Why Risk Models Should be Parameterised

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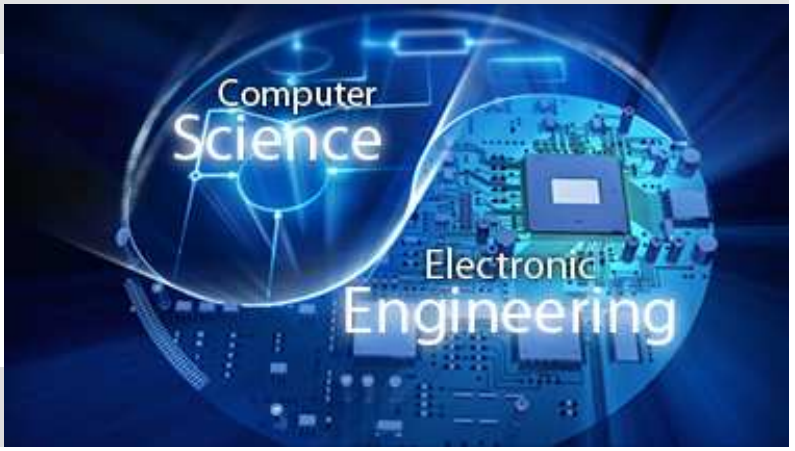


Acknowledgements

- Joint work with

  George Bearfield

  Rail Safety and Standards Board (RSSB), London

Aims

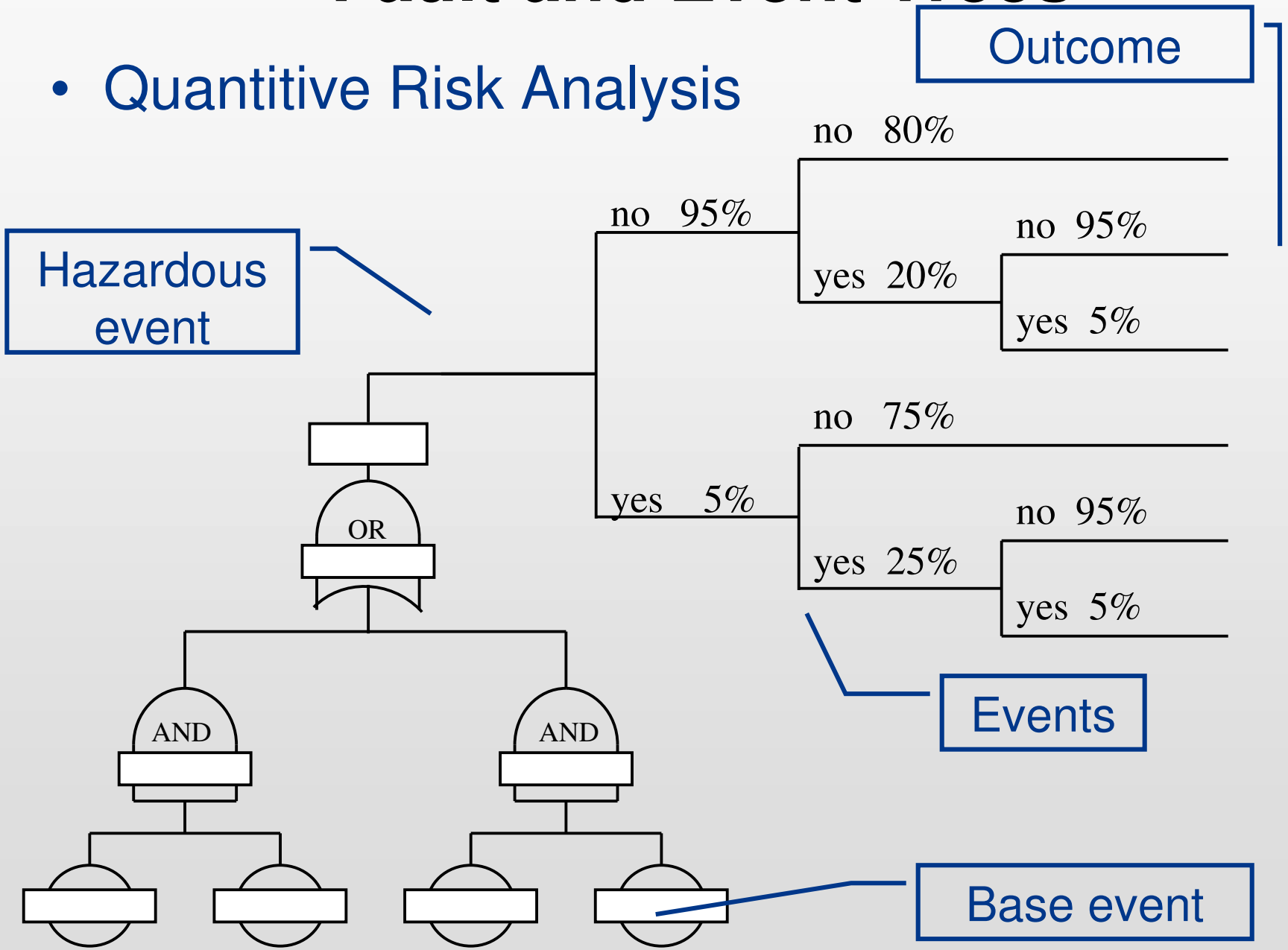
- Introduce idea of a '**parameterised risk model**'
- Explain how a **Bayesian Network** is used to represent a parameterised risk model
- Argue that a parameterised risk model is
  - Clearer
  - More useful

Outline

- Background
  - Risk modelling using fault and event trees
  - Bayesian networks
- An example parameterised risk model
- Using parameterised risk model

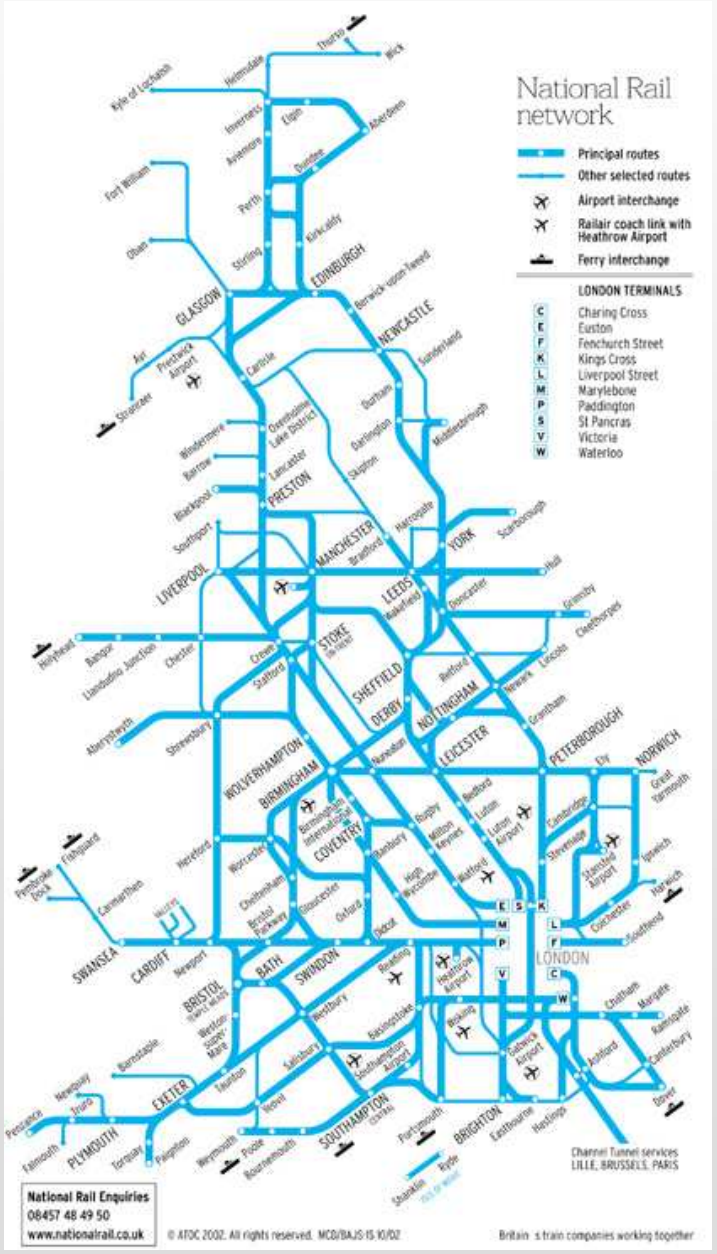
Fault and Event Trees

- Quantitive Risk Analysis



RSSB's Safety Risk Model

- 110 hazardous events
  - Fault and event trees
  - Data from past incidents
- UK rail network
  - Average
- Used to monitor risk for rail users and workers
- Informs safety decision making

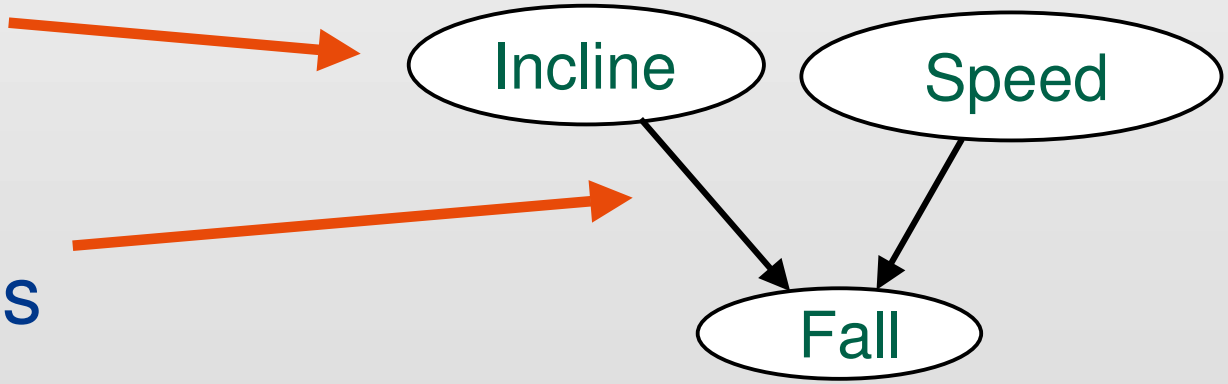


Bayesian Networks

$$P(A \mid B).P(B) = P(B \mid A).P(A)$$

Bayes' Theorem

- Uncertain variables
- Probabilistic dependencies



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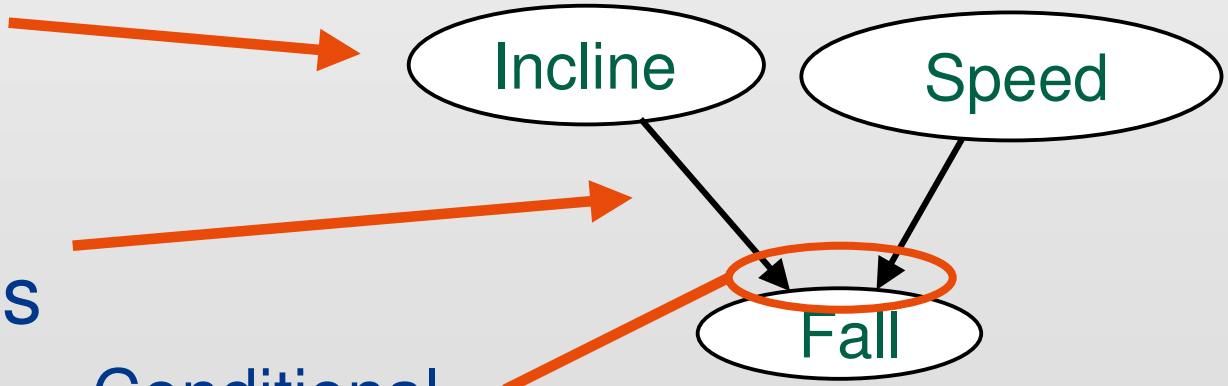

