A Bayesian Network Methodology for Infrastructure Seismic Risk Assessment and Decision Support

PI: Armen Der Kiureghian
GSI: Michelle Bensi

University of California, Berkeley

Sponsor: State of California through Transportation Systems Research Program of Pacific Earthquake Engineering Research (PEER) Center

Outline:

- Motivation and Goal of the study
- Current status
- Selected results
- Example application

Motivation and Goal:

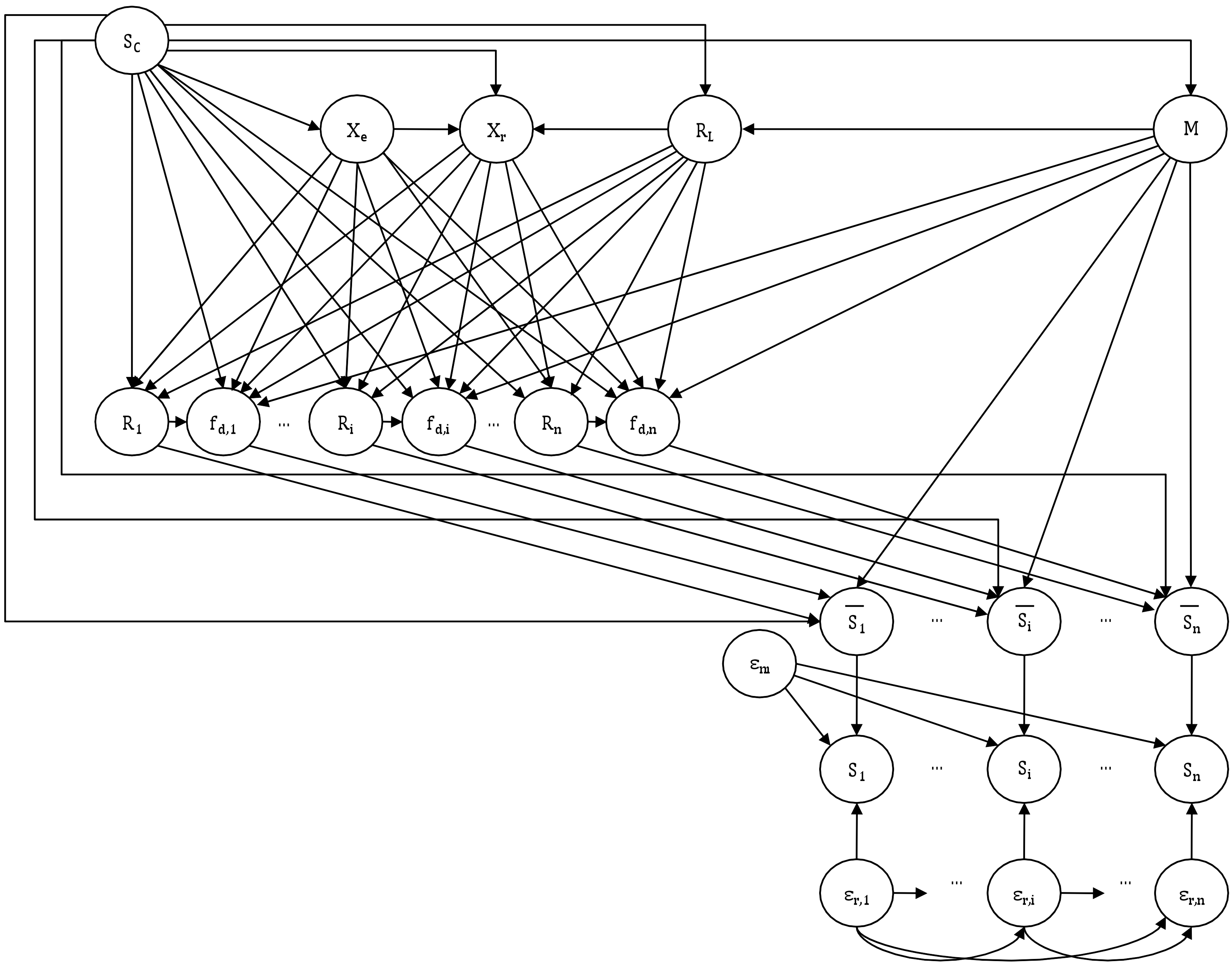
To develop a Bayesian network methodology for pre- and post earthquake infrastructure seismic risk assessment and decision support with capabilities for:

- Representation of seismic demand,
- Models for components and systems,
- Probabilistic updating upon evidence,
- Computational efficiency,
- Decision support models,
- Prototype applications.

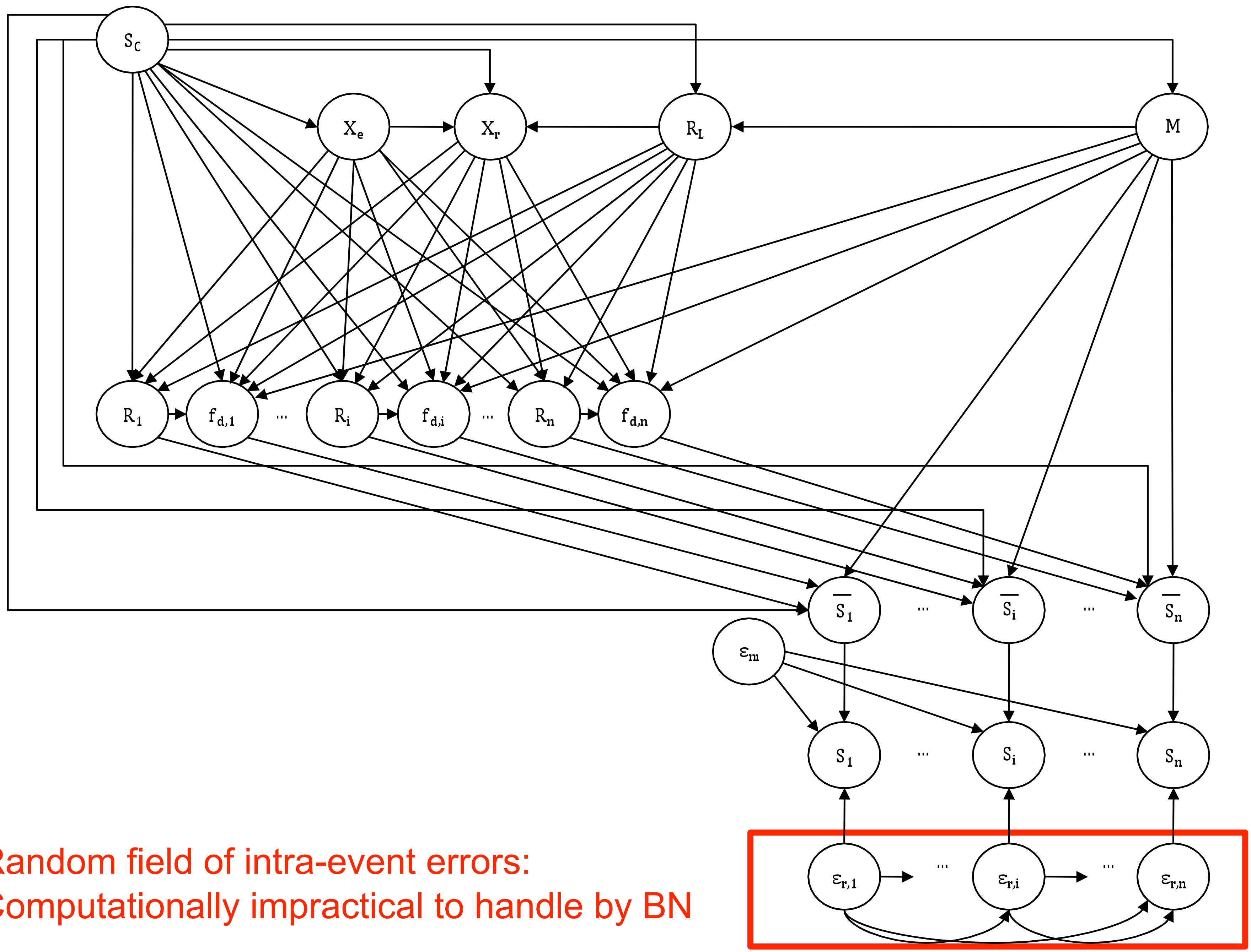
Status:

- Michelle Bensi has nearly completed her doctoral degree
- A comprehensive report (250+ pages) will soon be submitted as a PEER report. The report includes:
  - Chap 2: Introduction to BN
  - Chap 3: BN Seismic demand models
  - Chap 4: BN modeling of random fields
  - Chap 5: BN modeling of component performance
  - Chap 6: BN modeling of system performance
  - Chap 7: Decision support
  - Chap 8: Example applications
- Publications: 6 conference papers; 1 journal submitted ; 2 journal in preparation.
- All funds spent.

