Package ‘abcADM’

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Type Package

Title Fit Accumulated Damage Models and Estimate Reliability using ABC

Version 1.0

Description Estimate parameters of accumulated damage (load duration) models based on failure time data under a Bayesian framework, using Approximate Bayesian Computation (ABC). Assess long-term reliability under stochastic load profiles. Yang, Zidek, and Wong (2019) <doi:10.1080/00401706.2018.1512900>.

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`abcMCMC` *ABC-MCMC for load duration experiment data*

Description

Use modified ABC-MCMC algorithm to obtain posterior samples of $\theta = (\mu_a, \sigma_a, \mu_b, \sigma_b, \mu_c, \sigma_c, \mu_n, \sigma_n, \mu_{\sigma_0}, \sigma_{\sigma_0})$, given ramp and constant load failure time data.

Usage

```
abcMCMC(n, numBurning, numThining, inputD, dataNames, verbose = FALSE)
```

Arguments

`n`	number of posterior samples
`numBurning`	number of burn-in iterations
`numThining`	number of thining iterations
`inputD`	bandwidth δ for ABC approximation
`dataNames`	a vector of strings of the names of the datasets, which must be in the format "ID_(τ_c)_(t_c)Y" (see Details and Example)
`verbose`	displays information messages to console if TRUE

Details

The generated posterior samples are the parameters associated with (a, b, c, n, η), which are the random effects in the Canadian Model for load duration,

$$\frac{d}{dt}\alpha(t) = [(a\tau_s)(\tau(t)/\tau_s - \sigma_0)_+]^b + [(c\tau_s)(\tau(t)/\tau_s - \sigma_0)_+]^n \alpha(t),$$

where

- $a|\mu_a, \sigma_a \sim Log - Normal(\mu_a, \sigma_a)$;

- $b|\mu_b, \sigma_b \sim Log - Normal(\mu_b, \sigma_b)$;

- $c|\mu_c, \sigma_c \sim Log - Normal(\mu_c, \sigma_c)$;

- $n|\mu_n, \sigma_n \sim Log - Normal(\mu_n, \sigma_n)$;

- $\eta|\mu_{\sigma_0}, \sigma_{\sigma_0} \sim Log - Normal(\mu_{\sigma_0}, \sigma_{\sigma_0})$ and set $\sigma_0 = \frac{\eta}{1+\eta}$.

* $(x)_+ = max(x, 0)$.

* σ_0 serves as the stress ratio threshold in that damage starts to accumulate only when $\tau(t)/\tau_s > \sigma_0$.

* When sample pieces are subject to the load profile

$\tau(t) = kt$ if $t \leq T_0$

$\tau(t) = \tau_c$ if $t > T_0$

where τ_c is the selected constant-load level under the ramp-loading rate k, and T_0 is the time required for the load to reach τ_c under the ramp-loading rate k.

* The constant load level is assumed to be reached at the ramp-loading rate (k). The ramp-loading rate is 388,440 psi/hour.

* The constant load test ends at time t_c (in years).

* To achieve a ramp-load test, set τ_c to `Inf`.

Value

Returns a matrix of posterior samples where each row is one θ, and if verbose is TRUE, prints the acceptance rate.

References

Foschi, R. O., Folz, B., and Yao, F. (1989), Reliability-Based Design of Wood Structures (Vol. 34), Vancouver, BC: Department of Civil Engineering, University of British Columbia.

Wong, S. W., & Zidek, J. V. (2018). Dimensional and statistical foundations for accumulated damage models. Wood science and technology, 52(1), 45-65.

Yang, C. H., Zidek, J. V., & Wong, S. W. (2019). Bayesian analysis of accumulated damage models in lumber reliability. Technometrics, 61(2), 233-245.

Examples

```
# run the abc-mcmc algorithm to obtain 10 posterior samples
# example only, more iterations needed for convergence
resTheta = abcMCMC(10, 100, 10, 0.3, c("constLoad_4500_1Y"), TRUE)
```

`catConstants` *Display the current constants*

Description

Prints the constants currently associated with reliability assessment:

* ramp load rate (k);

* sample size of reliability simulation for each θ;

* start time;

* return period (in hours);

* time step of ODE solver.

Usage

```
catConstants()
```

`constLoad_4500_1Y` *Example data with $\tau\_c = 4500$ and $t\_c = 1Y(8760hours)$*

Description

An example dataset containing 300 failure times which can be used to obtain posterior samples of

$$\theta = (\mu_a, \sigma_a, \mu_b, \sigma_b, \mu_c, \sigma_c, \mu_n, \sigma_n, \mu_{\sigma_0}, \sigma_{\sigma_0})$$

via the abcMCMC algorithm.

Usage

```
constLoad_4500_1Y
```

Format

A vector with 300 entries

`default_param` *Default θ*

Description

Contains the values of $\theta = (\mu_a, \sigma_a, \mu_b, \sigma_b, \mu_c, \sigma_c, \mu_n, \sigma_n, \mu_{\sigma_0}, \sigma_{\sigma_0})$.

