Risk Modeling in Healthcare

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FOUR TOPICS TO COVER

1. Magnitude of the problem
2. Context: overview of a hybrid modeling approach
3. BBN for pressure ulcer
4. BBN for line infection

Magnitude of the Problem

Background 1

- Adverse events/errors remain a major concern in the healthcare system, despite efforts to improve quality and safety
- In the US healthcare system, estimated magnitude of problem:
  - 4% of all hospitalized patients incur treatment-related injury (1984,NY)
  - 14% of these injuries were fatal
  - 48000 to 98,000 people die in hospitals each year as the result of medical errors (IOM, 1999)
    - 2016 Hopkins study; 250000 death/year
    - OIG; 180000 in 2008
    - Mayo clinic study
  - Cost of managing treatment-related injures: $ 37.6 Billion

Background 2

- Despite awareness about adverse events, progress to render the system safer is slow. Why?
- Many reasons, but at least some of the difficulty relates to:
  - Complexity of the healthcare system
  - Dynamic nature of risk
  - Absence of good techniques to understand and model risk
- Challenges to modeling and analysis:
  - Wide variability in processes of care (non-standardization)
    - Organizational and human performance
    - Uncertainty
    - Reliability of information used in decision making
  - Heterogeneity in the patient response to interventions
  - Dynamic nature of risk in this environment
    - Exposure varies across time
    - Severity of effects changes with time

Background 3

- Formal approaches to risk modeling and analysis of adverse events:
  - Relatively uncommon, prior to 2000
  - Use of informal methods promoted by US regulatory and certification authorities (Joint Commission, Federal and private insurers)
  - Most notable tool – a simplified version of FMEA
- Quantitative approaches
  - Application/use limited to a few research studies

Overview of methods applied in healthcare

Informal Risk Assessment Methods

FMEA
Promoted by JCAHO

Highly subjective

Rarely quantitative

Does not capture many potential failures

Incapable of displaying the influence of policies and decisions

Miscellaneous Approaches

Retrospective studies
Core: linear regression
Checklists for risk assessment
- Reliability and validity

Formal Risk Assessment Methods

PRA

ESD, FT,..

Linearity assumption in classical PRA

Much of what happens in HC is subject feedback

Contributing factors are more complex than mechanical systems

Useful for specific aspects of risk
- Medication error

HRA

"cherry picked" theories and tools
Enormous diversity in healthcare and related tasks
Diversity in humans performing tasks
Response to human actions unpredictable
Wide range of tolerance to imperfect task execution

Desirable attributes of the model

- A tool to;
  - Provide a more realistic view, capture dynamics of risk/safety as function of policy and organizational decisions
  - Project unintended consequences of external and internal policies and decisions on safety
- Simple enough to be practical, detailed enough to be informative
- Comprehensive, integrating key elements: system, patient, provider
- Flexibility:
  - To tailor to individual hospital characteristics
  - Updatable with new qualitative and quantitative data

A Hybrid Modeling Approach

Approach

- To realistically address system based risk it is necessary to:
  - Display the complexity of contributing factors
  - Capture dynamic effects (i.e. reinforcing loops and feedback)

- The proposed model consists of two components:

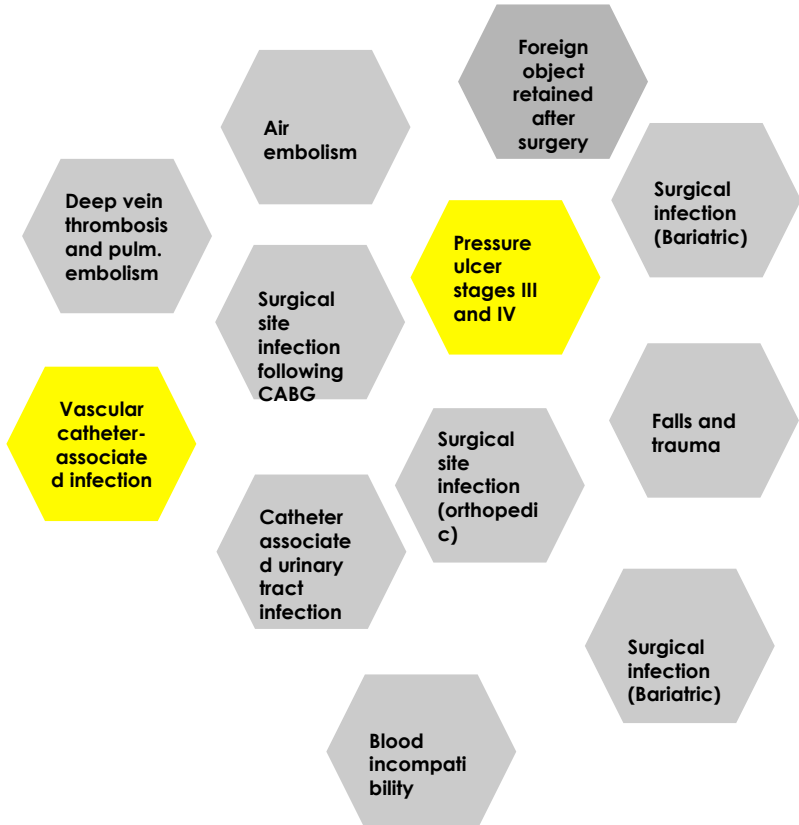
System dynamics framework
-To represent change over time
-Feedbacks
-Delays
Bayesian belief network structure
-Causality
-Uncertainty
-Incorporation of new knowledge