Seismic demand model:



Seismic demand model:



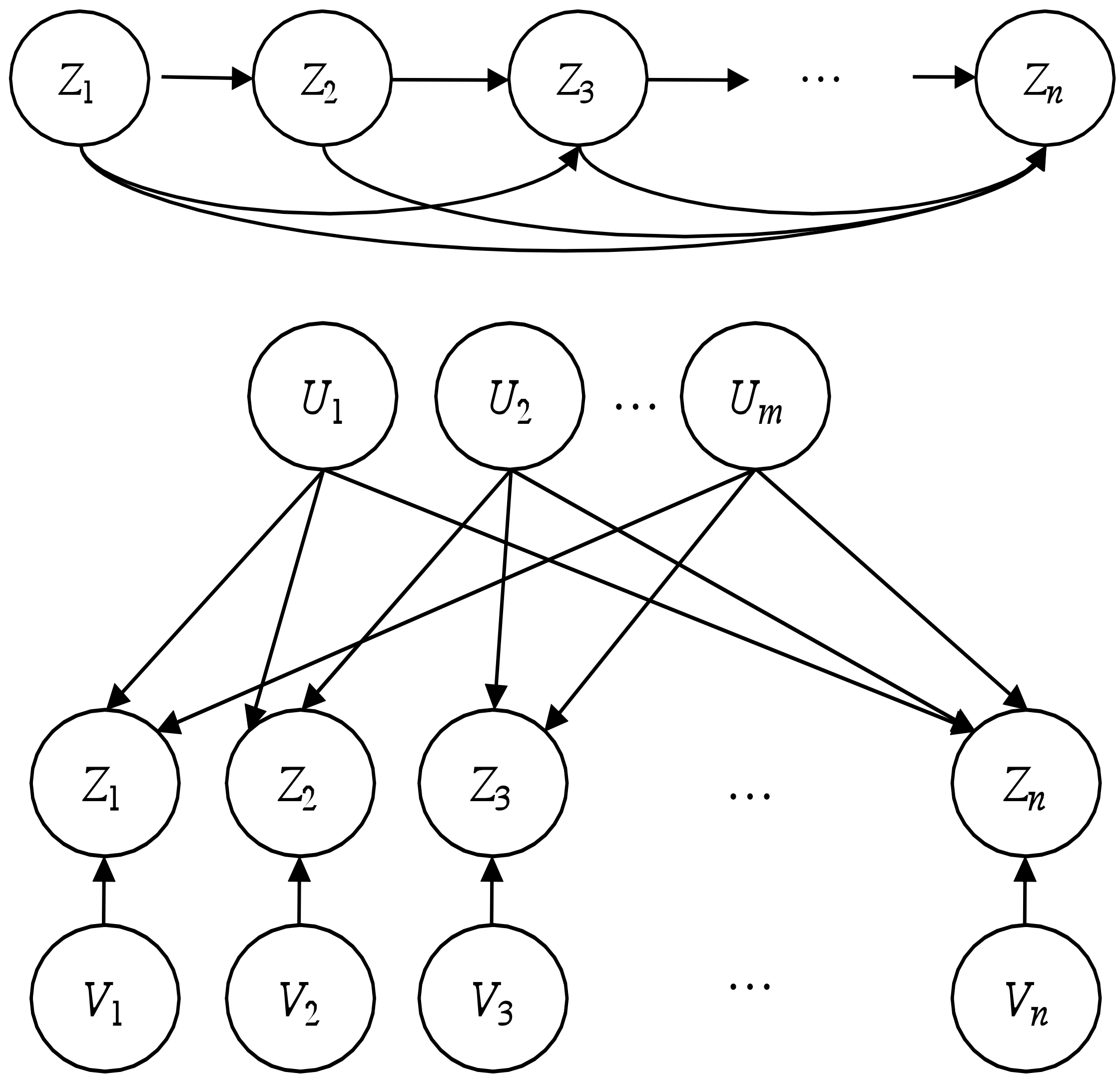
Random field of intra-event errors:
Computationally impractical to handle by BN

Efficient BN modeling of random variables drawn from a Gaussian random field:

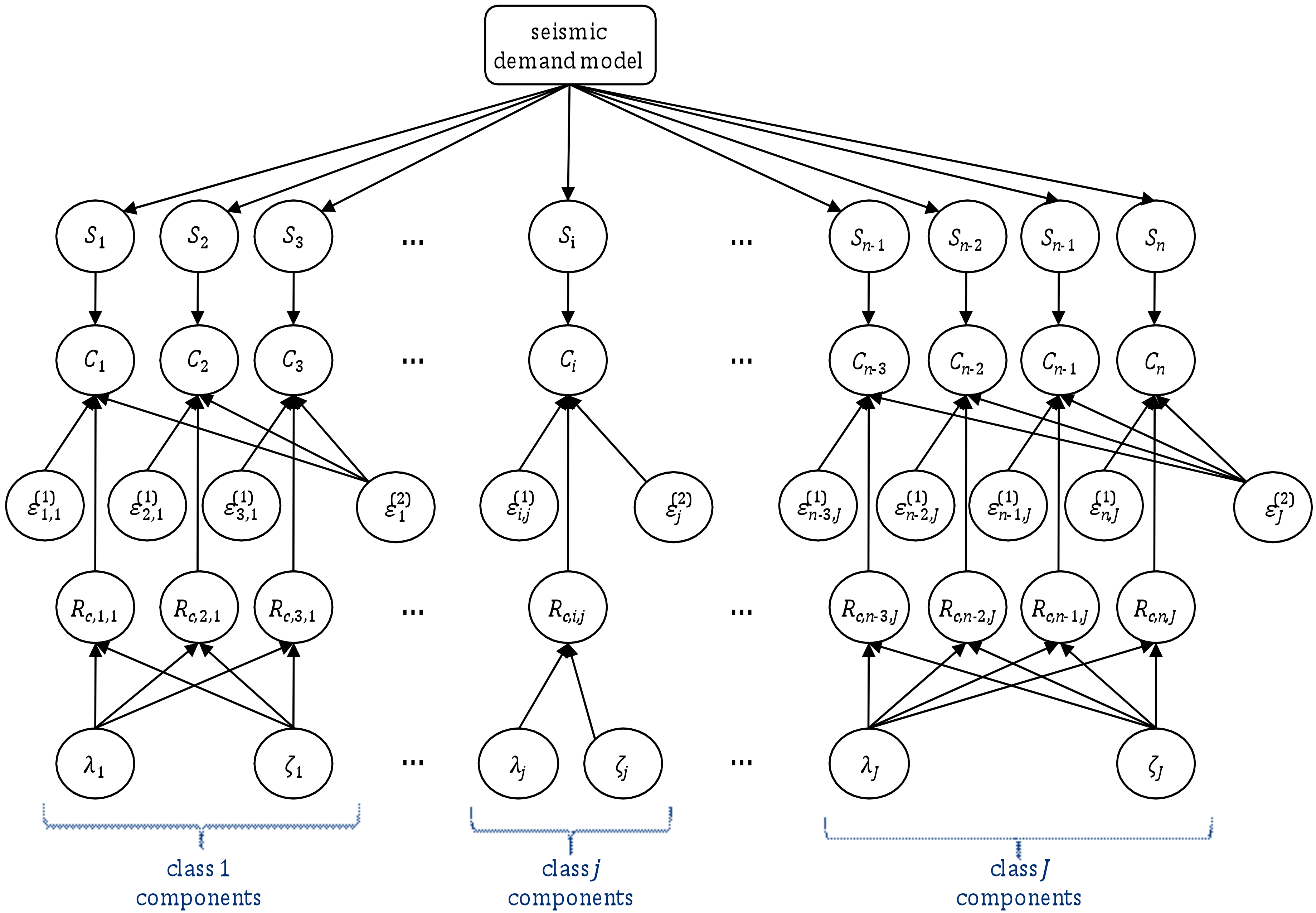
$$\hat{\mathbf{Z}} = \mathbf{SV} + \hat{\mathbf{T}}\mathbf{U}$$

Construct $n \times m$ matrix **T** with preselected number of non-zero elements by minimizing error in correlation matrix.

