

Assembly-Based Vulnerability for Hospitals and Lifelines

MCEER 2005 Annual Meeting

Earthquake Response and Recovery Research Thrust
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Problem to be solved

- Estimate a facility's earthquake performance in terms of
 - Post-earthquake operability
 - Repair time
 - Repair cost
- Applicability: hospitals, bridges, etc.
- Analytical features
 - Nonlinear time-history structural analysis
 - Propagate important sources of uncertainty
 - Avoid reliance on expert opinion
 - Employ full-size test specimen data
 - Include equipment and other contents



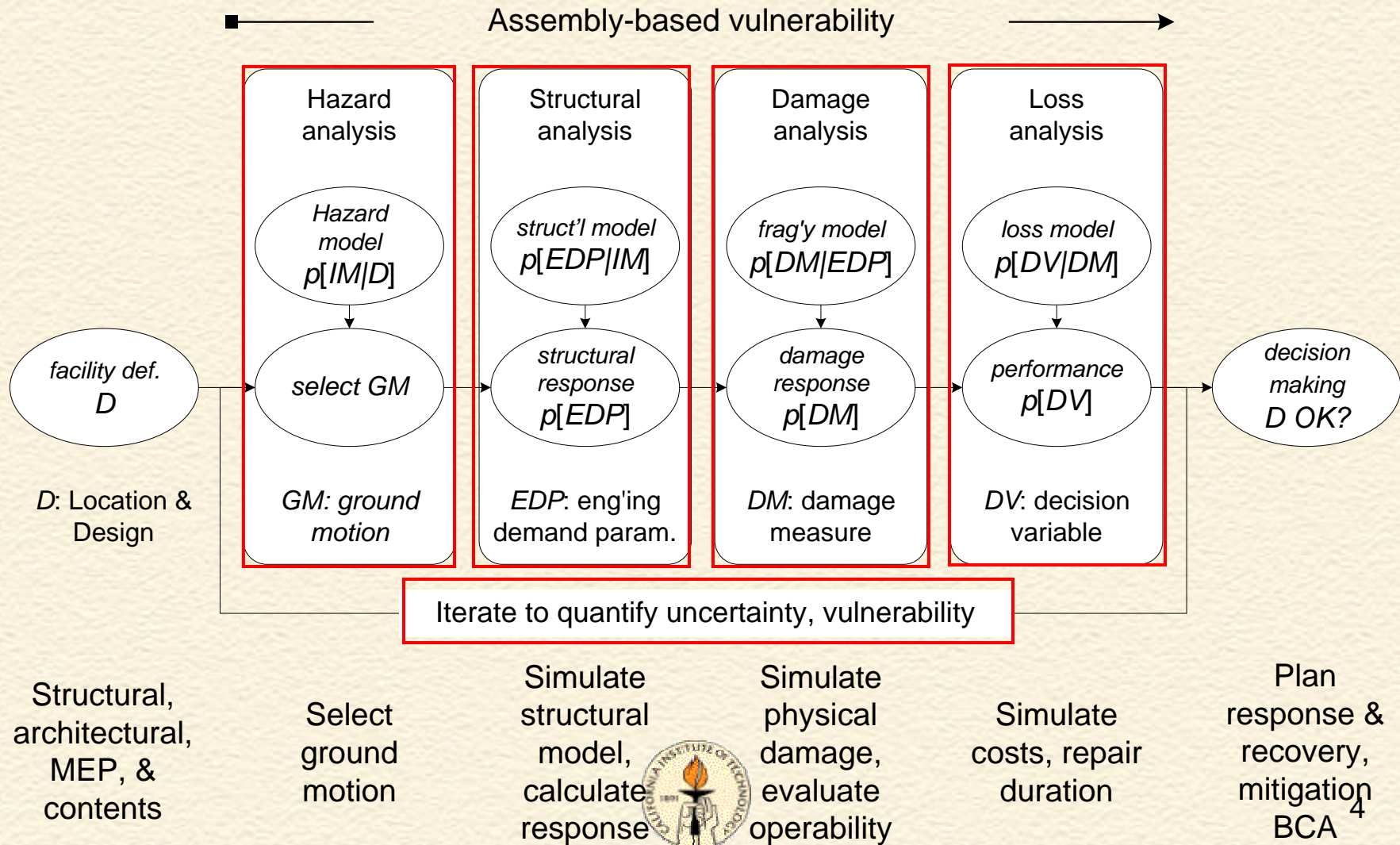
For example,

- Will the hospital be safe and occupiable after an event with $S_a = 0.5g$?
- Will critical equipment in a lab be damaged?
- What will it cost & how long will repairs take?
- Where should engineers look for hidden structural damage?

Answer these questions using the best available data and methods



Assembly-Based Vulnerability

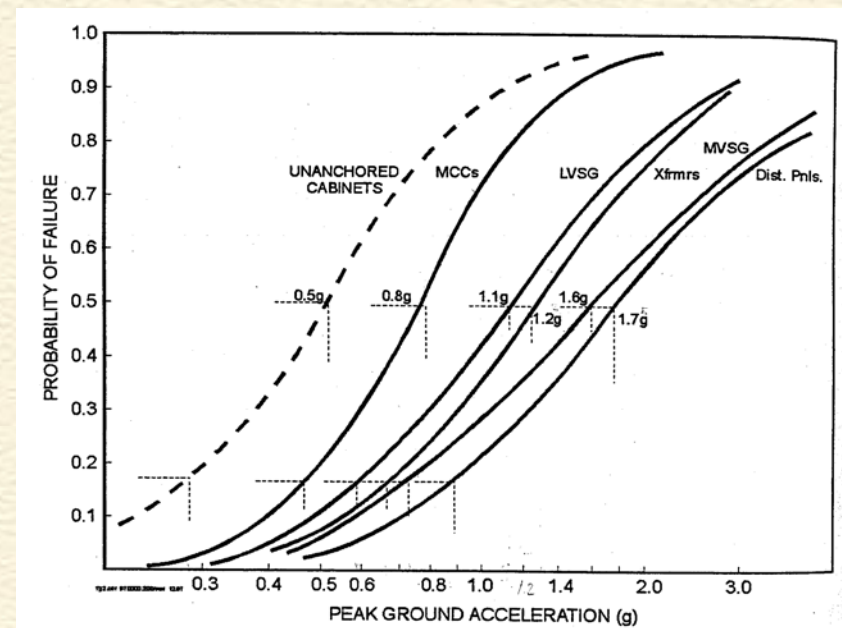
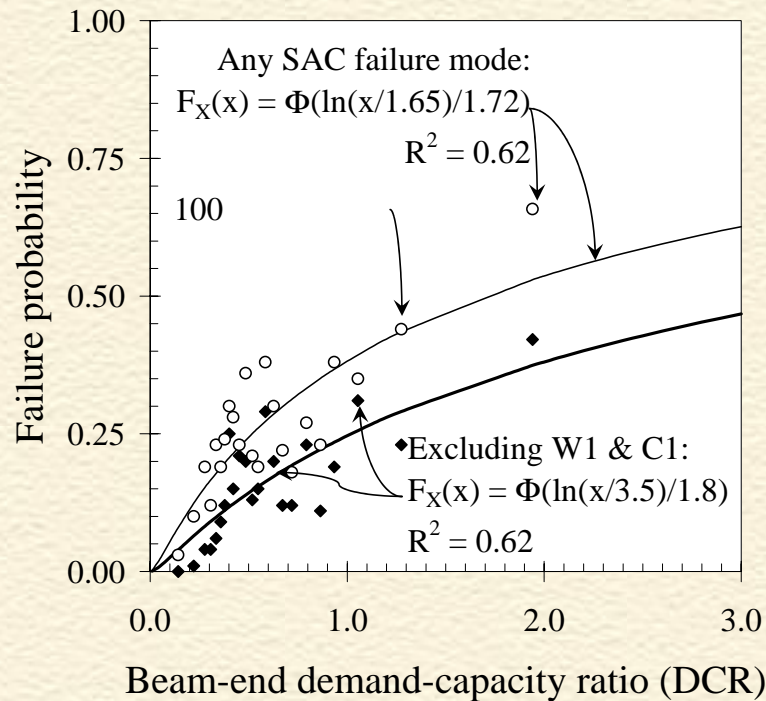