Modeling context

- Combination of increasing costs, decreasing reimbursement has created tremendous financial constraints for healthcare organizations
- Insurers have increased pressure by imposing penalties for adverse events
- This leaves hospitals in the following *risk-relevant* positions:
  - Few resources to invest proactively in safety
  - Operational decisions that focus on reducing costs may increase risk (e.g., staffing cuts, reducing patient length of stay)
  - Effects of these factors also depends on individual patient's conditions and provider's decisions

Adverse events that will be emphasized

- Adverse events
  - Set of hospital acquired conditions (HAC) that patients can experience while in the hospital
- Focus on these AEs because
  - Preventable
  - No reimbursement



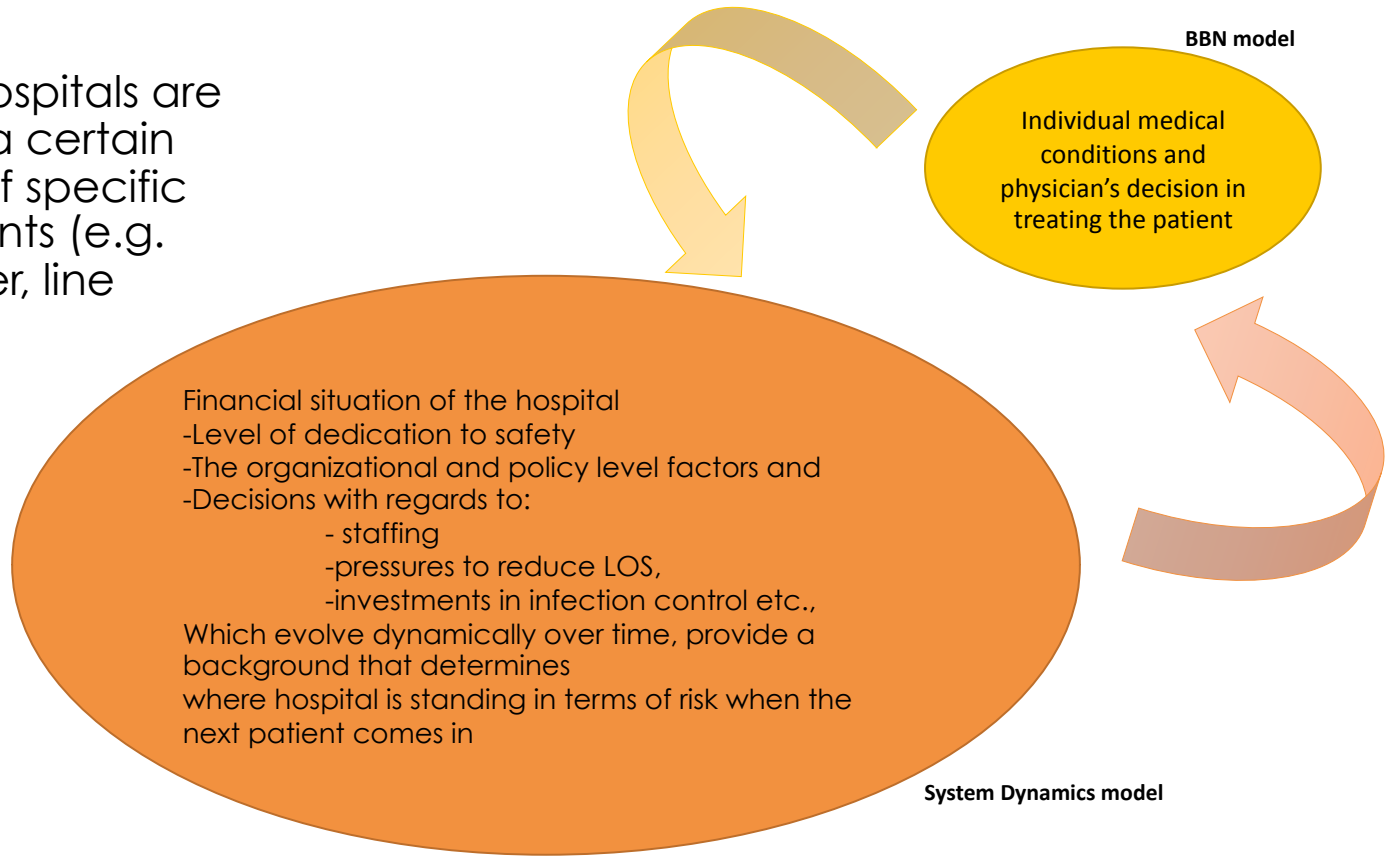
Model overview

- Limited utility of approaches adapted from engineering discipline in modeling system-based risk in healthcare
  - Underlying causal chains in healthcare are subject to feedback
  - Much greater number of contributing factors

- Hybrid modeling approach
  - Bayesian Belief Networks
    - Patient level, and patient provider level factors
  - System Dynamics
    - System level factors