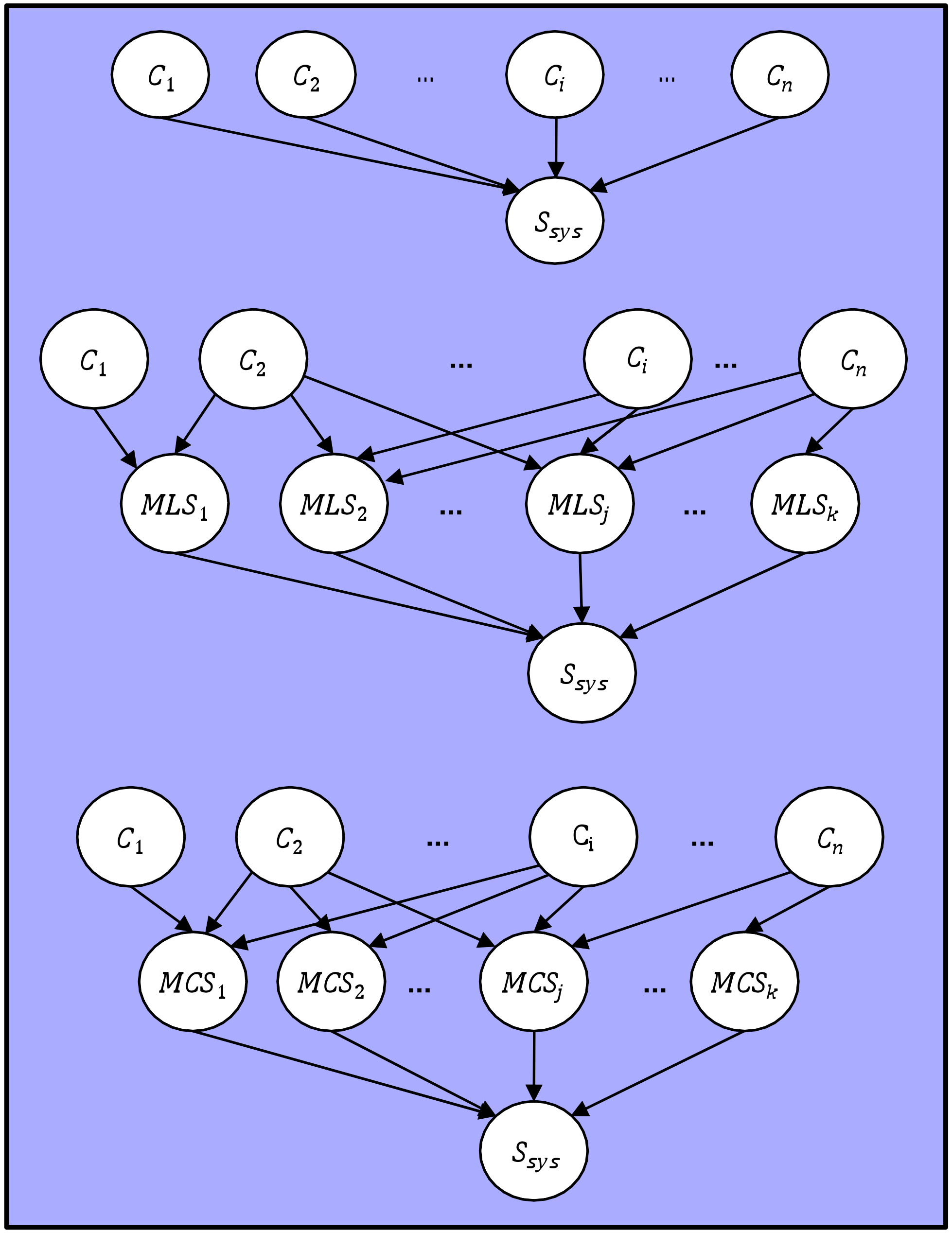
Construct $n \times m$ matrix S to correct variances.