Conditional Probability Table

Bayesian Networks

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Bayes' Theorem

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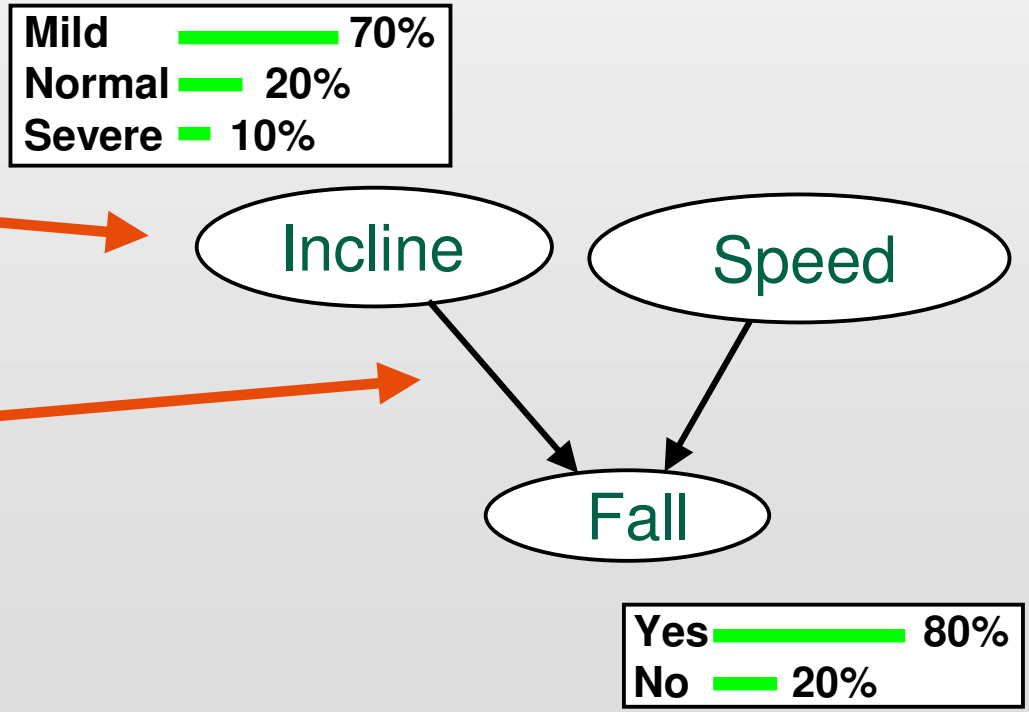
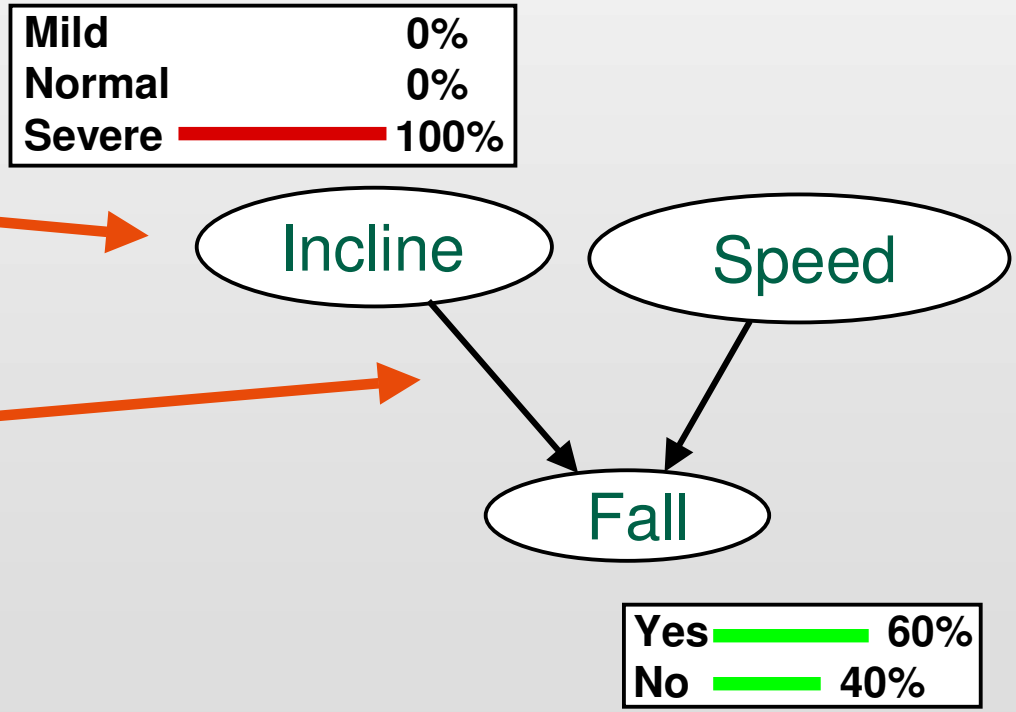


Bayesian Networks

$$P(A \mid B).P(B) = P(B \mid A).P(A)$$

Bayes' Theorem

- Uncertain variables
- Probabilistic dependencies
- Efficient inference algorithms

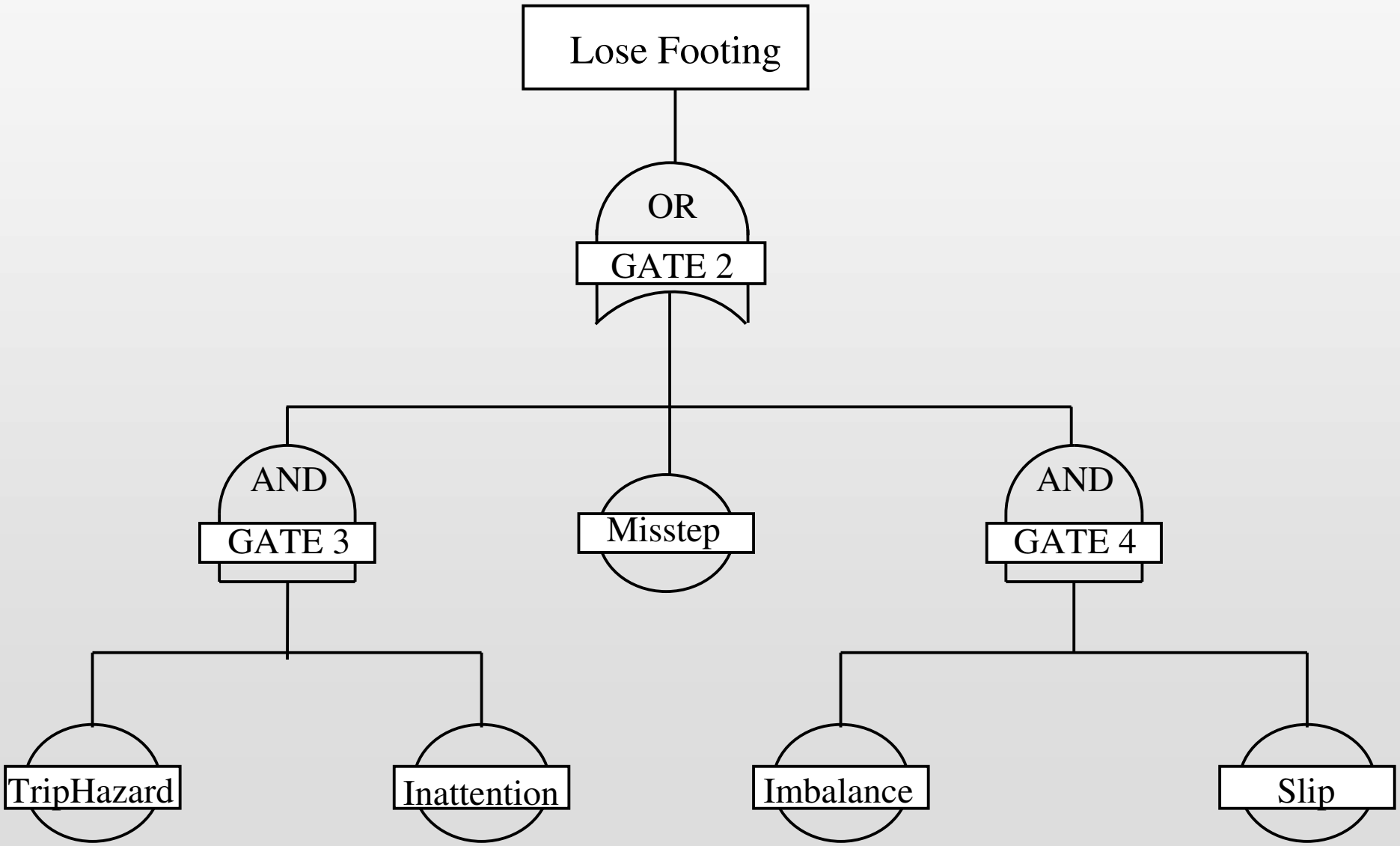


Example Parameterised Risk Model

Falls on Stairs

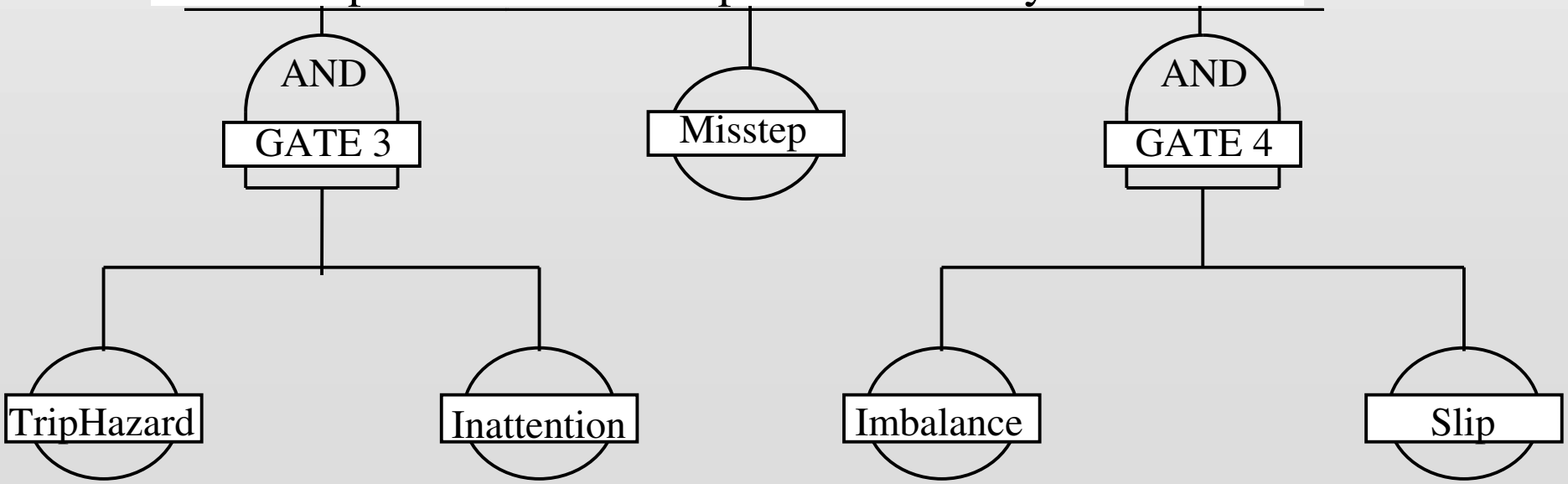
- *Falls on stairs common accident*
- *500 falls on stairs / year (2001)*
- *Influenced by*
  - *stair design & maintenance*
  - *the users' age, gender, physical fitness and behaviour*
- *Injuries*
  - *Non fatal: bruises, bone fractures and sprains …*
  - *Fatal injuries: fractures to the skull, trunk, lower limbs*