SD/BBN Combination

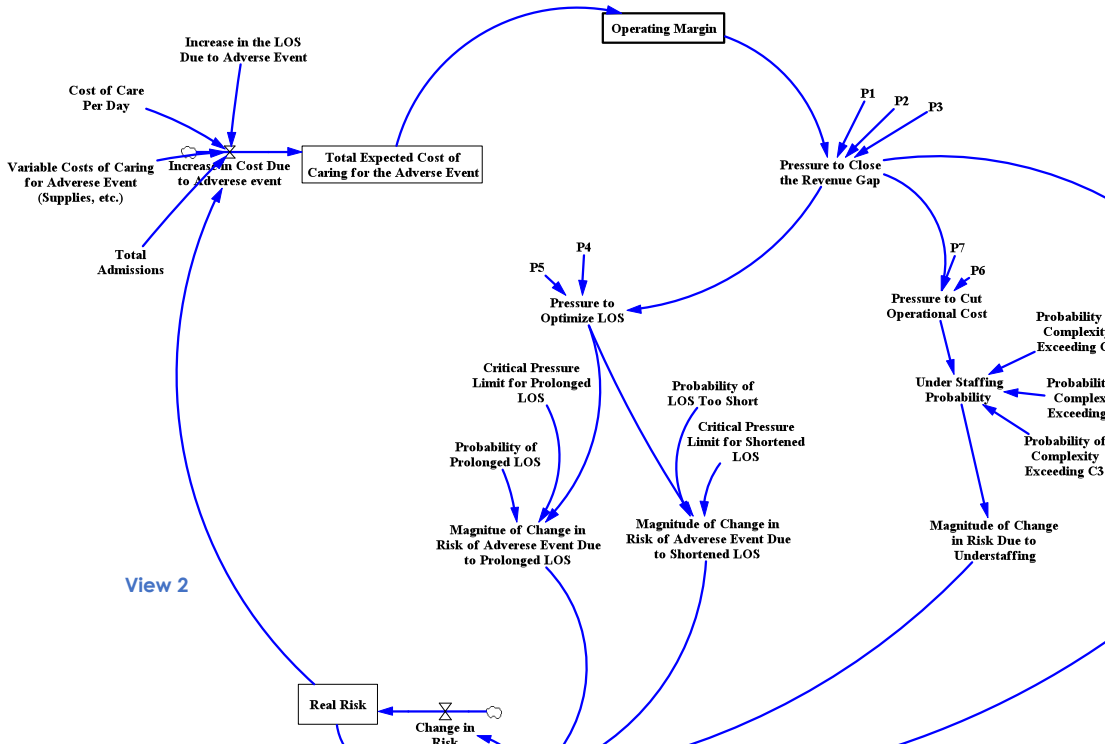
- Patients in hospitals are exposed to a certain level of risk of specific adverse events (e.g. pressure ulcer, line infection)



Model overview

View 1

View 2

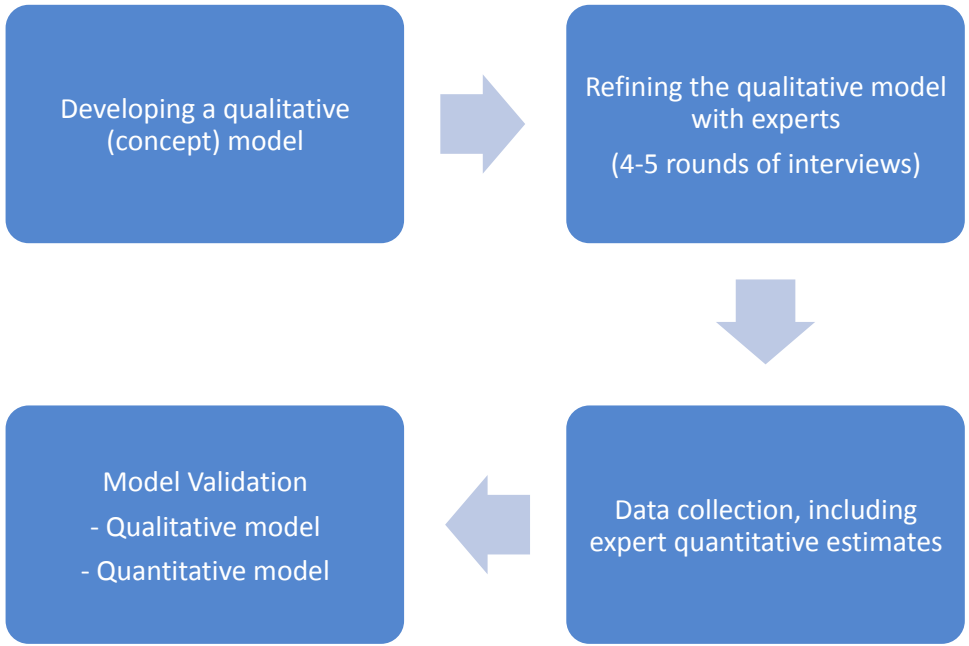


Data sources

- 8 years of clinical data
- Adverse event data; 10000 cases, 400 root-cause analysis
- 17 experts with average of 20 years of clinical experience

