'Why Should I Waste my Money on Monitoring?'

Daniele Zonta, University of Trento and University of Strathclyde

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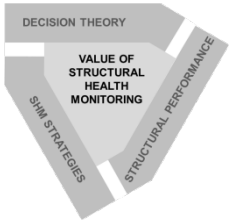
Barcelona, Mar 14, 2016



Benefit of Monitoring?

monitoring of bridges is commonly presented as a powerful tool supporting decisions

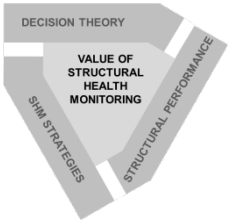
in real-life bridge owners are very skeptical

take decisions based on their experience or on common sense

a reinforcement intervention improves capacity

monitoring does NOT change capacity nor load

'why should I spend my money on monitoring?!'



Value of Information (VoI)

to appreciate the benefit monitoring, we must account for its impact on decision

Value of Information: money saved every time the manager interrogates the monitoring system

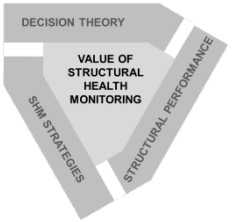
maximum price the rational agent is willing to pay for the information from the monitoring system

VoI = C - C*

C=operational cost w/o monitoring

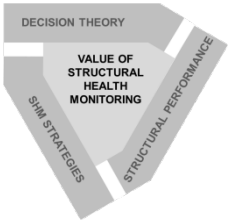
C*=operational cost with monitoring

implies the manager can undertake actions in reaction to monitoring response



Streicker Bridge at Princeton campus

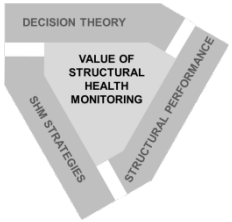
- Pedestrian bridge being built at Princeton University campus
- over Washington Road
- Funded by Princeton alumnus **John Harrison Streicker** (*64)
- design by **Christian Menn**
- design details by Princeton alumni **Ryan Woodward** (*02) and **Theodor Zoli** (*88)



Streicker Bridge at Princeton campus

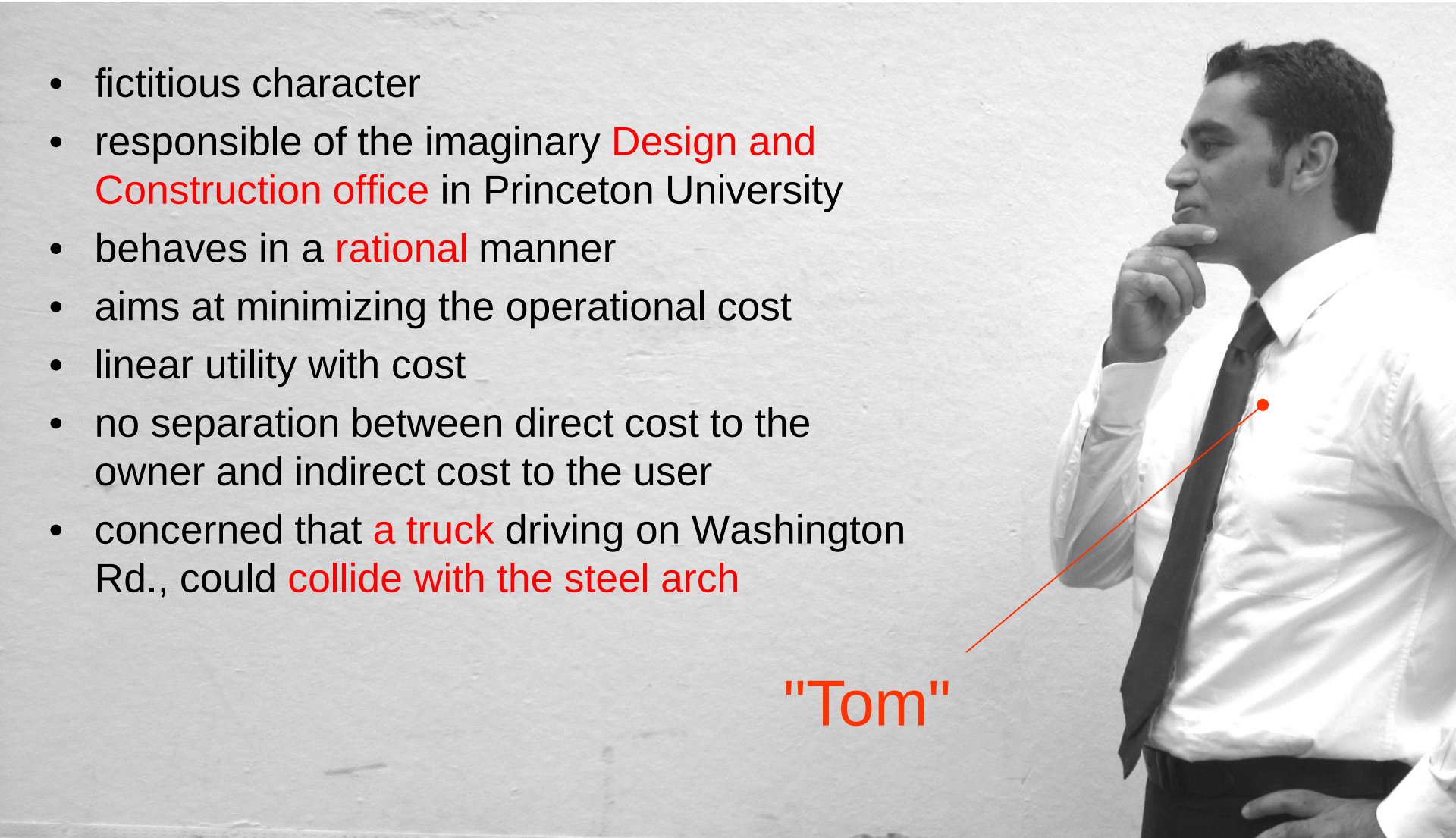
Main span: deck-stiffened arch, deck=post-tensioned concrete, arch=weathering steel

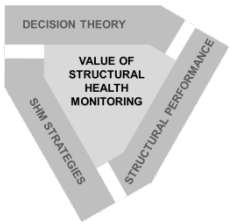
Approaching legs: curved post-tensioned concrete continuous girders supported on weathering steel columns



Introducing 'Tom'

- fictitious character
- responsible of the imaginary Design and Construction office in Princeton University
- behaves in a rational manner
- aims at minimizing the operational cost
- linear utility with cost
- no separation between direct cost to the owner and indirect cost to the user
- concerned that a truck driving on Washington Rd., could collide with the steel arch





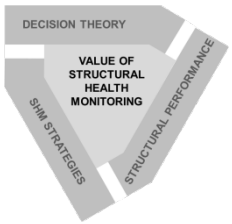
Possible states of the bridge

Severe Damage

- the bridge is still standing, but experienced severe damage at the steel arch structure; chance of collapse under design live load and under self-weight

No damage

- the structure has either no damage or mere cosmetic damage, with no or negligible loss in capacity



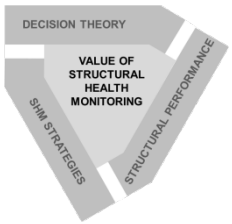
Tom's options

Do Nothing

- no special restriction is applied; bridge is open to pedestrian traffic; minimal repair or maintenance works con be carried out

Close bridge

- both Streicker bridge and Washington Rd. are closed to pedestrian and vehicular traffic; access to the nearby area is restricted



Tom's cost estimate

Close bridge

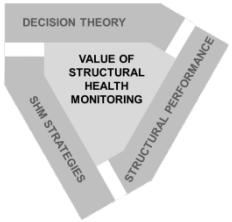
- Daily Road User Cost (DRUC)that considers the value of time per day as a monetary term (Kansas DOT 1991, Herbsman et al. 1995)
- estimated DRUC for Washington Road in $4660/day
- estimated downtime: 1 month
- total downtime cost

C_{DT}=4660 x 30 = $139,800

Tom's cost estimate

Do Nothing AND No damage

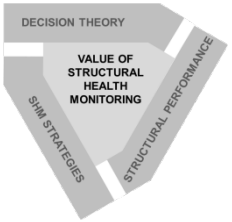
- Pay nothing!!