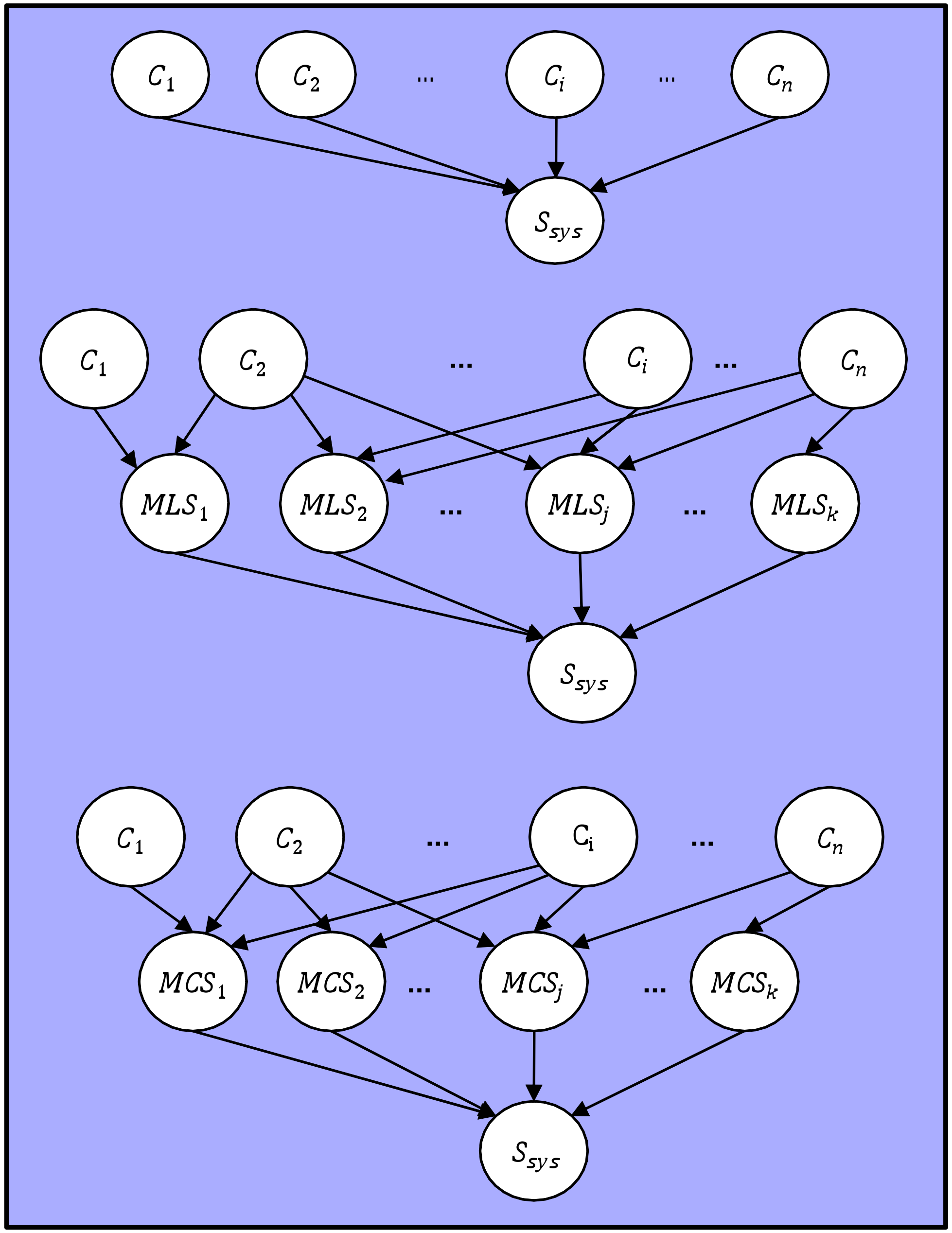
Component performance model

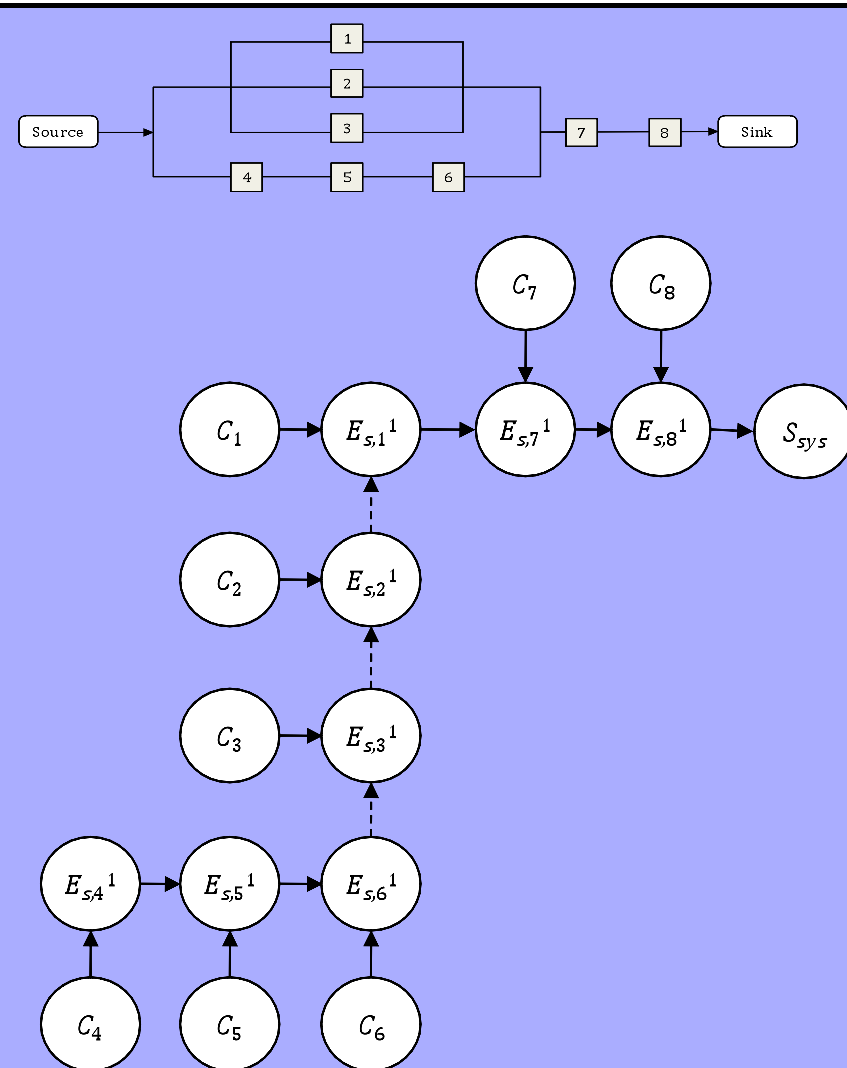


System performance model



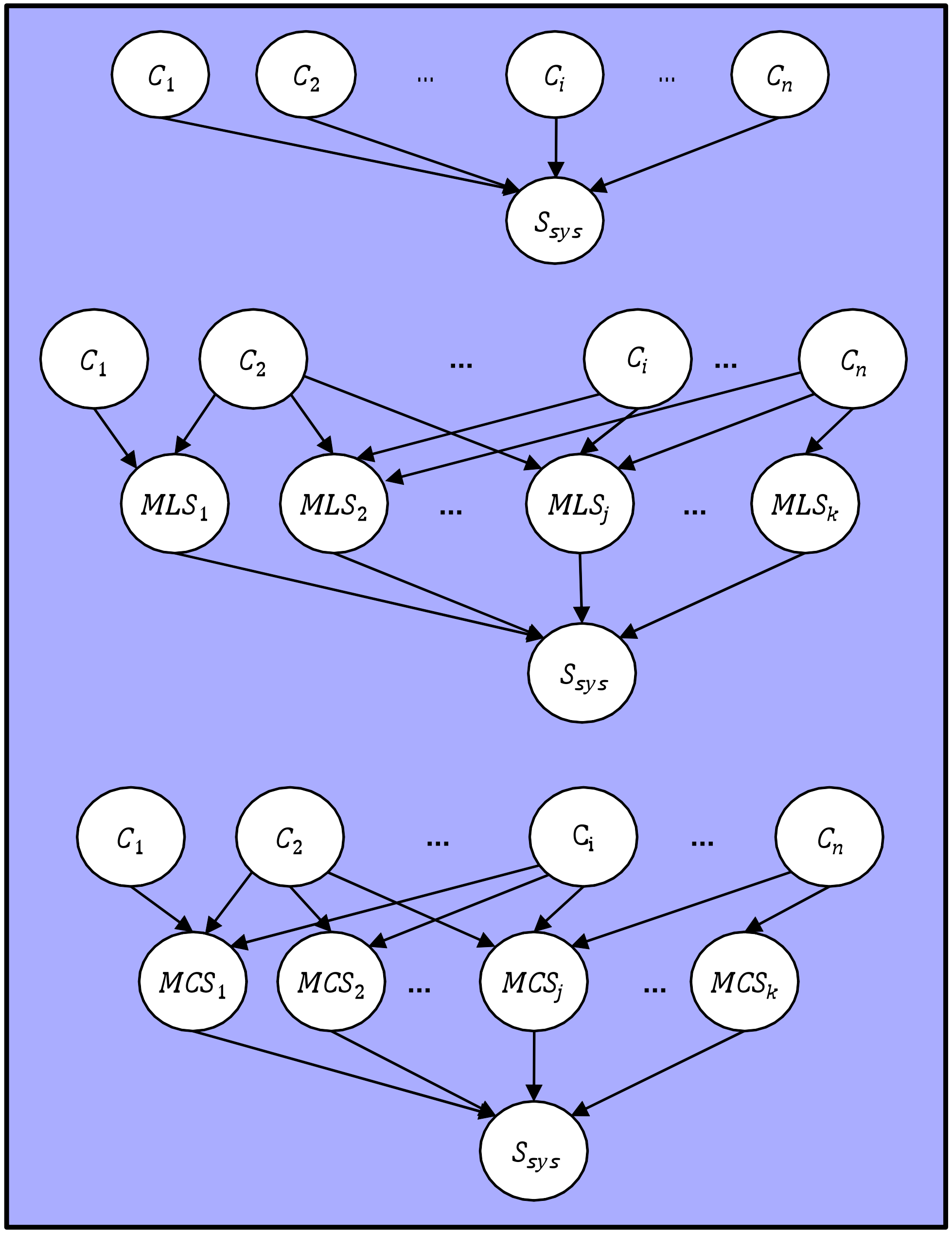