Model construction

- Overall 120 hours of expert interview



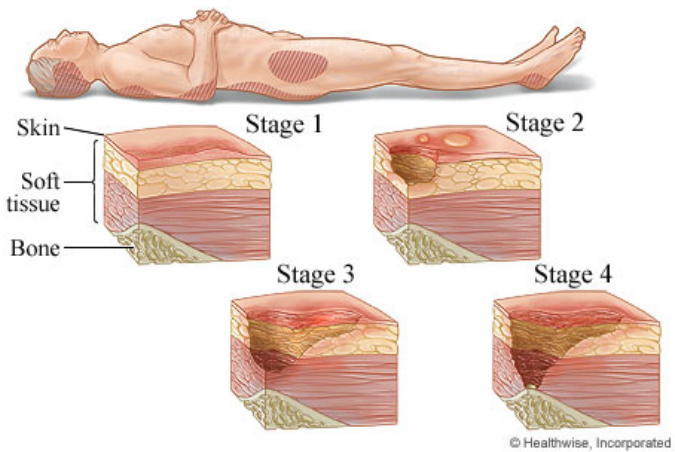
MODEL **ONE**

A Bayesian Belief Network Model for Risk of Pressure Ulcer

Pressure ulcer BBN model

- "Pressure Ulcer (PU) is a localized injury to the skin and/or underlying tissue usually over a bony area, as a result of pressure in combination with shear and/or friction" (NPUAP)
- 4 stages of severity

- Prevalence:
  - Estimated at 15% by NPUAP
  - Estimated cost an average of $25000 per patient (Lyder,2003)
  - Estimated Cost on healthcare as high as $11 billion (Reddy et al., 2006)



Current risk assessment tools for PU

Step 1 Set of internal and external factors (Mobility, nutrition, etc.)

Step 2 Assign a numerical value based on patient's conditions

Step 3 Compare the sum score to a threshold

Limitations
- Equal weighting
- Ignores synergic effects of factors

BRADEN SCALE FOR PREDICTING PRESSURE SORE RISK

Patient's Name _____ Evaluator's Name _____ Date of Assessment

SENSORY PERCEPTION ability to respond meaningfully to pressure-related discomfort	**1. Completely Limited** Unresponsive (does not moan, flinch, or grasp) to painful stimuli, due to diminished level of consciousness or sedation OR limited ability to feel pain over most of body.	**2. Very Limited** Responds only to painful stimuli. Cannot communicate discomfort except by moaning or restlessness OR has a sensory impairment which limits the ability to feel pain or discomfort over ½ of body.	**3. Slightly Limited** Responds to verbal commands, but cannot always communicate discomfort or the need to be turned OR has some sensory impairment which limits ability to feel pain or discomfort in 1 or 2 extremities.	**4. No Impairment** Responds to verbal commands. Has no sensory deficit which would limit ability to feel or voice pain or discomfort.				
MOISTURE degree to which skin is exposed to moisture	**1. Constantly Moist** Skin is kept moist almost constantly by perspiration, urine, etc. Dampness is detected every time patient is moved or turned.	**2. Very Moist** Skin is often, but not always moist. Linen must be changed at least once a shift.	**3. Occasionally Moist** Skin is occasionally moist, requiring an extra linen change approximately once a day.	**4. Rarely Moist** Skin is usually dry, linen only requires changing at routine intervals.				
ACTIVITY degree of physical activity	**1. Bedfast** Confined to bed.	**2. Chairfast** Ability to walk severely limited or non-existent. Cannot bear own weight and/or must be assisted into chair or wheelchair.	**3. Walks Occasionally** Walks occasionally during day, but for very short distances, with or without assistance. Spends majority of each shift in bed or chair.	**4. Walks Frequently** Walks outside room at least twice a day and inside room at least once every two hours during waking hours.				
MOBILITY ability to change and control body position	**1. Completely Immobile** Does not make even slight changes in body or extremity position without assistance.	**2. Very Limited** Makes occasional slight changes in body or extremity position but unable to make frequent or significant changes independently.	**3. Slightly Limited** Makes frequent though slight changes in body or extremity position independently.	**4. No Limitation** Makes major and frequent changes in position without assistance.				
NUTRITION usual food intake pattern	**1. Very Poor** Never eats a complete meal. Rarely eats more than ⅓ of any food offered. Eats 2 servings or less of protein (meat or dairy products) per day. Takes fluids poorly. Does not take a liquid dietary supplement OR is NPO and/or maintained on clear liquids or IVs for more than 5 days.	**2. Probably Inadequate** Rarely eats a complete meal and generally eats only about ½ of any food offered. Protein intake includes only 3 servings of meat or dairy products per day. Occasionally will take a dietary supplement OR receives less than optimum amount of liquid diet or tube feeding.	**3. Adequate** Eats over half of most meals. Eats a total of 4 servings of protein (meat, dairy products) per day. Occasionally will refuse a meal, but will usually take a supplement when offered OR is on a tube feeding or TPN regimen which probably meets most of nutritional needs.	**4. Excellent** Eats most of every meal. Never refuses a meal. Usually eats a total of 4 or more servings of meat and dairy products. Occasionally eats between meals. Does not require supplementation.				
FRICTION & SHEAR	**1. Problem** Requires moderate to maximum assistance in moving. Complete lifting without sliding against sheets is impossible. Frequently slides down in bed or chair, requiring frequent repositioning with maximum assistance. Spasticity, contractures or agitation leads to almost constant friction.	**2. Potential Problem** Moves feebly or requires minimum assistance. During a move skin probably slides to some extent against sheets, chair, restraints or other devices. Maintains relatively good position in chair or bed most of the time but occasionally slides down.	**3. No Apparent Problem** Moves in bed and in chair independently and has sufficient muscle strength to lift up completely during move. Maintains good position in bed or chair.					
				Total Score				