Tom's cost estimate

Do Nothing AND **Severe Damage**

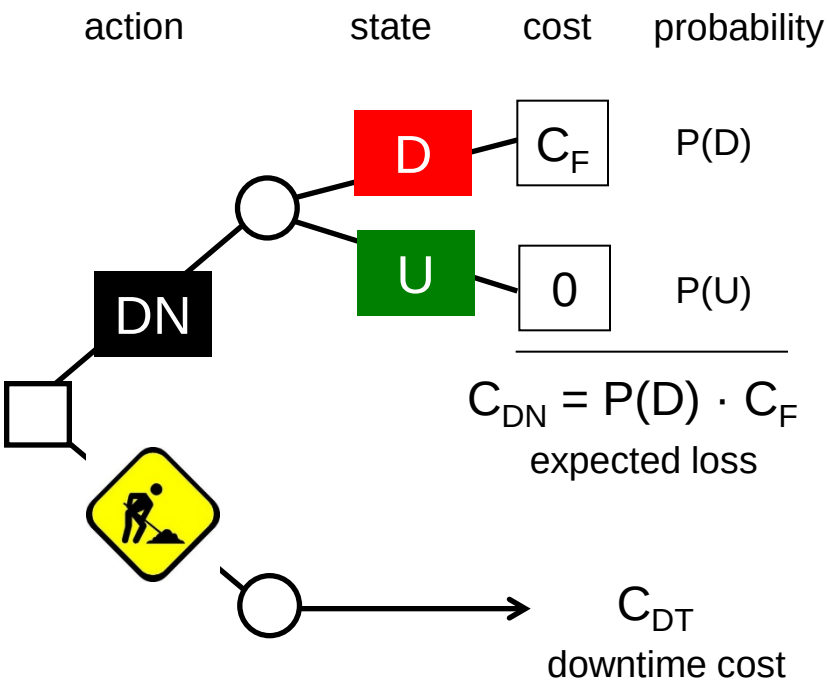
2 month DRUC	$279,600
cost of fatality: k$ 3840 chance of fatality: 15%	$576,000
cost of injury: k$ 52 chance of injury: 50%	$26,000
total failure cost	C_F=$881,600



cost per state and action

	Damage	No Damage
Do Nothing	C_F k$ 881.6	0
Close bridge	C_{DT} k$ 139.8	C_{DT} k$ 139.8

Decision tree w/o monitoring



action:

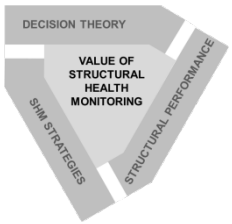
DN *Do Nothing*

Close Bridge

state:

D *Damaged*

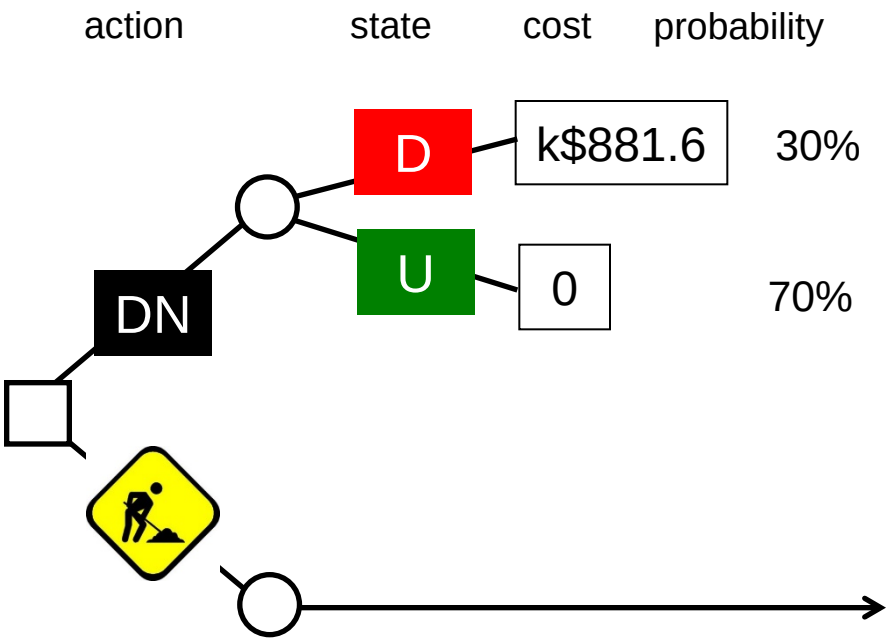
U *Undamaged*



Tom's prior expectation

	Damage P(D)=30%	No Damage P(U)=70%
Do Nothing	C_F k$ 881.6	0
Close bridge	C_{DT} k$ 139.8	C_{DT} k$ 139.8

Decision tree w/o monitoring



$C_{DN} = P(D) \cdot C_F = k\$264.5$

expected loss

$C_{DT} = k\$\ 139.8$

downtime cost

action:

DN *Do Nothing*

Close Bridge

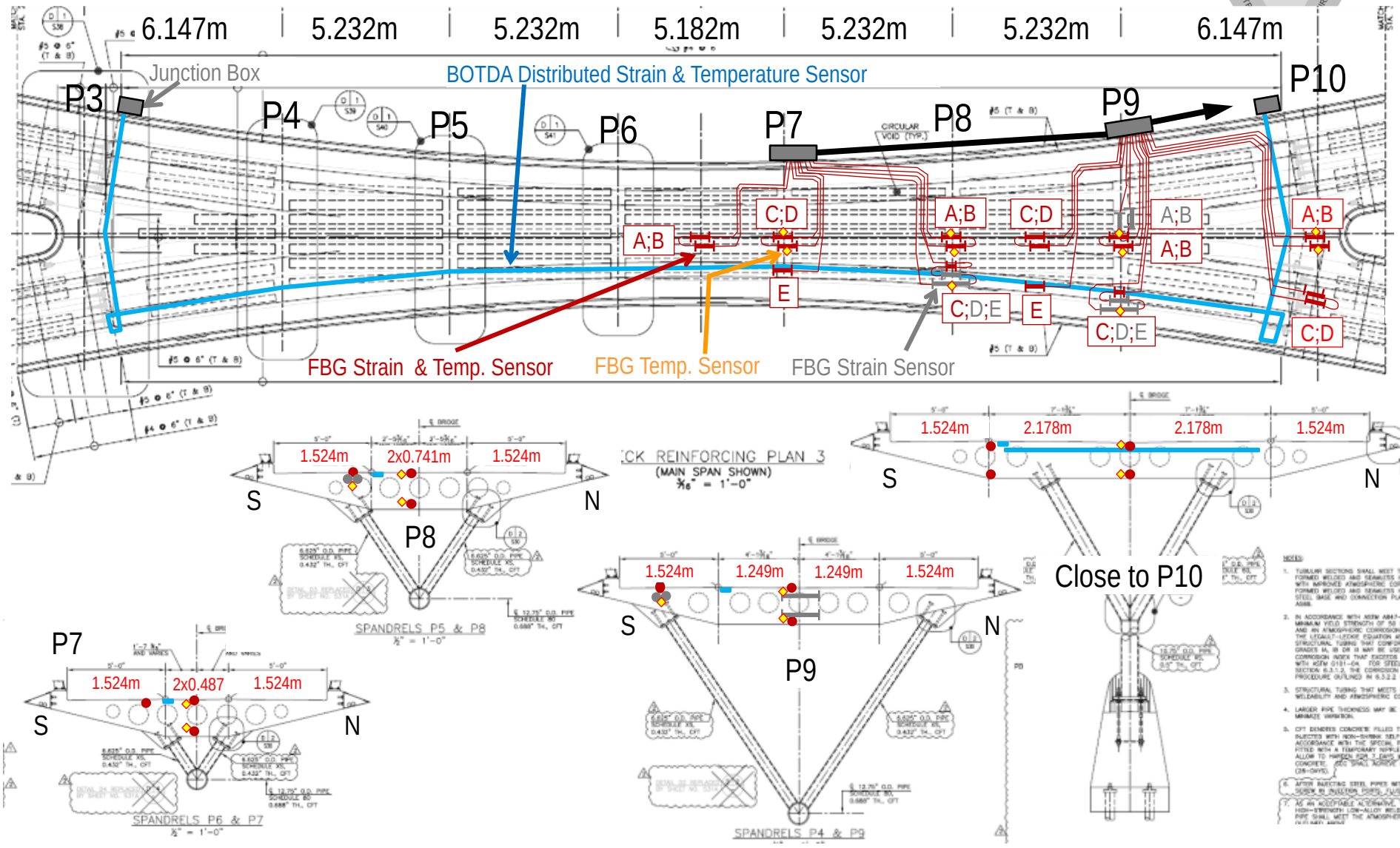
state:

D *Damaged*

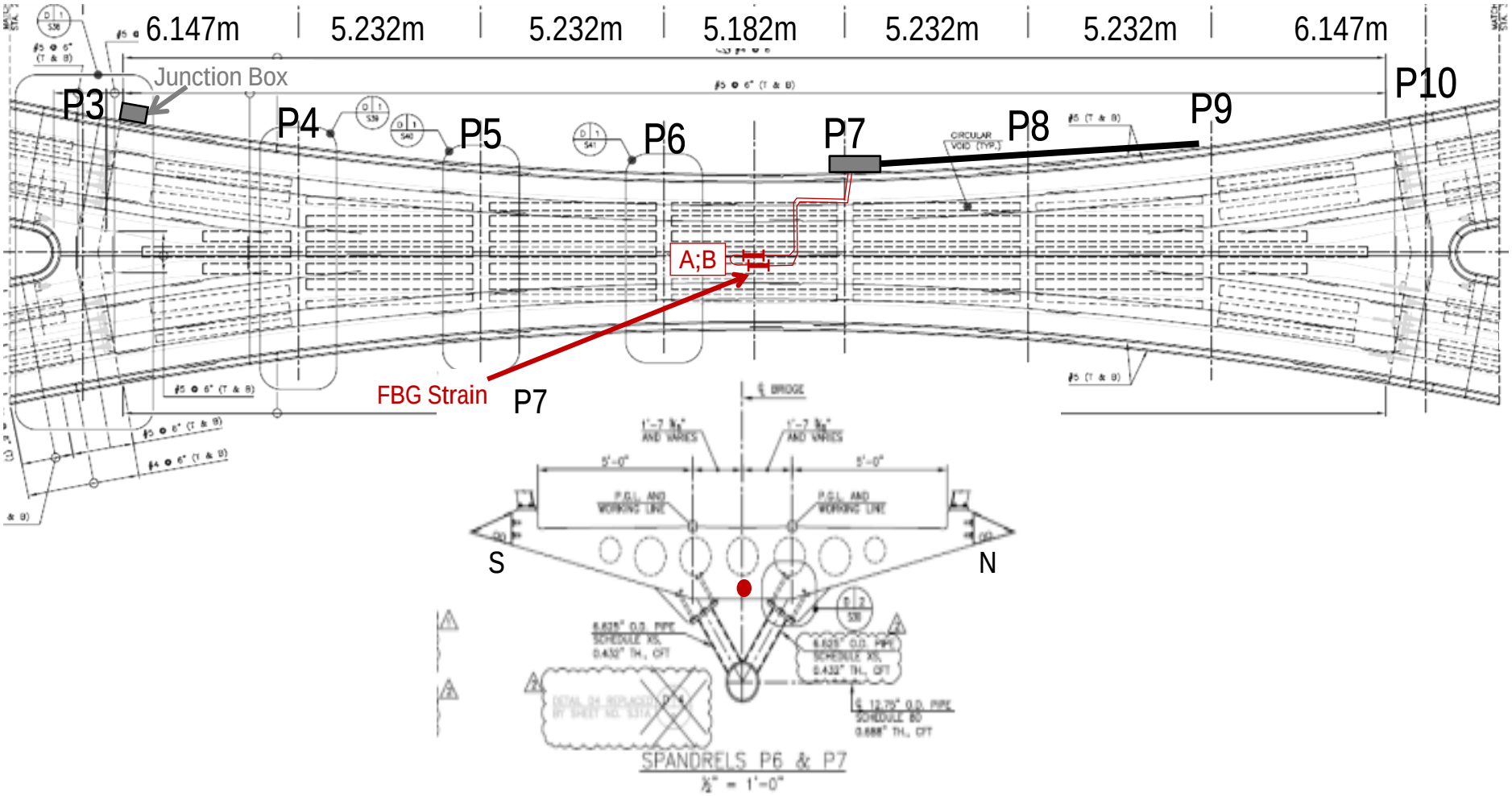
U *Undamaged*

expected cost w/o monitoring

$$C = \min\left(C_F P(D), C_{DT}\right) = k\$\ 139.8$$


6.147m
5.232m
5.232m
5.182m
5.232m
5.232m
6.147m
Junction Box
BOTDA Distributed Strain & Temperature Sensor
P3
P4
P5
P6
P7
P8
P9
P10
A;B
C;D
E
C;D;E
FBG Strain & Temp. Sensor
FBG Temp. Sensor
FBG Strain Sensor
1.524m
2x0.741m
1.524m
S
N
P8
SPANDRELS P5 & P8
1.524m
2.178m
2.178m
1.524m
P7
1.524m
2x0.487
1.524m
SPANDRELS P6 & P7
1.524m
1.249m
1.249m
1.524m
P9
SPANDRELS P4 & P9
Close to P10

Sensor location in main span



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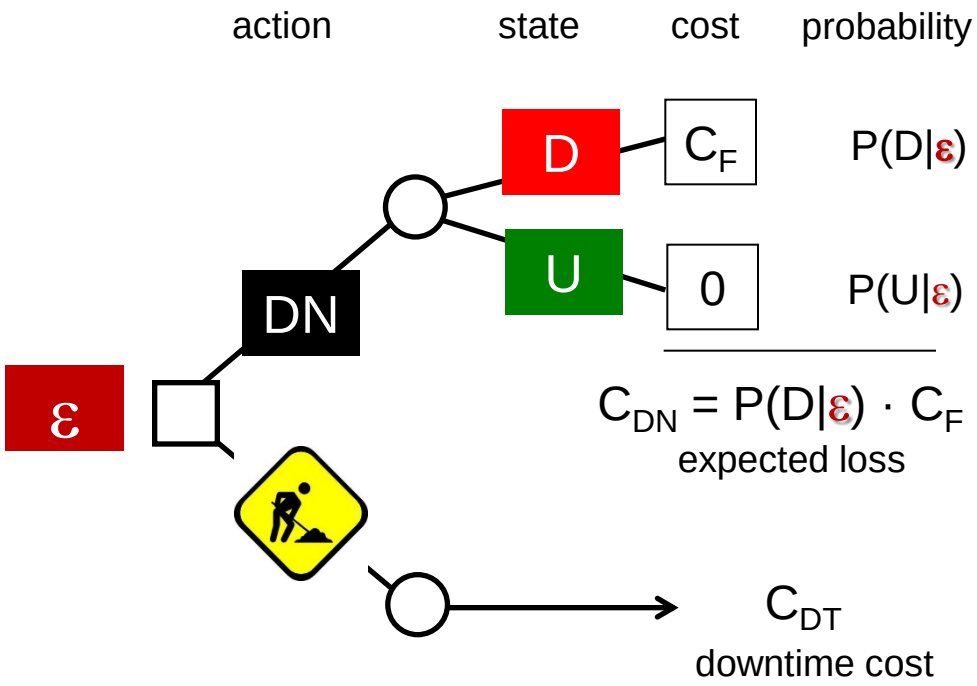

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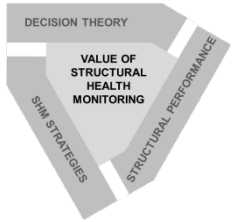
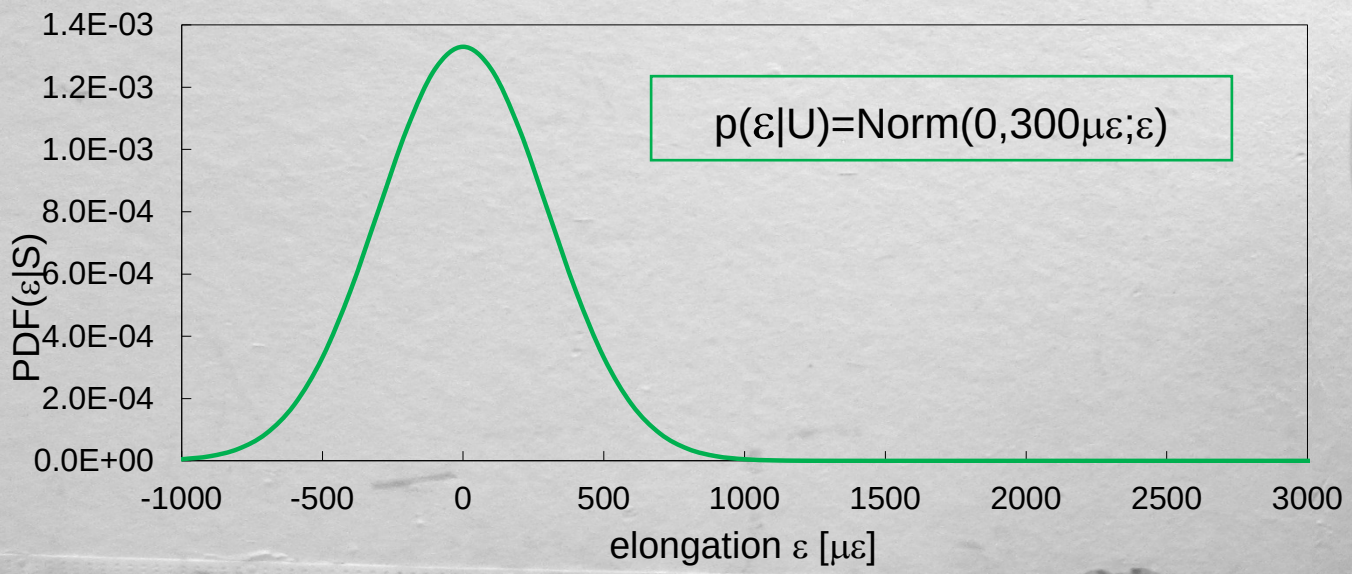
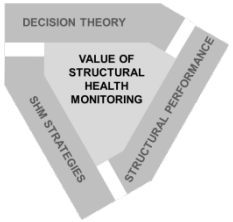


Likelihoods

No damage

- if the bridge is virtually undamaged, the change in strain will be close to zero.
- There is natural fluctuation of the midspan curvature, mainly due to thermal effects;
- Tom's monitoring system provider told him that this fluctuation might be of the order of ±300με.