Example assembly fragility functions

Commonly, $P[\text{failure} | EDP = x] = \Phi\left(\frac{\ln(x/x_m)}{\beta}\right)$

Pre-Northridge welded-steel moment-frame connections (Porter 2000)

Power-supply equipment (Swan & Kassawara 1998)



A fragility & cost database

RC - Microsoft Internet Explorer

File Edit View Favorites Tools Help eFax

Back Forward Stop Refresh Home Search Favorites Media Print Mail Site popups allowed

Address C:\Job\Porter (07 Dec 2004) fragility.htm

Google Search Web Search Site

Assembly Fragility and Repair Cost

Alias: Exterior wood shearwall 1 ID: 1

RS Means line: 4.5.110.2101.01 Unit: 64 sf

Description: Exterior shearwall, 3/8 C-D ply, 2x4, 16" OC, 7/8" stucco ext, no int finish

Fragility functions

DM: 1 DM description: Fracture of sheathing-to-framing connections

DM repair: Renail and patch

EDP type: PTD EDP units: unitless

FF distribution: LN

mFF: 0.008 sFF: 0.3

lowerFF: upperFF:

FF basis: L Peer reviewed

FF reference: Porter et al. (2002)

Repair cost

C distribution: LN

mC: 131 sC: 0.2

lowerC: upperC:

Cost year: 2001 Cost ZIP3: 904

Cost reference: Porter et al. (2002)

Comment:

RC 1 of 83

Safety & operability

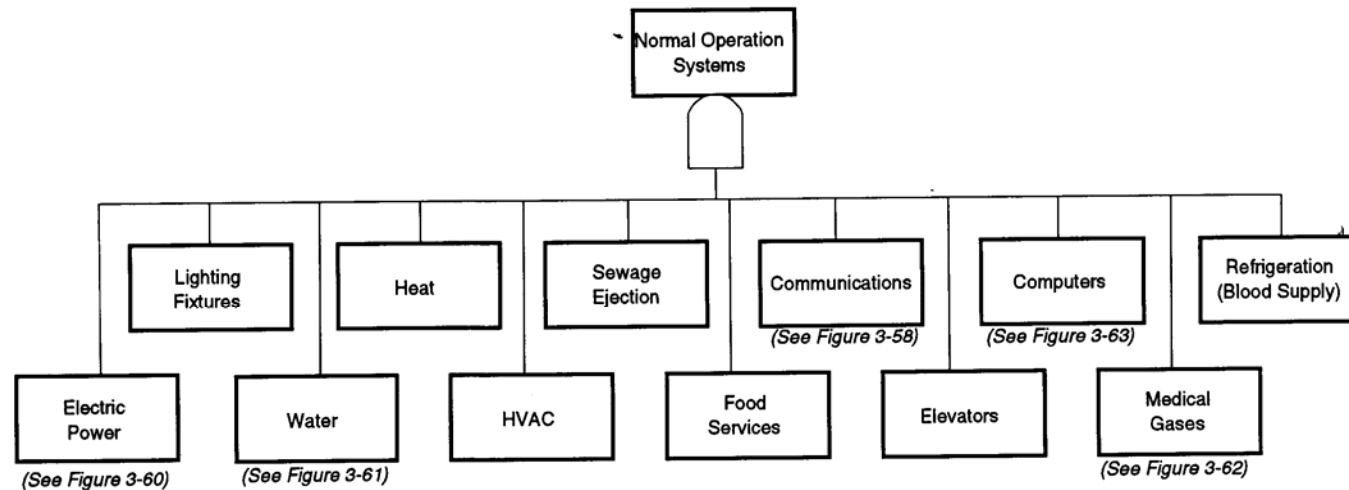
Table C1-5 Nonstructural Performance Levels and Damage¹—Architectural Components