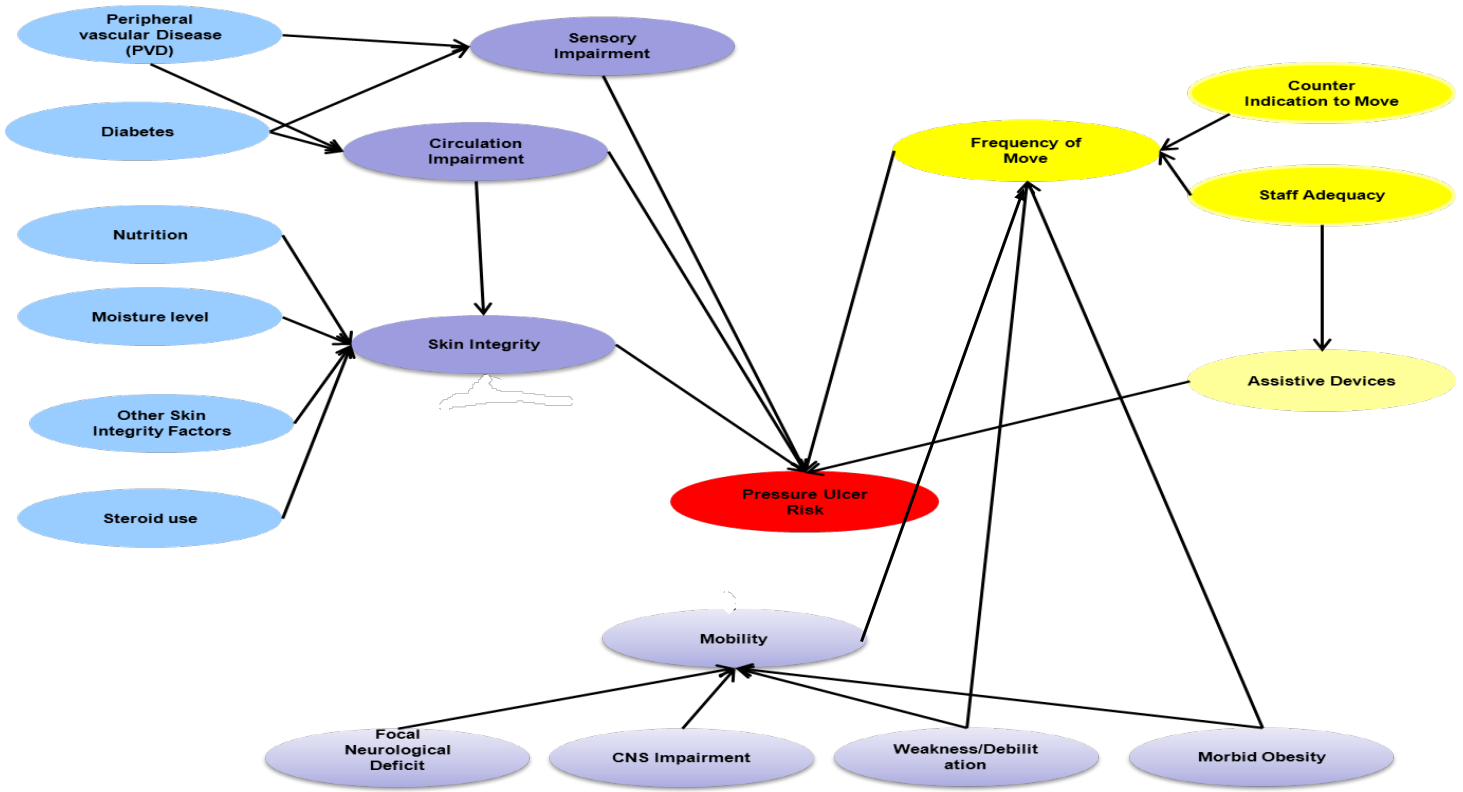
PU BBN development

- Bayesian Network are built based on the conditional probabilities, no equal weighting of the factors is assumed

- Using BBNs enables the analyst, to take into the account the fact that the degree of influence of one factor in risk of pressure ulcer may be different given the presence or absence of other risk factors.

- Bayesian Belief Networks are probabilistic in nature and the uncertainty in our assessment of pressure ulcer risk, given the state of all relevant risk factors can be expressed explicitly.