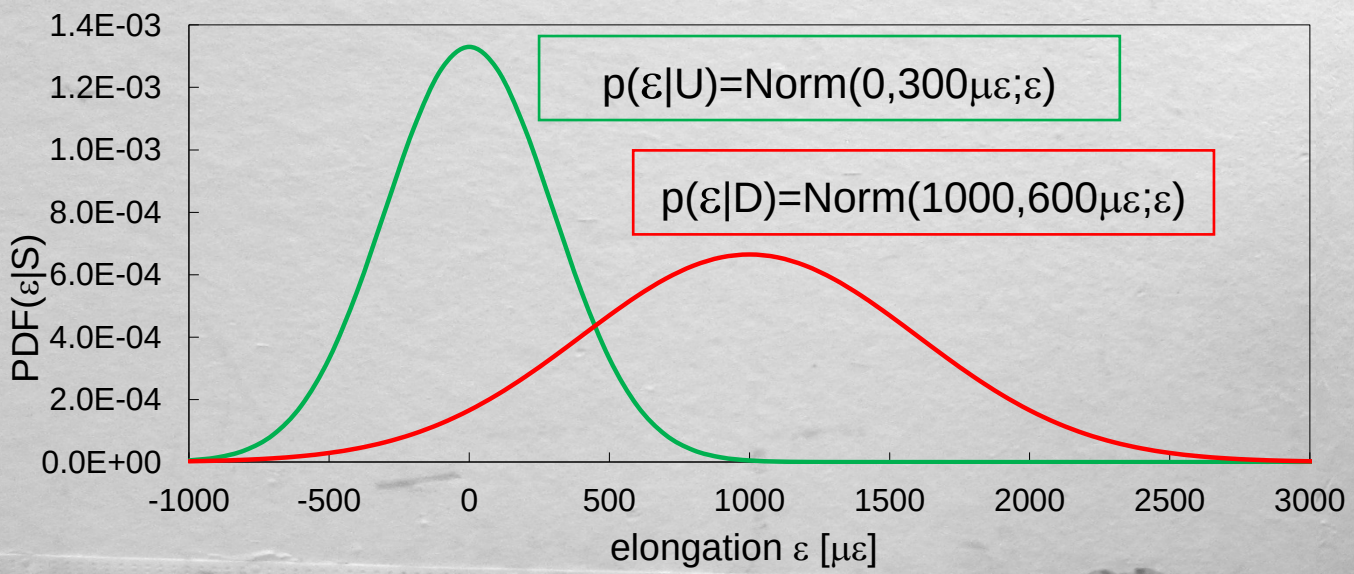




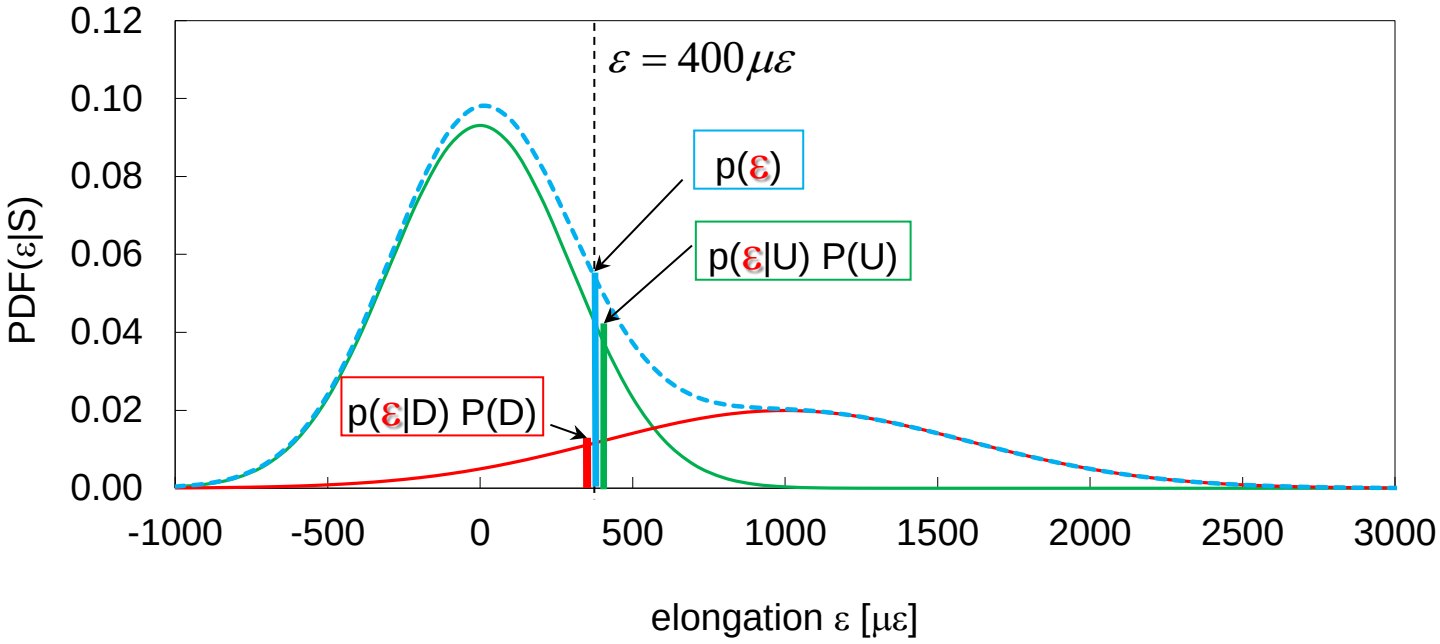
Likelihoods

Severe Damage

- assume the bridge is heavily damaged but still standing
- Tom expects a significant change in strain in the order of 1000 με



Joint probabilities and evidence

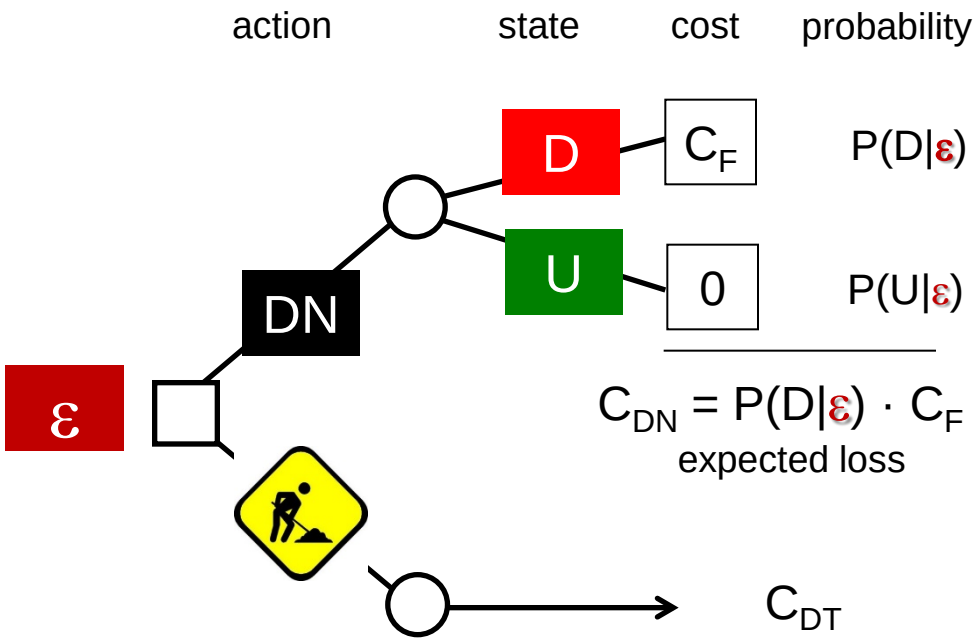


prior P(U) =70% P(D)=30%

likelihoods p(ε|U) p(ε|D)

posterior $P(D|\varepsilon) = \dfrac{p(\varepsilon|D)\,P(D)}{p(\varepsilon|U)\,P(U) + p(\varepsilon|D)\,P(D)} = \dfrac{p(\varepsilon|D)\,P(D)}{p(\varepsilon)}$

Decision tree w/o monitoring



action:

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Close Bridge

state:

D *Damaged*

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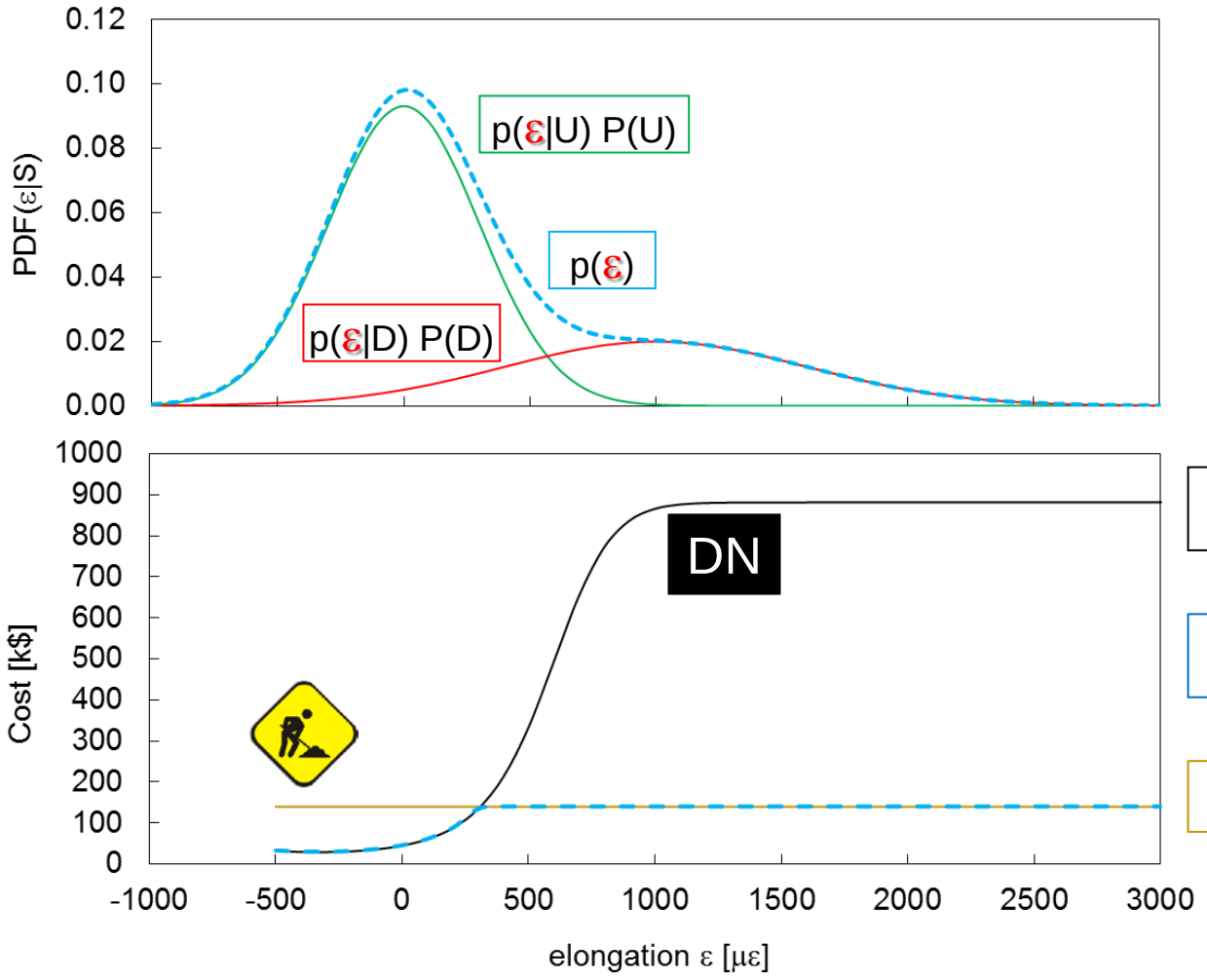
Likelihoods and evidence

