of the network. Using this framework, we visualized 24 major nuclear incidents in United States and analyzed their corresponding networks. While such simplistic method has several limitations, the visualized accident networks have shown promise in facilitating the understanding of complex accidents. Future efforts should evaluate the efficacy of this method to evaluate incidents in other domains.

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