POMDP based Maintenance Optimization of Offshore Wind Substructures including Monitoring

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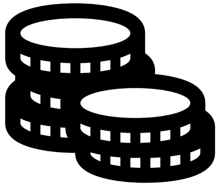
May, 2019 - Seoul, South Korea

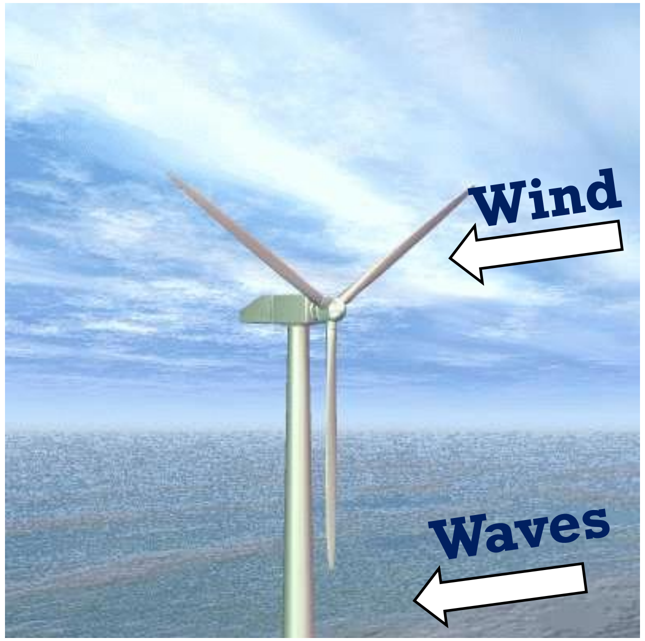
Sequential decision making under uncertainty

Deterioration
Fatigue & corrosion

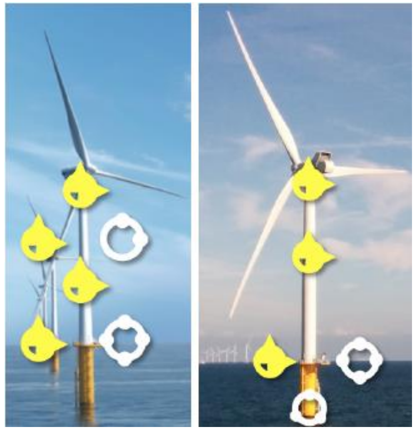
RISK



Information available
....Inspections
Monitoring...



Source:http://windpowernejikata.blogspot.com/2017/05/wind-power-gif.html



Source: https://www.researchgate.net/figure/Optical-strain-gauges-as-installed-at-a-Belwind-and-b-Northwind

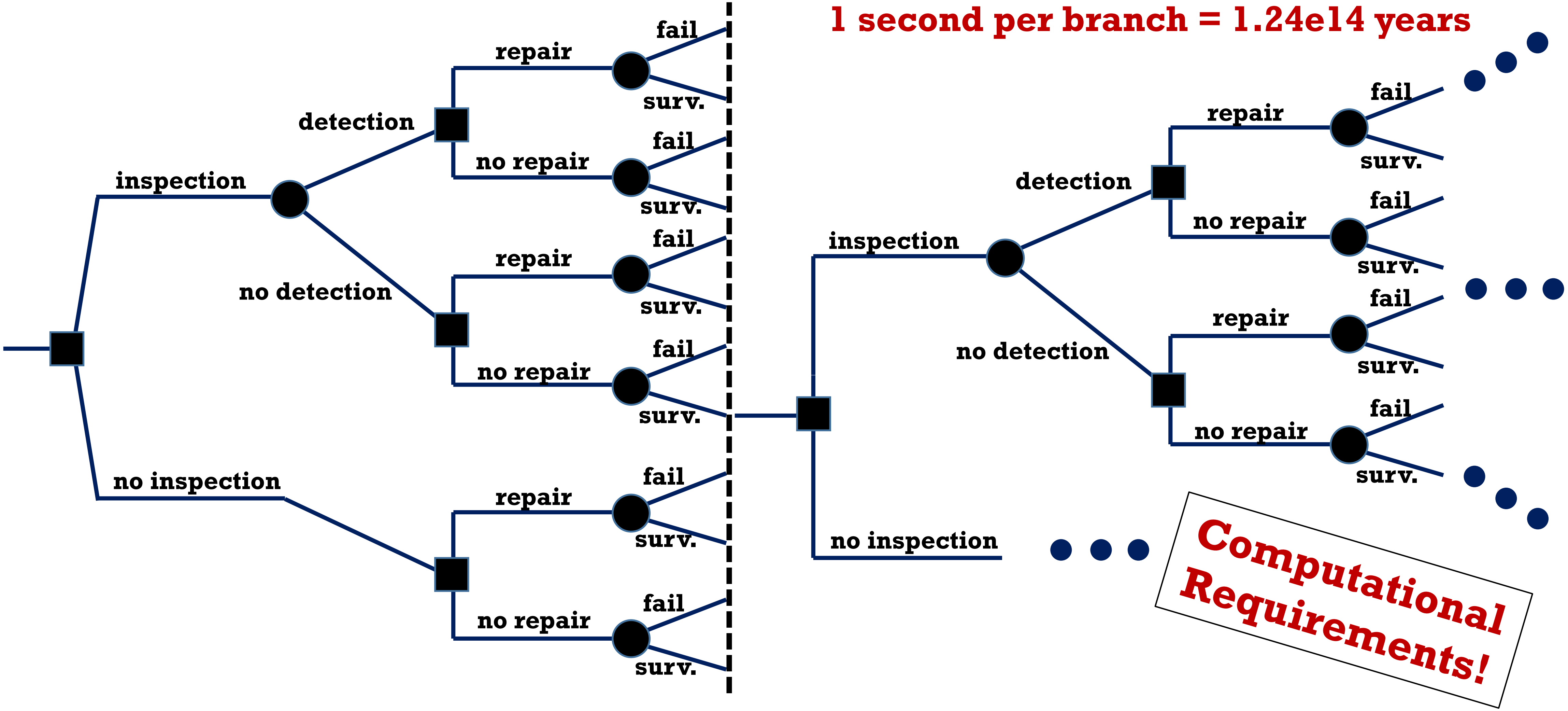
Source: https://www.deltares.nl/en/projects/cutting-maintenance-costs-offshore-wind-farms-using-improved-forecasts