System performance model

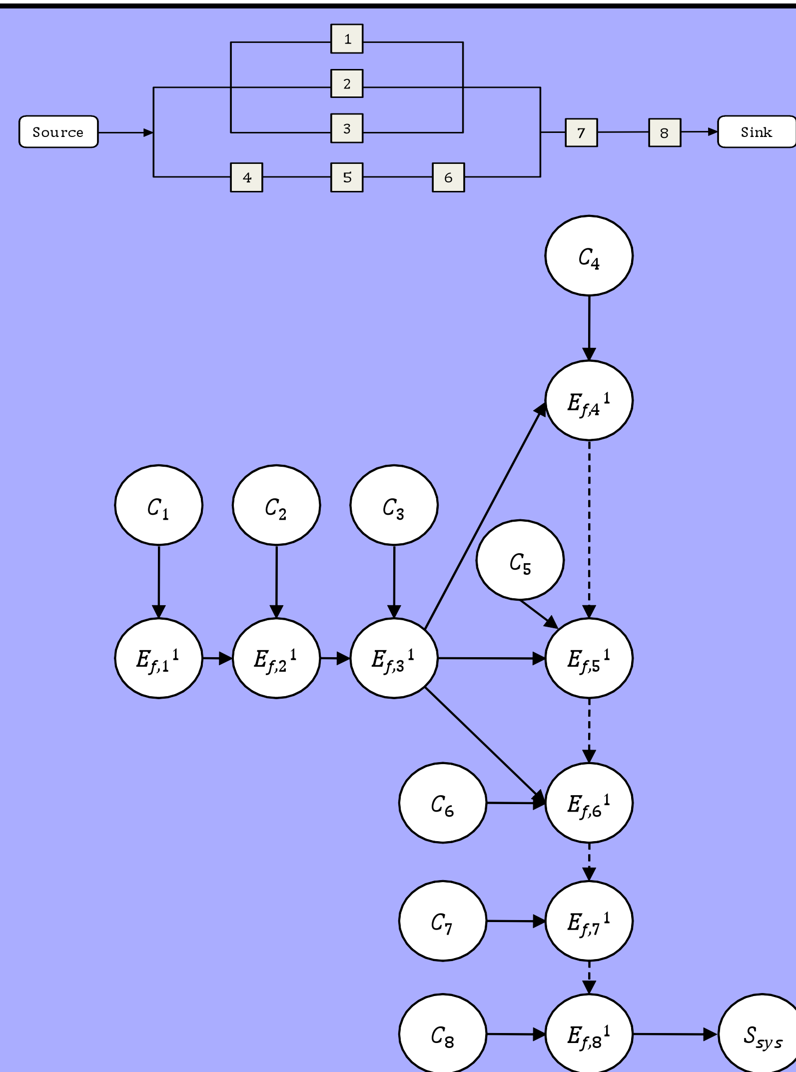




Efficient MLS formulation by use of Survival Path Sequences

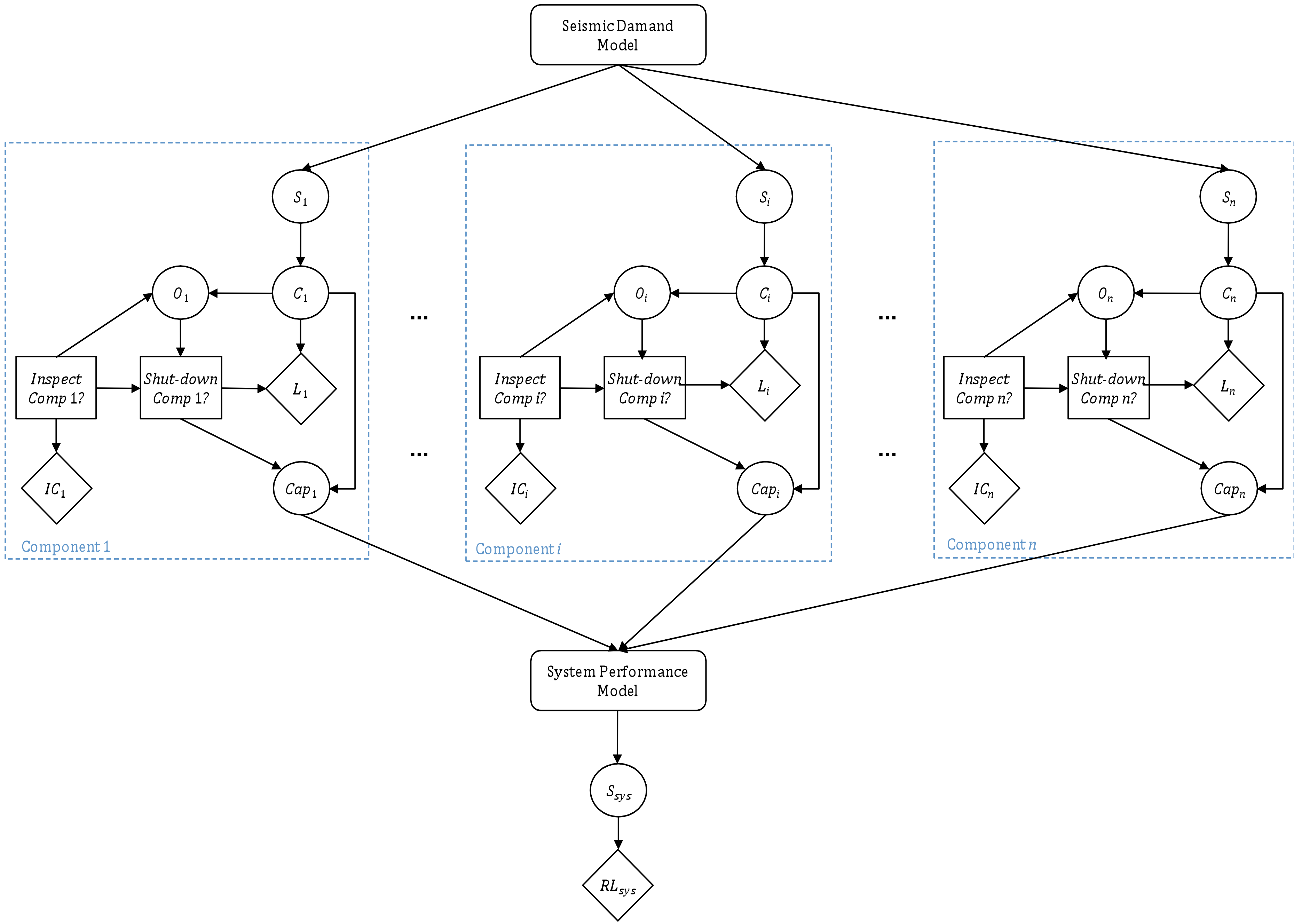