PU BBN model

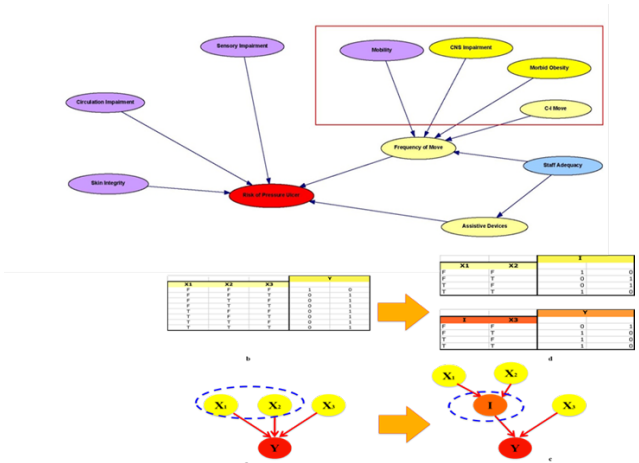

Peripheral vascular Disease (PVD)
Sensory Impairment
Diabetes
Circulation Impairment
Counter Indication to Move
Frequency of Move
Staff Adequacy
Nutrition
Moisture level
Skin Integrity
Assistive Devices
Other Skin Integrity Factors
Steroid use
Pressure Ulcer Risk
Mobility
Focal Neurological Deficit
CNS Impairment
Weakness/Debilit ation
Morbid Obesity

PU BBN model

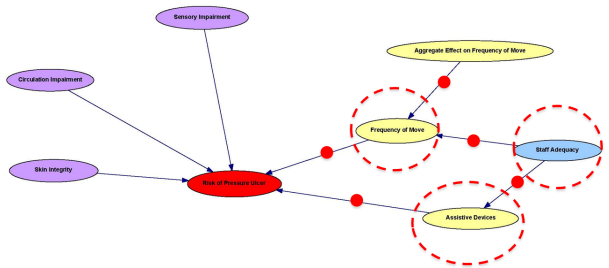
Factor	Description	Notes on quantification
Circulation Impairment	Poor blood circulation makes patients more susceptible to pressure ulcer	
Peripheral Vascular Disease (PVD)	Diseases of blood vessels outside heart or brain	
Sensory Impairment	Defect in sensing or passing on the impulse, which affects patients' ability to respond to pressure related pain and discomfort	
Skin Integrity	Description of whether patient's skin is intact	Normal or abnormal
Mobility	Patient's ability to change and control his/her body position	A patient with Focal Neurological Deficit, Central Nervous System Impairment, Weakness/Debilitation or Morbid Obesity has been counted as a case of impaired mobility
Frequency of Move	Whether the patient is being moved to different body positions frequently enough	Any patient with Central Nervous System Impairment, Morbid Obesity, Impaired Mobility or Counter Indication to Move (C-I Move) has been counted as patient with high aggregate effect on Frequency of Move
Assistive Devices	Include support surfaces such as cushions, mattress overlays, replacement mattresses or pressure relieving beds	Depends on their availability and also staff adequacy (whether or not the high level of workload prevents staff from providing patients with these devices)

Modeling techniques for quantification

- Structure related
  - Parent divorcing (Olesen, et al., 1989)



- Probability distribution related
  - Noisy-OR Gate (pearl, 1988)



Assumptions:

Xi's are each sufficient to cause Y

Xi's are independent of each other in causing Y

Xi has a probability , pi , of being sufficient to cause Y

Quantification

- 70,090 inpatients hospitalized over a 2 year period
- Queries were constructed to identify conditions that were present in two distinct cohorts of patients:
  - patients who did not acquire a pressure ulcer during hospitalization
  - patients who did
- In absence of clinical data, expert opinion were elicited and aggregated (Bayesian aggregation)
  - Example: Probability of use of assistive devices, given staff adequacy

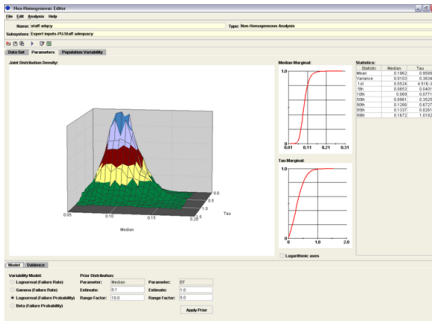
Bayesian aggregation

Expert Estimates

	Prob. Assistive Devices *Used* Given Staff Adequacy Situation	
Expert	**Adequate Staffing**	**In-adequate Staffing**
Expert 1	100%	20%
Expert 2	100%	25%
Expert 3	90%	40%
Expert 4	90%	30%
Expert 5	> 95%	20%
Expert 6	90%	25%

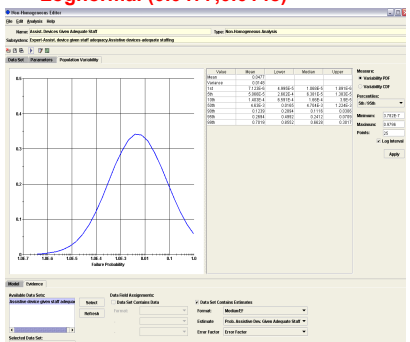
Bayesian Aggregation
(Mosleh and Apostolakis, 1986)

- **Unknown of interest x**



Distribution of parameters

Average Dist. Of Population variability
Lognormal (0.0477,0.0148)



- Integrating tools to increase the quality of model output, given the quality of available data