Maintenance decision problem

'Pre-posterior decision analysis'…

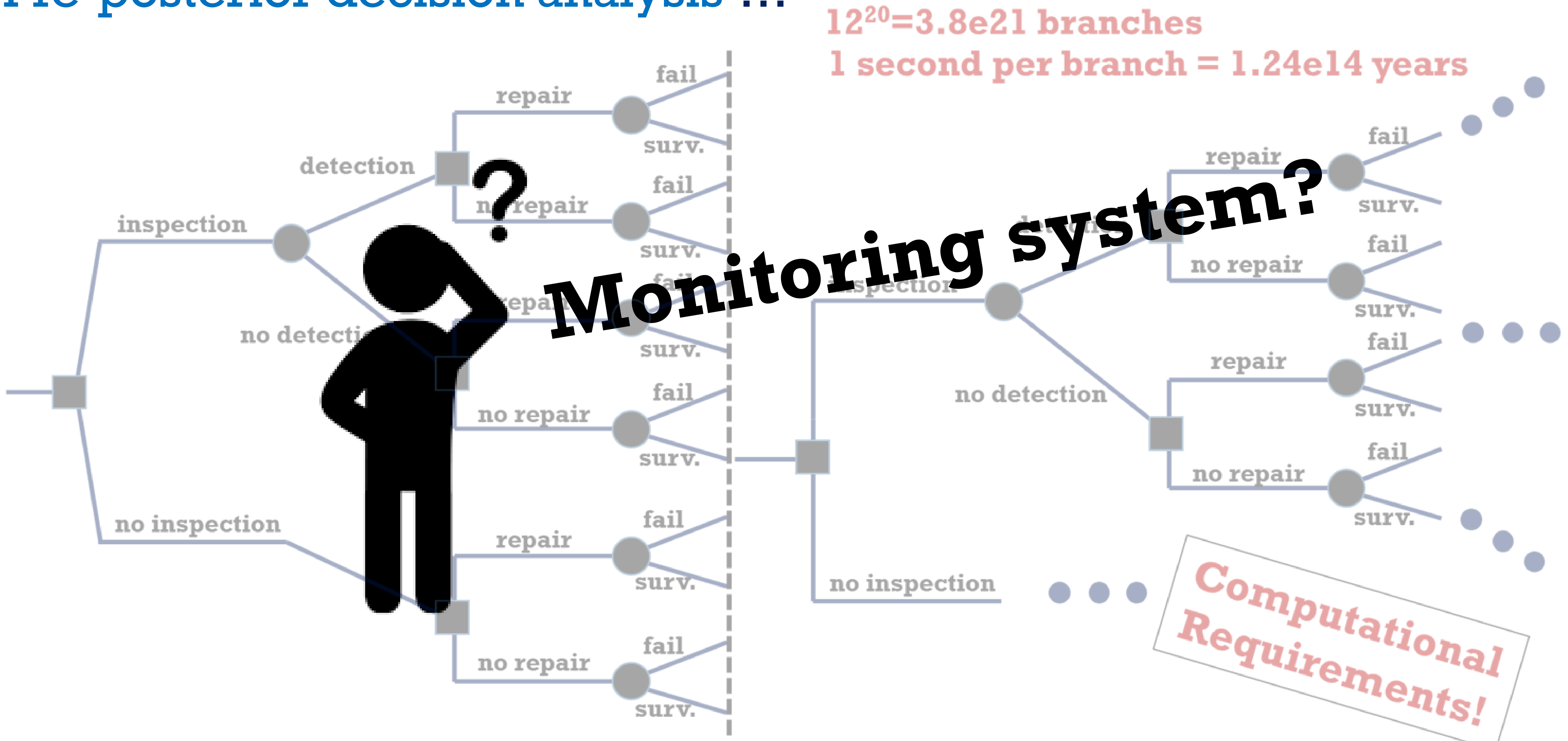
12^{20}=3.8e21 branches

1 second per branch = 1.24e14 years



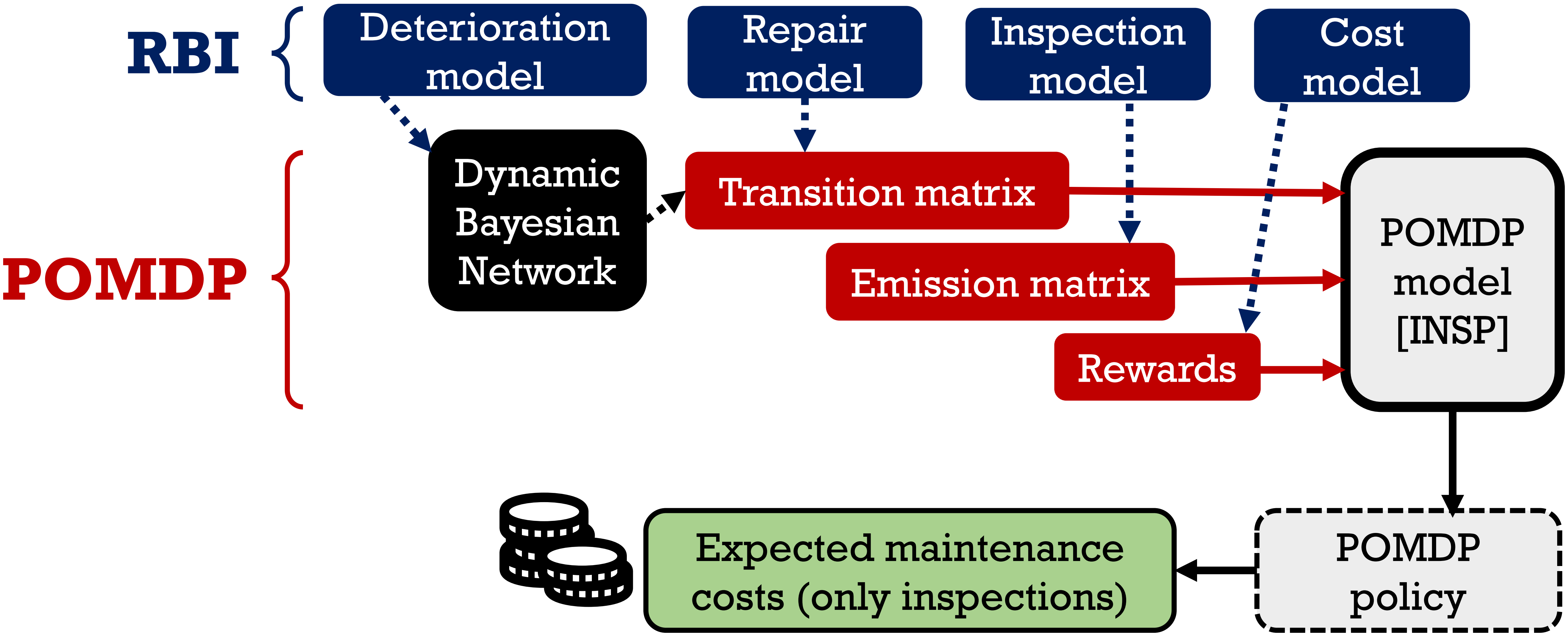
Maintenance decision problem

‘Pre-posterior decision analysis’…



Proposed POMDP methodology