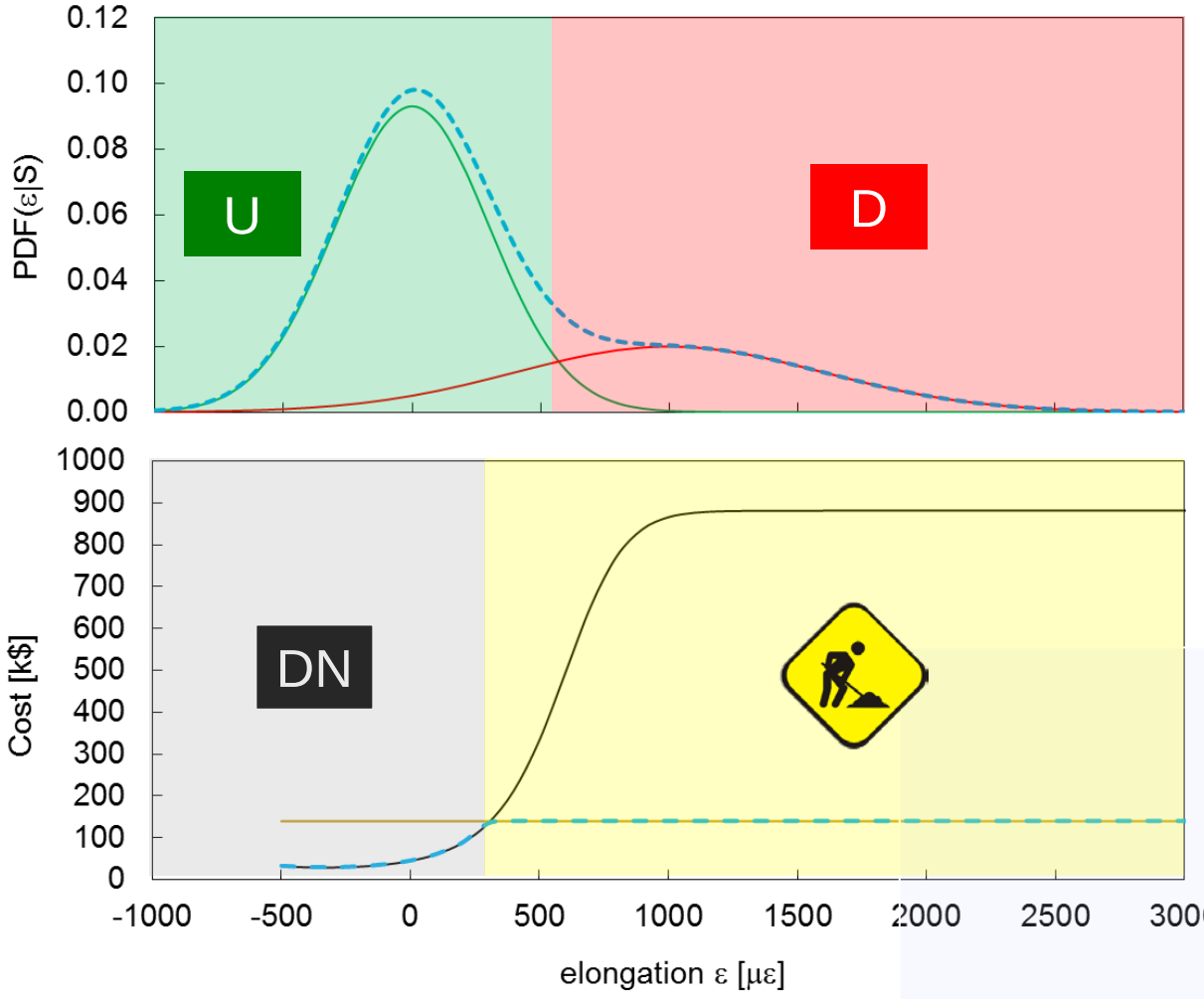


$C_{DN} = P(D|\varepsilon) \cdot C_F$

$c^*(\varepsilon)=\min \{ P(D|\varepsilon)C_F , C_{DT} \}$

C_{DT}=k$139.8

Likelihoods and evidence



$p(\varepsilon|U)\ P(U)$

$p(\varepsilon|D) \cdot P(D)$

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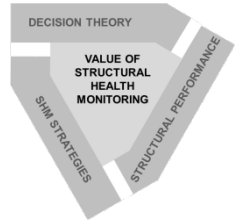
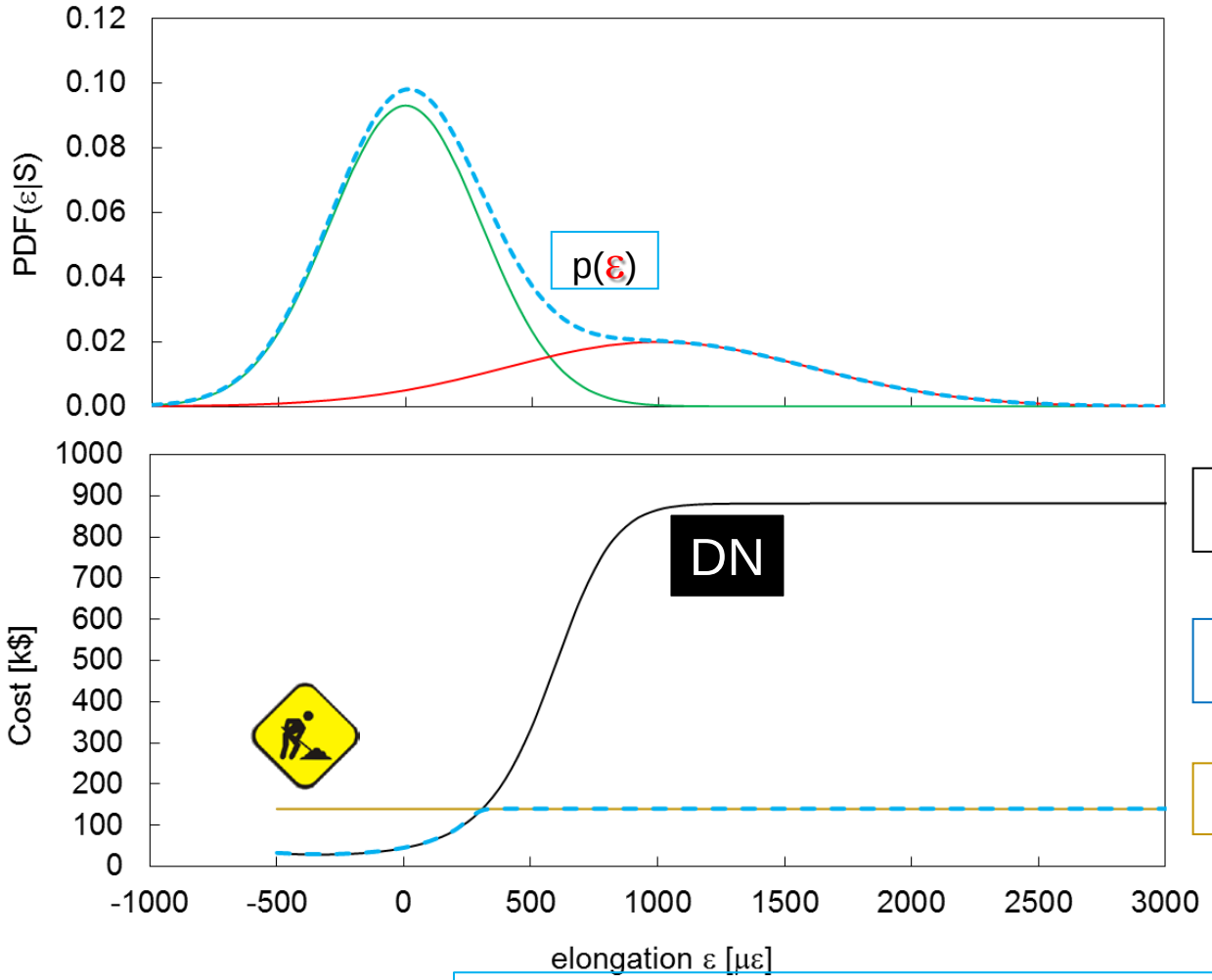


Cost with monitoring



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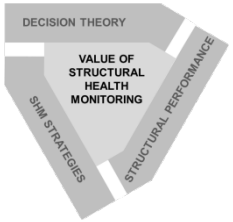
cost with monitoring

$$C^* = \int_0^\infty c^*(\varepsilon)p(\varepsilon)d\varepsilon = \int_0^\infty \min\{C_F p(\varepsilon|D)P(D), C_{DT}\}d\varepsilon = \text{k\$} \quad 84.6$$



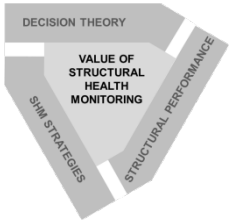
Summary

VoI: maximum price Tom is willing to pay for the information from the monitoring system

$$C = \min\left(C_F \, \mathrm{P}(\mathrm{D}), C_{DT}\right) \qquad \text{k\$ } 139.8$$

$$C^* = \int_0^{\infty} \min\left(C_F \, \mathrm{p}(\varepsilon|\mathrm{D})\mathrm{P}(\mathrm{D}), C_{DT}\right) \mathrm{d}\varepsilon \qquad \text{k\$ } 84.6$$

$$VoI = C - C^* \qquad \text{k\$ } 55.2$$



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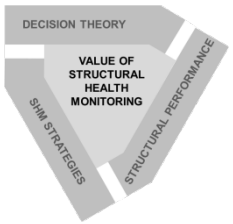
VoI depends on:

(i) expected financial impact of actions C_F and C_{DT}



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VoI depends on:

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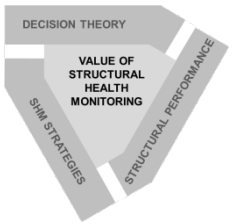
(ii) prior knowledge of structure state P(D)



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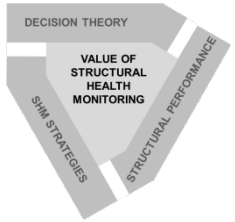
$$VoI = C - C^* \qquad \text{k\$ } 55.2$$

VoI depends on:

(i) expected financial impact of actions C_F and C_{DT}

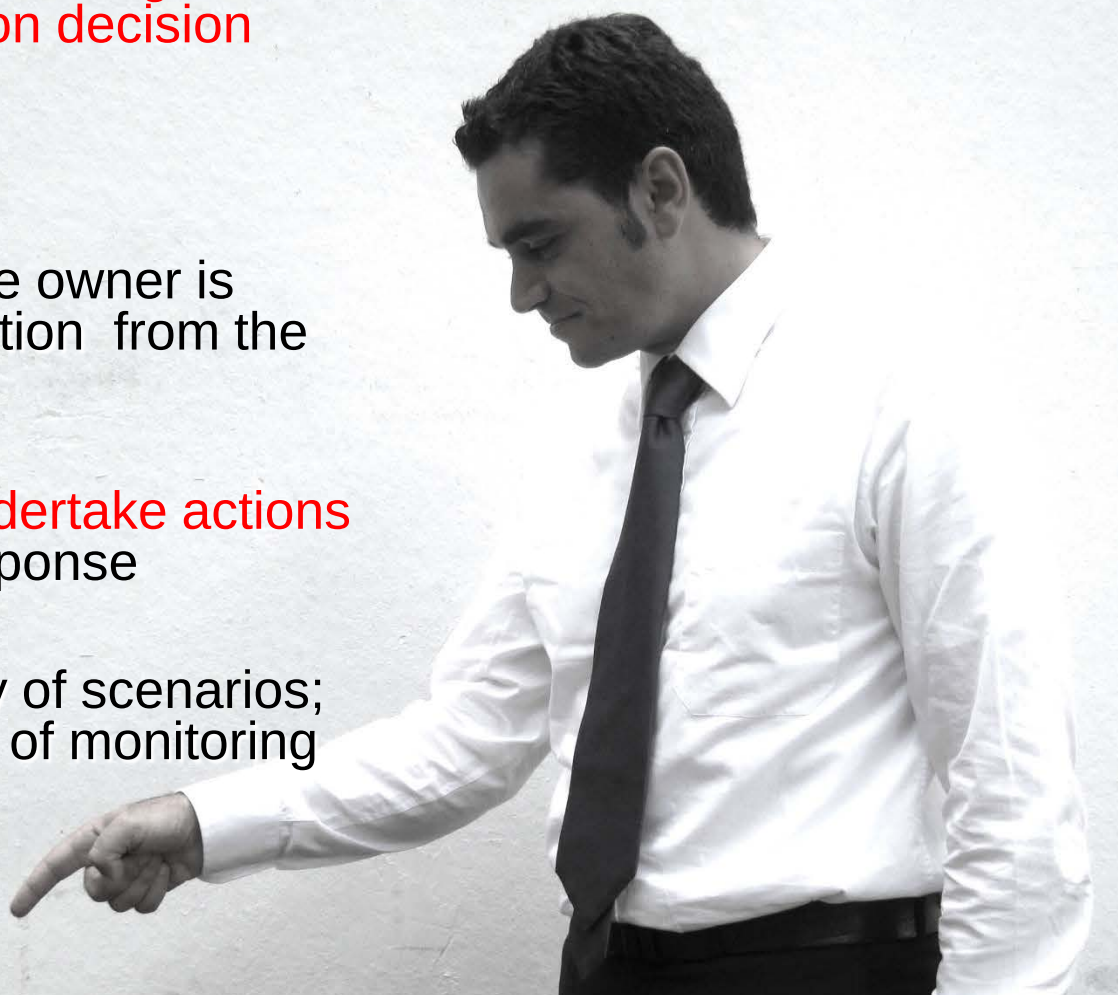
(ii) prior knowledge of structure state P(D)

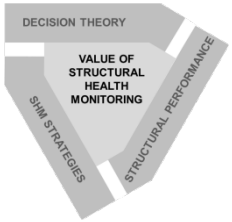
(iii) sensor sensitivity to damage: pdf(ε|D)



Conclusions

- to appreciate the benefit monitoring, we must account for its impact on decision
- quantified using VoI
- VoI is the maximum price the owner is willing to pay for the information from the monitoring system
- implies the manager can undertake actions in reaction to monitoring response
- depends on: prior probability of scenarios; impact of actions; sensitivity of monitoring system to damage
- depends on the owner!