System performance model



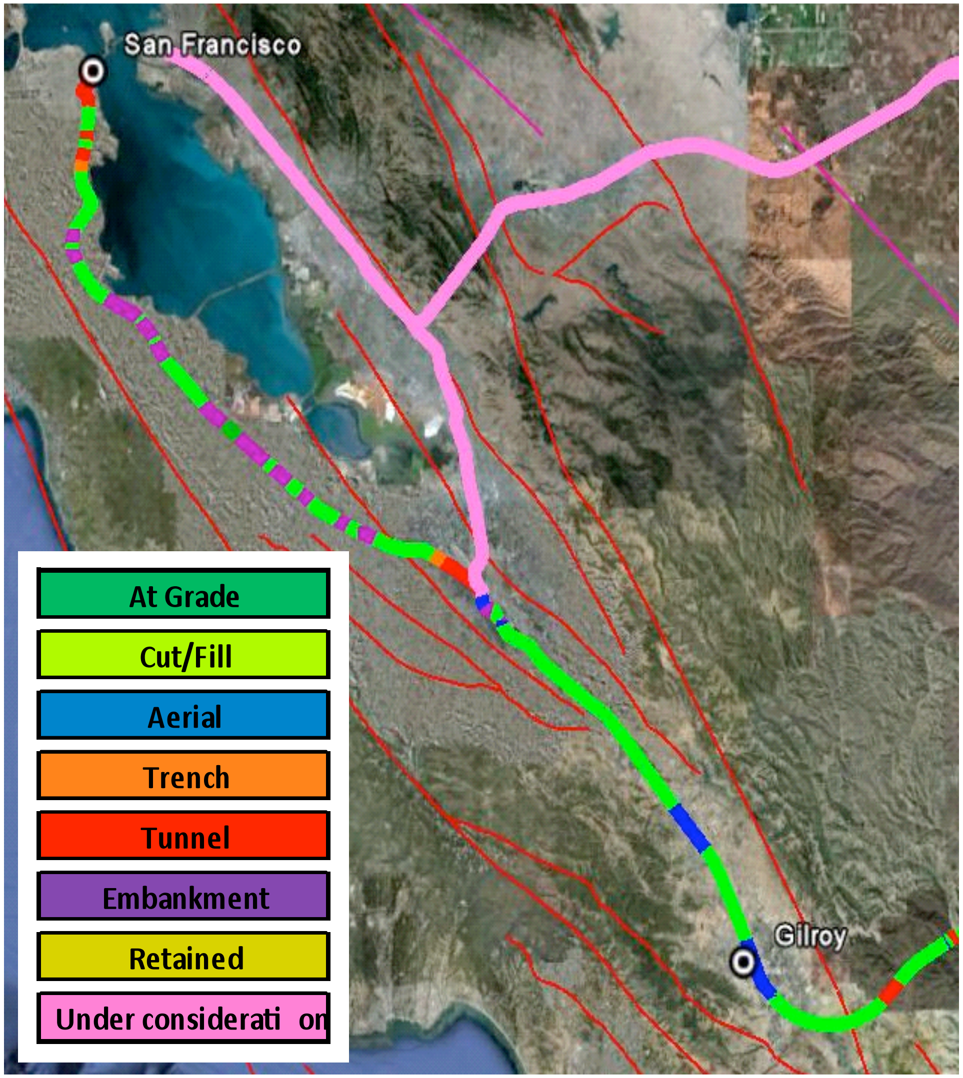


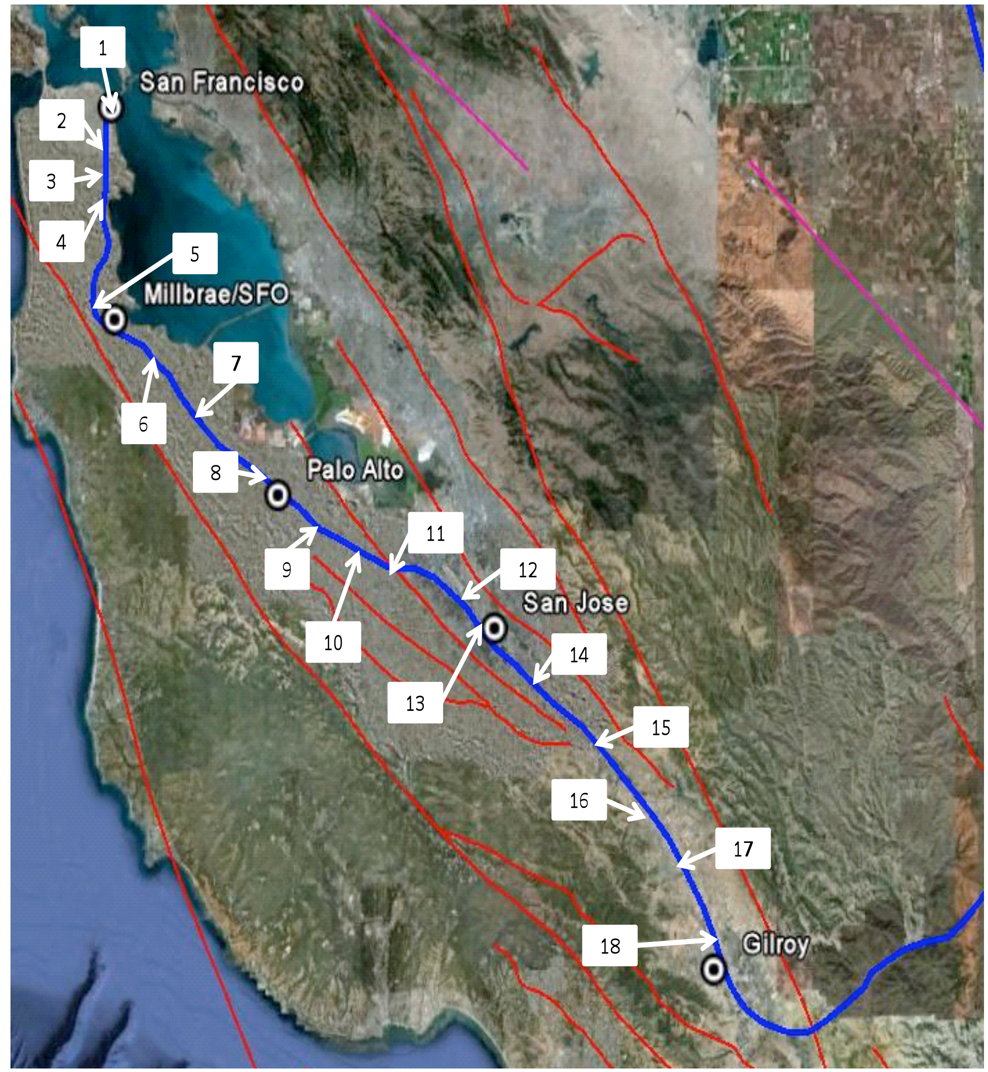
Efficient MCS formulation by use of Failure Path Sequences