Partially Observable Markov Decision Process **(POMDP)**



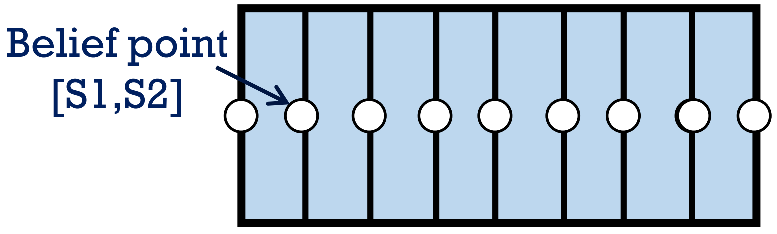
Proposed POMDP methodology

(1) Able to solve large state problems

(2) Evaluation of the Value of Monitoring

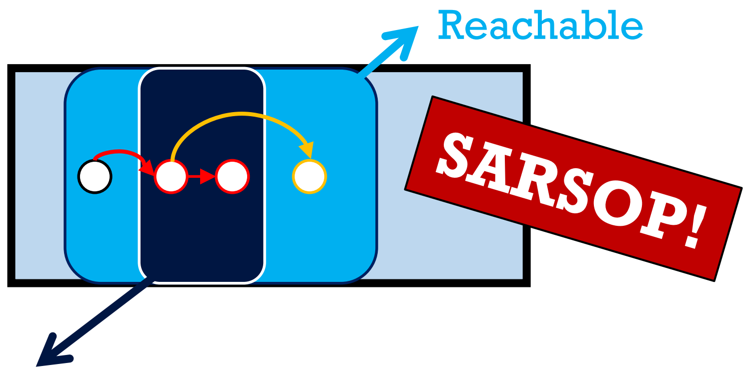
(3) Easy to model/evaluate: Dynamic Bayesian Net