Thank you for your attention!

Acknowledgments

- Branko Glisic, Sigrid Adraenssens, Princeton University
- Turner Construction Company; R. Woodward and T. Zoli, HNTB Corporation; D. Lee and his team, A.G. Construction Corporation; S. Mancini and T.R. Wintermute, Vollers Excavating & Construction, Inc.; SMARTEC SA; Micron Optics, Inc.
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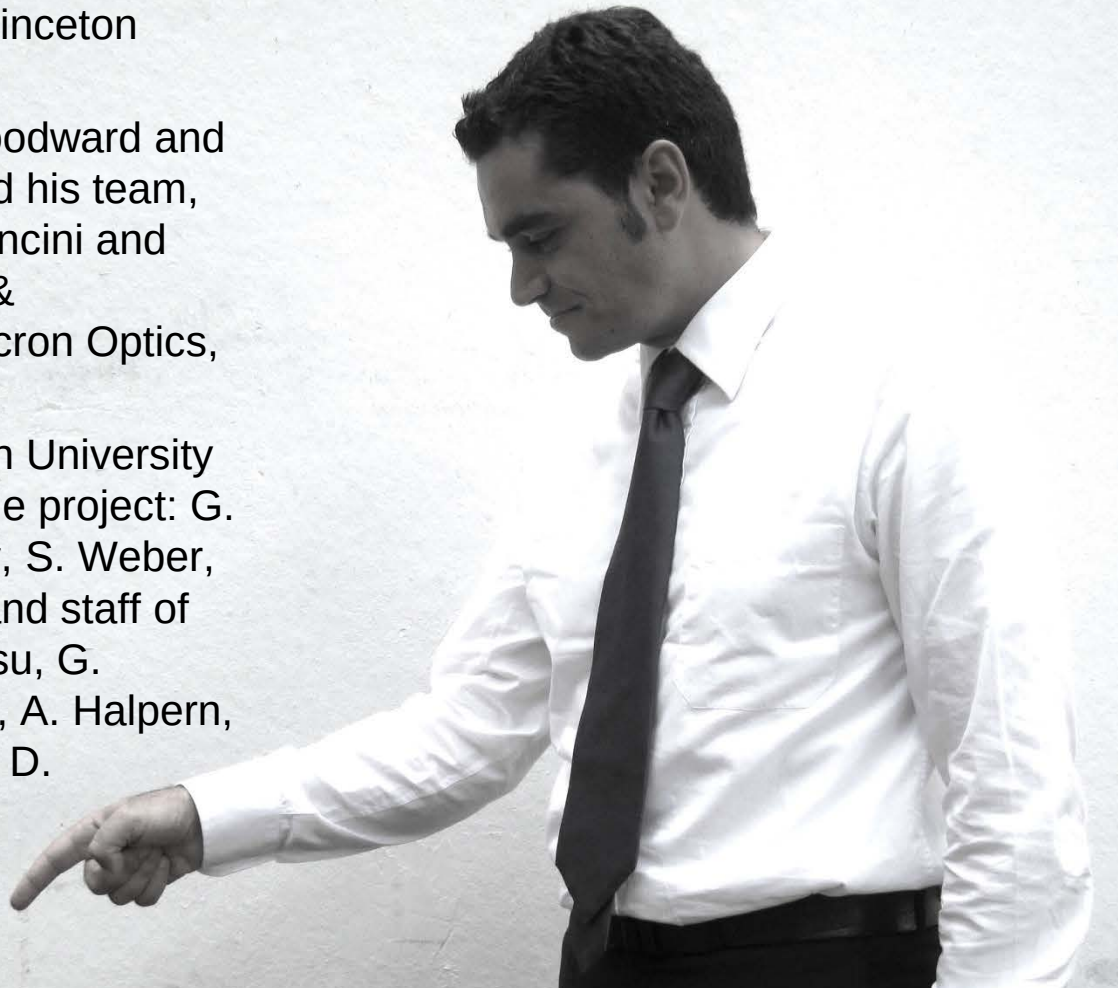
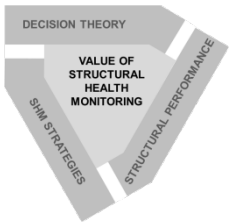
- Matteo Pozzi, CMU
- Ivan Bartoli, 'Tom', Drexel University





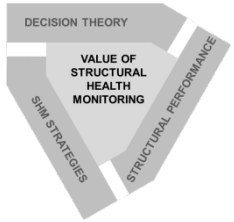
Perfect information

- assume that the monitoring system provides perfect information
- means that Tom can always determine univocally the state of the bridge based on the sensor measurements
- this happens when the two likelihood distributions pdf(ε|U) and pdf(ε|D) do not overlap, thus only one possible state is associated to any one value of strain

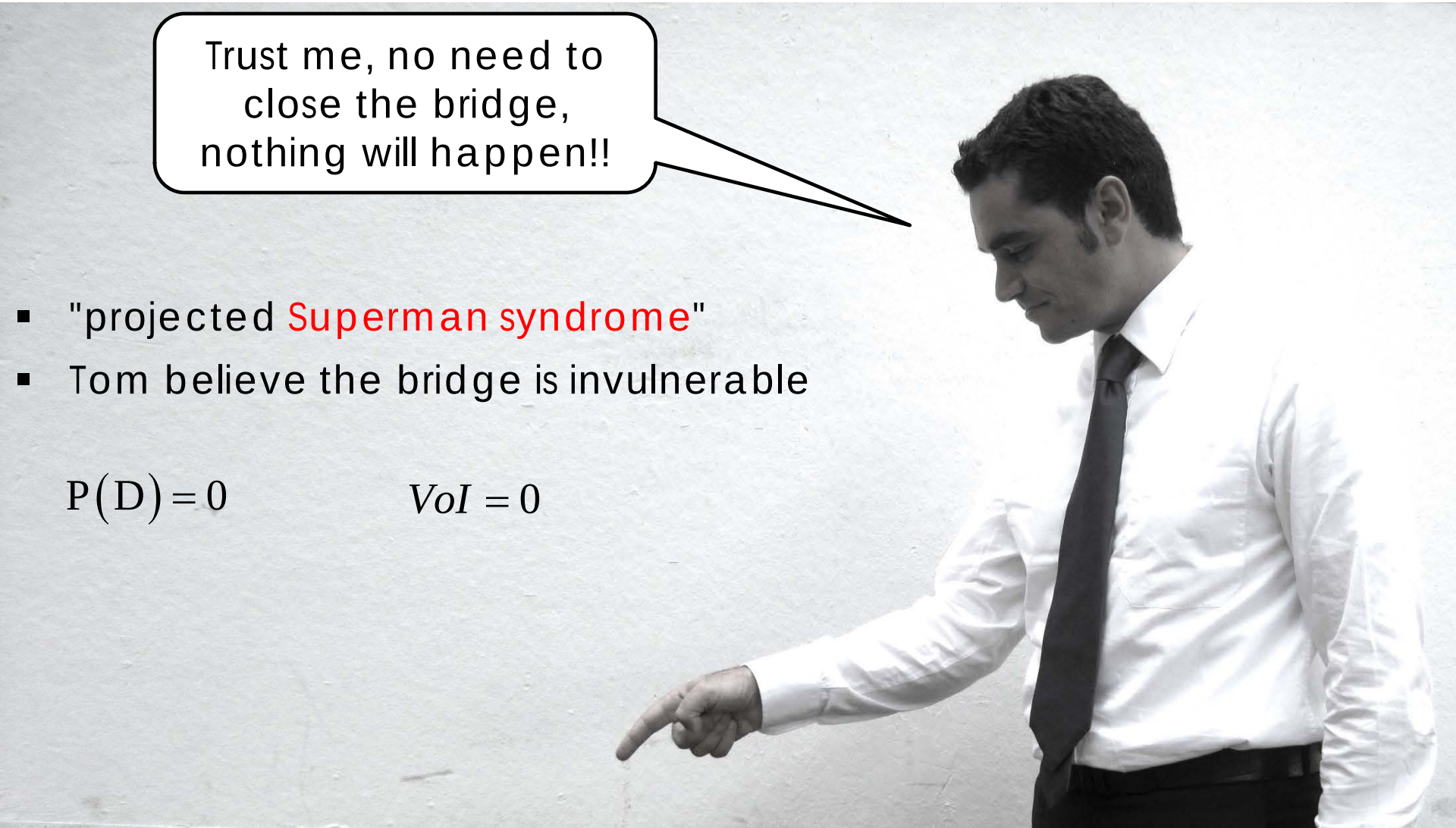
$$C^* = C_{DT}\mathrm{P}(\mathrm{D})$$

$$VoI = C - C^* = C_{DT} - C_{DT}\mathrm{P}(\mathrm{D}) = C_{DT}\mathrm{P}(U)$$

- cost Tom will incur for taking the wrong decision due to his lack in knowledge
- represents the upper bound value of VoI

