Open Library of Models in Rt

Under Development

Latest update: December 11, 2012

Overview

Rt is a framework for utilizing multiple probabilistic models in conjunction with reliability analysis. Applications for this approach includes modern performance-based analysis and risk assessment. A variety of models are under development and several models are already available. The list below provides the overview of the currently available models, with details on the following pages. (Please note: the input to all models should be given as parameter objects, unless otherwise noted.)

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Poisson Pulse Process

- Location in tree
  - Model>Occurrence

- DDM sensitivities
  - No

- Model form:
  - This model produces the time instants at which a hazard occurs
- Input:
  - Magnitude Model = magnitude/severity model associated with the hazard
  - Associated Model List = list of any other models associated with this hazard that should not be evaluated when the hazard is inactive, e.g., a location model
  - Nonzero Occurrence Rate = occurrence rate of the events with nonzero intensity (given as a real number)
  - Mean Duration = mean duration of events (given as a real number)
  - Time Instant Generation Scheme = method of time generation. The "Exact" option generates the time instants according to the occurrence rate of the underlying process. The "Approximate" option will generate the time instants according to the nonzero occurrence rate.
- Output:
  - This model does not generate response objects. Rather, it provides the generated time instants to the orchestrating algorithm.

Moment Magnitude

- Location in tree
  - Model>Hazard>Earthquake>Magnitude

- DDM sensitivities
  - Yes

- Model form: $$M = \theta_1 \cdot \log_{10}\underbrace{\left(G \cdot A \cdot D \cdot 10^7\right)}_{\text{"Seismic Moment"}} - \theta_2 + \varepsilon$$

- Input:
  - G = shear modulus, typically $30 \cdot 10^9$ N/m^2
  - A = rupture area in m^2
  - D = rupture displacement in m
  - θ_1 = model parameter, typically 2/3
  - θ_2 = model parameter, typically 10.7
  - ε = model error

- Output (automatically generated generic response object):
  - M = magnitude

Bounded Exponential Magnitude

- Location in tree
  - Model>Hazard>Earthquake>Magnitude

- DDM sensitivities
  - Yes

- Model form:
  - The basis for this model is the following PDF:

$$f(m) = \frac{\beta \cdot \exp\left[-\beta \cdot \left(m - M_{\min}\right)\right]}{1 - \exp\left[-\beta \cdot \left(M_{\max} - M_{\min}\right)\right]} \quad \text{for} \quad M_{\min} \le m \le M_{\max}$$

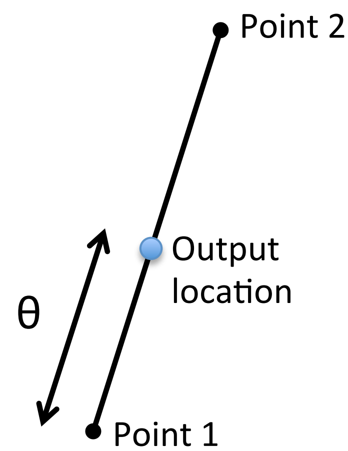
  A standard normal random variable, θ, is given to the model, and transformed according to the probability-preserving transformation F(m)=Φ(y), where F(m) is the CDF corresponding to the given PDF, to obtain the corresponding outcome of M.

- Input:
  - M_{min} = lower magnitude bound
  - M_{max} = upper magnitude bound
  - β = model parameter, usually in the range of 1 to 2
  - θ = a standard-normal random variable
  - ε = model error

- Output (automatically generated generic response object):
  - m = magnitude

Single Line Source

- Location in tree
  - Model>Hazard>Earthquake>Location



- DDM sensitivities
  - Yes

- Model form:
  - This model produces a location on a straight line between Point1 and Point 2; typically an earthquake fault

- Input:
  - Point 1 Location= location object for one end of the line
  - Point 2 Location= location object for the other end of the line
  - θ = value between 0 and 1 that defines the output location, typically a random variable uniformly distributed between 0 and 1
  - Depth = depth of the output location, in km

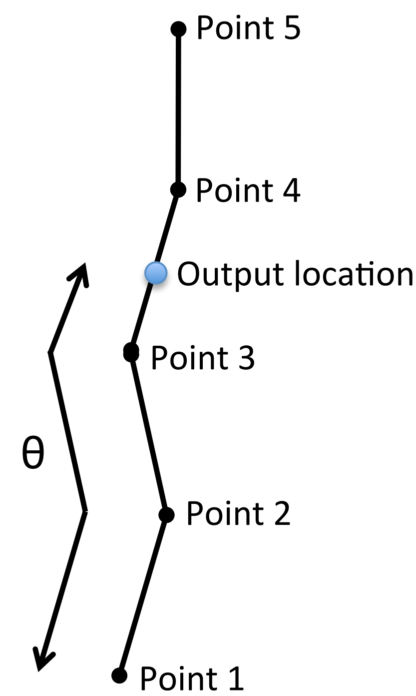
- Output (automatically generated generic response object):
  - Location object carried by a location response object

Multipoint Line Source

- Location in tree
  - Model>Hazard>Earthquake>Location

- DDM sensitivities
  - No

- Model form:
  - This model produces a location on a multi-linear line between; typically an earthquake fault