‘Grid-based’ technique



- Finite set of belief points
- Extrapolation/interpolation

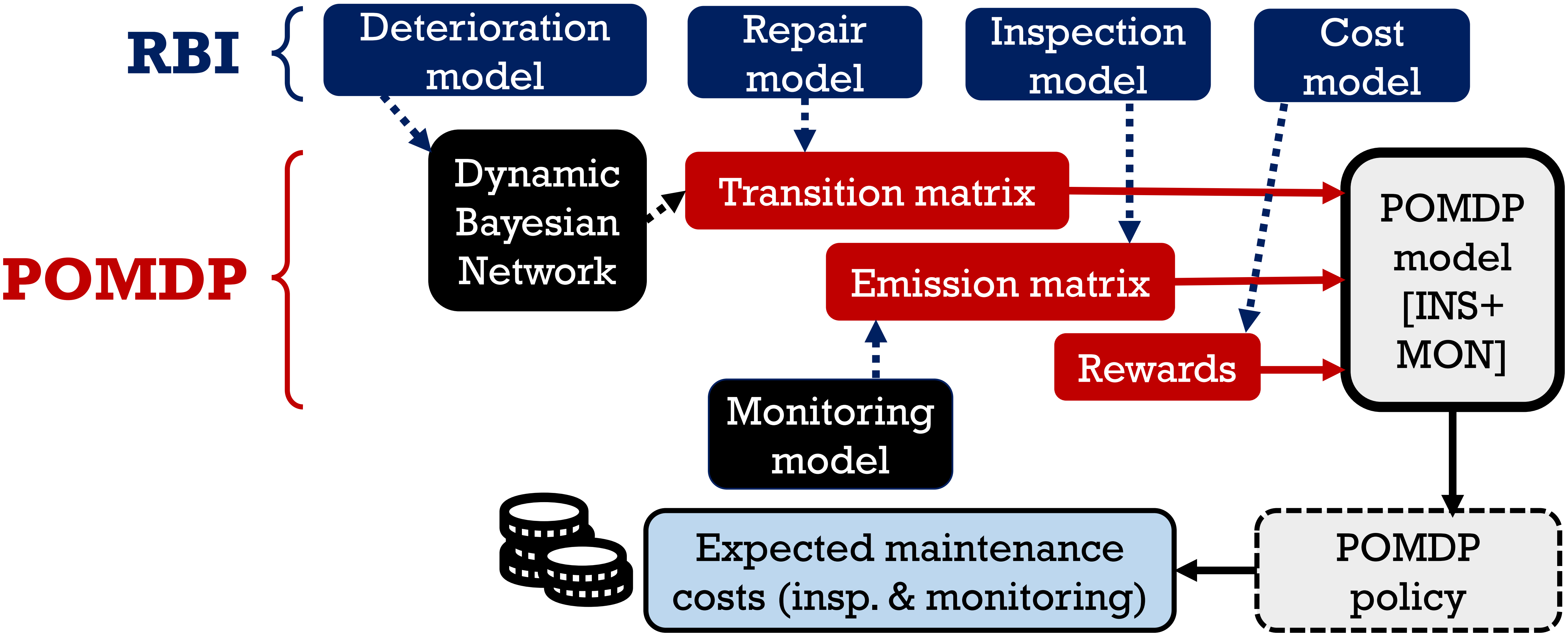
‘Point-based’ technique



- ‘Optimally’ reachable beliefs
- Large state space (Robotics)

Proposed POMDP methodology

Methodology (Inspection + **Monitoring**)



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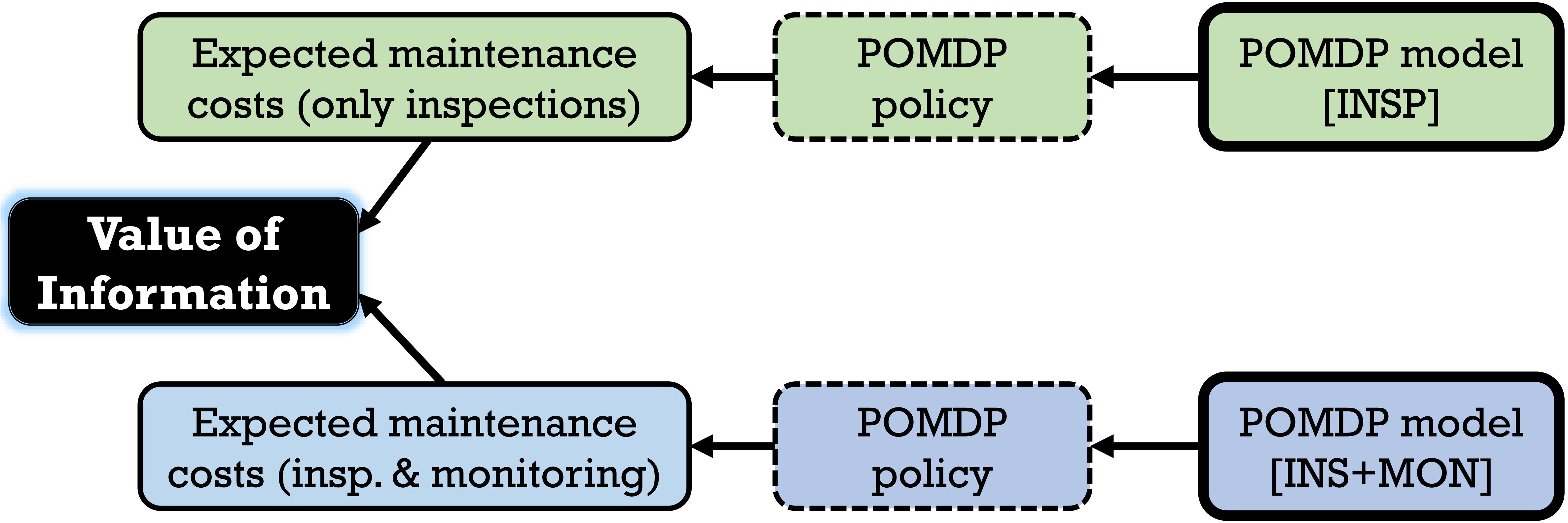