Fault Tree

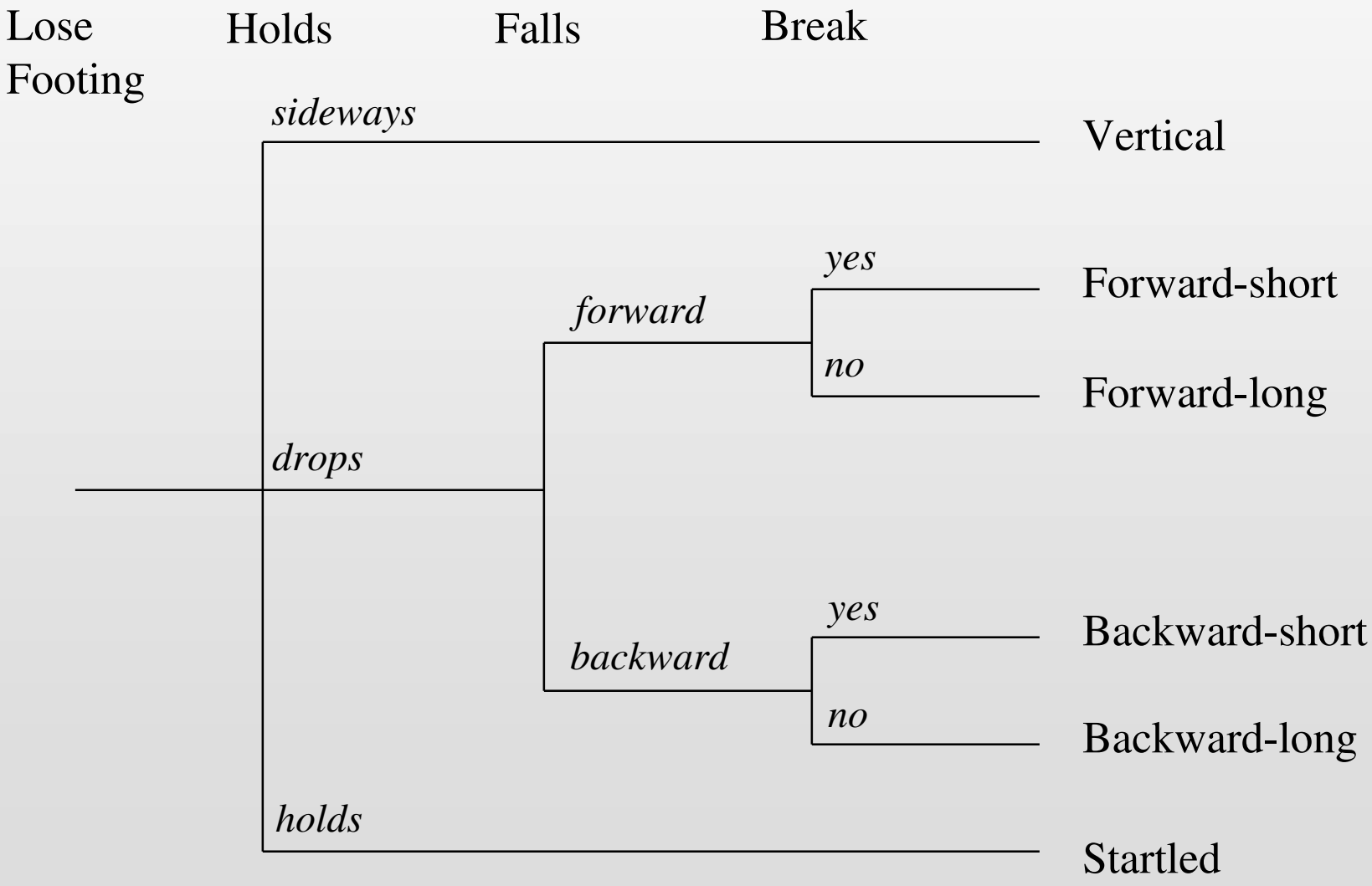

Lose Footing
OR
GATE 2
AND
GATE 3
Misstep
AND
GATE 4
TripHazard
Inattention
Imbalance
Slip

Fault Tree

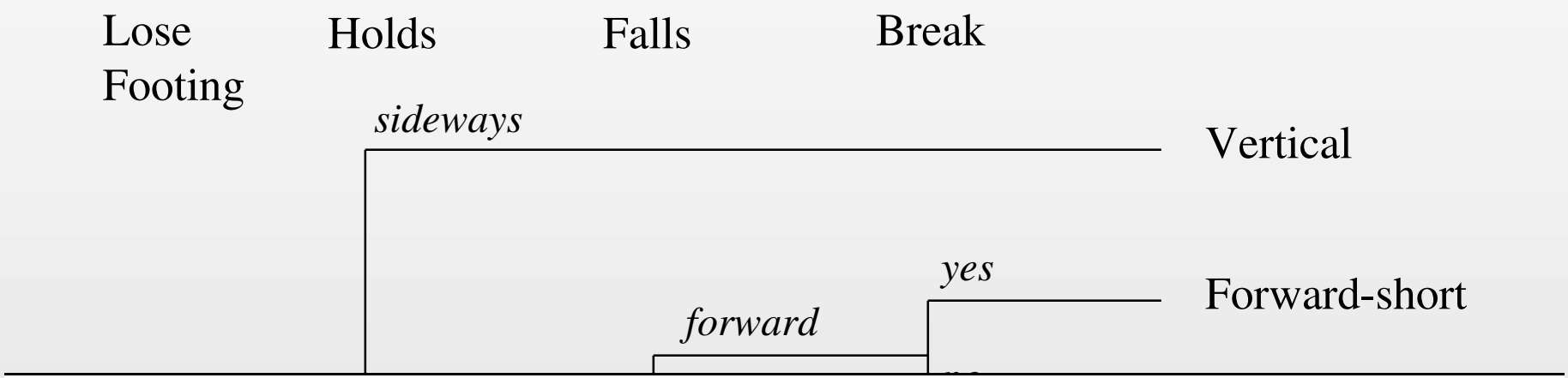
Failures	Description
TripHazard	Condition or design of stair covering creates a trip hazard
InAttention	Lack of attention to possible trip hazard
Imbalance	Imbalance causes sliding force between foot and step
Slip	Lack of friction causes foot to slip
Misstep	Foot not placed correctly on stair



Events and Outcomes



Events and Outcomes



Events	States	Description
Lose	*initiating*	
Holds	Holds, drops, sideways.	The person catches the railing, fall forwards or backward, or overbalances sideways into the stairwell.
Falls	Forward, backward	Person falls forwards or backwards
Breaks	Yes, no	Person breaks their fall at a landing

Can the Model be Generalised?

- Logic of accidents same (nearly) but numbers vary with design
- Reuse logic
- Estimating probabilities once only

Factors – Risk Model Parameters

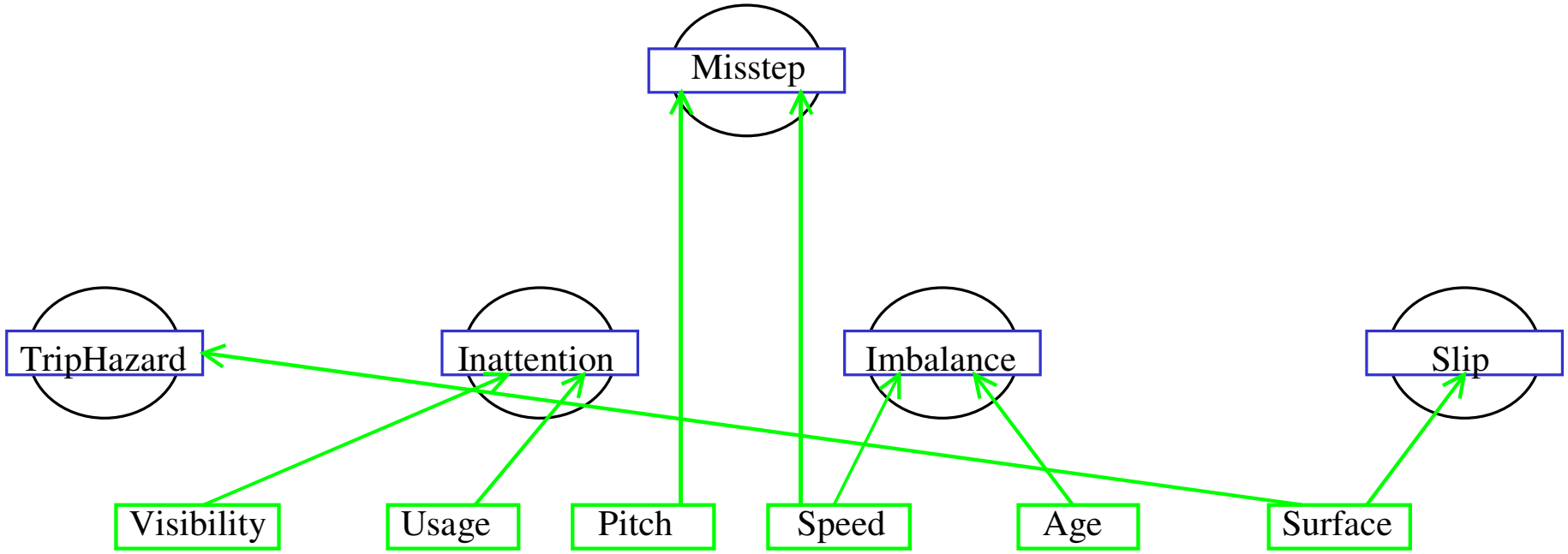
- Factors with discrete values

Factor	Description	Values
Age	Age of the person.	young / old
Design	An open staircase has not sidewall. A straight staircase is a single flight, not broken by landings.	open / straight / landings
Length	The length of the stairs, as determined by the number of steps.	short / long
Pitch	The pitch of the staircase.	gentle / steep
Surface	The material exposed on the floor.	wooden / concrete / carpeted
Speed	The speed with which the person descends the stairs (before falling).	normal / fast
Usage	Are the stairs used by a single person at a time ('single') or many people or a rush of people?	single / many / rush
Visibility	How easy it is to see the steps. Visibility may be enhanced by contrasting colours of the edge of the steps.	enhanced / lighted / poor
Width	The width of the steps (not the width of the tread).	wide / narrow

Factors to Base Events

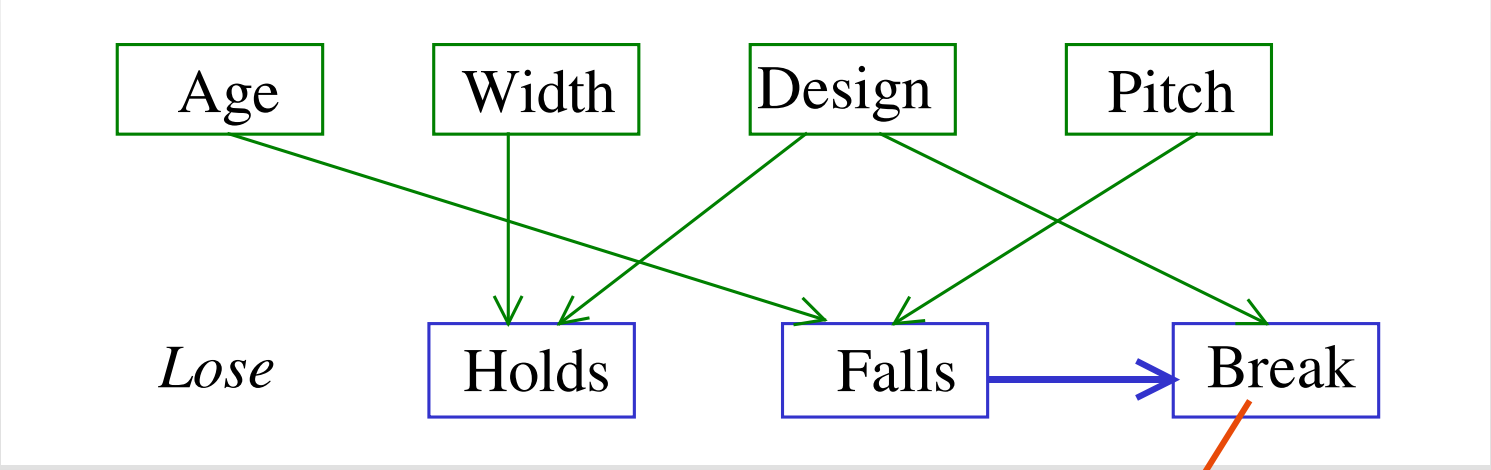
- Base event probabilities depend on factors