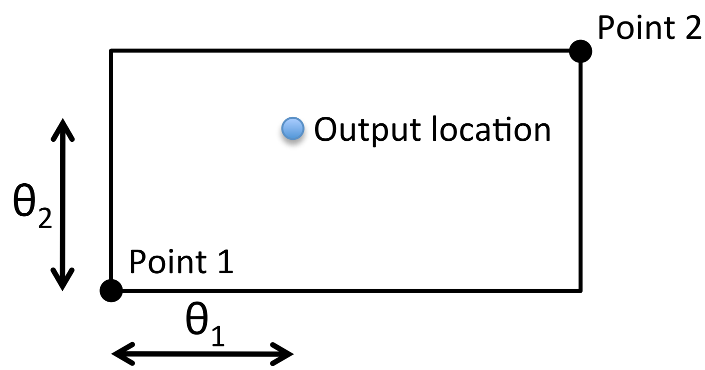
- Input:
  - Point Location List = location objects that define the line
  - θ = value between 0 and 1 that defines the output location, typically a random variable uniformly distributed between 0 and 1
  - Depth = depth of the output location, in km

- Output (automatically generated generic response object):
  - Location object carried by a location response object

Rectangular Area Source

- Location in tree
  - Model>Hazard>Earthquake>Location

- DDM sensitivities
  - Yes



- Model form:
  - This model produces a location within a rectangular area that is defined by two diagonal corner points. The sides of the area align with Earth's latitudes and longitudes.

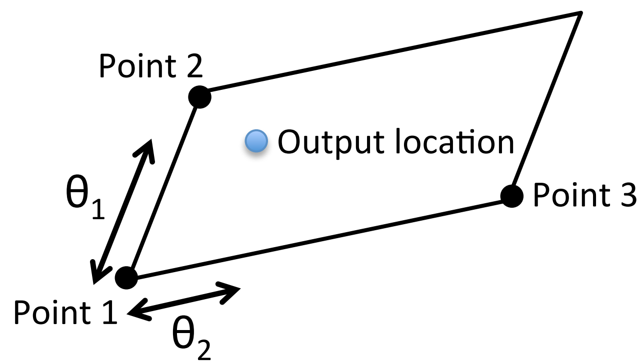
- Input:
  - Point 1 Location= location object for one corner of the area
  - Point 2 Location = location object for the diagonally opposite corner
  - θ_1 = value between 0 and 1 that defines the output longitude, typically a random variable uniformly distributed between 0 and 1
  - θ_2 = value between 0 and 1 that defines the output latitude, typically a random variable uniformly distributed between 0 and 1
  - Depth = depth of the output location, in km

- Output (automatically generated generic response object):
  - Location object carried by a location response object

Quadrilateral Area Source

- Location in tree
  - Model>Hazard>Earthquake>Location

- DDM sensitivities
  - No



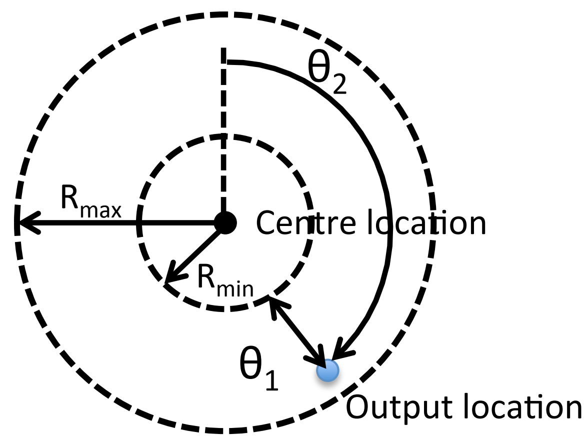
- Model form:
  - This model produces a location within a quadrilateral area that is defined by three corner points. The fourth corner point will be automatically considered to produce a parallelogram.
- Input:
  - Point 1 Location= location object for one corner of the area
  - Point 2 Location = location object for another corner of the area
  - Point 3 Location = location object for another corner of the area
  - θ_1 = value between 0 and 1, typically a random variable uniformly distributed between 0 and 1
  - θ_2 = value between 0 and 1, typically a random variable uniformly distributed between 0 and 1
  - Depth = depth of the output location, in km

- Output (automatically generated generic response object):
  - Location object carried by a location response object

Circular Area Source

- Location in tree
  - Model>Hazard>Earthquake>Location

- DDM sensitivities
  - Yes



- Model form:
  - This model produces a location within a circular area that is defined by the centre point

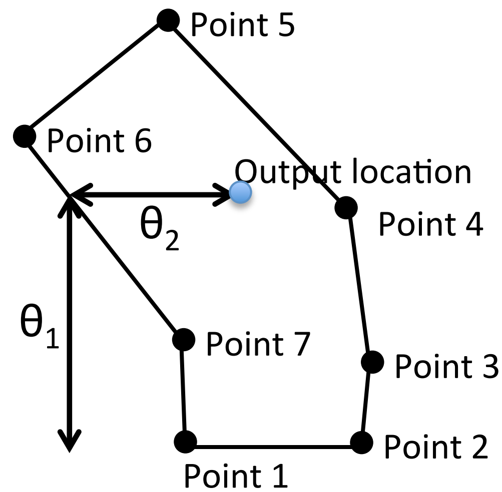
- Input:
  - Centre Location = location object for the centre of the source
  - R_{min} = minimum radius of the source (given as a real number)
  - R_{max} = maximum radius of the source (given as a real number)
  - θ_1 = value between 0 and 1 that defines the location alongside the radius, typically a random variable uniformly distributed between 0 and 1
  - θ_2 = value between 0 and 1, typically a random variable uniformly distributed between 0 and 1
  - Depth = depth of the output location in km

- Output (automatically generated generic response object):
  - Location object carried by a location response object

Polygonal Area Source

- Location in tree
  - Model>Hazard>Earthquake>Location

- DDM sensitivities
  - Yes



- Model form:
  - This model produces a location within a polygonal area that is defined by the a of points.