PU BBN validation

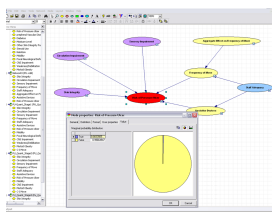
Model error

- The modifications made to model structure
- No possibility of calibrating expert opinion
- Model parameters quantified based on 2 years of reliable data
- Hospital acquired pressure ulcer data only available after 2008 (extrapolated for other years)

	Actual Relative Frequency from Data	BBN Model Prediction	% Error
Pressure Ulcer	2.20E-03	2.40E-03	8%

3

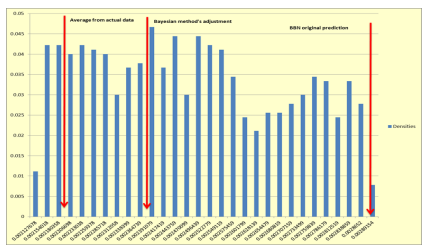
1



2

Model Prediction:
3.3 e -3
Actual data: 2.2 E-3
Errorr~30%

Bayesian method for model uncertainty treatment (Mosleh and Droguett 2008 , Droguett 1999)



Posterior mean:
2.4 e -3
Actual data: 2.2 E-3
Errorr~8%

Bayesian treatment for model uncertainty

- Prediction error
- Evidence: Model's prediction
- Objective: develop uncertainty distribution of PU probability given the evidence

- Available information; model performance
- Additive error model
- Flexible likelihood: Normal with mean

- Posterior function of parameters

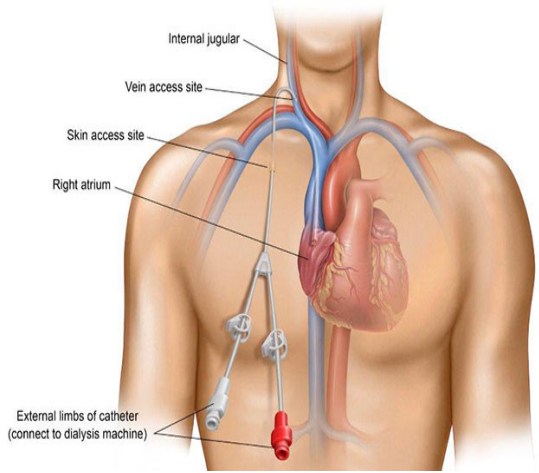
- Posterior of the new model prediction

MODEL **TWO**

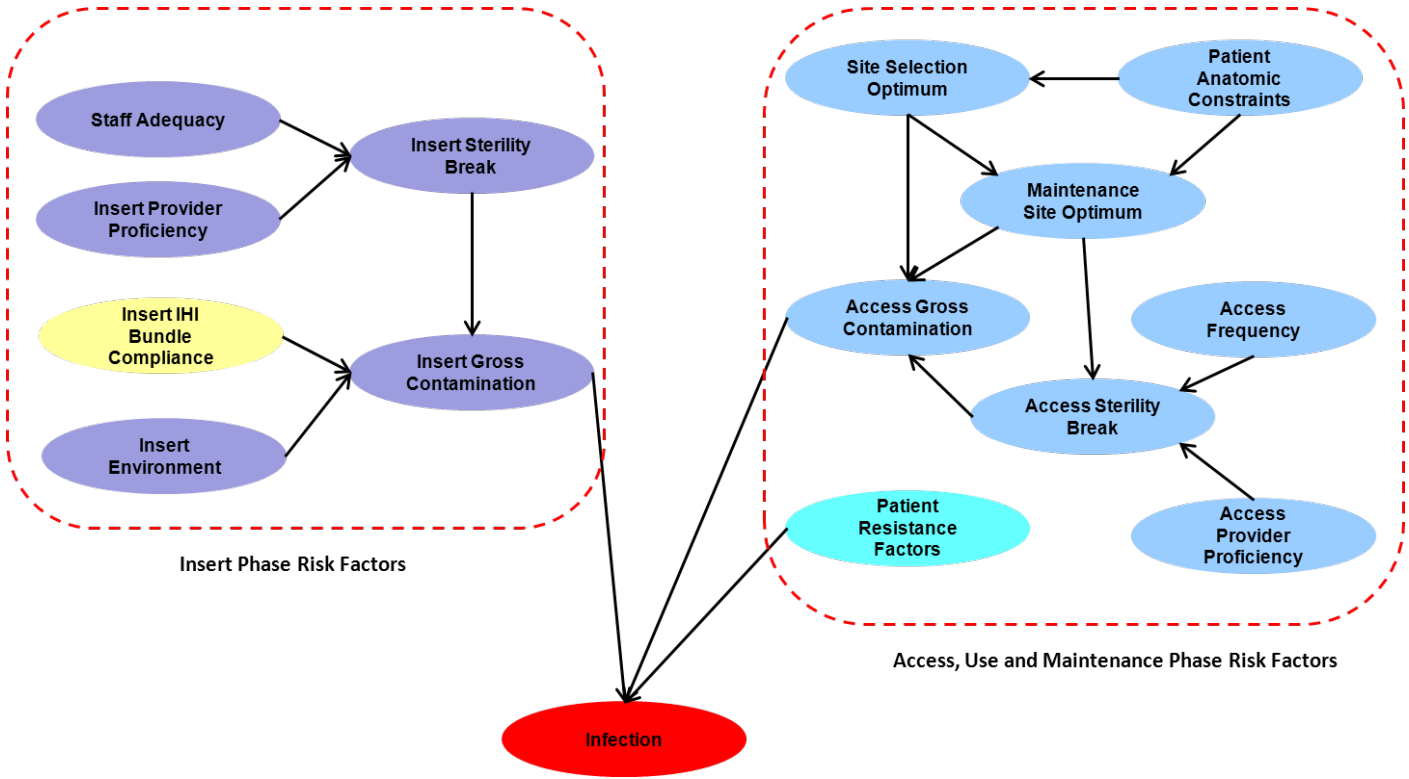
A Bayesian Belief Network Model for Risk of Risk of Vascular Catheter-Associated Infection