Influence diagrams

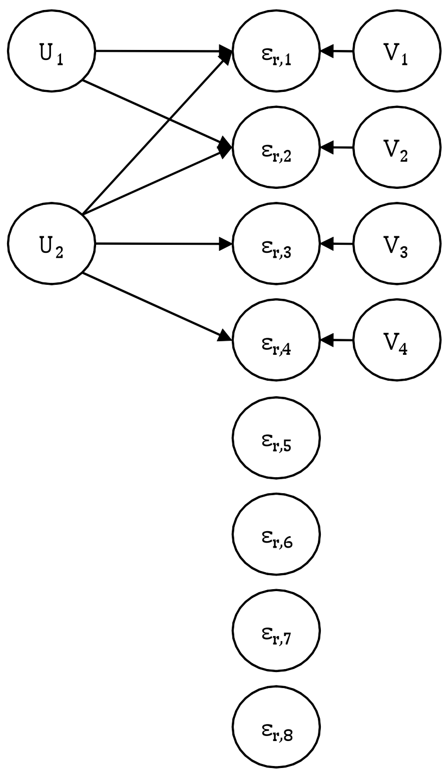


Application to hypothetical model of California HSR system

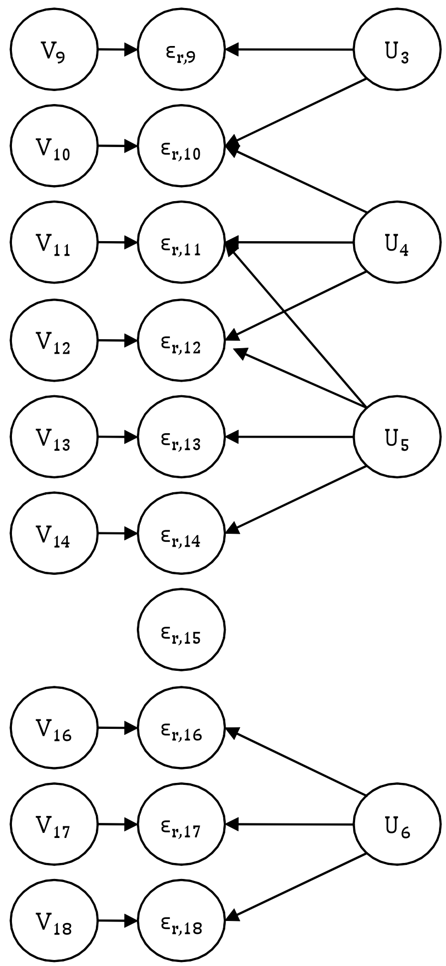


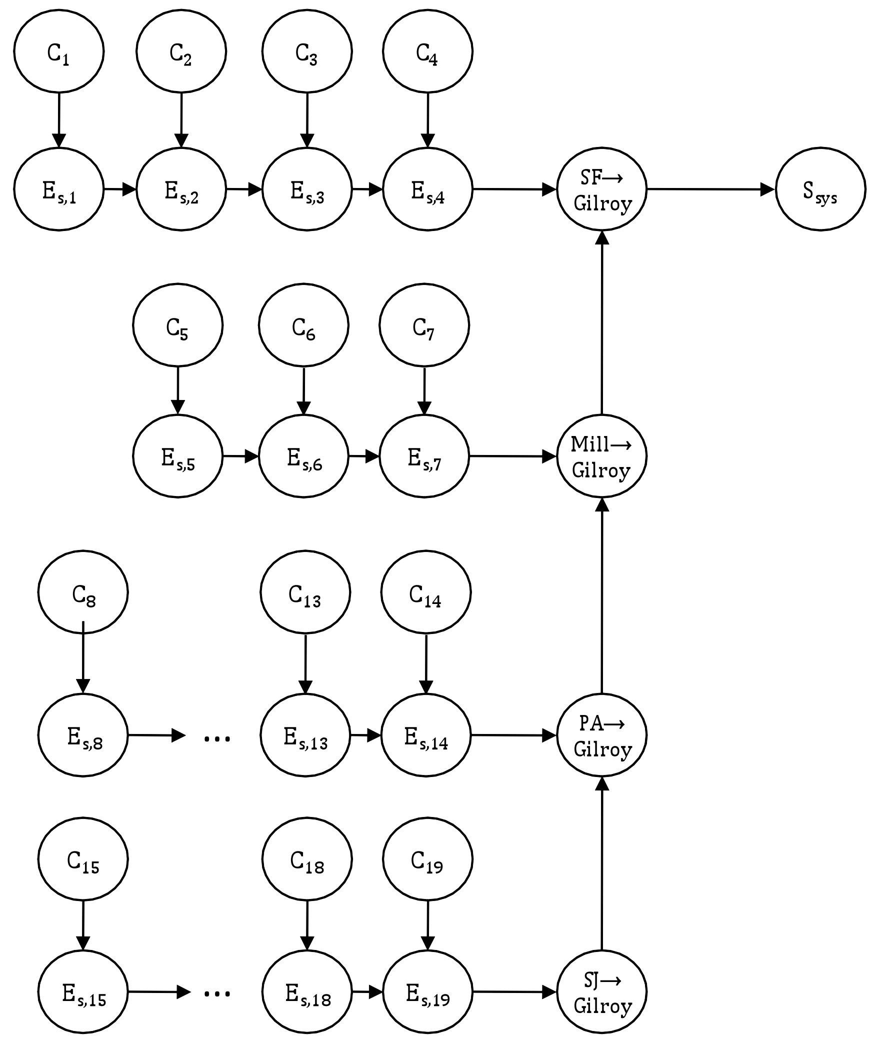


Application to hypothetical model of California HSR system



Random field model



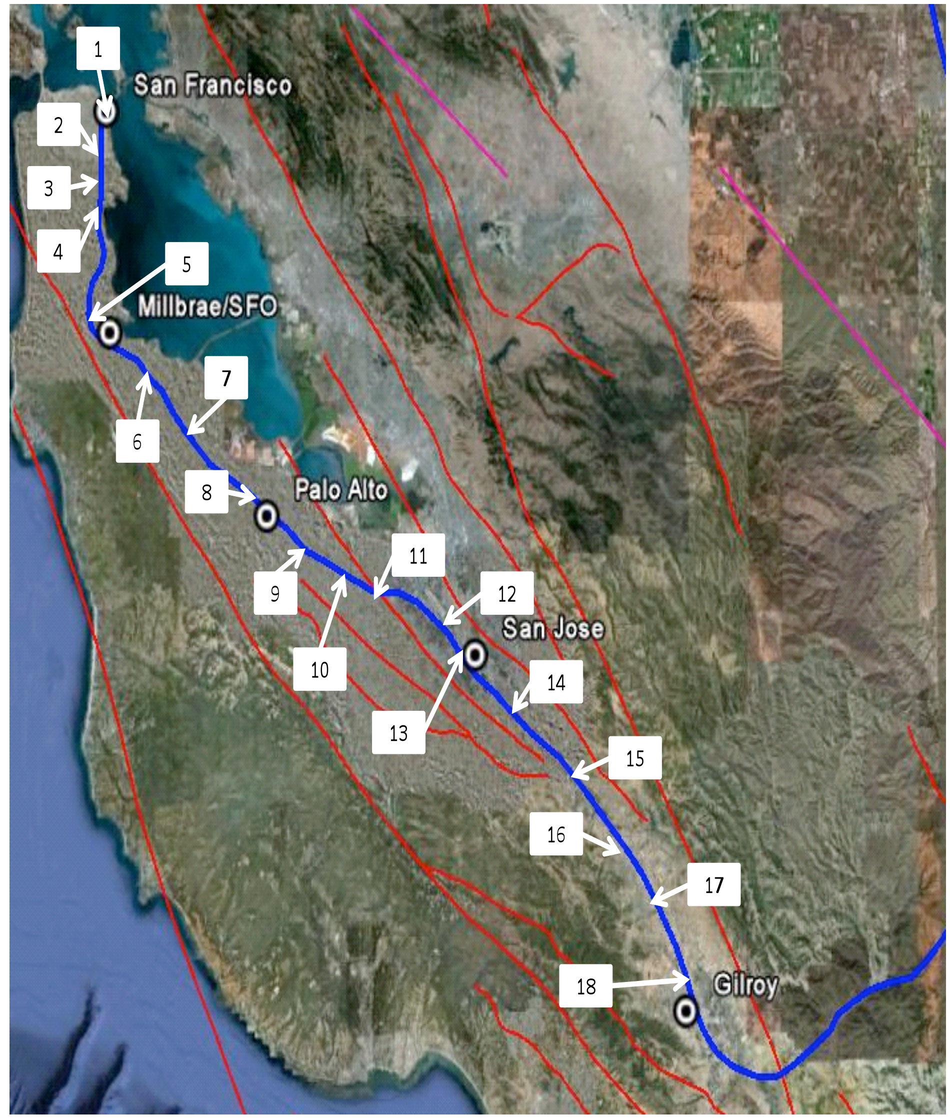


System performance model

Application to hypothetical model of California HSR system

Evidence Cases:

- EC#1: M=6.8, X_e=30km from north end of Hayward fault
- EC #2: EC #1 + spectral acceleration at GMPP 2 = 0.45-0.50g
- EC #3: EC #2 + pulse-like ground motion at GMPP 9
- EC #4: EC #3 + extensive damage of C_{17}



Component state probabilities for different evidence cases

	EC #1		EC #2		EC #3		EC #4	
Component	No damage	Moderate or severe damage	No damage	Moderate or severe damage	No damage	Moderate or severe damage	No damage	Moderate or severe damage
1	0.939	0.058	0.893	0.100	0.893	0.100	0.860	0.131
2	0.949	0.049	0.911	0.083	0.911	0.083	0.888	0.105
3	0.953	0.045	0.898	0.098	0.898	0.098	0.861	0.134
4	0.951	0.048	0.914	0.083	0.914	0.083	0.879	0.118
5	0.962	0.037	0.949	0.050	0.949	0.050	0.918	0.080
6	0.960	0.039	0.946	0.053	0.945	0.054	0.911	0.086
7	0.958	0.041	0.944	0.055	0.941	0.057	0.905	0.092
8	0.960	0.039	0.946	0.052	0.935	0.059	0.895	0.096
9	0.953	0.045	0.939	0.059	0.920	0.074	0.877	0.114
10	0.946	0.053	0.930	0.068	0.902	0.093	0.853	0.139
11	0.959	0.039	0.945	0.052	0.929	0.067	0.891	0.103
12	0.952	0.034	0.941	0.042	0.919	0.059	0.884	0.085
13	0.961	0.037	0.949	0.049	0.934	0.063	0.898	0.097
14	0.966	0.023	0.956	0.030	0.940	0.043	0.910	0.066
15	0.964	0.035	0.952	0.046	0.942	0.056	0.909	0.088
16	0.966	0.033	0.955	0.043	0.946	0.052	0.506	0.493
17	0.970	0.029	0.960	0.038	0.951	0.048	0.000	1.000
18	0.947	0.033	0.934	0.042	0.917	0.057	0.667	0.237
19	0.977	0.021	0.970	0.028	0.960	0.039	0.902	0.094

Component state probabilities for different evidence cases

	EC #1		EC #2		EC #3		EC #4	
Component	No damage	Moderate or severe damage	No damage	Moderate or severe damage	No damage	Moderate or severe damage	No damage	Moderate or severe damage
1	0.939	0.058	0.893	0.100	0.893	0.100	0.860	0.131
2	0.949	0.049	0.911	0.083	0.911	0.083	0.888	0.105
3	0.953	0.045	0.898	0.098	0.898	0.098	0.861	0.134
4	0.951	0.048	0.914	0.083	0.914	0.083	0.879	0.118
5	0.962	0.037	0.949	0.050	0.949	0.050	0.918	0.080
6	0.960	0.039	0.946	0.053	0.945	0.054	0.911	0.086
7	0.958	0.041	0.944	0.055	0.941	0.057	0.905	0.092
8	0.960	0.039	0.946	0.052	0.935	0.059	0.895	0.096
9	0.953	0.045	0.939	0.059	0.920	0.074	0.877	0.114
10	0.946	0.053	0.930	0.068	0.902	0.093	0.853	0.139
11	0.959	0.039	0.945	0.052	0.929	0.067	0.891	0.103
12	0.952	0.034	0.941	0.042	0.919	0.059	0.884	0.085
13	0.961	0.037	0.949	0.049	0.934	0.063	0.898	0.097
14	0.966	0.023	0.956	0.030	0.940	0.043	0.910	0.066
15	0.964	0.035	0.952	0.046	0.942	0.056	0.909	0.088
16	0.966	0.033	0.955	0.043	0.946	0.052	0.506	0.493
17	0.970	0.029	0.960	0.038	0.951	0.048	0.000	1.000
18	0.947	0.033	0.934	0.042	0.917	0.057	0.667	0.237
19	0.977	0.021	0.970	0.028	0.960	0.039	0.902	0.094