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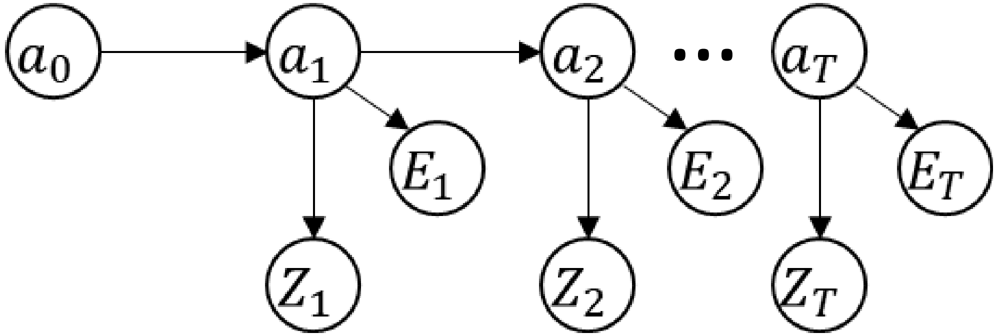
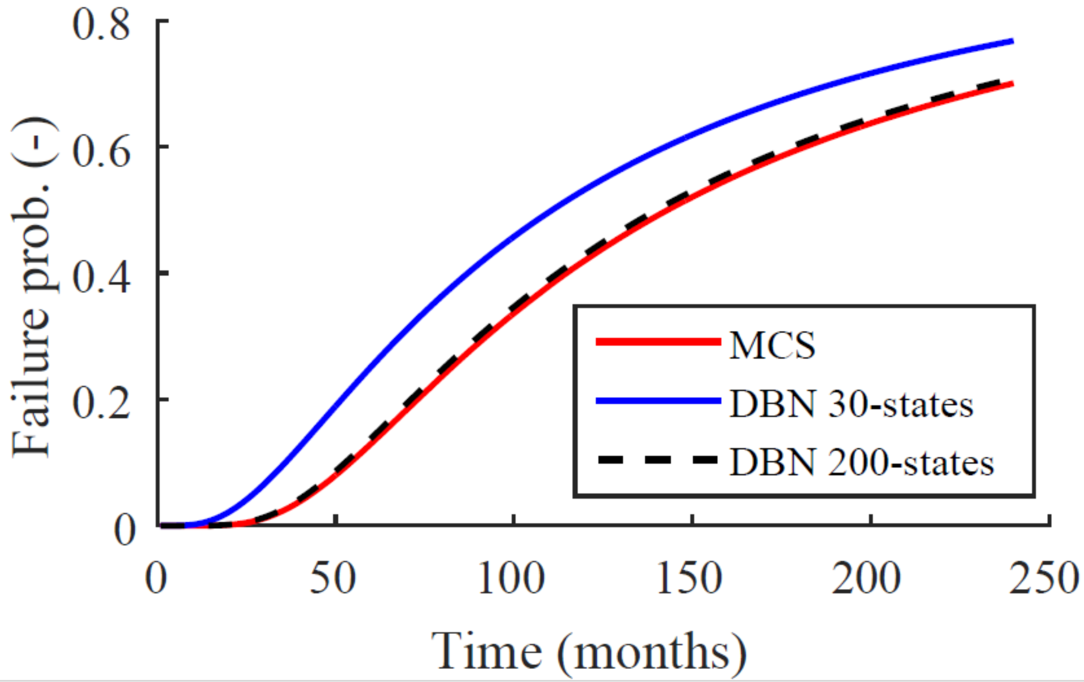




Application: Fatigue deterioration

Fracture mechanics - Paris' Law

$$g_{FM(t)} = a_c - \left[\left(1-\frac{m}{2}\right) C\pi^{\frac{m}{2}}\Delta S^m \Delta n + a_{t-1}^{\left(1-\frac{m}{2}\right)}\right]^{\frac{2}{2-m}}$$

given a_0

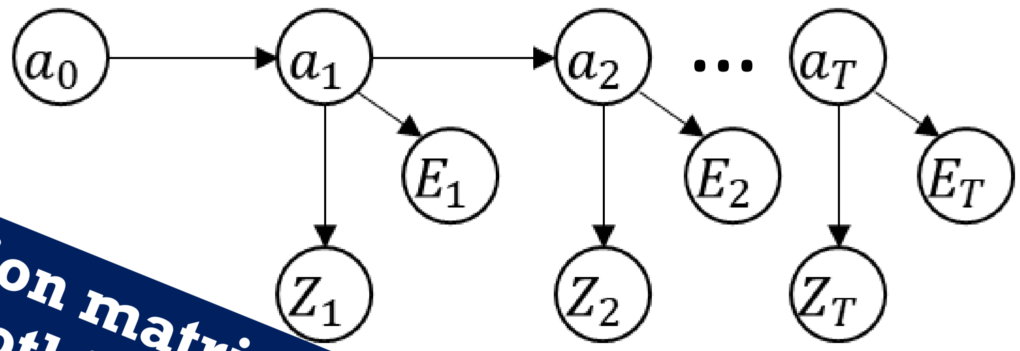
Parameter	Distribution	Mean	StDev
a_0	EXP	0.2	-
a_c	Determ.	9	-
$\ln(C)$	Determ.	-33.5	-
m	Determ.	3.5	-
ΔS	NORMAL	60	10
Δn	Determ.	10^6	-