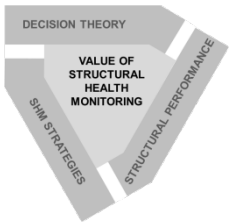


Strong prior: Cocky Tom

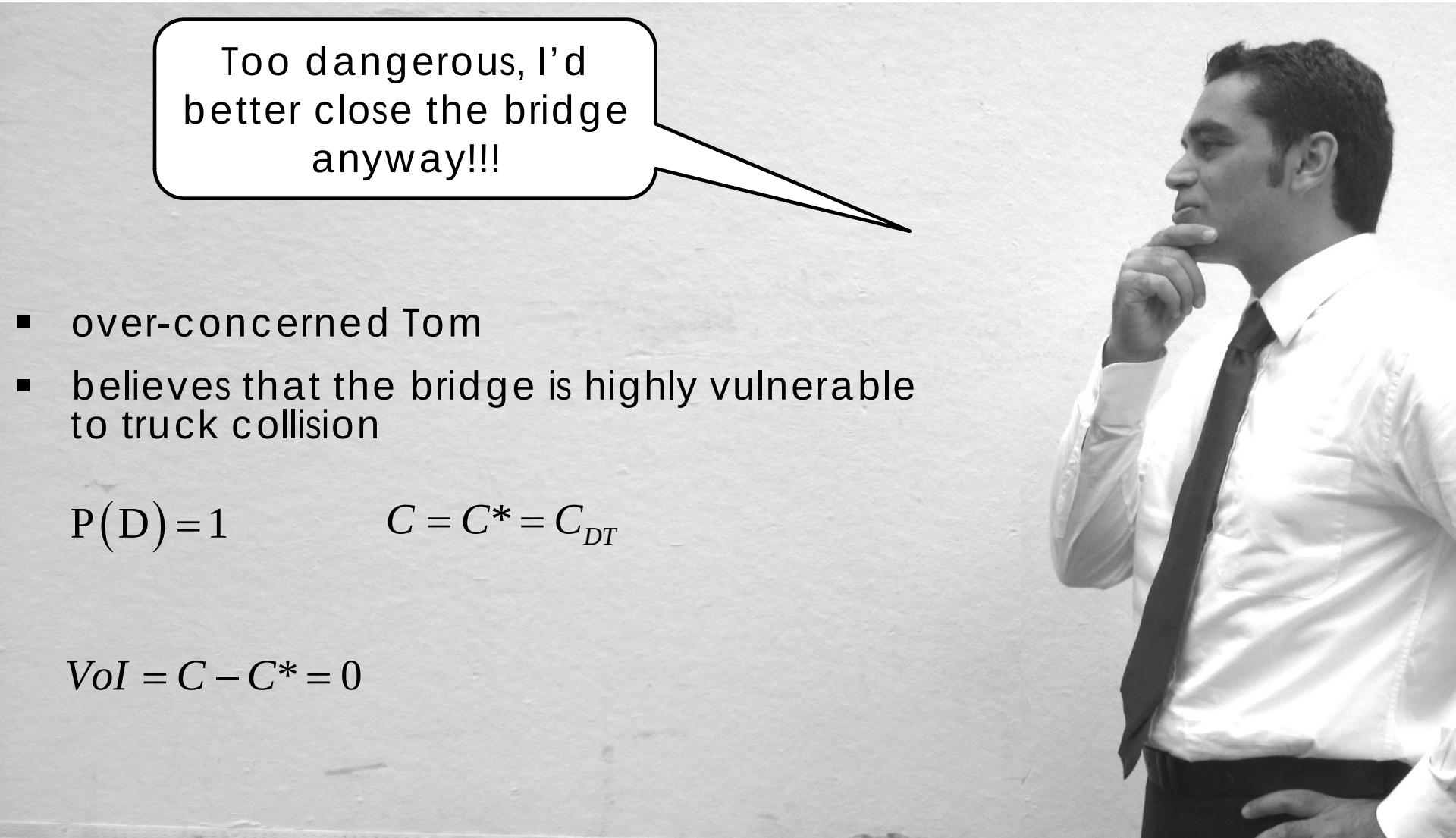


- "projected Superman syndrome"
- Tom believe the bridge is invulnerable

$$P(D) = 0 \qquad VoI = 0$$



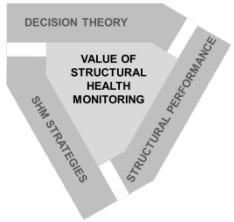
Strong prior 2: chicken-hearted Tom



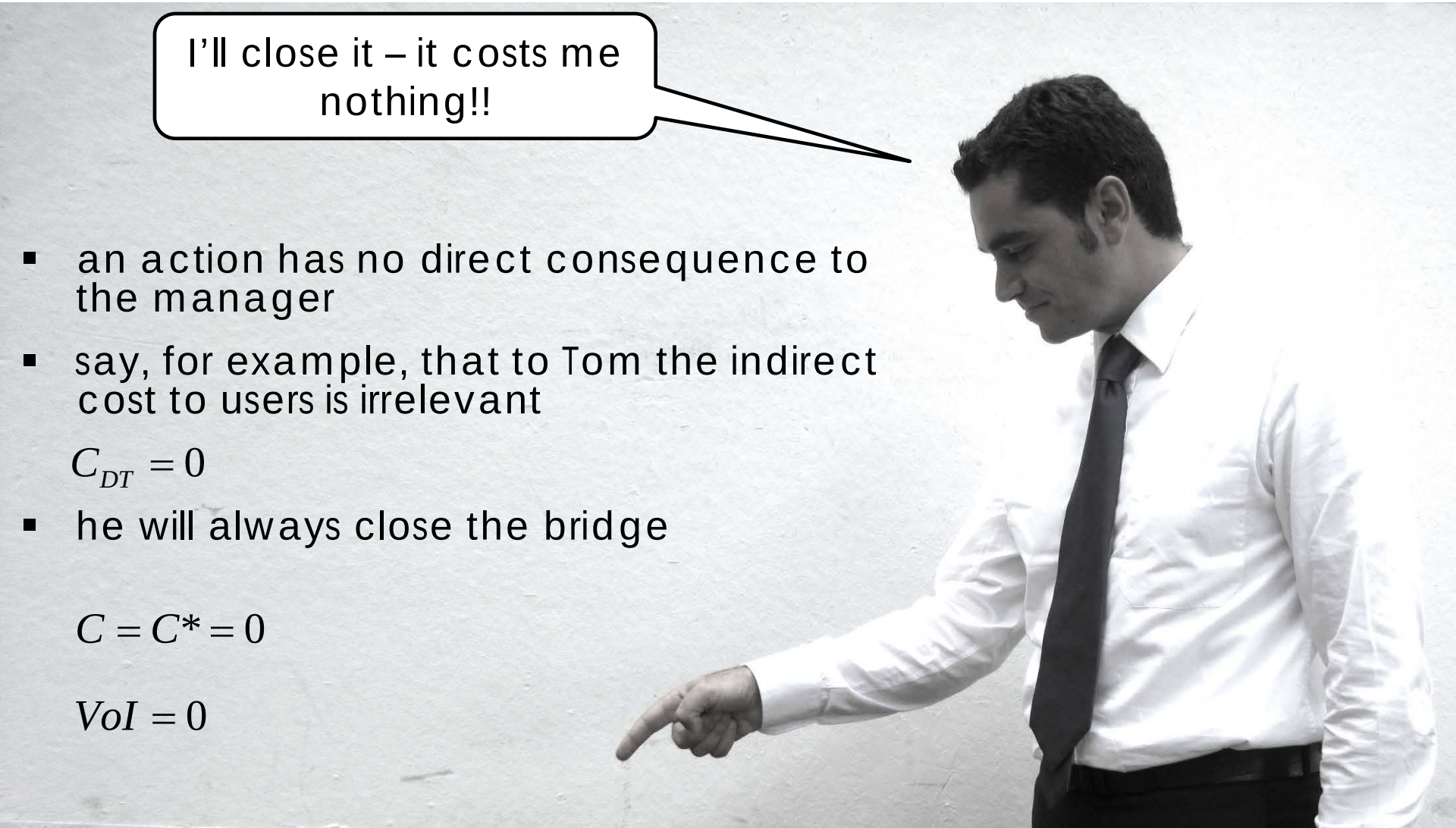
- over-concerned Tom
- believes that the bridge is highly vulnerable to truck collision

$$\mathrm{P}(\mathrm{D}) = 1 \qquad C = C^* = C_{DT}$$

$$VoI = C - C^* = 0$$



No consequence to the manager



- an action has no direct consequence to the manager
- say, for example, that to Tom the indirect cost to users is irrelevant

$$C_{DT} = 0$$

- he will always close the bridge

$$C = C^* = 0$$

$$VoI = 0$$