Age	Young		Old	
Speed	Normal	Fast	Normal	Fast
Imbalance=True	0.001	0.002	0.003	0.005



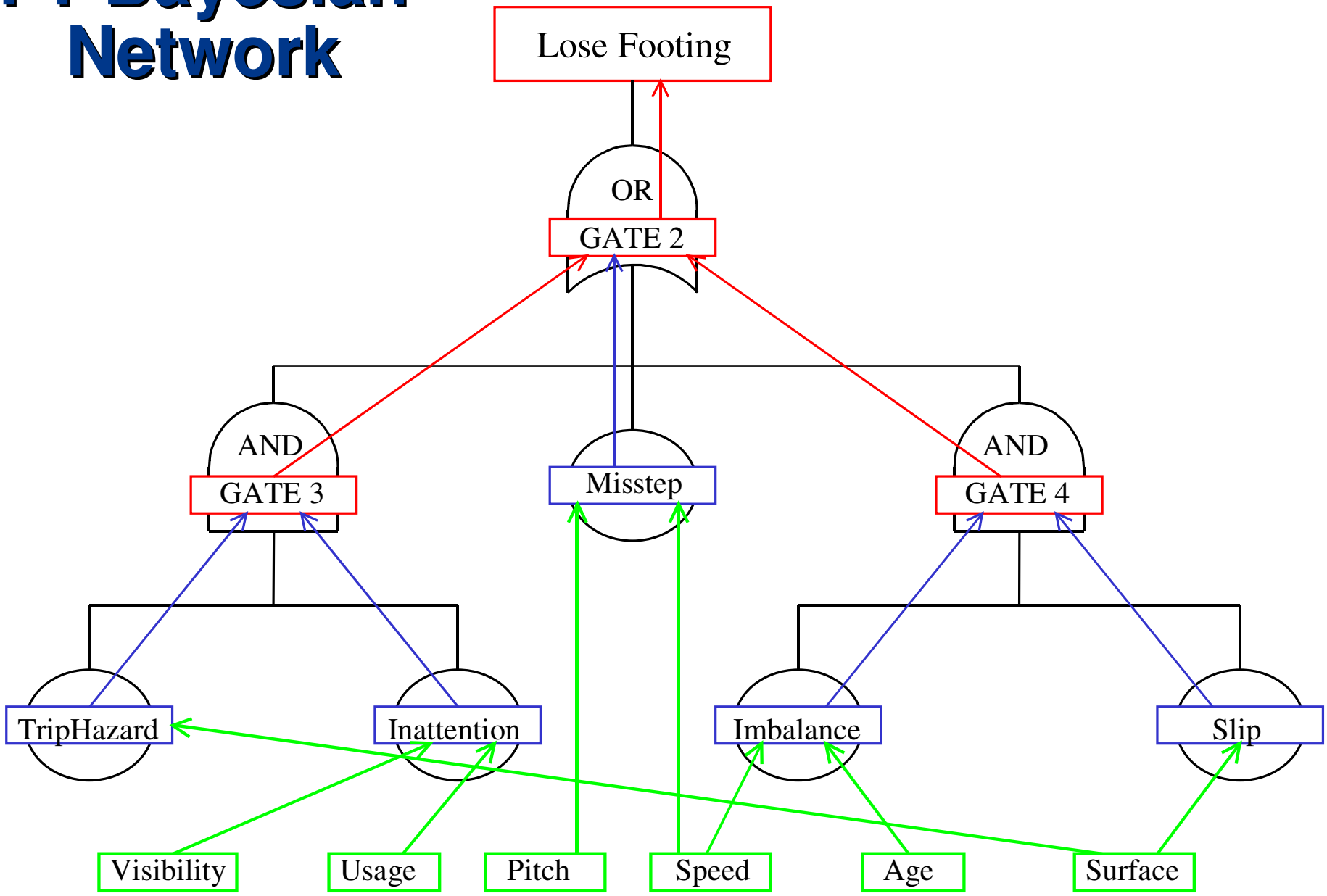
Factors to Events

- Probabilities of event branches depend on factors
- … also on earlier events

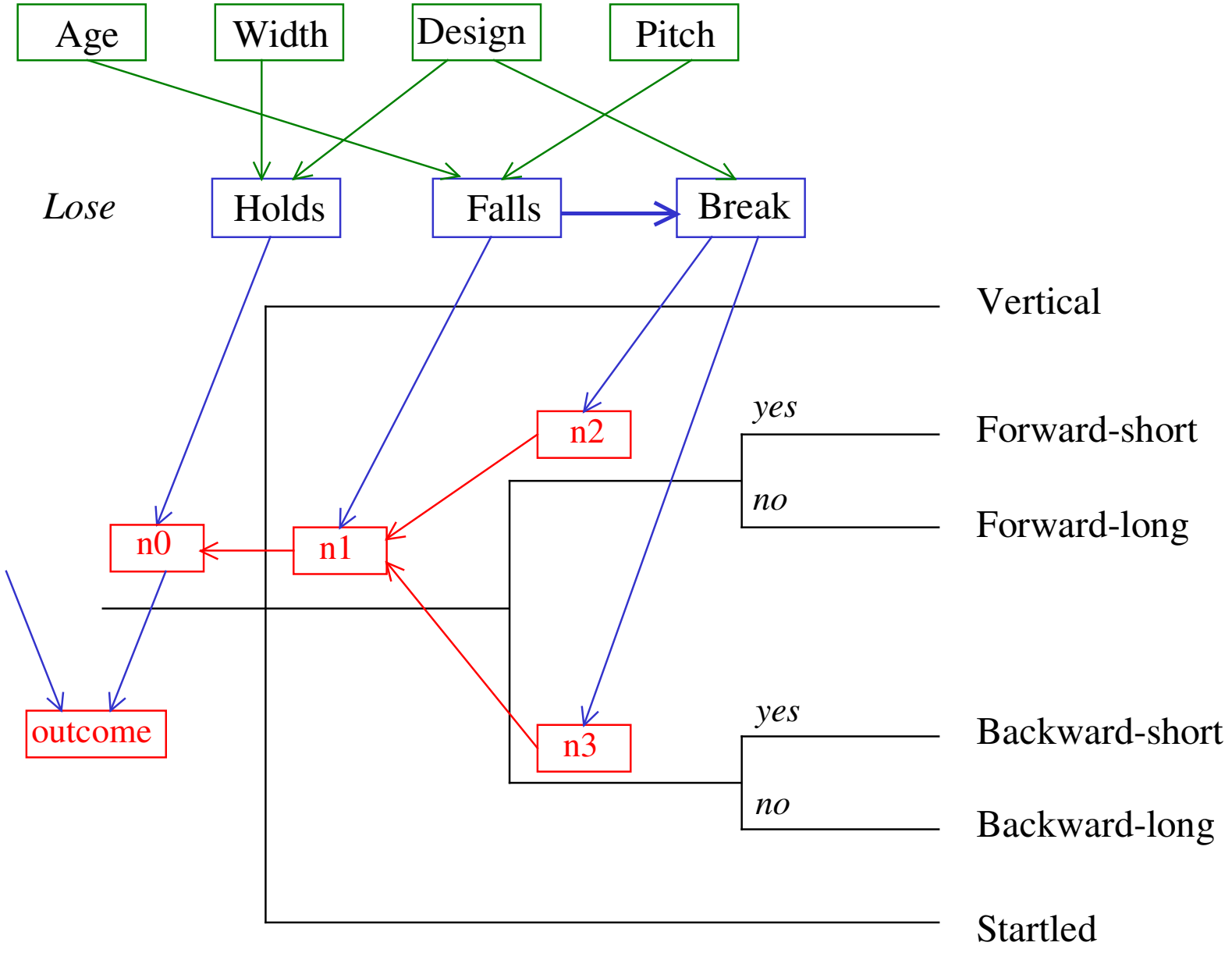


Falls	Backwards			Forwards		
Design	**Open**	**Straight**	**Landings**	**Open**	**Straight**	**Landings**
Breaks=Yes	40%	50%	90%	50%	75%	95%
Breaks=No	60%	50%	10%	50%	25%	5%

FT Bayesian Network

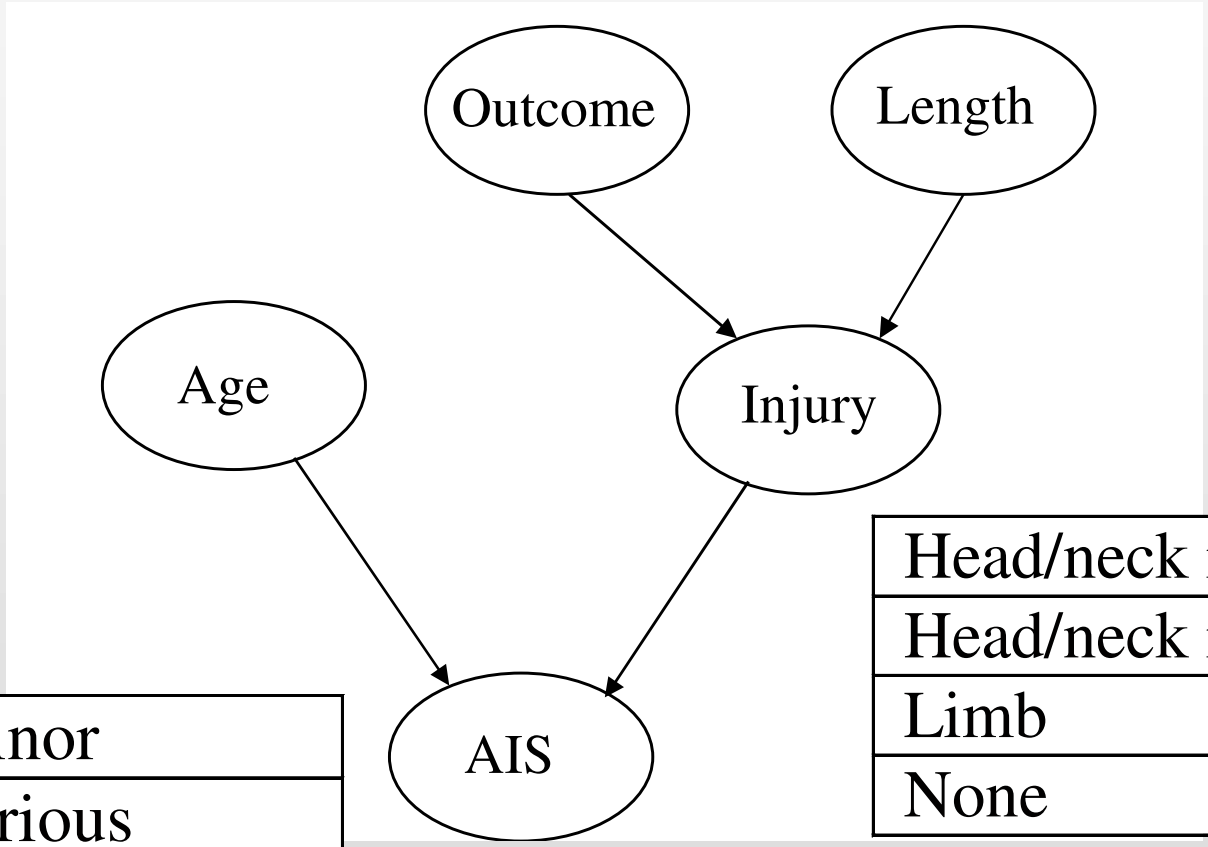


Event Tree Bayesian Network



Accident Injury Score (AIS)