- Input:
  - Boundary Location List = location objects that define the polygon
  - θ_1 = value between 0 and 1 that defines the output latitude, typically a random variable uniformly distributed between 0 and 1
  - θ_2 = value between 0 and 1 that defines the output longitude, typically a random variable uniformly distributed between 0 and 1
  - Depth = depth of the output location in km

- Output (automatically generated generic response object):
  - Location object carried by a location response object

Generic Attenuation

- Location in tree
  - Model>Hazard>Earthquake>Intensity
- DDM sensitivities
  - Yes
- Model form:
  - This model produces an intensity at specified locations for given magnitude and hypocentre location of several earthquake sources as input

$$I = 10^{-\theta_1 + \theta_2 \cdot M - \theta_3 \cdot \log_{10}(R) + \theta_4 \cdot R + \varepsilon}$$

- Input:
  - Structure Location List = list of locations where the intensity will be computed (the output will give as many intensity values as locations provided here)
  - Magnitude List (M) = magnitudes of various earthquake sources
  - Hypocentre Location List = hypocentre locations of earthquake sources, which automatically will yield the radius R to the various output locations
  - θ_1 = model parameter, typically 1.02 (Joyner & Boore)
  - θ_2 = model parameter, typically 0.249 (Joyner & Boore)
  - θ_3 = model parameter, typically 1 (Joyner & Boore)
  - θ_4 = model parameter, typically 0.00255 (Joyner & Boore)
  - ε = model error
- Output (automatically generated generic response object):
  - I = intensities (as many as the locations in the input)

Joyner Boore 1981 Intensity

- Location in tree
  - Model>Hazard>Earthquake>Intensity
- DDM sensitivities
  - Yes
- Model form:
  - This model produces the peak ground acceleration at specified locations for given magnitude and hypocentre location input, based the Joyner-Boore (1981) attenuation relation

$$PGA = 10^{-1.02\alpha + 0.249\beta \cdot M - \log_{10}(R) + b \cdot R + 0.26\varepsilon}$$

- Input:
  - M = magnitude
  - α = 1, typically a normal random variable with unit mean
  - β = 1, typically a normal random variable with unit mean
  - b = 1, typically a normal random variable with unit mean
  - ε = model error
  - Hypocentre Location = location of the hypocentre, which automatically will yield the radius R to the various output locations
  - Structure Location List = list of locations where the intensity will be computed (the output will give as many intensity values as locations provided here)
- Output (automatically generated generic response object):
  - PGA = peak ground accelerations (as many as the locations in the input)

Atkinson Boore 2003 Intensity

- Location in tree
  - Model>Hazard>Earthquake>Intensity

- DDM sensitivities
  - No

- Model form:
  - This model produces the spectral acceleration or the peak ground acceleration at specified locations for given magnitude and hypocentre location of several earthquake sources as input , based the Atkinson-Boore (2003) attenuation relation

- Input:
  - Magnitude List = magnitudes of various earthquake sources
  - Hypocentre Location List = hypocentre locations of earthquake sources, which automatically will yield the radius R to the various output locations
  - ε = model error
  - Event Type = type of the earthquake event that can be either Interface or In-slab
  - Response Type = type of the response than can be either Sa or PGA
  - Smoothness = "Smoothed" option will smooth the kinks in the model and the "Original" option will use the model as is
  - Period List = List of the natural periods at which the intensity is evaluated
  - Structure Location List = list of locations where the intensity will be computed (the output will give as many intensity values as locations provided here)
  - Shear Wave Velocity List = list of the shear wave velocities at the specified locations

- Output (automatically generated generic response object):
  - Earthquake intensities (as many as the locations in the input)

Boore Atkinson 2008 Intensity

- Location in tree
  - Model>Hazard>Earthquake>Intensity

- DDM sensitivities
  - No

- Model form:
  - This model produces the spectral acceleration, peak ground acceleration, or peak ground velocity at specified locations for given magnitude and hypocentre location of several earthquake sources as input , based the Boore-Atkinson (2008) attenuation relation

- Input:
  - Magnitude List = magnitudes of various earthquake sources
  - Hypocentre Location List = hypocentre locations of earthquake sources, which automatically will yield the radius R to the various output locations
  - ε = model error
  - Fault Type = fault mechanism that can be either Unspecified, Normal-slip, Strike-slip, or Reverse-slip
  - Response Type = type of the response than can be either Sa, PGA, or PGV
  - Smoothness = "Smoothed" option will smooth the kinks in the model and the "Original" option will use the model as is
  - Period List = List of the natural periods at which the intensity is evaluated
  - Structure Location List = list of locations where the intensity will be computed (the output will give as many intensity values as locations provided here)
  - Shear Wave Velocity List = list of the shear wave velocities at specified locations