Component	Nonstructural Performance Levels			
	Hazards Reduced ² N-D	Life Safety N-C	Immediate Occupancy N-B	Operational N-A
Cladding	Severe distortion in connections. Distributed cracking, bending, crushing, and spalling of cladding elements. Some fracturing of cladding, but panels do not fall in areas of public assembly.	Severe distortion in connections. Distributed cracking, bending, crushing, and spalling of cladding elements. Some fracturing of cladding, but panels do not fall.	Connections yield; minor cracks (<1/16" width) or bending in cladding.	Connections yield; minor cracks (<1/16" width) or bending in cladding.
Glazing	General shattered glass and distorted frames in unoccupied areas. Extensive cracked glass; little broken glass in occupied areas.	Extensive cracked glass; little broken glass.	Some cracked panes; none broken.	Some cracked panes; none broken.
Partitions	Distributed damage; some severe cracking, crushing, and racking in some areas.	Distributed damage; some severe cracking, crushing, and racking in some areas.	Cracking to about 1/16" width at openings. Minor crushing and cracking at corners.	Cracking to about 1/16" width at openings. Minor crushing and cracking at corners.

NCEER-93-0022
(Porter et al. 1993)

FEMA 356 (ASCE 2000)

KEY		
SYMBOL	NAME	MEANING
	AND GATE	Component above gate functions if all components below function
	OR GATE	Component above gate functions if any component below functions