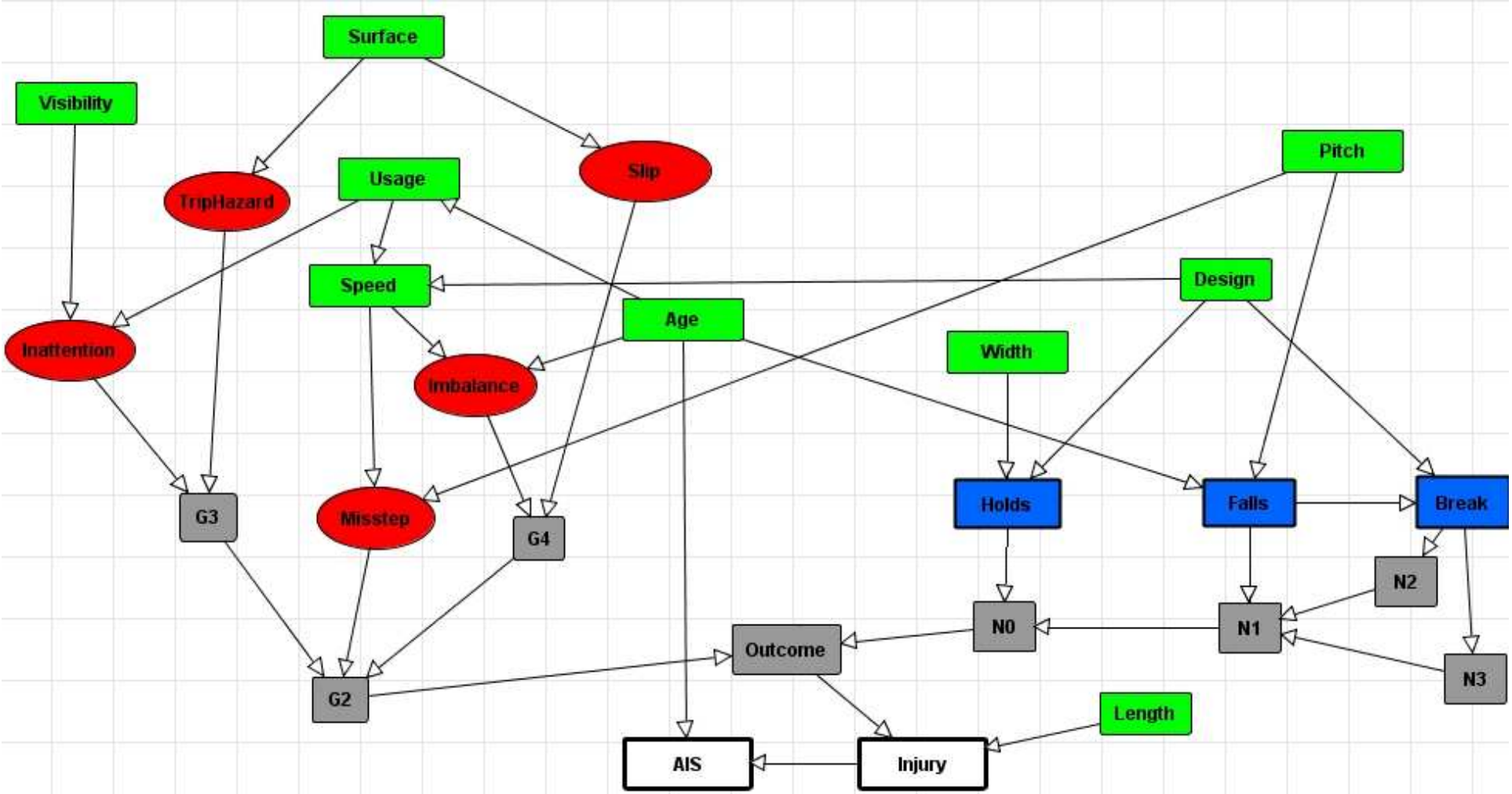
- Harm from accident



1-2	Minor
3-4	Serious
5	Critical
6	Unsurvivable

Head/neck major
Head/neck moderate
Limb
None

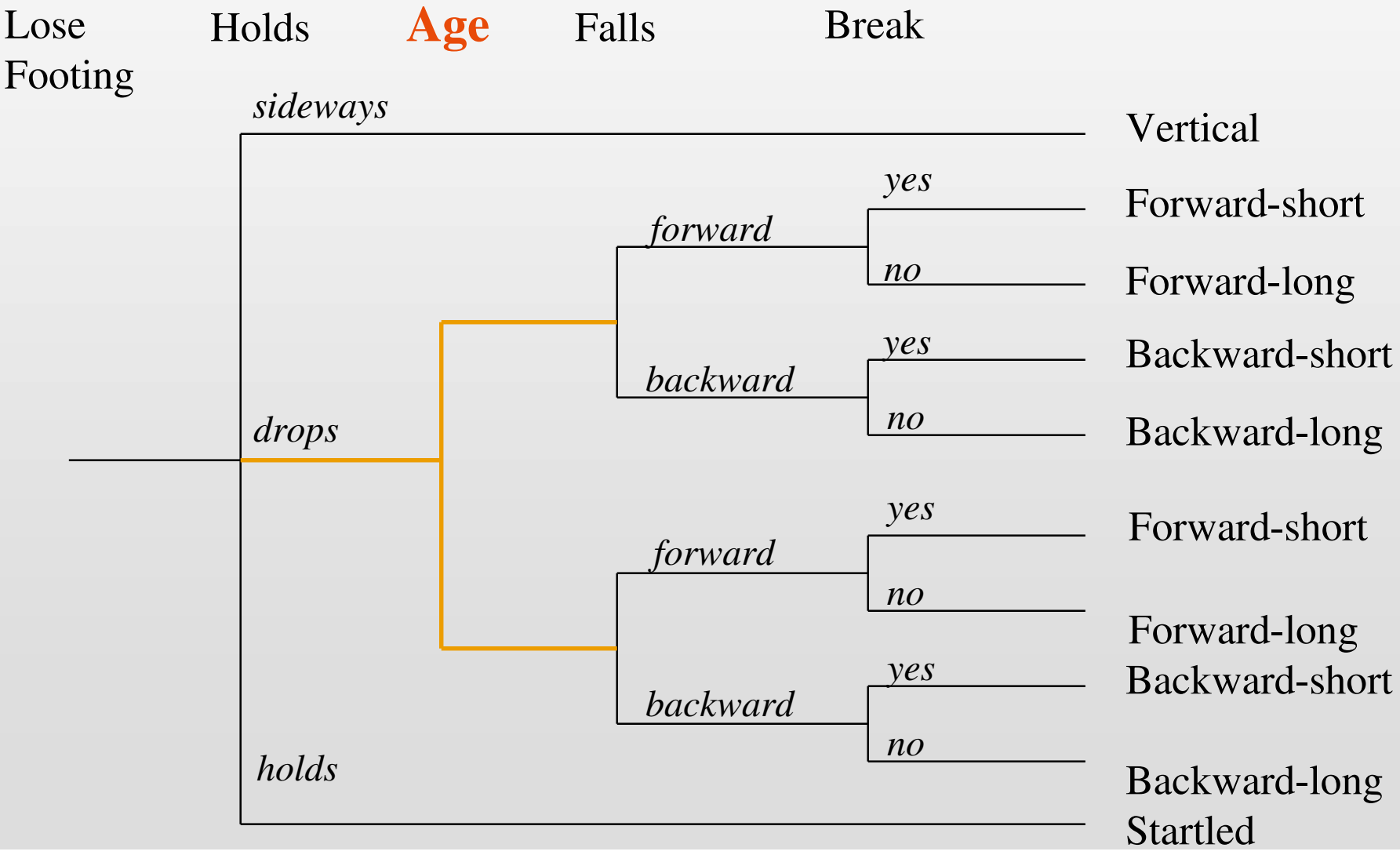
Complete Bayesian Network



AgenaRisk see: http://www.agenarisk.com/

Explicit Factors make Clearer Models

- Are there factors in the fault or event tree?

