

# Development of a Bayesian Network Model Schema that Builds on Existing FMECAs

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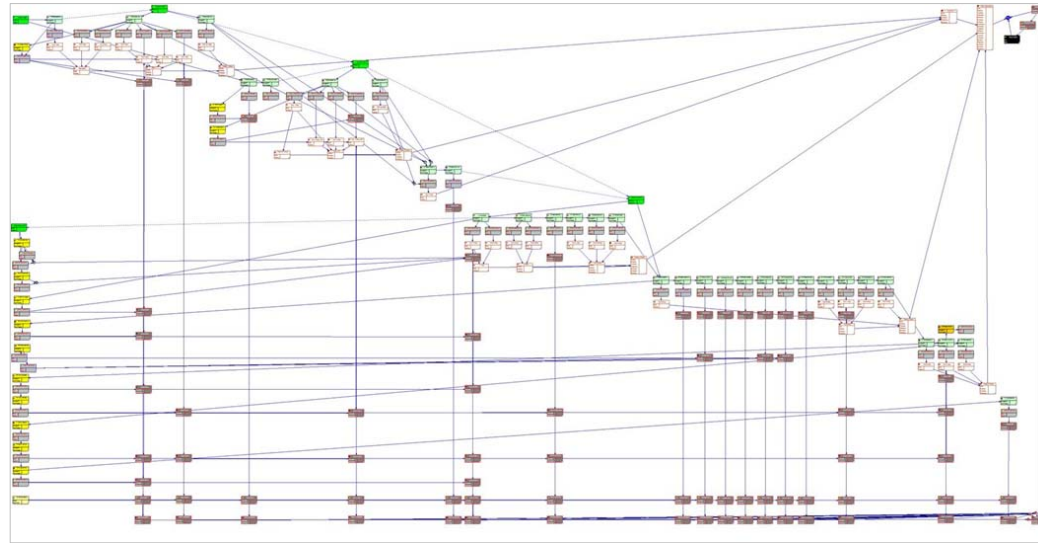
## Abstract

**Background** The Institute of Medicine's 2000 report entitled *To Err is Human* states that as many as 98,000 people die each year as a result of medical error in the United States. Subsequent studies indicate that this may be an underestimate. Awareness of the patient safety problem has led to widespread attempts to encourage quality improvement in America, from legislation requiring incident reporting to pay-for-performance programs. Evaluating and improving process design has been recognized as a critical element in improving patient safety. The Joint Commission on the Accreditation of Healthcare Organizations (JCAHO) recommends a technique called failure mode effect and criticality analysis (FMECA), which has been widely used in improving the safety of medical processes. This tool's uses are limited because of its inability to examine the possibility of multiple errors occurring in a process.

**Methods** Efforts were centered on the creation of a generalizable schema that could be used in creating models more descriptive of the possibility of multiple errors contributing to undesirable outcomes. For this purpose, we used a Bayesian Network (BN) to incorporate both the process flow diagram and the probabilities/frequencies of various failures and their consequences for a given procedure. Steps from process flow diagrams used in creating FMECAs are categorized into action steps and validation steps, which are organized with potential outcomes and probabilities into a resulting matrix that represents all possible combinations of errors as well as the probability that any given error (or combination of errors) will occur. The model is first used as an influence diagram to determine which possible branches in a chain of steps may be eliminated. Once branches with higher probabilities of error are eliminated, the streamlined BN will indicate the probability that any outcome is reached by any combination of steps with any combination of errors. An existing FMECA completed for blood transfusion is used to illustrate our method.

**Results** The resulting model is useful for several reasons. Decision analysis can be performed to ascertain what potential errors can simply be eliminated from the process. High probability errors are noticeable, but more importantly, dangerous combinations of error are highlighted. Depending on the level of specificity achieved in the initial FMECA, specific health outcomes can be attached to specific errors, creating a diagnostic tool for use in later root-cause analyses. The model can be adjusted readily, so proposed changes in the process can be examined in a hypothetical setting before being tested in an actual health care setting.

**Conclusion** Creation of a BN model increases the value of time intensive labor already performed during FMECAs. This method shares some of the benefits of more sophisticated modeling approaches but builds off of the widely used FMECA framework already recommended by JCAHO. It achieves the goal of determining which combinations of error lead to undesired outcomes.



The complete influence diagram at left has five decision nodes. These decision nodes allow the program to "decide" what the best course of action is to ensure that no adverse events occur. The program indicates that orders should never be faxed. Computer orders are far more reliable. Additionally, physicians should never rely on verbal orders for transfusions. They should always use an MD order sheet. The entire series of 2.0 steps can be eliminated.