Background

- Central Venous Catheter (also called CVC, central line, or Vascular Access Device (VAD)), is a catheter that is placed into a large vein in the neck (internal jugular vein), chest (subclavian vein), or groin (femoral vein) to give medicines, fluids, nutrients or blood products to the patients
- An essential component of modern medical care
- One of the most commonly inserted medical devices
- One of the most common cause of hospital acquired bloodstream infection



Catheter infection BBN



Risk factors

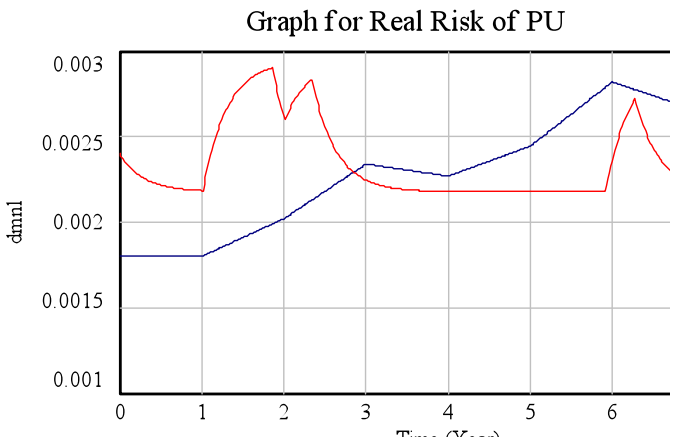
Factor	Description	Notes on quantification
Insert Environment	Bedside versus controlled environment	ICU patient room (a semi-controlled environment) or the operating or procedure room. suboptimal environment: trauma room, ED or regular non-ICU clinical unit, or during an emergency resuscitation.
Insert IHI Compliance	IHI bundle protocol hand hygiene, skin preparation,	Bundle checklist
Insert Provider Proficiency	Provider's experience, proficiency and judgment	
Staff Adequacy	Assistance to provider performing the procedure	Nursing or staff availability
Anatomic Constraints	Influences site selection, de novo vs. change, dressing change	True or false
Site Selection	Chest, neck, groin	Femoral access is considered suboptimal here.
Access Frequency	Frequency of port access	No widely accepted standard. Based on concurrent drug use. 4 or more IV infusions is considered high frequency.
Access Sterility break	Unrecognized break in sterility	Based on documentation of major break
Access Provider Proficiency	Provider's experience, proficiency and judgment	Primary nurse coverage
Patient Resistance Factors	Physiological and pharmacological	Evidence of profound immunosuppression such as acute lymphoma resulted in diminish resistance. Patients on broad-spectrum antibiotic are deemed high resistant.

Quantification and Validation

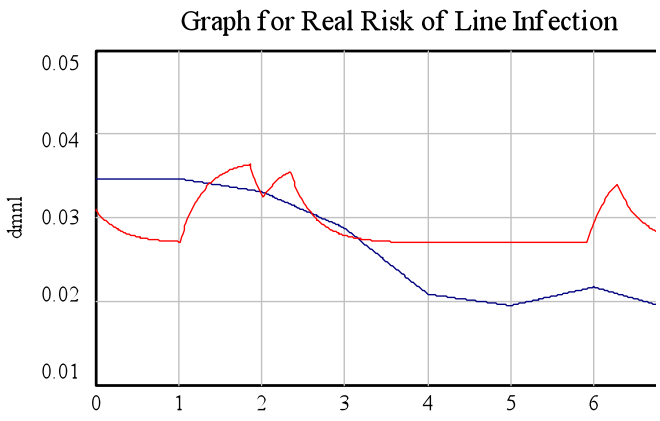
- Extracted data from ICU patients
  - Data is more reliable
  - Most lines are placed in ICU
  - 12897 records, 8 years

	Actual Relative Frequency from Data	BBN Model Prediction	% Error
Line Infection	3.06E-02	3.12E-02	2%

The hybrid model



Risk of PU; hybrid model predictions for each year versus actual data calibrating the model using both BBNs



Risk of line infection; hybrid model predictions for each year versus actual data calibrating the model using both BBNs

Could it be improved?

- More expert opinion, from a diverse set of hospitals, on the soft factors in the model

- More adverse event data from a variety of hospitals
  - finding clean reliable clinical data, could be challenging to say the least
- Meticulous modeling of the cost and reimbursement structure
- Modeling more adverse events

BACK UP