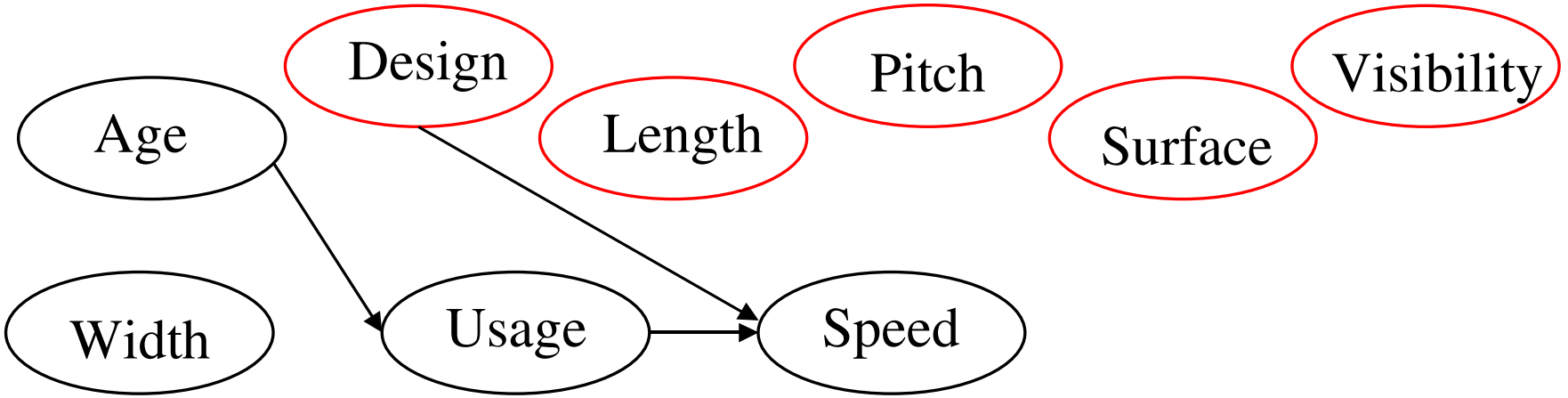


Using the Parameterised Model

- Reuse of the model
- Modelling multiple scenarios

Using the Parameterised Model

- Observe (some) factors



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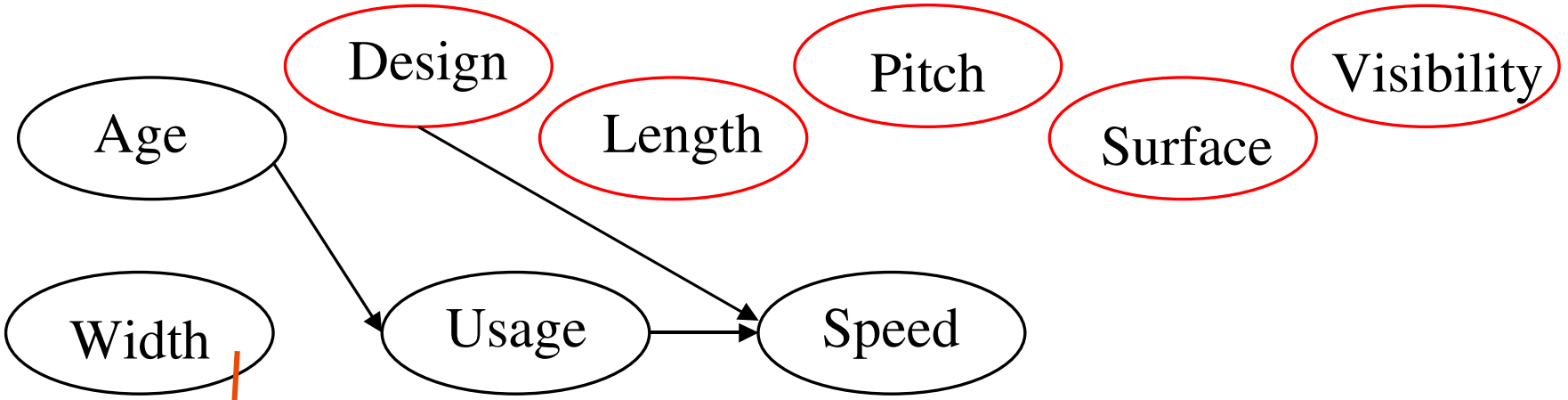
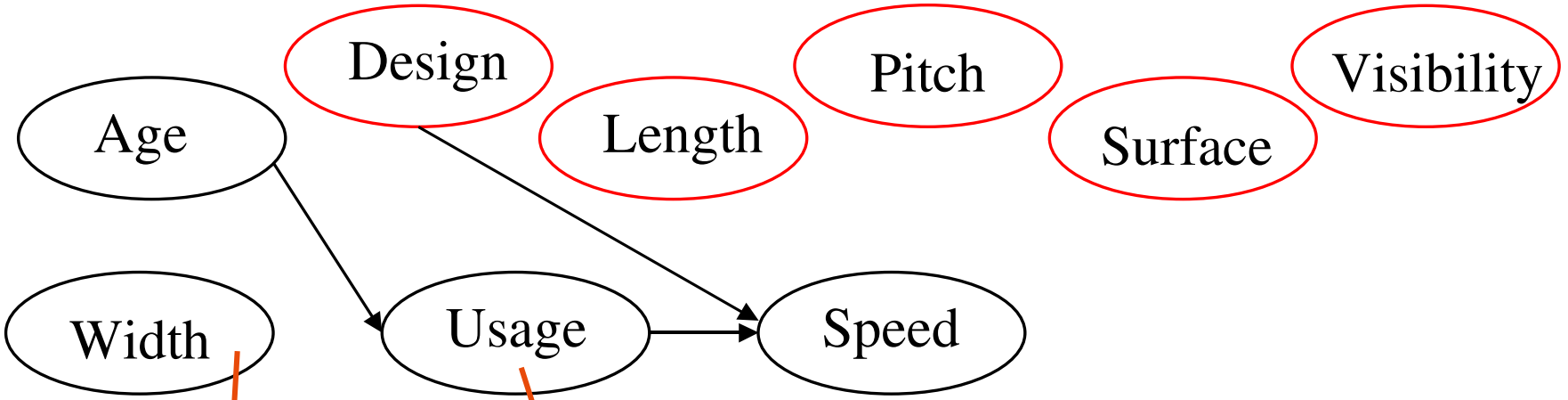


Prior probability distribution

Age=Young	65%
Age=Old	35%

Using the Parameterised Model

- Observe (some) factors



Prior probability distribution

Age	Young	Old
Usage=Single	10%	80%
Usage=Many	50%	20%
Usage=Rush	40%	0%

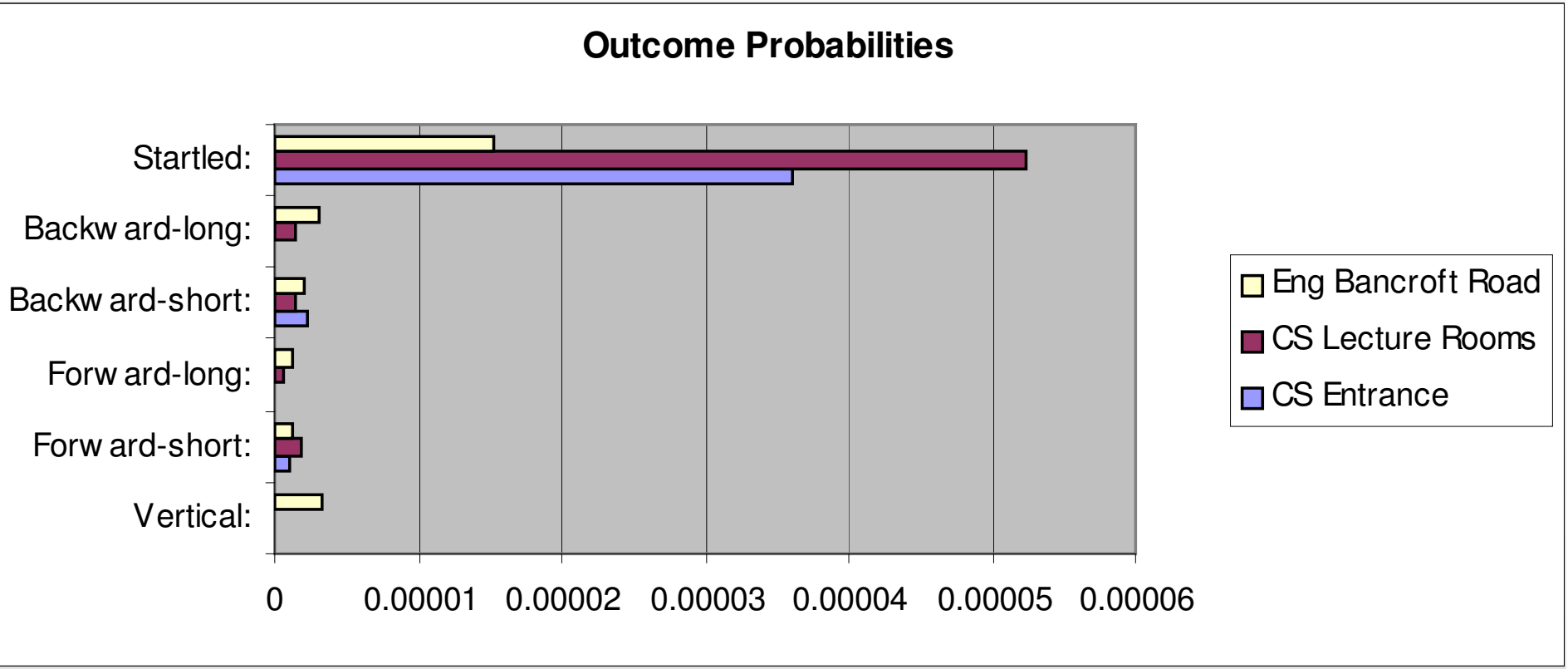
Age=Young	65%
Age=Old	35%

Using the Parameterised Model

- Suppose 3 stairs
  - Value of each observed factor

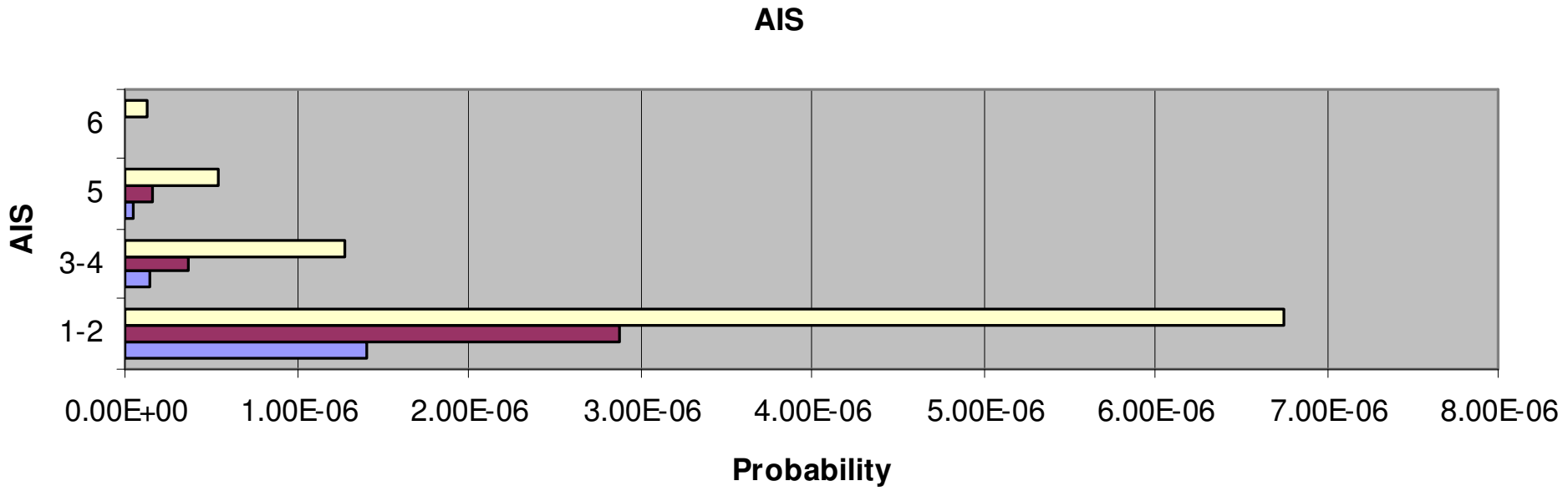
	Design	Length	Pitch	Surface	Vis
CS, Entrance	Landing	Short	Gentle	Carpeted	Poor
CS, Lecture Rooms	Straight	Long	Steep	Wooden	Enhanced
Eng, Bancroft Road	Open	Long	Gentle	Concrete	Lighted

Results – Outcome



- Probability distribution
  - Outcome of a ‘stair descent’
  - Hidden ‘nothing happens’ outcome

