Agent-Based Modelling for Risk Assessment of Routine Clinical Processes

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Talk Outline

- Risk Assessment
  - Existing Approaches
  - Sociotechnical Systems
- The Patient Transfer Process
- Agent-Based Modelling
  - Brahms Agent Model
  - Misidentification Scenario
  - Infection Control Scenario
- Conclusion

Quality and Safety in Healthcare

- Safety = Freedom from hazard
  - Inversely related to risk
- Risk = Chance of adverse event
  - Influenced by exposure
- Adverse event = Incident resulting in harm
  - Measure of severity
- Risk Management = Risk Analysis + Mitigation
  - Reduce exposure
  - Focus on controllable conditions

➡ Cannot eliminate risk, only mitigate

Death Rates from Various Activities

Activity	Deaths per 100 million people per year
Being pregnant[12]	150
Working in the manufacturing industry[11]	240
Travelling by train[11]	2
Drowning in the bathtub[11]	120
Getting HIV from a unit of donated blood[13]	1
Being in traffic (overall in any capacity)[11]	15,000
Flying in a commercial aircraft[11]	50
Undergoing anaesthesia[14]	100
Being a patient in an acute-care hospital[15]	33,000
Parachute jumping[16]	9
Undergoing elective abdominal aortic surgery[17]	320
Undergoing emergency abdominal aortic surgery[18]	640

Adverse Event Rates (Medical Reviews)

Country in which the study was done	No of records studied	Adverse events % of admissions	Permanent harm and death % of admissions
Australia[15]	14,179	10.6	2.0
America[34]	14,565	~10.0[35]	2.0
Canada[36]	3,745	7.5	1.6
Denmark[37]	1,097	9.0	0.4
England[38]	1,014	11.7	1.5
New Zealand[39]	6,579	12.9	1.9

Main Types of Adverse Event

Problem with or failure of an operation or procedure[49]	18%
Hospital acquired infection[50]	16%
Wrong, delayed or missed – diagnosis or treatment[51]	14%
Complication of a body system[52]	11%
Hospital acquired injury[53]	8%
Medication error or problem with a drug[54]	7%
Pain, headache, nausea and vomiting, ileus, fever[55]	6%
Haemorrhage or haematoma[56]	5%
Maternal/foetal problem	3%
Thromboembolism, failure of or no prophylaxis	3%
Problem with a device, prosthesis, catheter, or cannula	2%
Unnecessary procedure	2%
Process problem (delayed admission, premature discharge)	2%
Problem from radiotherapy or chemotherapy	1%
Eye problem	1%
Miscellaneous	1%
TOTAL	**100%**

Sentinel Events

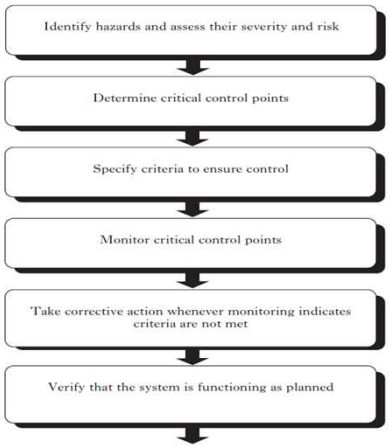
Type of adverse event	USA[85] % of 1579	Australia[86,87] % of 175
Suicide of an inpatient or within 72 hours of discharge	29	13
Surgery on the wrong patient or body part	29	47
Medication error leading to death	23	7
Rape/assault/homicide in an inpatient setting[88]	8	na[89]
Incompatible blood transfusion	6	1
Maternal death (labour, delivery)	3	12
Infant abduction/wrong family discharge	1	-
Retained instrument after surgery	1	21
Unanticipated death of a full-term infant	-	na[89]
Severe neonatal hyperbilirubinaemia	-	na[89]
Prolonged fluoroscopy	-	na[89]
Intravascular gas embolism	na[89]	-

Formal Approaches to Risk Analysis

- Root Cause Analysis
- Hazard Analysis and Critical Control Points
- Failure Mode and Effects Analysis
- Probabilistic Risk Assessment
  - Event/Fault Tree Analysis

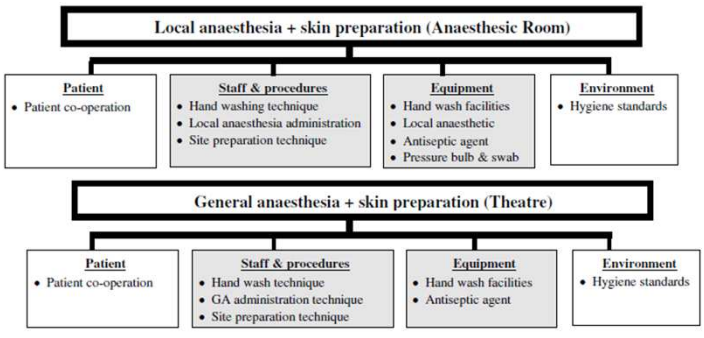
➧ Come from food, aviation, nuclear industries