After eliminating all event chains with a higher probability of error, a streamlined BN remains. This BN can be used to determine which combinations of error are most likely to result in particular consequences. The more critical errors can then be addressed in a prioritized order that takes into account the possibility of multiple errors leading to adverse events.

**A Note on Bayesian Networks and Bayes' Theorem:** Bayesian Networks are driven by calculations based on Bayes' Theorem. The Theorem relates the "prior" probability (*a priori*, also called the "direct" probability) of a hypothesis, conditional upon certain evidence,  $P_e(H)$ , to the "posterior" probability (*a posteriori*, also called the "inverse" probability) of the evidence, conditional upon the hypothesis,  $P_e(E)$ .

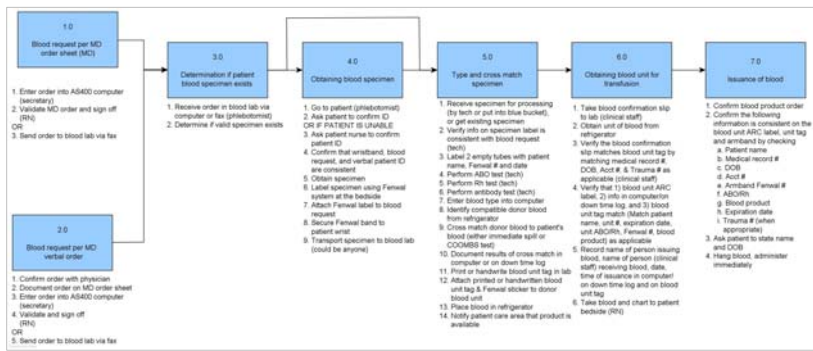
$$P_e(H) = [P(H) / P(E)] P_e(E)$$

BNs' calculations of posterior probabilities make them useful in diagnosing causal relationships. For example, Bayesian Network models have been used to successfully diagnose which pathogens cause ventilator-associated pneumonia, which patients have acute appendicitis, and which patients are eligible for asthma guideline treatment. BNs have also been used to assess the reliability of processes.

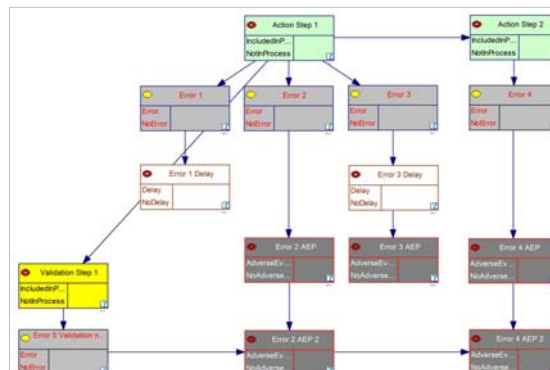
This body of notes represents the generic matrix pattern developed for transferring data from existing FMECAs to new influence diagrams and Bayesian Networks. An influence diagram differs from a BN because it includes decision nodes.

This table is a portion of the FMECA worksheet completed in conjunction with the process flowchart. F1 and F2 stand for "Less than once a year" and "Once a year" respectively; the highest frequency category, F4, stands for "Once a week". These frequencies can be transformed into numerical values which are entered into the model. CP1, 2, and 3 stand for "little", "some," and "significant" impact on the probability of a wrong-type blood transfusion occurring. S2 is the second highest safeguard category, indicating a formalized, built-in double-check step during the process. S5 is the lowest safeguard category, indicating that the error cannot be detected once it has occurred.

Step ID	Step	Success Criteria	Failure Mode	Cause	Frequency Category	Consequence Category	Safeguard Category	Comments	Risk
5.10	Document results in computer or on downtime log	Correct cross match	Enter incorrect information	Human error, interruption	F1	CP4	S5	Computer or log only triggers blood issuance	High
5.11	Print or handwritten cross match results on blood and tag in lab	Document correct patient and blood type	Incorrect or illegible handwritten label	Human error	F2	CP1	S2	Only make hand-written labels during computer downtime (1% of time); if illegible is wrong, blood specimen returned on patient with lab error	Low
5.12	Attach printed or hand-written blood unit tag to donor Blood and Frenal # sticker	Correct tag on correct unit	Put wrong tag on unit	Processing multiple units at one time	F2	CP3	S2	Label the Red Cross Label and be checked against the unit tag	Med



Existing work on the process of completing a blood transfusion was used as an example of our method's utility. The above process flowchart illustrates the steps which must occur during a blood transfusion. This diagram was elicited from personnel in an unnamed hospital as an initial step in the FMECA.



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