Results – Accident Injury Score



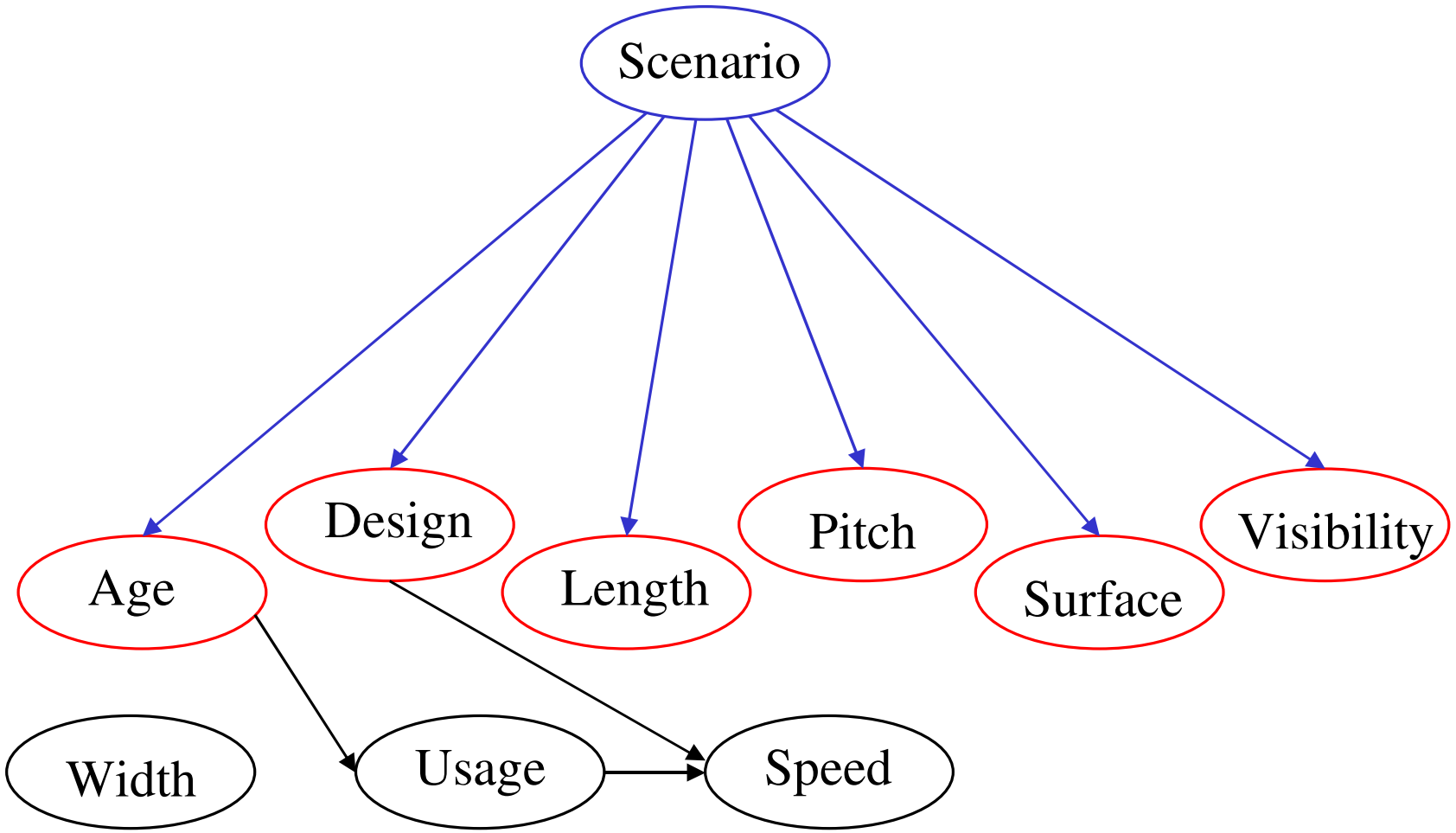
AIS	Accidents Per Year		
	CS Entrance	CS Lecture Rooms	Eng Bancroft Rd
1-2	0.153	0.518	4.864
3-4	0.016	0.066	0.920
5	0.006	0.029	0.397
6	0.001	0.003	0.096

System Risk

- University has many stairs in different buildings
- How to assess the total risk?
- Solution 1
  - Used parameterised model for each stairs
  - Aggregate results
- Solution 2
  - Model ‘scenario’ in the Bayesian Network
  - Scenario: each state has shared characteristics e.g. geographical area

Scenario

- Each value is a ‘scenario’ for which we wish to estimate risk



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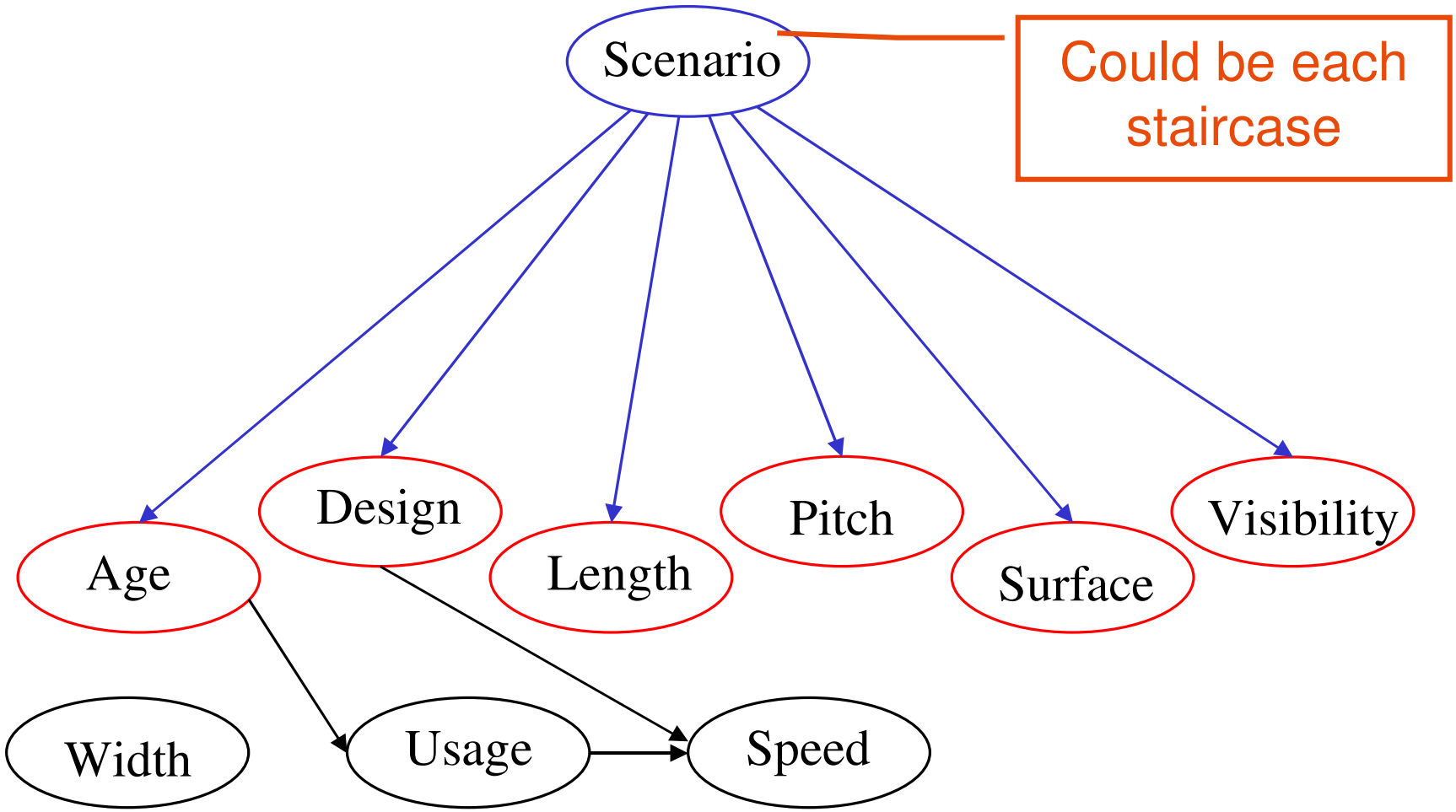

Imprecise Scenarios

- Imagine three departments
  - Factors do not have single value
  - Probability distribution over factor values

	Age	Design	Length	Pitch
Maths	Young: 80% Old: 20%	Landing: 80% Straight: 15% Open: 5%	Short: 50% Long: 50%	Gentle: 25% Steep: 75%
Law	Young: 70% Old: 30%	Landing: 70% Straight: 30% Open: 0%	Short: 75% Long: 25%	Gentle: 75% Steep: 25%
Arts	Young: 60% Old: 40%	Landing: 50% Straight: 50% Open: 0%	Short: 30% Long: 70%	Gentle: 50% Steep: 50%

Exposure

- Some scenarios more common
- Distribution of ‘stair descents’

Scenario	Maths	Laws	Arts	Total
Daily descents	3000	1500	2000	6500
Proportion	46%	23%	31%	

Exposure

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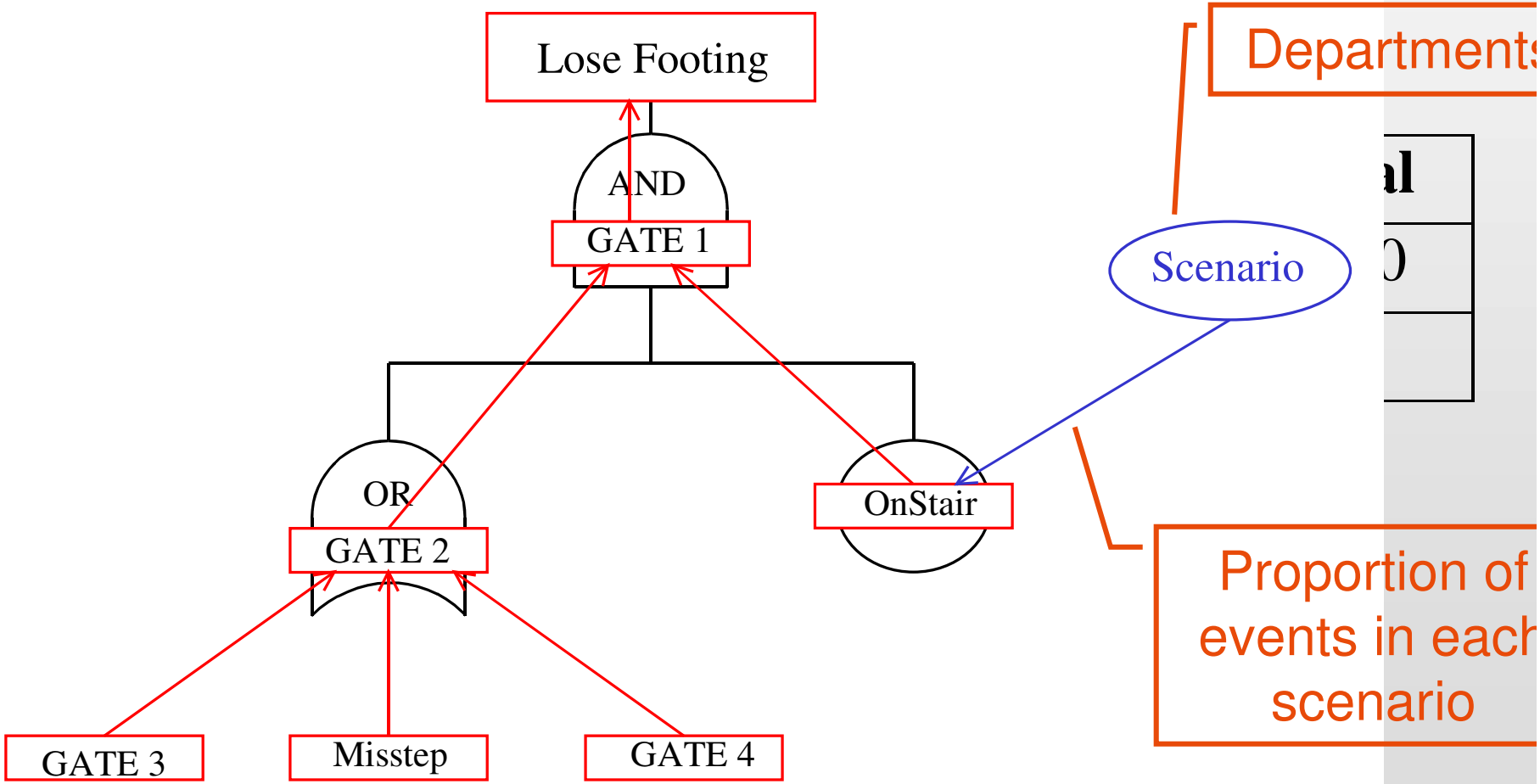
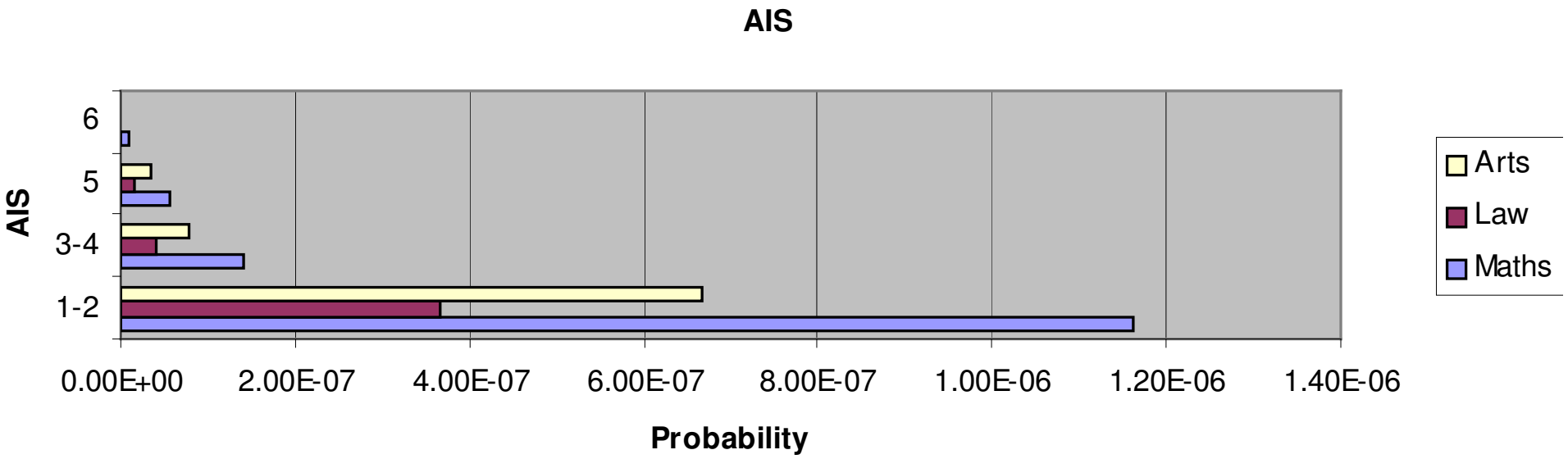