- Output (automatically generated generic response object):
  - Earthquake intensities (as many as the locations in the input)

Simple Wind Velocity

- Location in tree
  - Model>Hazard>Wind

- DDM sensitivities
  - No

- Model form:
  - This model produces wind velocity according to a Gumbel distribution with parameters that are based on characteristic wind velocities
- Input:
  - θ = a standard-normal random variable
  - V_{10} = 1-in-10-year wind velocity
  - V_{10} = 1-in-50-year wind velocity

- Output (automatically generated generic response object):
  - V = wind velocity

Simple Wind Pressure

- Location in tree
  - Model>Hazard>Wind

- DDM sensitivities
  - No

- Model form: $$q = \frac{1}{2}\rho \cdot V^2 \cdot C_e \cdot C_g \cdot C_p \cdot \varepsilon$$

- Input:
  - ρ = air density
  - V = wind velocity
  - C_e = exposure factor
  - C_g = gust factor
  - C_p = external pressure factor
  - ε = model error

- Output (automatically generated generic response object):
  - q = wind pressure

Simple Snow Load

- Location in tree
  - Model>Hazard>Snow

- DDM sensitivities
  - No

- Model form: $$d = \frac{d_p}{2} \cdot \left(1 + \sin\left(2\pi \cdot \frac{t - m_s}{m_e - m_s} - \frac{\pi}{2}\right)\right) \cdot \varepsilon$$
  $$q = \rho \cdot d$$

- Input:
  - d_p = peak seasonal snow depth
  - t = current time, typically a Time parameter
  - m_s = start month of the snow season (given as a real number)
  - m_e = end month of the snow season (given as a real number)
  - ε = model error
  - ρ = snow density

- Output (automatically generated generic response object):
  - d = snow depth
  - q = snow load per unit area

St

- Location in tree
  - Model>Infrastructure

- DDM sensitivities
  - Not yet

- Model form:
  - This is a 3D linear elastic structural analysis program with truss, frame, and 2D element. All elements can be placed in any orientation in space. For more details, please see the webpage on St linked at the Rt page.

- Input:
  - St Input File = the absolute path to the structural model. This file should be pre-checked by running St first. *A note on the use of Parameters: In St the Constant Parameter is available and can be used to give the value of material, geometry, and load variables. When running the structural analysis as a model in Rt, these input parameters can also be random variables, decision variables, and even responses from other models. To do this, create those parameters in Rt BEFORE you give the St Input File path. Use the same names of the random variables, etc as the parameter names used in the St input file.*
  - List of responses, for example

    Node2.YDisplacementResult ; Element5.End2ZZMomentResult

- Output (automatically generated generic response objects):
  - Response objects corresponding to the list provided in the last item of the input

Building Information

- Location in tree
  - Model>Infrastructure

- DDM sensitivities
  - No

- Model form:
  - This model is a database of building information. The model is passed to any other model that needs the building information.

- Input:
  - Location = location of the building
  - Time of construction = a time object signifying the construction time
  - Load Bearing System
  - Material
  - Number of Storeys = list of the number of storeys with the same storey area
  - Footprint Area = list of the area of the storeys specified above
  - Plan Shape
  - I_{PI} = Plan Irregularity
  - I_{VI} = Vertical Irregularity
  - I_{SS} = Soft Storey
  - I_{O} = Opening
  - I_{SC} = Short Column
  - I_{P} = Pounding
  - Retrofitted
  - Basement
  - Balcony

- Output:
  - This model does not generate any responses

Building Response

- Location in tree
  - Model>Infrastructure

- DDM sensitivities
  - No

- Model form:

$$T = \exp(-\theta_1) \cdot H^{\theta_2} \qquad V = \exp\left(-\theta_3 - \theta_4 \cdot H\right) \cdot \frac{2 + (\alpha - 2) \cdot (\alpha - 1)}{8}$$

$$\delta_y = \frac{T^2}{4\pi^2} \cdot \frac{V \cdot g}{H} \qquad \mu = \exp(\theta_5) \cdot H^{-\theta_6} \cdot \frac{10 + (\alpha - 2) \cdot (\alpha - 1)}{16}$$

$$\delta_u = \mu \cdot \delta_y \qquad \kappa = \exp\left(-\theta_7 \cdot Sa \cdot \alpha^{-\theta_8}\right)$$

$$\ln(\delta_p) = \theta_9 \cdot \ln(\delta_y) + \theta_{10} \cdot \ln(\delta_u) - \theta_{11} \cdot \ln(V) - \theta_{12} \cdot \ln(\kappa) + \theta_{13} \cdot \ln(Sa) + \theta_{14} \cdot Sa - \theta_{15} + \sigma_1 \cdot \varepsilon_1$$

$$\ln(A_p) = -\theta_{16} \cdot \ln(\delta_y) + \theta_{17} \cdot \ln(V) - \theta_{18} \cdot \ln(\mu) + \theta_{19} \cdot \ln(\kappa) + \theta_{20} \cdot \ln(Sa) - \theta_{21} + \sigma_2 \cdot \varepsilon_2$$