(1) States: 200

(2) Combined actions

- **Do-nothing** + No inspection
- **Do-nothing** + Inspection
- **Do-nothing** + Monitoring
- Repair + No inspection

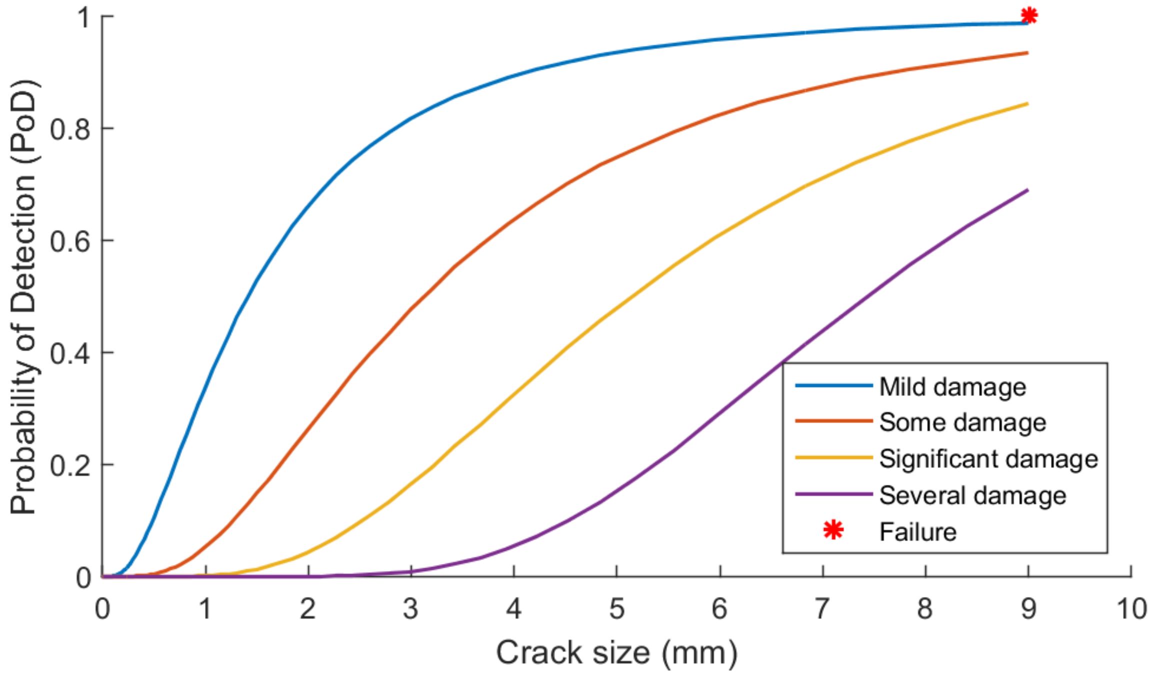
(3) Transitions



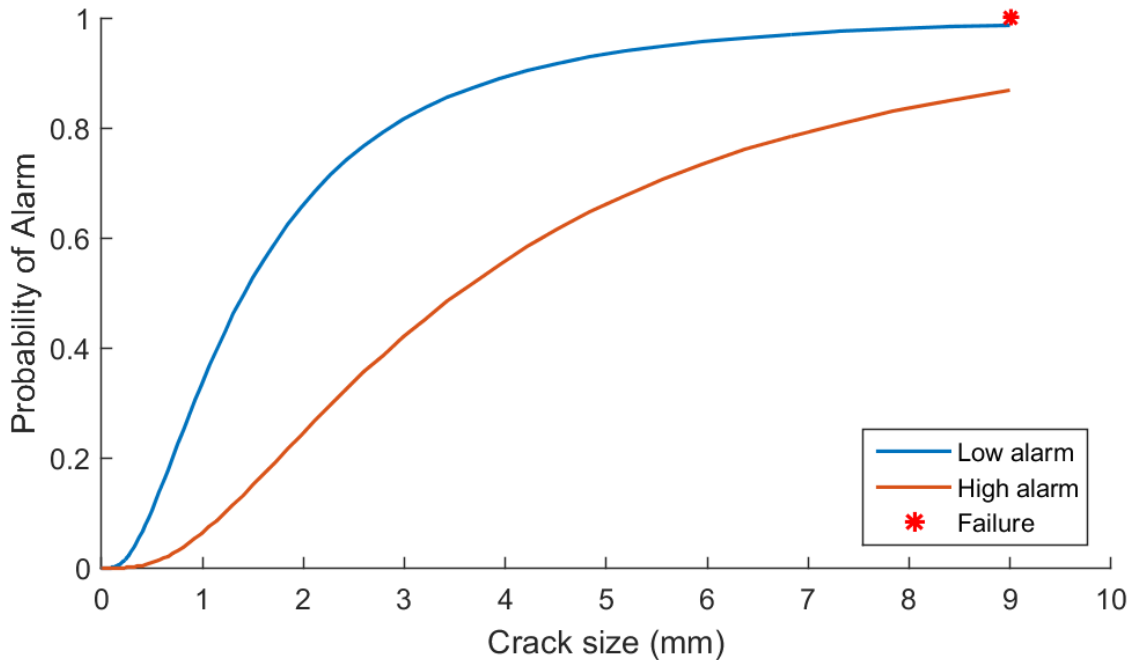
Transition matrix: Do-nothing

(4) Observations

Inspections



Monitoring



No inspection?

