Incorporation of Seismic Considerations in Bridge Management Systems

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Introduction

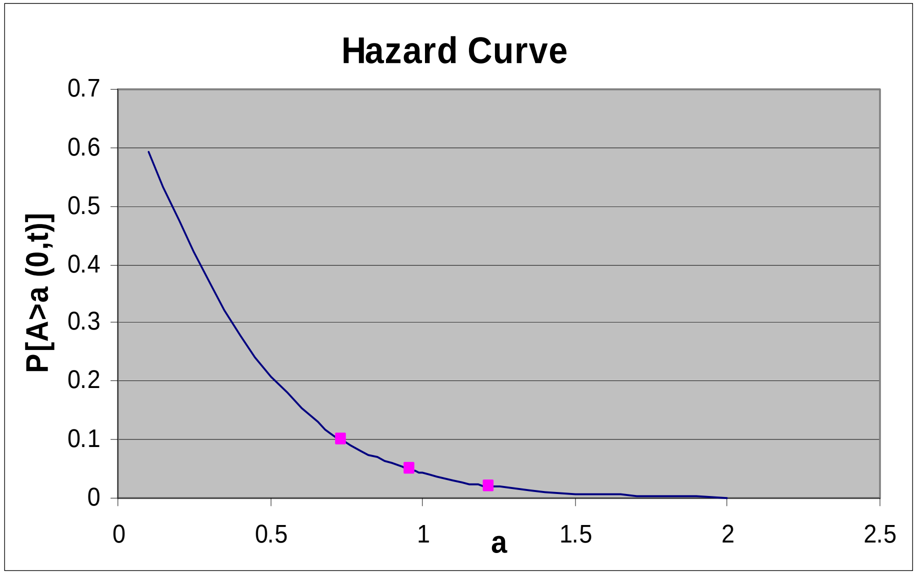
- Research establishes a link between two existing fields
- Bridge management
  - **optimal maintenance, repair and replacement policies**
  - **focus: gradual deterioration over time**

and

- Earthquake risk analysis

Seismic risk analysis

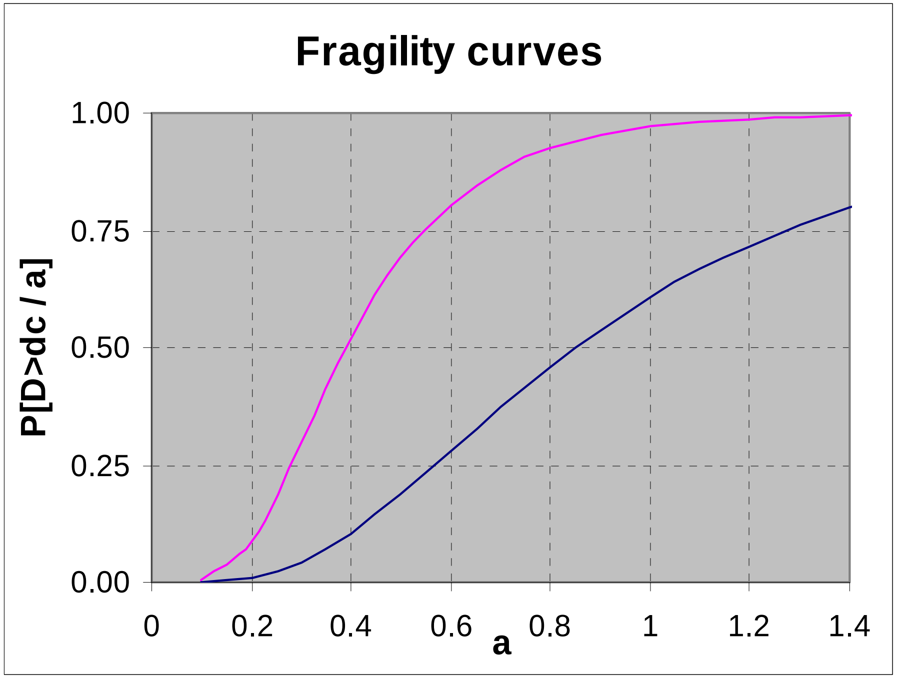
- **Random var. A**
  - **for each quake**
  - **PDF $f_A(a)$**
  - **CDF $F_A(a)$**



- **Hazard curve**
  - **USGS data for Berkeley(94702)**

Seismic risk analysis

- **Fragility curves**
  - **P[D>d /a]**
  - **HAZUS curves**
  - **extensive damage**
  - **complete damage**



- **Classifications**
  - **curves available for bridge classes**
  - **HAZUS (12 classes)**
  - **very rough classes**

Probability of destruction

- Our model
  - **only considers ‘destruction’**
  - **level of damage which implies replacement by a new bridge.**
  - **order of magnitude**
    - **formula applied for 12 classes of HAZUS**
    - **1% is reasonable for Berkeley**
    - **independent of deterioration state ?**
  - **ignores correlation across bridges**

Bridge management concepts

- System description
  - **deterioration state i**
    - **1 = brand new to 4 = rusted steel, etc.**
  - **action a**
    - **maintenance, repair, replacement…**
  - **Markov transition probability P_{aij}**
    - **Annual probability of moving from i to j given action a**
  - **w_{ai} : fraction of system in state i and receiving action a**