Repair duration, R

$$R = \sum_{j,d} \frac{N_{j,d} U_{j,d}}{w E_j} + n R_T + R_{T0}$$

$N_{j,d}$ = no. damaged assemblies

$U_{j,d}$ = hr to restore 1 assembly

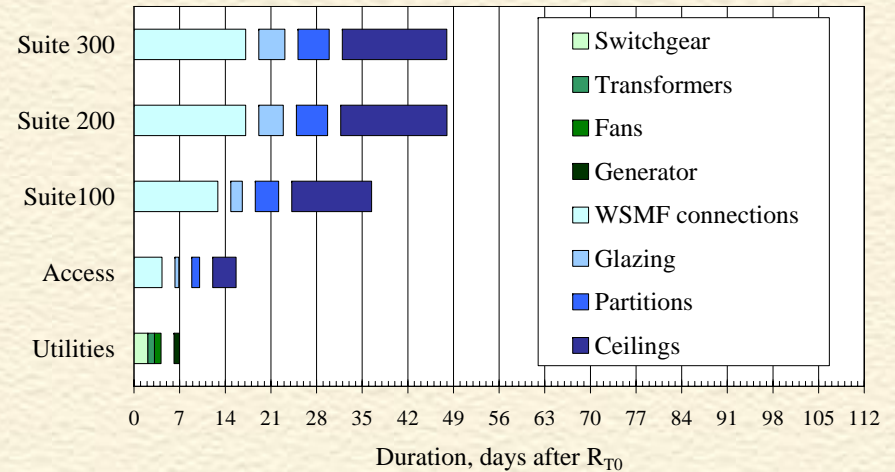
w = workhours/workday

E_j = no. crews available

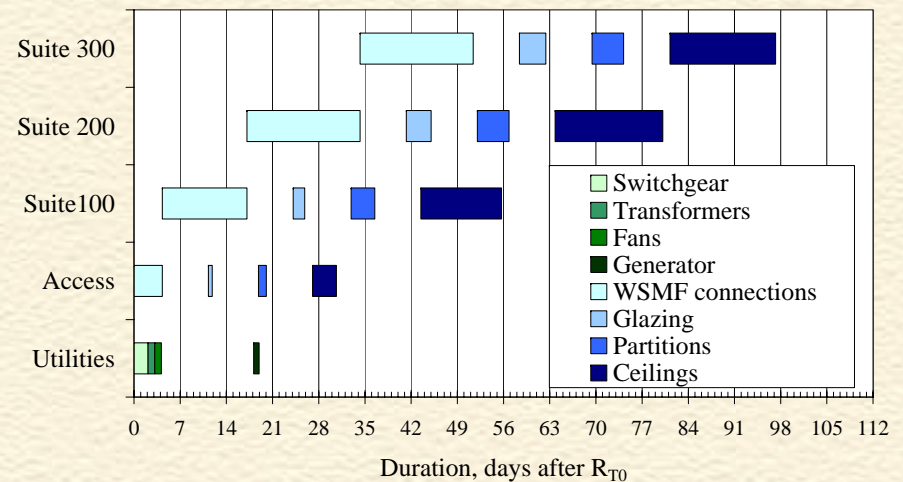
n = no. changes of trade

R_T = change-of-trade delay

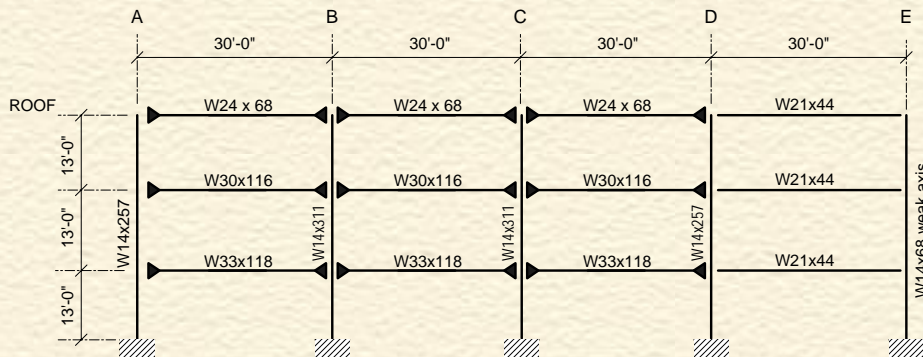
R_{T0} = start-up time



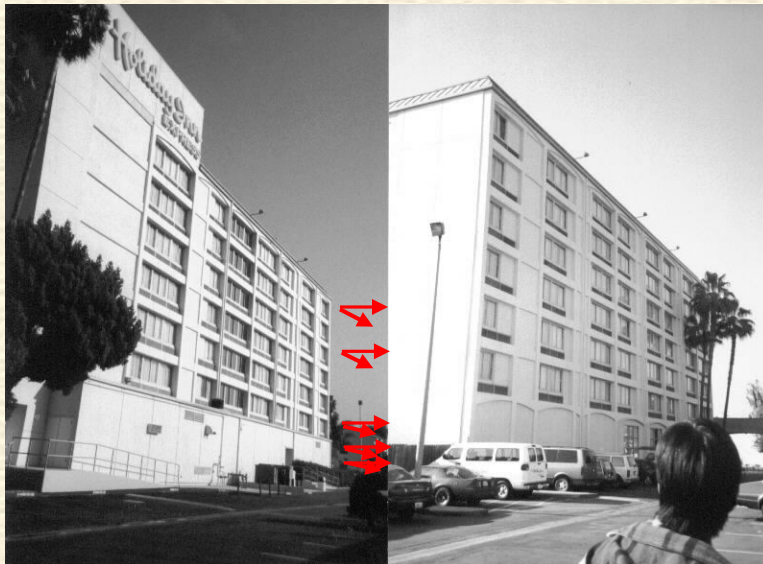
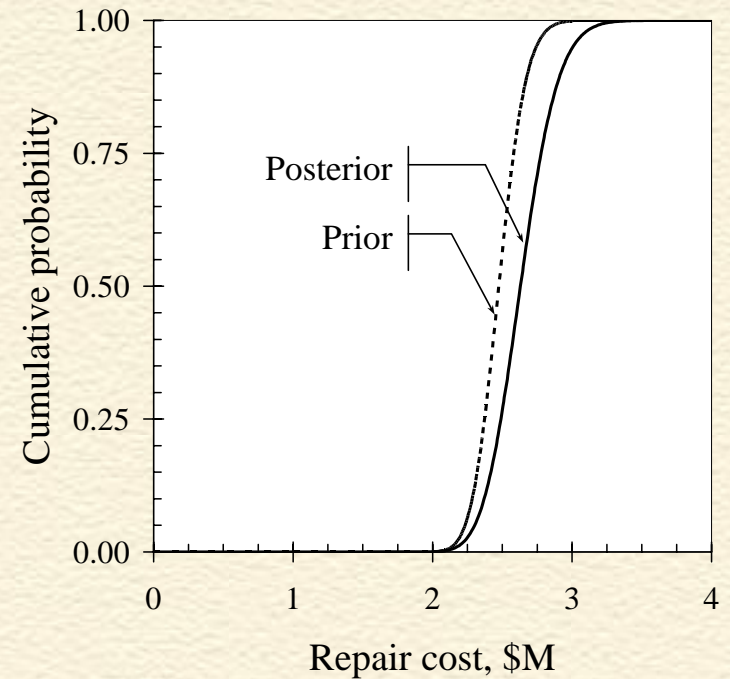
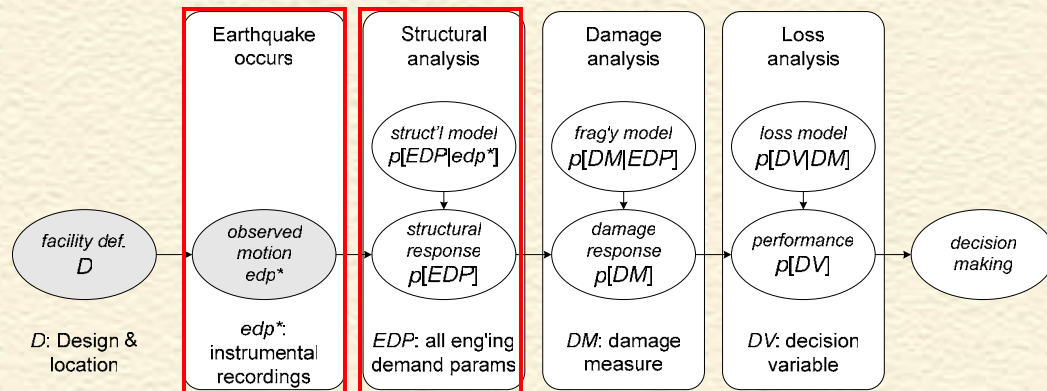
Fast, parallel, short change-of-trade



Slow, serial, long change-of-trade



Real time performance evaluation



See Caltech EERL 2004-08,
<http://caltecheerl.library.caltech.edu/374>



Recap

- One method to model response, damage, operability, repair duration, repair cost
 - Best structural analysis, lab data, construction practices
 - Has been applied to various facility types
- Response & recovery modeling:
 - Will the facility be operational?
 - What will repair cost, & how long will it take?
 - Where to look for concealed damage?
- Decision-making
 - E.g., mitigation or planning needed to meet performance objectives?



Research gaps

- Synthesis & simplification
 - Repository of interpreted fragility, cost, etc. parameters
 - Revisit FEMA 356-style criteria for operability, safety
 - Aggregate operability, cost, & downtime functions for hospitals, other important facilities, with a few *key* parameters
 - Automate performance modeling with open-source software
- New fragility data
 - Various MEP, contents of contents, contents on shelves with lips
 - Contents → casualties
 - Good use of NEES
- Other basic data
 - Uncertainty in unit repair duration
 - Model start-up time R_{T0} , change-of-trade delays,