Usage

```
default_param
```

Format

An object of class `numeric` of length 10.

Details

Example values of θ from preliminary data analysis of Hemlock load duration data.

References

Yang, C. H., Zidek, J. V., & Wong, S. W. (2019). Bayesian analysis of accumulated damage models in lumber reliability. Technometrics, 61(2), 233-245.

Examples

```
default_param
#modify one of the values
default_param[10] = 0.049
```

`print_LoadProfile` *Print the load profile parameters*

Description

Displays the value of parameters in the current load profile.

Usage

```
print_LoadProfile(paramName)
```

Arguments

`paramName`	the name of the parameter in load profile

`sample_load_profile` *Residential load profile*

Description

`sample_load_profile` contains the default residential load profile. It can be invoked via `sample_load_profile`. Its parameters can be modified with `sample_load_profile["parameterName"]`.

Usage

```
sample_load_profile
```

Format

An object of class `data.frame` with 1 rows and 13 columns.

Details

- The load is defined as

$$\tau(t) = \phi R_o \frac{\gamma D_d + D_s(t) + D_e(t)}{\gamma \alpha_d + \alpha_l}$$

- Following the National Building Code of Canada (NBCC) standards document CAN/CSA-O86, assume that γ = 0.25, α_d = 1.25, α_l = 1.5.

- R_o is the characteristic value depending on the lumber population. By default, R_o = 2722psi.

- ϕ is the performance factor.

- According to Foschi, Folz, and Yao(1989)

1. D_d is the normalized dead load for the weight of the structure, and D_d ~ N(load_d_mean, load_d_sd). By default, `load_d_mean = 1`, `load_d_sd = 0.01`.

2. $D_s(t)$ is the sustained load. $D_e(t)$ is the extraordinary load. $D_s(t)$ and $D_e(t)$ are two independent processes.

3. The sizes of the loads are modelled using gamma distributions $G(k, \theta)$ where k and θ represent the shape and scale parameters. The random times between and during live load events are modeled using exponential distributions $Exp(\lambda)$ with mean λ^{-1}. Parameters for these models were previously fitted using survey data.

4. The process $D_s(t)$ consists of a sequence of successive periods of sustained occupancy each with iid duration T_s ~ Exp(1 / mean_Ts). During these periods of occupancy D_{ls} ~ G(load_s_shape, load_s_scale) iid. By default, `mean_Ts = 10`, `load_s_shape = 3.122`, and `load_s_scale = 0.0481`.

5. The process $D_e(t)$ consists of brief periods of extraordinary loads, separated by longer periods with no load T_e ~ Exp(mean_Te) of expected duration 1 year. When extraordinary loads occur, they last for iid periods of random duration T_p ~ Exp(1 / mean_Tp). The normalized loads D_{le} during these brief periods are iid with gamma distribution D_{le} ~ G(load_p_shape, load_p_scale). By default, `mean_Te = 1`, `mean_Tp = 0.03835`, `load_p_shape = 0.826`, and `load_p_scale = 0.1023`.

References

Foschi, R. O., Folz, B., and Yao, F. (1989), Reliability-Based Design of Wood Structures (Vol. 34), Vancouver, BC: Department of Civil Engineering, University of British Columbia.

Corotis, R. B., and Doshi, V. A. (1977), “Probability Models for Live-Load Survey Results,” Journal of the Structural Division, 103, 1257–1274.

Chalk, P. L., and Corotis, R. B. (1980), “Probability Model for Design Live Loads,” Journal of the Structural Division, 106, 2017–2033.

Harris, M. E., Bova, C. J., and Corotis, R. B. (1981), “Area-Dependent Pro-cesses for Structural Live Loads,” Journal of the Structural Division, 107,857–872.

Yang, C. H., Zidek, J. V., & Wong, S. W. (2019). Bayesian analysis of accumulated damage models in lumber reliability. Technometrics, 61(2), 233-245.

set_LoadProfile *Set load profile*

Description

Modifies the current load profile for reliability assessments.

Usage

```
set_LoadProfile(profile, verbose = FALSE)
```

Arguments

`profile`	desired load profile
`verbose`	prints the result of the new load profile to console if TRUE

Details

- The load is defined as

$$\tau(t) = \phi R_o \frac{\gamma D_d + D_s(t) + D_e(t)}{\gamma \alpha_d + \alpha_l}$$

- Following the National Building Code of Canada (NBCC) standards document CAN/CSA-O86, assume that γ = 0.25, α_d = 1.25, α_l = 1.5.

- R_o is the characteristic value depending on the lumber population. By default, R_o = 2722psi.

- ϕ is the performance factor.

- According to Foschi, Folz, and Yao(1989)

1. D_d is the normalized dead load for the weight of the structure, and D_d ~ N(load_d_mean, load_d_sd). By default, `load_d_mean = 1`, `load_d_sd = 0.01`.

2. $D_s(t)$ is the sustained load. $D_e(t)$ is the extraordinary load. $D_s(t)$ and $D_e(t)$ are two independent processes.