Application: Setting up the model

(5) Rewards / costs

Failure state

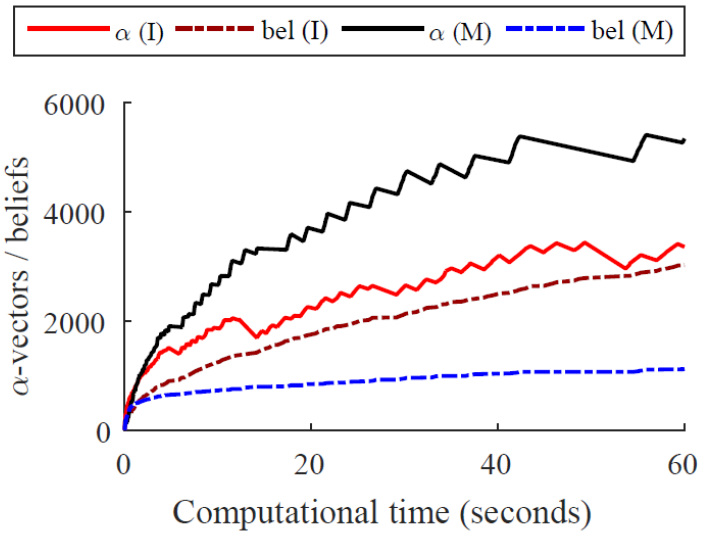
Parameter	State 1	…	State 200
Do nothing + No inspection	0	0	-500
Do nothing + Inspection	-1	-1	-1
Repair + No inspection	-50	-50	-50

