Human reliability analysis (HRA) is the field tasked with understanding, modeling, and quantifying the human contribution to the reliability of complex engineering systems. Human machine teams (HMTs, the groups of operators and human-system interface technologies that together control a system) currently contribute to over 60% of industrial accidents and will continue to serve an important operational role in complex engineering systems. As a result, it is critical to develop robust methods for characterizing HMT performance and reliability. One of the factors limiting the technical basis of HRA is the treatment of dependency, how task performances and influencing factors are causally connected. Currently, HRA does not have a sound framework for conceptualizing, modeling, or quantifying dependency. The concept of dependency is poorly defined, the modeling is lacks a causal basis, and the quantification of dependency is unsupported by literature or data. This research closes these gaps in the foundations of HRA dependency by enforcing a rigorous, quantitative causal basis for the conceptualization and modeling of dependency.

First, this research addresses the definitional and conceptual foundations of HRA dependency to provide a consistent technical basis for the field. This work proposes a single, complete, and appropriate definition for the general concept of dependency; one that is rooted in causality. This research also provides definitions for dependency-related concepts from multiple fields including probability, statistics, and set theory. The definitional basis laid out by this work standardizes the foundations of the field and promotes the ability to more easily translate between previously disparate HRA methods.

Second, this work develops the causal structure of dependency in HRA. Whereas current methods for dependency modeling in HRA focus on correlational attributes, this method recognizes that causality, not correlation, is the driving mechanism of dependency. This work identifies six distinct relationship archetypes (idioms) that describe the general dependency relationships possible between HRA variables. Furthermore, this work creates the graphical structures that describe the idioms using Bayesian Networks (BNs) as the modeling architecture. The task/function-level idiom structures created in this work provide robust, traceable models of dependency relationships that can be used to both build HRA models and decompose full models into more understandable pieces.

Third, this work develops the methodology to build and quantify causal, formative dependency BN HRA models using the idiom structures and HRA data. Whereas many HRA methods rely on expert elicitation alone for assigning probabilities, this methodology quantifies the network directly from HRA data. The methodology developed in this work produces a full, causal, formative dependency scenario model without requiring expert elicitation of probabilities. This methodology is implemented to build and quantify a scenario model using real HRA data collected from operator crews working in a full-scope nuclear reactor simulator, which shows both that causal dependency can be modeled and quantified, and that the methodology is traceable and useful. Finally, this work develops a set of recommendations for the collection, storage, and use of HRA data, and for the implementation of this methodology within mature HRA frameworks. This dissertation will improve our knowledge of, and ability to model, dependency in human reliability.