Hazard Analysis Critical Control Points



- Qualitative approach to improve processes

Hazard Analysis Critical Control Points



- But no estimate of likely improvement

Failure Mode and Effects Analysis

1. Select a high-risk process to be reviewed.
2. Establish a multidisciplinary team that includes key stakeholders and those who actually perform the work process.
3. Collect baseline data.
4. Develop a flow chart of the entire process, which may be divided if it is lengthy or complex.
5. Identify all the potential failure points in each step of the process.
6. Describe the effects of the failure and the severity of the failure.
7. Identify the root cause or the most fundamental reasons for the potential failures in the process.
8. Assign a risk priority mumber (RPN) for each failure point. The RPN is calculated on the basis of the severity of the failure, the likelihood of the failure (error) reaching the patient, and the likelihood of the system detecting the error.
9. Develop strategies to reduce the risks in the process and to prevent failures--especially those areas with the highest RPN.
10. Implement strategies that decrease the likelihood of error occurrence, decrease the severity of effects of the error, and/or increase the probability of detecting errors.
11. Monitor compliance with the new work processes.
12. Collect data after implementation to measure outcomes and to detect any new failure points created by process changes.
13. Share the completion of the FMEA project with other departments and other institutions.

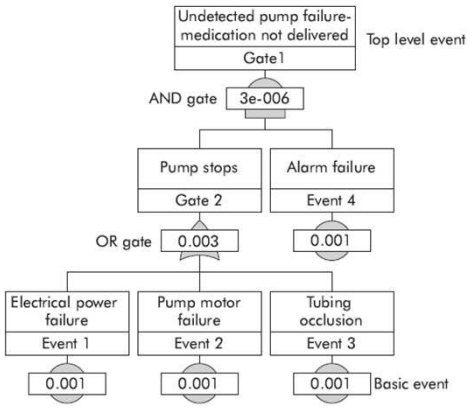
Failure Mode and Effects Analysis

Table 3. Risk Priority Numbers Assigned During the FMEA Process*

Potential Failure Modes	Frequency (Likeliness Scale 1-10)	Severity (Potential for Harm Scale 1-10)	Detectability (Potential Discovery Scale 1-10)	Risk Priority Number (RPN)
Prescribing	4	9	3	108
Dispensing	3	8	4	96
Administering	3	9	7	189

➧ Risk Priority Numbers are rough measures

Fault Tree Analysis (Logic+Probability)



➡ Focus on single events, not complex processes

Weaknesses of Existing Approaches

- Retrospective models do not show how to reduce risk
- Hard to estimate severity of adverse events
- Hard to compare different risk mitigation strategies
- Hard to estimate cost/benefit tradeoffs
- Models based on limited data or subjective factors
- Models do not capture unobserved or rare events

Healthcare as Sociotechnical System

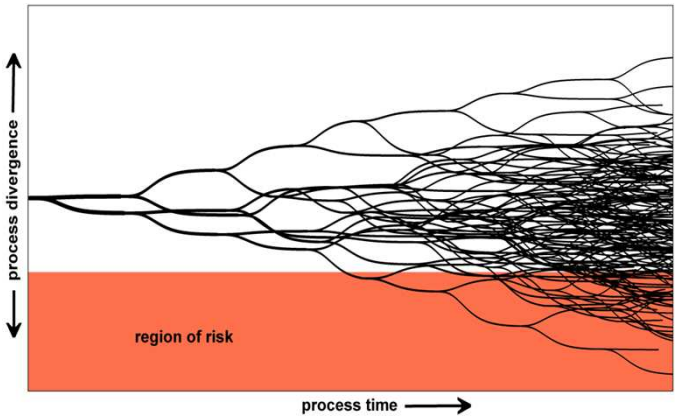
- Complex, dynamic, “non-linear” systems
  - Diverse range of activities and operations
  - Many convergent and divergent pathways
  - Need to model combinations of events
- Systems of humans and computers
  - Need to model “human factors”
  - Redundancy does not necessarily reduce risk
  - Diffusion of responsibility
- Patients are vulnerable
  - Increases liability to serious harm

Safety and Quality Tradeoffs

- Errors/mistakes/slips
  - Knowledge, rule or skill-based mistake
  - Forced or unforced errors
  - Outcomes subject to chance
- Violations
  - Deliberate deviation from standard work practice
  - May optimize work practice in response to time pressure
- Workarounds
  - Entrenched violation of work practice
  - May be unconscious “accepted practice”