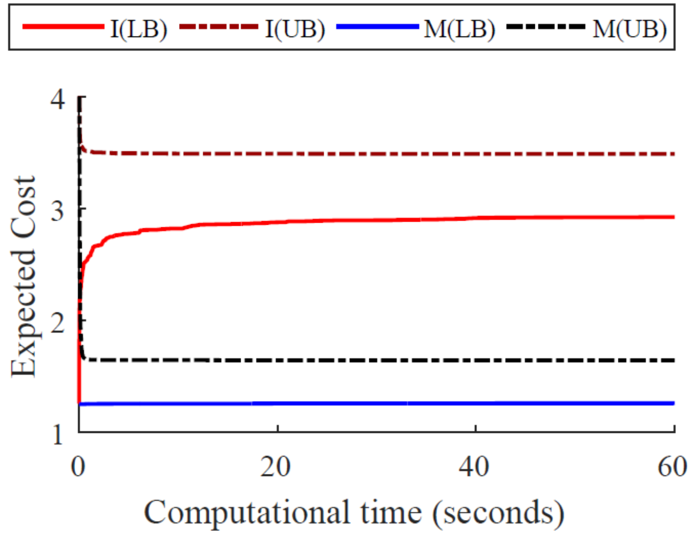
*Discount factor:
$\gamma = 0.95$

Infinite horizon POMDP - SARSOP

Solving ………………

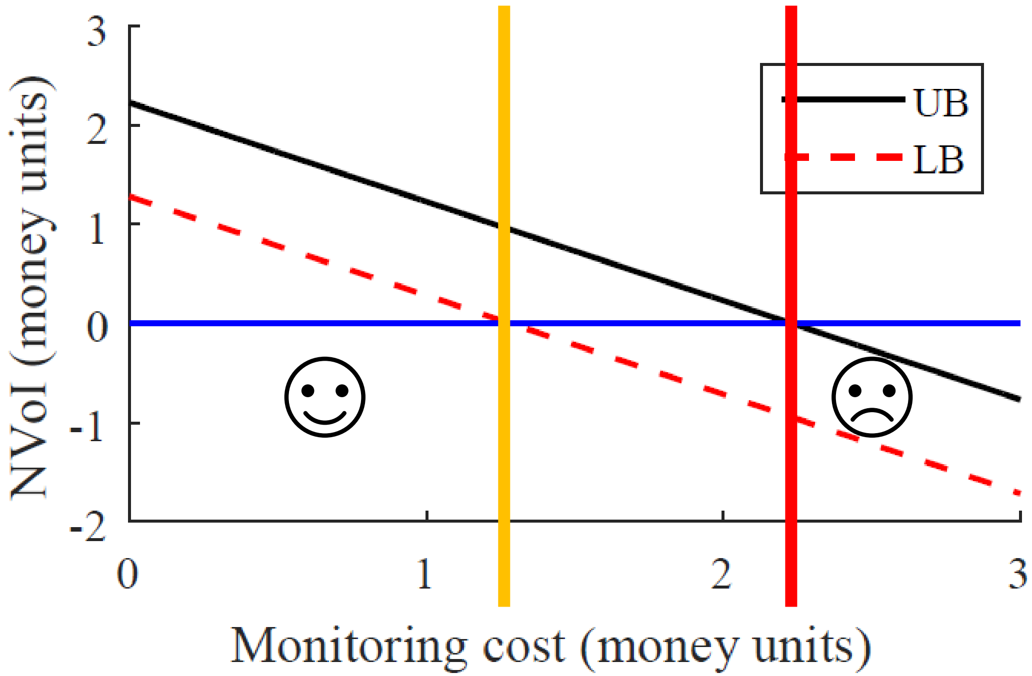
Application: Results





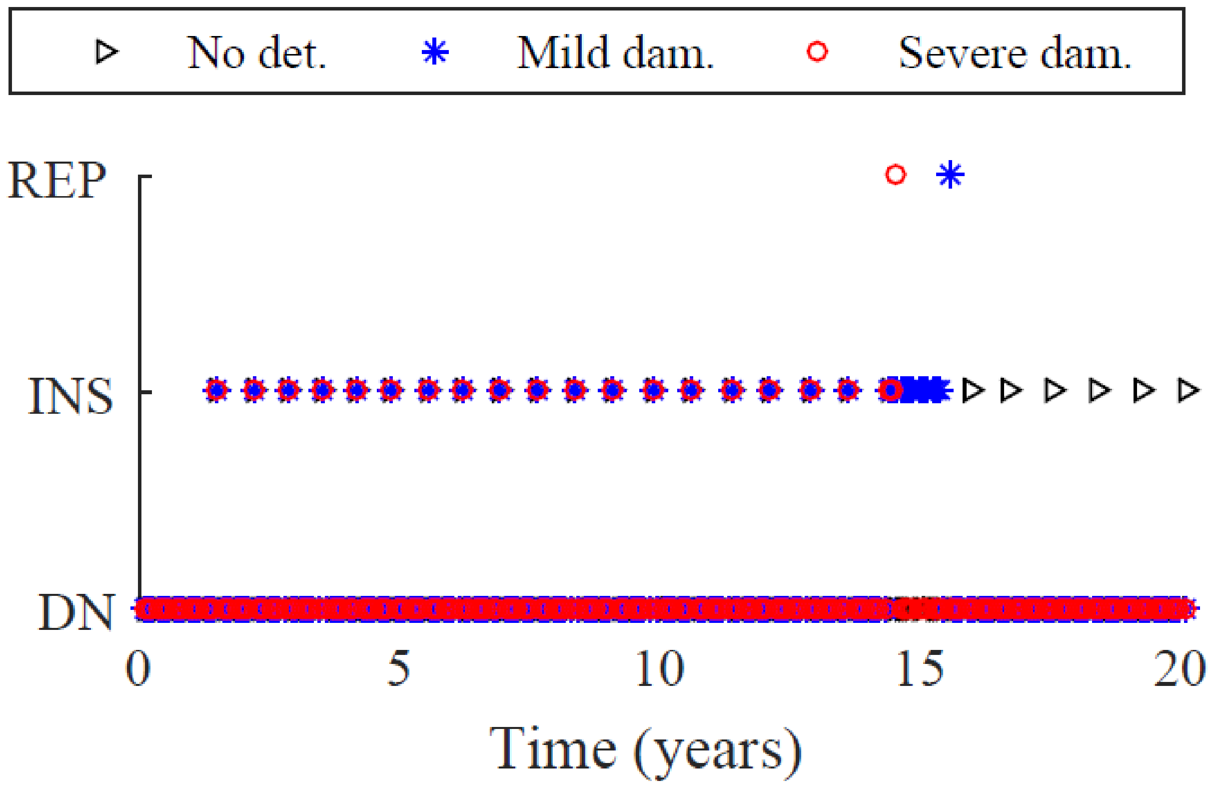
'SARSOP Algorithm': POMDP 200 states

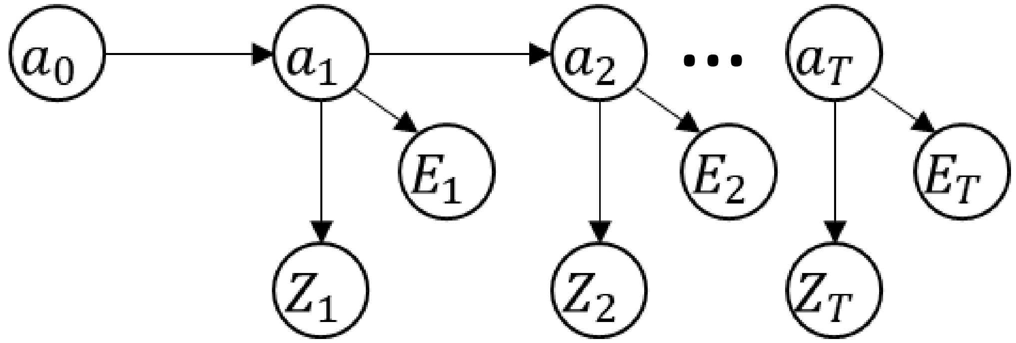
$$NVoI = VoI - C_{mon} = \mathrm{E}(C_0) - \mathrm{E}(C_1) - C_{mon}$$



Application: Policy evaluation

‘SARSOP Algorithm’: POMDP 200 states





- **No detection**
- **Mild damage**
- **Severe damage**

Discussion & Conclusions

- Estimation of the Value of Monitoring
- Large state space - Reasonable CPU Time
- Only time-variant parameters
- Future:
  - Include time-invariant parameters
  - Compare with finite horizon POMDPs

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International Civil Engineering Risk and Reliability Association
CERRA

Questions?

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May, 2019 - Seoul, South Korea