Using the System Model

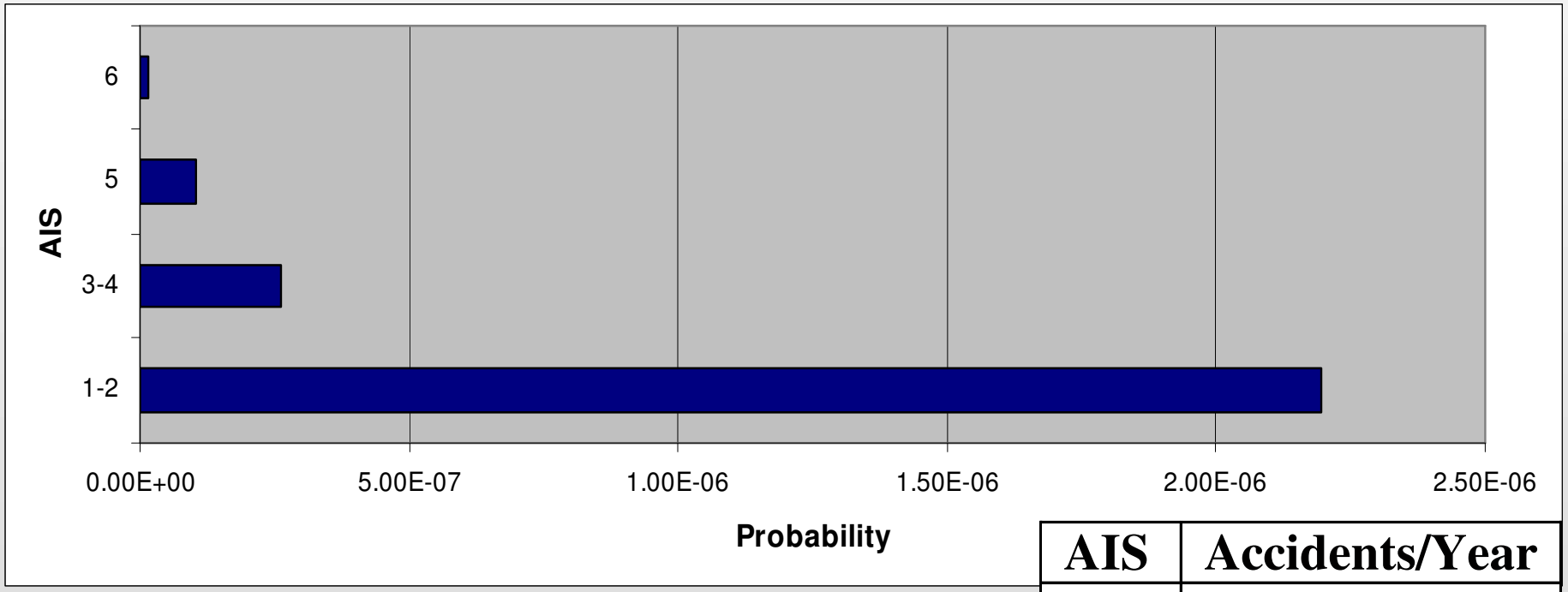
- Use 1
  - Select a scenario
  - … like the parameterised model
  - Scaled by total system events

AIS	Accidents per Year		
	Maths	Law	Arts
1-2	2.722	0.859	1.559
3-4	0.332	0.096	0.187
5	0.129	0.037	0.078
6	0.019	0.004	0.009



Using the System Model

- Use 2
  - Whole system risk,
  - … weighted by exposure for each scenario



AIS	Accidents/Year
1-2	5.141
3-4	0.615
5	0.244
6	0.032

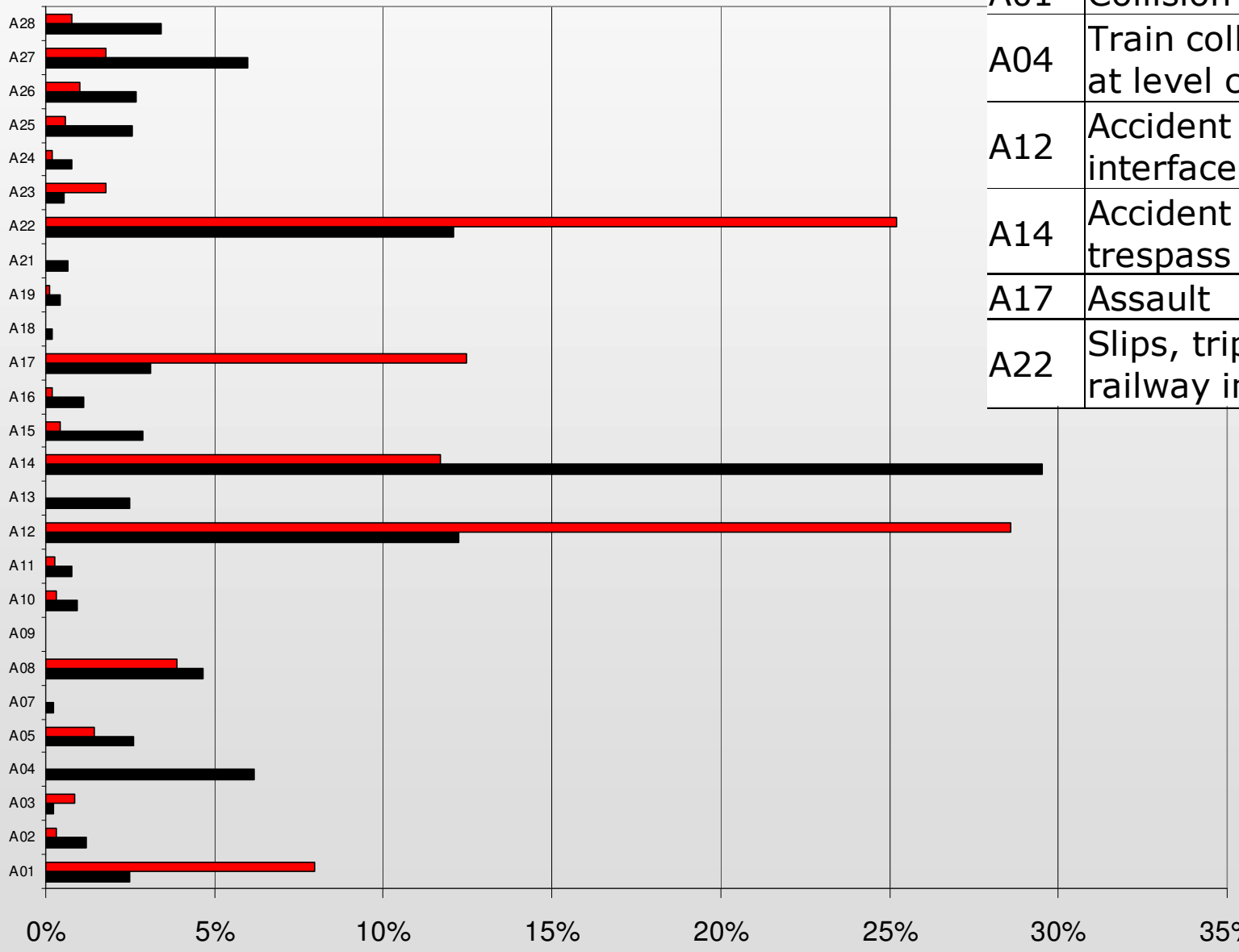
Parameterised Risk Models in Practice

Improving Safety Decision Making

Better Safety Decision Making

- Safety benefits of improvements
  - Existing models only support system-wide improvements
- Detection of local excess risk
  - E.g. poor maintenance in one area
  - Requires risk distribution (not average)
  - … variations in equipment type and condition
  - … procedural and staffing variations

Risk Profile: Sector and Network



A01	Collision between trains
A04	Train collision with vehicle at level crossing
A12	Accident at platform/train interface
A14	Accident involving trespass or surfing
A17	Assault
A22	Slips, trips and falls on railway infrastructure

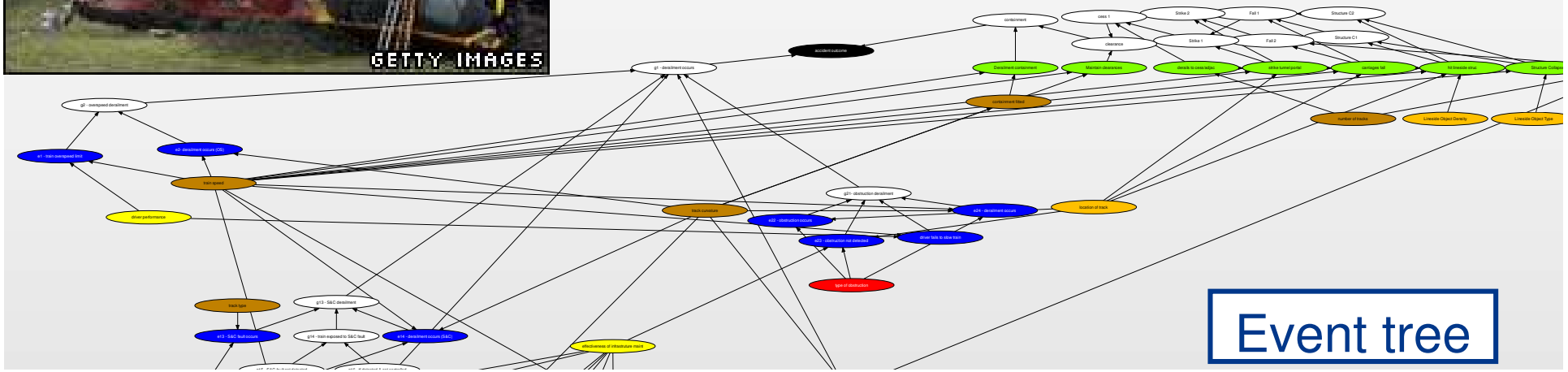
Derailment

Event tree

Fault tree

Factors

Derailment



Investigation found the cause to be:

‘the poor condition of points 2182A at the time of the incident, and that this resulted from inappropriate adjustment and from insufficient maintenance ….’

Summary

- Parameterised ET + FT
  - Using Bayesian Networks
  - Factors made explicit
  - Clearer and more compact
- Reuse of risk model
- Risk profiles
  - Guide changes to reduce risk
  - Challenge of including more causes

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Thank You