➡ Need to model actual work practices

Agent-Based Modelling of Risk: Idea



- Risk creation, propagation, amelioration

Patient Transfer Process

1. Ward requests patient transfer
2. Radiology Coordinator initiates transfer
   a) Fills in Patient Transfer Form from information system
   b) Instructs Porter to transfer patient
3. Porter goes to ward, gives form to Ward Nurse
4. Ward Nurse signs-off patient ID, infection control
5. Porter transports patient to Radiology
   a) If nursing escort required, clinical handover to Radiology Nurse at Radiology

Patient Transfer Form

Medical Imaging staff have confirmed:

Ward
Full Name
Date of Birth
MRN

Destination: ☐ DSA ☐ General X-ray ☐ CT ☐ Fluoro ☐ Ultrasound ☐ MRI

Region / Procedure Name

Nurse Escort required: ☐ Yes ☐ No

Oxygen ☐ Yes ☐ No

On Arrival to Medical Imaging:

Patient (or person responsible) states correct name and DOB which matches patient ID and medical record? ☐ Yes

Mode of Transport: ☐ Bed ☐ Trolley ☐ Chai

Checked by (print name)
Signature (sign)

Precautions required in addition to standard precautions: ☐ Droplet ☐ Airborne ☐ Contact ☐ Protective isolation

Ward nurse in charge or ward nurse caring for the patient has confirmed:

Patient (or person responsible) states correct name and DOB which matches patient ID and medical record ☐ Yes

Nurse Escort required: ☐ Yes ☐ No

Patient notes and x-rays with patient ☐ Yes

Patient's red dot status: ☐ 1 ☐ 2 ☐ 3 ☐ 4

Checked by (print name)
Signature (sign)

Precautions required confirmed? (see above) ☐ Yes ☐ No

Observational Data

Inadequate handover of patient information	
Transfer form not used	7
Patient's name not handed over	2
Information omitted from transfer form (Radiology)	75
Infection control precautions	10
Destination	11
Escort	71
Oxygen	71
Transport mode	7
Information omitted from transfer form (ward)	56
Confirmation of patient ID check	36
Confirmation of patient documentation check	36
Name of nurse responsible	26
Signature of nurse responsible	30
Escort	30
Red dot status	32
Infection control precautions	34
Incorrect information in transfer form	16
Incorrect transport mode	5
Incorrect escort requirement	7
Incorrect ward	2
Incorrect control infection precautions	2
Incorrect oxygen requirement	2
Transfer form not signed off by ward nurse	25
Failure to verify patient identification	
Failed to perform identification check on patient collection	101
Ward nurse failed to verify ID band	91
Ward nurse failed to verbally verify patient's full name	100
Ward nurse failed to verbally verify patient's date of birth	100
Failed to perform identification check on arrival at Radiology	75
Radiology nurse failed to verify ID band	54
Radiology nurse failed to verbally verify patient's full name	43
Radiology nurse failed to verbally verify patient's date of birth	31
Patient did not have ID band	7
Error during transport	
Inadequate infection control precautions	12
Inadequate escort	9
Inadequate mode of transport	9
Equipment failure during transport	1
Poor organisation	
Patient not ready for transfer	31
Transport equipment unavailable	3

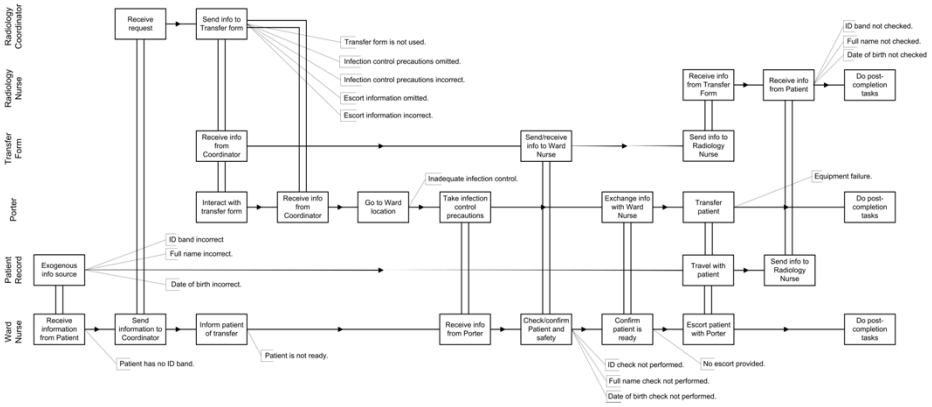
➡ 420 violations in 101 episodes

Brahms Agent-Based Model

- 6 Agents: Humans and Information Systems
  - Radiology Coordinator, Ward Nurse, Porter
  - Radiology Nurse, Transfer Form, Patient Record
- Beliefs
  - Patient ID, Infection control precautions, etc.
- 186 activities
  - 31 with probabilities assigned from observational data
  - Includes communication actions between agents that may not succeed or may not occur