- Input:
  - Building Information Model = a Building Information Model object that returns the height, H, and the code level, α, to this model
  - Period Information = a Constant object that will take the value of the natural period of the building
  - Sa = 5%-damped elastic spectral acceleration at the building site at the natural period of the building
  - $\theta_1 - \theta_8$ = sub-model parameters
  - $\theta_9 - \theta_{15}$ = peak drift ratio model parameters
  - σ_1 = standard deviation of the peak drift ratio model error
  - ε_1 = peak drift ratio model error
  - $\theta_{16} - \theta_{21}$ = peak acceleration model parameters
  - σ_2 = standard deviation of the peak acceleration model error
  - ε_2 = peak acceleration model error

- Output (automatically generated generic response object):
  - δ_p = peak drift ratio
  - A_p = peak acceleration

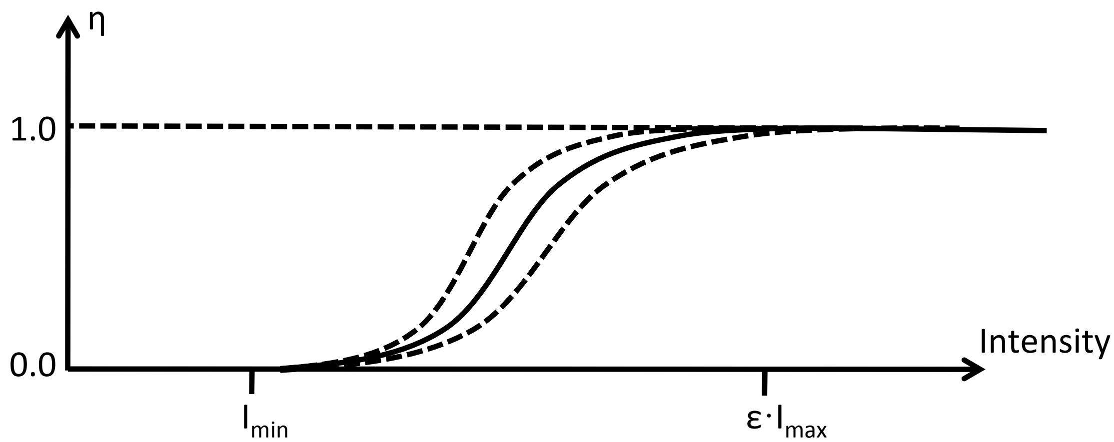
Simple Deterioration

- Location in tree
  - Model>Infrastructure
- DDM sensitivities
  - No
- Model form: $\alpha = \exp(-r \cdot t)$
- Input:
  - t= Time object
  - r = annual deterioration rate
- Output (automatically generated generic response object):
  - α = deterioration factor

Simple Damage Curve

- Location in tree
  - Model>Consequence

- DDM sensitivities
  - Yes



- Model form: Sine curve from θ_1 to θ_2

$$\eta = \frac{1}{2} \cdot \left(\sin\left(\frac{\pi}{\varepsilon \cdot I_{\max} - I_{\min}} \left(I - I_{\min} \right) - \frac{\pi}{2} \right) + 1 \right)$$

- Input:
  - I = intensity
  - I_{min} = intensity at which the damage factor exceeds 0.0
  - I_{max} = intensity at which the damage factor reaches 1.0
  - ε = multiplicative model error

- Output (automatically generated generic response object):
  - η = Damage ratio

FEMA-NIBS Bridge Damage

- Location in tree
  - Model>Consequence
- DDM sensitivities
  - No
- Model form:
  - This model produces the damage ratio and the percent functional for a bridge subjected to the ground shaking and the permanent ground deformation based on the HAZUS (FEMA-NIBS 2003) approach
- Input:
  - Bridge Type = type of the bridge according to FEMA-NIBS
  - Sa_1 = 5%-damped elastic spectral acceleration at the period of 1.0s at the bridge site
  - Sa_2 = 5%-damped elastic spectral acceleration at the period of 0.3s at the bridge site
  - Time = number of days elapsed since the earthquake event
  - Number of Spans (given as an integer)
  - Angle of Skew = angle between the centerline of a pier and a line normal to the roadway centerline (given as a real number)
  - PGD = permanent ground deformation
  - Bridge Length (given as a real number)
  - Span Width (given as a real number)
  - Model Uncertainty = a standard-normal random variable
- Output (automatically generated generic response object):
  - Damage Ratio
  - Percent Functional

Building Damage

- Location in tree
  - Model>Consequence

- DDM sensitivities
  - No

- Model form:

$$\eta_S = \Phi\left(\theta_1 \cdot \ln\left(\delta_p\right) + \theta_2 \cdot \ln\left(H\right) - \theta_3 \cdot \alpha + \theta_4\right) \cdot \exp\left(\theta_5 \cdot I_{VI} + \theta_6 \cdot I_{PI} + \theta_7 \cdot I_{SS} + \theta_8 \cdot I_{SC} + \theta_9 \cdot I_P\right) + \sigma_1 \cdot \varepsilon_1$$

$$\eta_{ND} = \Phi\left(\theta_{10} \cdot \ln\left(\delta_p\right) + \theta_{11}\right) + \sigma_2 \cdot \varepsilon_2$$

$$\eta_{NA} = \Phi\left(\theta_{12} \cdot \ln\left(A_p\right) - \theta_{13} \cdot \alpha\right) + \sigma_3 \cdot \varepsilon_3$$

$$\eta_C = \Phi\left(\theta_{14} \cdot \ln\left(A_p\right) - \theta_{15} \cdot \alpha\right) + \sigma_4 \cdot \varepsilon_4$$