Bridge management concepts

- Costs
  - **u_{ai} user costs : delays, vehicle wear and tear…**
  - **c_{ai} agency costs, depending on actions**
  - **budget constraint**
    - **maximum allowed expenditure**
    - **excludes facilities destroyed by earthquakes**

Decision making model

- Formulation of infinite horizon model

$$\min \sum_a \sum_i w_{ai}.(c_{ai} + u_{ai}) \quad \textit{subject to} \quad \begin{array}{l} w_{ai} \geq 0, \quad \sum_a \sum_i w_{ai} = 1 \\ \sum_a \sum_i w_{ai}.P_{aij} = \sum_a w_{aj} \\ \frac{1}{1-P} \sum_a \sum_{i<=4} w_{ai}.c_{ai} < B_{\max} \end{array}$$

- Key concepts
  - **minimization of cost per year**
  - **steady state**

Joint model

- **Transition matrices**
  - **probabilities w/o earthquake**
  - **4 deterioration states**
  - **3 possible actions**

- **Earthquake**
  - **5th state = destruction**
  - **forced reconstruction**

do nothing				
	1	**2**	**3**	**4**
1	0.7	0.3		
2		0.9	0.1	
3			0.5	0.5
4				1

maintenance				
	1	**2**	**3**	**4**
1	0.8	0.2		
2		0.95	0.05	
3			0.7	0.3
4				1

reconstruction				
	1	**2**	**3**	**4**
1	1	0	0	0
2	1	0	0	0
3	1	0	0	0
4	1	0	0	0

Joint model

- **Agency costs**
  - **maintenance cheap**
  - **reconstruction expensive**

- **User costs**
  - **depends on state**
  - **detour if reconstruction**
  - **cost of destruction**

Total	d	m	r
1	0	5	200
2	5	10	200
3	15	20	200
4	30	35	200
5	400	400	400

Agency	d	m	r
1	0	5	150
2	0	5	150
3	0	5	150
4	0	5	150
5	150	150	150

Users	d	m	r
1	0	0	50
2	5	5	50
3	15	15	50
4	30	30	50
5	250	250	250

Joint model

- **Case**
  - **0% vs. 1% destruction**
  - **no budget constraint**
  - **deterministic policy**
- **Observation**
  - **some difference in state distribution**
  - **little importance for policy**

NO EARTHQUAKE		**Agency cost**	9.8
NO BUDGET CONSTRAI		**Total cost**	16.2
Wai	**d**	**m**	**r**
1	0.0%	17.9%	0.0%
2	0.0%	71.4%	0.0%
3	7.1%	0.0%	0.0%
4	0.0%	0.0%	3.6%
5	0.0%	0.0%	0.0%

1% DESTRUCTION		**Agency cost**	9.5
NO BUDGET CONSTRAI		**Total cost**	19.5
Wai	**d**	**m**	**r**
1	0.0%	20.6%	0.0%
2	0.0%	68.4%	0.0%
3	6.7%	0.0%	0.0%
4	0.0%	0.0%	3.3%
5	0.0%	0.0%	1.0%

Joint model

- **Case**
  - **0% vs. 1% destruction**
  - **budget < 9**
  - **randomized policy for state 4**
- **Observation**
  - **higher fraction of facilities in state 1**
  - **higher reconstruct. fraction in state 4**

0% DESTRUCTION		**Budget**	9
BUDGET < 9		**Total cost**	17.0
Wai	**d**	**m**	**r**
1	12.0%	0.0%	0.0%
2	0.0%	72.0%	0.0%
3	7.2%	0.0%	0.0%
4	5.2%	0.0%	3.6%
5	0.0%	0.0%	0.0%

1% DESTRUCTION		**Budget**	9
BUDGET < 9		**Total cost**	19.7
Wai	**d**	**m**	**r**
1	14.6%	0.0%	0.0%
2	0.0%	72.7%	0.0%
3	7.1%	0.0%	0.0%
4	1.1%	0.0%	3.5%
5	0.0%	0.0%	1.0%

Joint model

- **Case**
  - **variable vs. 1% destruction**
  - **variable among the states : 0.5% to 2%**
  - **budget < 9**
- **Observation**
  - **significant impact on state distributions and optimal policy**

1% DESTRUCTION		**Budget**	9
BUDGET < 9		**Total cost**	19.7
Wai	**d**	**m**	**r**
1	14.6%	0.0%	0.0%
2	0.0%	72.7%	0.0%
3	7.1%	0.0%	0.0%
4	1.1%	0.0%	3.5%
5	0.0%	0.0%	1.0%

VAR % DESTR.		**Budget**	9
BUDGET < 9		**Total cost**	19.6
Wai	**d**	**m**	**r**
1	14.6%	0.0%	0.0%
2	0.0%	73.5%	0.0%
3	7.1%	0.0%	0.0%
4	0.2%	0.0%	3.5%
5	0.0%	0.0%	1.0%

Conclusions

- **Significant impact of earthquakes**
  - **on state distribution**
  - **on policies if budget constraints**
- **Need for more precise bridge classes**
  - **variable % of destruction among states may be important**
- **Extension must account for correlation between destructions !**