➡ Situated: does not assume rational decisions

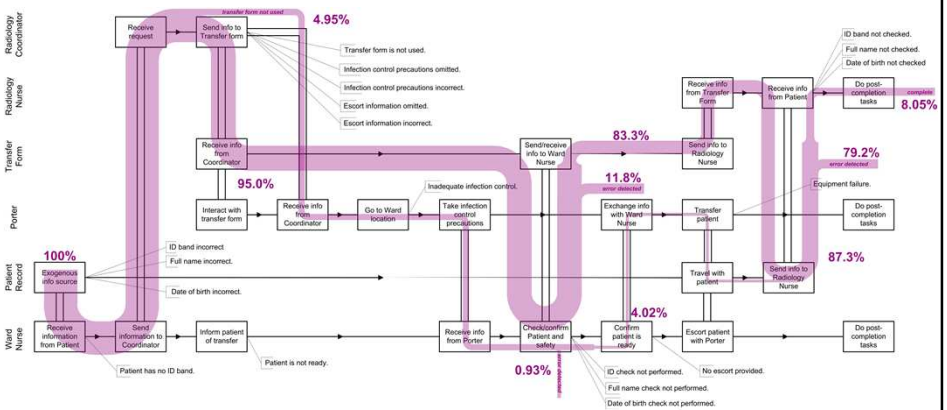
Patient Transfer Process



Estimating Within-Process Risk

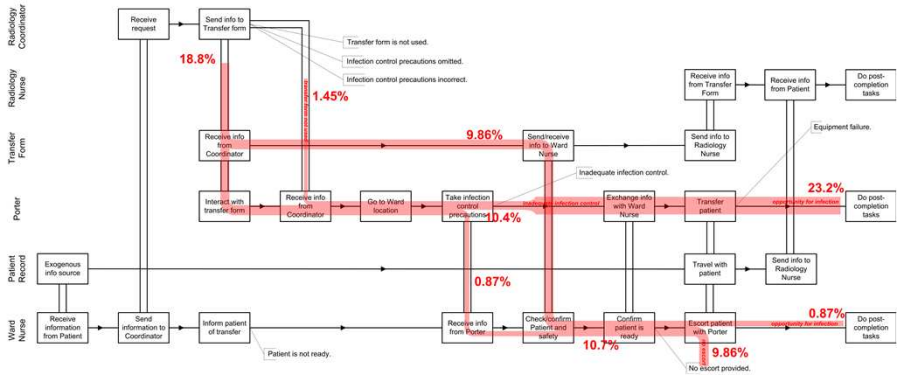
- Run simulator 500 times
- Misidentification Scenario
  - Assume the process starts with the wrong patient
  - Measure risk of still having wrong patient at the end
  - Risk reduces throughout the process
- Infection Control Scenario
  - Assume the process starts with infectious patient
  - Measure risk of inadequate controls being taken
  - Risk accumulates throughout the process

Misidentification Scenario



➤ 8% chance of misidentification at process end

Infection Control Scenario



➧ 23% chance of inadequate infection control

Validation of Model

- Misidentification Scenario
  - Cannot validate since no corresponding observations
- Infection Control Scenario
  - Observed 12 of 27 inadequate infection control
  - Simulation 80 of 345 inadequate infection control
- Number of simulations
  - 500 simulations to find trajectory that has $p=6x10^{-3}$ at 95% confidence
  - If true probability of event is 44%, 1000 simulations gives p=42%-47% at 95% confidence

Limitations of Model

- Assumes independence of events
  - Same probabilities across episodes
- Ignores contextual cues
  - Gender, obvious patient signs
- Ignores knowledge of agents
  - Trust some agents more than others
- Ignores variations between agents of same type
  - Some agents more unreliable than others

➡ Could be seen as a conservative estimate

Improving Patient Transfer

- Misidentification Scenario
  - Most captured but also much inefficiency
- Infection Control Scenario
  - Communication & procedural errors contribute equally
- Further redundant checks increase complexity
  - May not reduce risk due to additional workarounds
- Recommend reducing task complexity and enhancing effectiveness of current steps

➡ Interventions currently being evaluated

Advantages of Agent-Based Modelling

- Generalizes to any routine clinical process
- Captures combinations of events
- Captures timing and decision making
- Handles many distinct trajectories
- Greater precision than existing models
- Same model accounts for multiple scenarios
- Model includes unobserved and rare events
- Models “near misses” and unforeseen risks

Limitations of Agent-Based Modelling

- Requires a well defined workflow
- Does not identify new causes (c.f. SARS)
- Agent-based model is complex
- Constructing the model is time consuming
- Requires reliable observational data
- Observational data is only approximate
- Validation of the model is difficult

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