- Input:
  - Building Information Model = a Building Information Model object that returns the height, H, the code level, α, and the irregularity information, $I_{(.)}$, to this model
  - δ_p = peak drift ratio
  - A_p = peak acceleration
  - $\theta_1 - \theta_9$ = structural damage model parameters
  - σ_1 = standard deviation of the structural damage model error
  - ε_1 = structural damage model error
  - $\theta_{10} - \theta_{11}$ = non-structural drift damage model parameters
  - σ_2 = standard deviation of the non-structural drift damage model error
  - ε_2 = structural damage model error
  - $\theta_{12} - \theta_{13}$ = non-structural acceleration damage model parameters
  - σ_3 = standard deviation of the non-structural acceleration damage model error
  - ε_3 = non-structural acceleration damage model error
  - $\theta_{14} - \theta_{15}$ = content damage model parameters
  - σ_4 = standard deviation of the content damage model error
  - ε_4 = content damage model error

- Output (automatically generated generic response object):
  - η_S = structural damage ratio
  - η_{ND} = non-structural drift damage ratio
  - η_{NA} = non-structural acceleration damage ratio
  - η_C = content damage ratio

Visual Damage

- Location in tree
  - Model>Consequence
- DDM sensitivities
  - No
- Model form:
  - This model produces the total crack length in a shear wall. The model form reads

$$\frac{l_{\text{crack}}}{l_w} = \theta_1 \cdot \delta + \theta_2 \cdot \frac{h_w}{l_w} + \theta_3 \cdot \frac{P}{f_c \cdot A_g} + \theta_4 \cdot \rho_{lw} + \sigma \cdot \varepsilon$$

- Input:
  - l_w = length of the wall
  - δ = drift ratio
  - h_w = height of the wall
  - P = axial force
  - f_c = concrete compressive strength
  - A_g = gross cross-sectional area
  - ρ_{lw} = flexural reinforcement ratio in the web
  - θ_1 = model parameter
  - θ_2 = model parameter
  - θ_3 = model parameter
  - θ_4 = model parameter
  - σ = standard deviation of the model error
  - ε = model error
- Output (automatically generated generic response object):
  - l_{crack} = total crack length

Simple Building Repair Cost

- Location in tree
  - Model>Consequence
- DDM sensitivities
  - Yes
- Model form: $l = \eta \cdot N \cdot A \cdot C + \varepsilon$
- Input:
  - η = damage ratio, typically between 0 and 1
  - N = number of storeys (given as an integer)
  - A = footprint area of the building (given as a real number)
  - C = cost of repair per unit area, perhaps around \$2,000/m^2
  - ε = model error
- Output (automatically generated generic response object):
  - l = loss due to the repair Cost

FEMA-NIBS Building Repair Cost

- Location in tree
  - Model>Consequence

- DDM sensitivities
  - No

- Model form:
  - This model produces the repair cost of a building subjected to ground shaking based on the HAZUS (FEMA-NIBS 2003) approach

- Input:
  - Building Type = type of the building based on FEMA-NIBS
  - Occupancy Class = occupancy class based on FEMA-NIBS
  - Code Design Level = code level based on FEMA-NIBS
  - Sa_1 = 5%-damped elastic spectral acceleration at the period of 1.0s at the building site
  - Sa_2 = 5%-damped elastic spectral acceleration at the period of 0.3s at the building site
  - Magnitude = earthquake moment magnitude
  - Number of Storeys (given as an integer)
  - Footprint Area (given as a real number)

- Output (automatically generated generic response object):
  - Repair Cost

Regional Loss

- Location in tree
  - Model>Consequence
- DDM sensitivities
  - No
- Model form: $$l = \left(\sum_{k=1}^{K} \eta_k \cdot A_k \cdot C_k \right) \cdot \exp(-r \cdot t)$$
  $$\ln(\eta_k) = \ln\left[\theta_{1k} \cdot \Phi\left(\theta_{2k} \cdot Sa_2^{\theta_{5k}} + \theta_{3k} \cdot Sa_1^{\theta_{5k}} - \theta_{4k}\right)\right] + \varepsilon_k$$
- Input:
  - Boundary Location List = list of location objects of corner points of the region
  - Centroid Location = a location object that will take the region's centroid coordinates
  - Sa_1 = 5%-damped elastic spectral acceleration at the period of 1.0s at the region's centroid
  - Sa_2 = 5%-damped elastic spectral acceleration at the period of 0.3s at the region's centroid
  - C_k = unit area cost list for different zones within the region
  - A_k = area ratio list, that is the ratio of different zone areas to the total area of the region
  - t = Time object
  - r = annual interest rate
  - θ_{1k} = list of θ_1 model parameters for different zones within the region
  - θ_{2k} = list of θ_2 model parameters for different zones within the region
  - θ_{3k} = list of $\theta_3$model parameters for different zones within the region
  - θ_{4k} = list of θ_4 model parameters for different zones within the region
  - θ_{5k} = list of θ_5 model parameters for different zones within the region
  - ε_k = list of ε model error for different zones within the region
  - Color = color of the region on Google Maps
- Output (automatically generated generic response object):
  - l = total regional loss due to repair cost of buildings