Component state probabilities for different evidence cases

	EC #1		EC #2		EC #3		EC #4	
Component	No damage	Moderate or severe damage	No damage	Moderate or severe damage	No damage	Moderate or severe damage	No damage	Moderate or severe damage
1	0.939	0.058	0.893	0.100	0.893	0.100	0.860	0.131
2	0.949	0.049	0.911	0.083	0.911	0.083	0.888	0.105
3	0.953	0.045	0.898	0.098	0.898	0.098	0.861	0.134
4	0.951	0.048	0.914	0.083	0.914	0.083	0.879	0.118
5	0.962	0.037	0.949	0.050	0.949	0.050	0.918	0.080
6	0.960	0.039	0.946	0.053	0.945	0.054	0.911	0.086
7	0.958	0.041	0.944	0.055	0.941	0.057	0.905	0.092
8	0.960	0.039	0.946	0.052	0.935	0.059	0.895	0.096
9	0.953	0.045	0.939	0.059	0.920	0.074	0.877	0.114
10	0.946	0.053	0.930	0.068	0.902	0.093	0.853	0.139
11	0.959	0.039	0.945	0.052	0.929	0.067	0.891	0.103
12	0.952	0.034	0.941	0.042	0.919	0.059	0.884	0.085
13	0.961	0.037	0.949	0.049	0.934	0.063	0.898	0.097
14	0.966	0.023	0.956	0.030	0.940	0.043	0.910	0.066
15	0.964	0.035	0.952	0.046	0.942	0.056	0.909	0.088
16	0.966	0.033	0.955	0.043	0.946	0.052	0.506	0.493
17	0.970	0.029	0.960	0.038	0.951	0.048	0.000	1.000
18	0.947	0.033	0.934	0.042	0.917	0.057	0.667	0.237
19	0.977	0.021	0.970	0.028	0.960	0.039	0.902	0.094

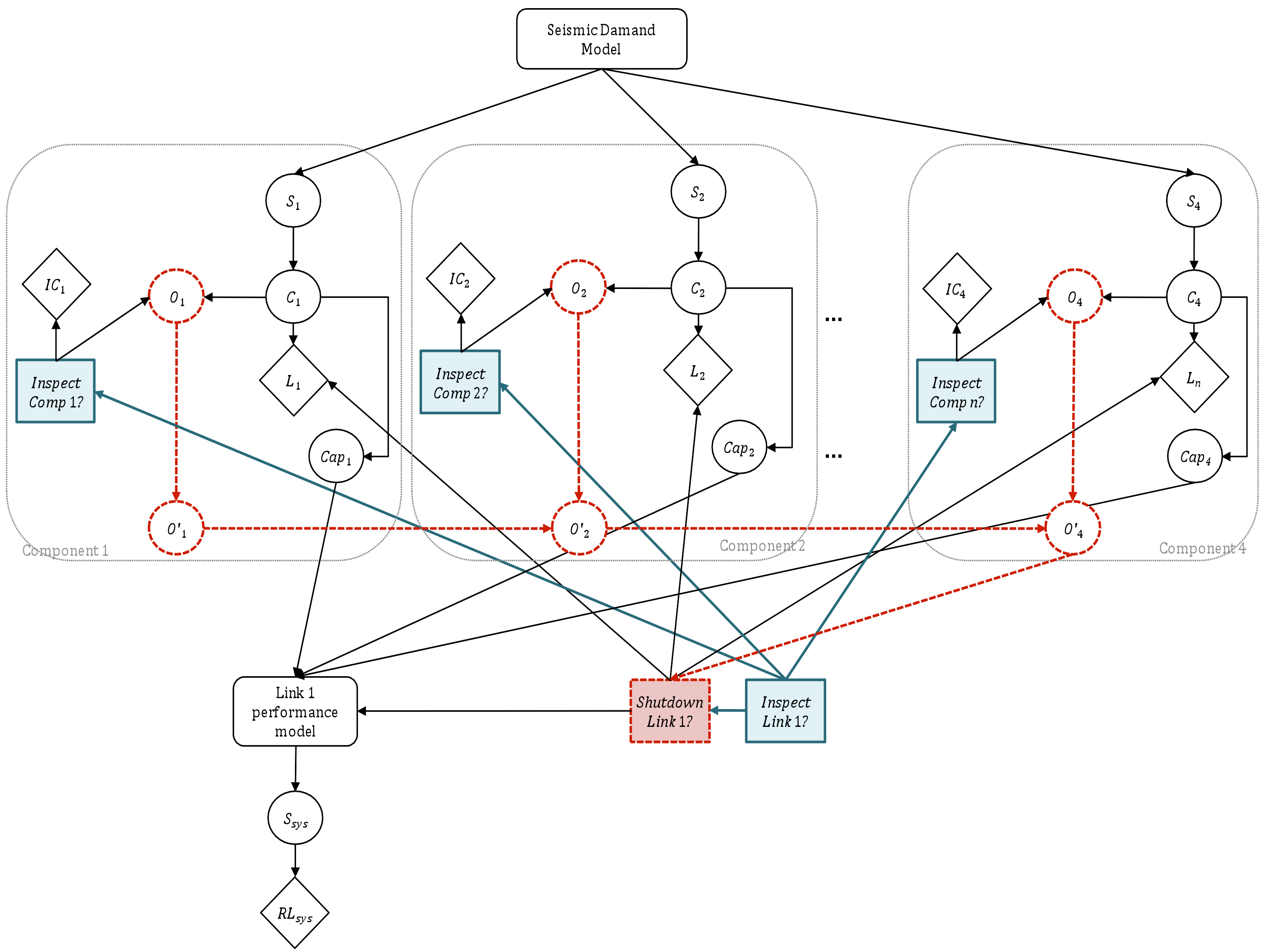
Component state probabilities for different evidence cases

	EC #1		EC #2		EC #3		EC #4	
Component	No damage	Moderate or severe damage	No damage	Moderate or severe damage	No damage	Moderate or severe damage	No damage	Moderate or severe damage
1	0.939	0.058	0.893	0.100	0.893	0.100	0.860	0.131
2	0.949	0.049	0.911	0.083	0.911	0.083	0.888	0.105
3	0.953	0.045	0.898	0.098	0.898	0.098	0.861	0.134
4	0.951	0.048	0.914	0.083	0.914	0.083	0.879	0.118
5	0.962	0.037	0.949	0.050	0.949	0.050	0.918	0.080
6	0.960	0.039	0.946	0.053	0.945	0.054	0.911	0.086
7	0.958	0.041	0.944	0.055	0.941	0.057	0.905	0.092
8	0.960	0.039	0.946	0.052	0.935	0.059	0.895	0.096
9	0.953	0.045	0.939	0.059	0.920	0.074	0.877	0.114
10	0.946	0.053	0.930	0.068	0.902	0.093	0.853	0.139
11	0.959	0.039	0.945	0.052	0.929	0.067	0.891	0.103
12	0.952	0.034	0.941	0.042	0.919	0.059	0.884	0.085
13	0.961	0.037	0.949	0.049	0.934	0.063	0.898	0.097
14	0.966	0.023	0.956	0.030	0.940	0.043	0.910	0.066
15	0.964	0.035	0.952	0.046	0.942	0.056	0.909	0.088
16	0.966	0.033	0.955	0.043	0.946	0.052	0.506	0.493
17	0.970	0.029	0.960	0.038	0.951	0.048	0.000	1.000
18	0.947	0.033	0.934	0.042	0.917	0.057	0.667	0.237
19	0.977	0.021	0.970	0.028	0.960	0.039	0.902	0.094

System state probabilities for different evidence cases

	State	EC #1	EC #2	EC #3	EC #4
SF→ Gilroy	*Open*	0.64	0.50	0.46	0.00
	Reduced/Closed	0.36	0.50	0.54	1.00
Millbrae → Gilroy	*Open*	0.71	0.64	0.58	0.00
	Reduced/Closed	0.29	0.36	0.42	1.00
Palo Alto → Gilroy	*Open*	0.75	0.69	0.63	0.00
	Reduced/Closed	0.25	0.31	0.38	1.00
San Jose → Gilroy	*Open*	0.88	0.84	0.81	0.00
	Reduced/Closed	0.12	0.16	0.19	1.00

Influence diagram for Link #1



Inspection prioritization

Value of inspection and prioritization rank for each link

Link	EC #1	EC #2	EC #3	EC #4
1	17.20(2)	23.23 (1)	23.22 (1)	25.88 (2)
2	14.25 (3)	15.73 (3)	15.85 (2)	19.45 (3)
3	18.93 (1)	21.05 (2)	No Insp	33.91 (1)
4	No Insp	No Insp	No Insp	No Insp

Value of inspection and prioritization rank for reach component of Link #1

Comp	VoI	Rank
1	27.75	1
2	13.95	4
3	18.22	2
4	17.32	3