Building Repair Cost

- Location in tree
  - Model>Consequence
- DDM sensitivities
  - No
- Model form: $l = \left(\eta_S \cdot C_S + \eta_{ND} \cdot C_{ND} + \eta_{NA} \cdot C_{NA} + \eta_C \cdot C_C\right) \cdot A \cdot \exp\left(-r \cdot t\right) \cdot \varepsilon$
- Input:
  - Building Information Model = a Building Information Model object that returns the total area of the building, A, to this model
  - η_S = structural damage ratio
  - η_{ND} = non-structural drift damage ratio
  - η_{NA} = non-structural acceleration damage ratio
  - η_C = content damage ratio
  - C_S = structural unit area cost (given as a real number)
  - C_{ND} = non-structural drift unit area cost (given as a real number)
  - C_{NA} = non-structural acceleration unit area cost (given as a real number)
  - C_C = content unit area cost (given as a real number)
  - t = Time object
  - r = annual interest rate
  - ε = model error
- Output (automatically generated generic response object):
  - l = loss due to the repair cost

Discounting

- Location in tree
  - Model>Consequence
- DDM sensitivities
  - No
- Model form: $$l_p = l_f \cdot \exp(-r \cdot t)$$
- Input:
  - l_f = future value
  - r = annual interest rate
  - t = Time object
- Output (automatically generated generic response object):
  - l_p = present value

Detailed Energy Building

- Location in tree
  - Model>Consequence
- DDM sensitivities
  - No
- Model form:
  - This model produces the lifecycle energy usage in a building at a fine level of detail
  - Extraction and manufacturing phase $$E_{EM} = E_p + E_t = \sum q i_p + \sum q i_t d = \sum q(i_p + i_t d)$$
  - On-site construction phase $$E_{OC} = r_h t_{wh} i_{hm} + (1 - r_h) i_m t_{wh} + \frac{1}{t_s} t_{wh} i_{wt} d_{wt} n_w$$
  - Operation phase $$E_O = t_{des} E_a$$
  - Maintenance phase $$E_M = \sum \left(\frac{t_{des}}{t_{mat}} - 1 \right) i_{mat} \ , \quad t_{mat} < t_{des}$$ $$E_M = 0 \ , \ t_{mat} \geq t_{des}$$
  - End-of-life phase $$E_{EoL} = q_{total} i_{eol}$$
- Input:
- Output (automatically generated generic response object):

Coarse Energy Building

- Location in tree
  - Model>Consequence

- DDM sensitivities
  - No

- Model form:
  - This model produces the lifecycle energy usage in a building at a coarse level of detail
  - Pre-use phase $$E_{PU} = a_f (n_s i_{pu} + i_p)$$
  - Operation phase $$E_O = t_{des} \left(\frac{24(3600)(A(r_{ww} U_{win} + (1 - r_{ww}) U_{wall}) + 0.33NV) D_{HDD}}{\eta} \right)$$
  - End-of-life phase $$E_{EoL} = n_s a_f i_{eol}$$

- Input:

- Output (automatically generated generic response object):

Detailed Water Usage Building

- Location in tree
  - Model>Consequence

- DDM sensitivities
  - No

- Model form:
  - This model produces the lifecycle water usage in a building at a fine level of detail
  - Pre-use phase $$E_{PU} = a_f (n_s i_{pu} + i_p)$$
  - Operation phase $$E_O = t_{des} \left(\frac{24(3600)(A(r_{ww} U_{win} + (1 - r_{ww}) U_{wall}) + 0.33NV) D_{HDD}}{\eta} \right)$$
  - End-of-life phase $$E_{EoL} = n_s a_f i_{eol}$$

- Input:

- Output (automatically generated generic response object):

Coarse Water Usage Building

- Location in tree
  - Model>Consequence

- DDM sensitivities
  - No

- Model form:
  - This model produces the lifecycle water usage in a building at a coarse level of detail

  - Entire lifecycle $$W_{LC} = n_s A_f (w_{pud} + t_d w_d)$$

- Input:

- Output (automatically generated generic response object):

Detailed Global Warming Potential

- Location in tree
  - Model>Consequence
- DDM sensitivities
  - No
- Model form:
  - This model produces the lifecycle global warming potential of a building at a fine level of detail
  - Extraction and manufacturing phase $GWP_{EM} = q\sum i_{gp} + i_{gt}d$
  - On-site construction phase $GWP_{OC} = E_{OC} i_{gc}$
  - Operation phase $GWP_{OP} = E_{OP} i_{go}$
  - End-of-life phase $GWP_{EoL} = E_{EoL} i_{geol}$
- Input:
- Output (automatically generated generic response object):

Coarse Global Warming Potential

- Location in tree
  - Model>Consequence

- DDM sensitivities
  - No

- Model form:
  - This model produces the lifecycle global warming potential of a building at a coarse level of detail

  - Entire lifecycle (100 years) $$GWP_{LC} = i_n(E_{total} - E_{OP}) + E_{OP} i_{op}$$

- Input:

- Output (automatically generated generic response object):

OpenSees

- Location in tree
  - Model>External Software
- DDM sensitivities
  - No
- Model form:
  - For users who have Tcl and OpenSees installed on the computer, this model allows parameters to be given to OpenSees and results to be returned to Rt.
- Input:
  - Parameter List = list of the parameters that should be mapped into the OpenSees model
  - Executable File = absolute path to the opensees.exe file, for example *C:/OpenSees/opensees.exe*
  - Input File = absolute path to the location of the OpenSees inputfile, for example *C:/mystructure.tcl* NOTE: This file contains $x entries, where "x" is the name of an Rt parameter, for example: *uniaxialMaterial Concrete01 1 -$fprime -0.002 0.0 -0.006*
- Output:
  - This model does not automatically create any response objects. Rather, create Command Response objects and/or File Response objects. In those objects, specify the name of the OpenSees model. In Command Response objects, specify the command that should be issued to OpenSees to get the response. In File Response objects, specify the name of the file where OpenSees puts the response.

EMME

- Location in tree
  - Model>External Software
- DDM sensitivities
  - No
- Model form:
  - This is an interface to the EMME transportation simulation software.
- Input:
  - Parameter List = list of the parameters that should be mapped into the EMME model
  - Input Scenario File = this is a template input file to EMME that contains Rt parameter names
  - Output Scenario File = this is the final input file to EMME, in which the parameter names have been replaced by their value
- Output:
  - This model does not automatically create any response objects. Rather, create File Response objects. In those objects, specify the name of the EMME model and the name of the file where EMME puts the response.

Algebraic Expression

A unique feature in Rt is that it is possible to implement user-defined models in a variety of ways, without any need for software compilation. One possibility is to write an arbitrary mathematical expression in the "Algebraic Expression" model. The expression can contain any of the basic mathematical functions. Parameters are input to this model by using parameter names in the expression. The output is given to an automatically generated Generic Response object.

- Location in tree
  - Model>Generic

- DDM sensitivities
  - No

- Model form:
  - This model evaluates a mathematical.

- Input:
  - Expression = expression to be evaluated

- Output (automatically generated generic response object):
  - Expression value

Random Variable with Random Parameters

This model is employed when the distribution parameters of a random variable are themselves random variables. The distribution type of that random variable is given as input, together with a list of parameters that serve as its parameters, in the order prescribed for the standard distribution types in Rt. The input also includes a standard normal random variable that is transformed inside the model to represent the actual random variable. The output is a Generic Response object with the realization of the random variable.

- Location in tree
  - Model>Generic

- DDM sensitivities
  - No

- Model form:
  - This model produces the realization of a random variable with random parameters. It transforms the realization of a standard-normal random variable to the realization of another random variable with the specified distribution type and distribution parameters

- Input:
  - Standard normal random variable
  - Distribution Type
  - Random Parameter Type = type of the parameters that are specified that can be either "Parameter 1 to Parameter 4" or "Mean, Standard Deviation, Parameter 3, and Parameter 4"
  - Parameter List = list of the distribution parameters

- Output (automatically generated generic response object):
  - Realization of the random variable with random parameters

Root Finding

- Location in tree
  - Model>Generic

- DDM sensitivities
  - No

- Model form:
  - This model finds the root of a general nonlinear single-variable equation

- Input:
  - Expression = expression of the equation, for example: x^2 – sin(x). In the expression, “x” is the unknown variable
  - Algorithm = algorithm of the solver that can be one of the following: Newton, Secant, Steffenson, Bisection, False Position, and Brent Dekker
  - Maximum Iterations = maximum number of iterations
  - Tolerance = acceptable error in finding the root
  - Initial Root = starting point of searching for root, used in derivative-based algorithms, namely Newton, Secant, and Steffenson
  - Lower Bound = lower bound of the searching interval, used in bracketing algorithms, namely Bisection, False Position, and Brent Dekker
  - Upper Bound = upper bound of the searching interval, used in bracketing algorithms, namely Bisection, False Position, and Brent Dekker

- Output (automatically generated generic response object):
  - The root of the equation

Script

A powerful approach for implementing user-defined models is the Script model. By utilizing the ECMA Script Language it is possible to implement complex algorithms as JavaScript models in Rt, without any recompilation. The language specification for ECMA is available at http://www.ecma-international.org/publications/standards/Ecma-262.htm, and many other references on Java Script programming are available online. The input to the Script model is a parameter list that names the parameters that are give to the script. A path to the location of the script file and an indication of whether the implementation includes DDM sensitivities are also given. This model does NOT automatically generate any response objects. Instead, Generic Response objects must be created, in which the name of the script model is given. The script must compute the value of the variables that have exactly the same name as these Generic Response objects. Parameters from Rt, like random variables, are employed in the script by utilizing the exact parameter name in the script. The naming convention to return "DDM sensitivities" from a script model is d_response_d_input as shown in one of the Rt examples.

- Location in tree
  - Model>Generic

- DDM sensitivities
  - Yes

- Model form:
  - This model runs a user-written script in the language of JavaScript, which is based on ECMAscript

- Input:
  - Input Parameter List = list of parameters used in the script
  - Script File = script file path
  - DDM = indicator of whether the script file includes DDM implementations or not. The naming convention to return DDM sensitivities from a script model is d_response_d_input.

- Output:
  - This model does not automatically create any response objects. Rather, create Generic Response objects. In those objects, specify the name of the Script model. The script should evaluate variables with the same name as these Generic Response objects.