3. The sizes of the loads are modelled using gamma distributions $G(k, \theta)$ where k and θ represent the shape and scale parameters. The random times between and during live load events are modeled using exponential distributions $Exp(\lambda)$ with mean λ^{-1}. Parameters for these models were previously fitted using survey data.

4. The process $D_s(t)$ consists of a sequence of successive periods of sustained occupancy each with iid duration T_s ~ Exp(1 / mean_Ts). During these periods of occupancy D_{ls} ~ G(load_s_shape, load_s_scale) iid. By default, `mean_Ts = 10`, `load_s_shape = 3.122`, and `load_s_scale = 0.0481`.

5. The process $D_e(t)$ consists of brief periods of extraordinary loads, separated by longer periods with no load T_e ~ Exp(mean_Te) of expected duration 1 year. When extraordinary loads occur, they last for iid periods of random duration T_p ~ Exp(1 / mean_Tp). The normalized loads D_{le} during these brief periods are iid with gamma distribution D_{le} ~ G(load_p_shape, load_p_scale). By default, `mean_Te = 1`, `mean_Tp = 0.03835`, `load_p_shape = 0.826`, and `load_p_scale = 0.1023`.

- The default load profile is the residential load profile, which is included in the package and can be invoked via `sample_load_profile`. It can also be modified with `sample_load_profile["parameterName"]`.

References

Foschi, R. O., Folz, B., and Yao, F. (1989), Reliability-Based Design of Wood Structures (Vol. 34), Vancouver, BC: Department of Civil Engineering, University of British Columbia.

Corotis, R. B., and Doshi, V. A. (1977), “Probability Models for Live-Load Survey Results,” Journal of the Structural Division, 103, 1257–1274.

Chalk, P. L., and Corotis, R. B. (1980), “Probability Model for Design Live Loads,” Journal of the Structural Division, 106, 2017–2033.

Harris, M. E., Bova, C. J., and Corotis, R. B. (1981), “Area-Dependent Pro-cesses for Structural Live Loads,” Journal of the Structural Division, 107,857–872.

Yang, C. H., Zidek, J. V., & Wong, S. W. (2019). Bayesian analysis of accumulated damage models in lumber reliability. Technometrics, 61(2), 233-245.

Examples

```
p1 = sample_load_profile
set_LoadProfile(p1)
```

---

set_returnPeriod — *Set end time of reliability assessment*

Description

Modifies the ending time of the simulation period (in hours) for the reliability assessment. In solveCanADM, the load profile is simulated for a return period of `time_end` to determine whether failure has occurred.

Usage

```
set_returnPeriod(time_end, verbose = FALSE)
```

Arguments

`time_end`	end of simulation period (in hours)
`verbose`	prints information message to the console if TRUE

Details

The default is a reliability assessment period of 262980 hours (30 years).

Examples

```
set_returnPeriod(131400)
```

set_simuSampleSize *Set the number of simulated samples*

Description

Modifies the sample size of reliability simulations for solveCanADM.

Usage

```
set_simuSampleSize(n, verbose = FALSE)
```

Arguments

n	the number of samples to simulate for each θ to estimate failure probability
verbose	prints information message to the console if TRUE

Details

The default number of samples is 1000

Examples

```
set_simuSampleSize(10000)
```

set_timeStep *Set time step*

Description

Modifies time step (in hours). The step size to use when solving the Canadian model numerically with solveCanADM for reliability assessments.

Usage

```
set_timeStep(time_step, verbose = FALSE)
```

Arguments

time_step	step of time
verbose	prints information message to the console if TRUE

Details

The default step of time is 100 hours.

Examples

```
set_timeStep(50)
```

---

simu_failTime *Simulate samples of failure time using parameters θ*

Description

Simulate n observations of failure time from $\theta = (\mu_a, \sigma_a, \mu_b, \sigma_b, \mu_c, \sigma_c, \mu_n, \sigma_n, \mu_{\sigma_0}, \sigma_{\sigma_0})$ for constant load test or ramp load test.

Usage

```
simu_failTime(paras, n, tau_c, t_c, verbose = FALSE)
```

Arguments

`paras`	either a vector or a matrix where each row is θ
`n`	number of samples
`tau_c`	constant load level (can be set to infinity for ramp load test)
`t_c`	ending time of the constant load test in hours (can be set to infinity for ramp load test)
`verbose`	print information messages to console if TRUE

Details

* The default θ is provided and can be invoked via `default_param`.

* When sample pieces are subject to the load profile

$\tau(t) = kt$ if $t \leq T_0$

$\tau(t) = \tau_c$ if $t > T_0$

where τ_c is the selected constant-load level under the ramp-loading rate k, and T_0 is the time required for the load to reach τ_c under the ramp-loading rate k.

* The constant load level is assumed to be reached at the ramp-loading rate (k). The ramp-loading rate is 388,440 psi/hour.

Utilizes routines from the BRENT C++ root-finding library.

Value

Return a matrix of failure times. Each column contains samples from one θ. The name of the output matrix must be in the format "ID_τ_c_t_c(in years)", e.g. simuConstLoad_4500_1Y.

References

Brent, R. (2002). Algorithms for Minimization without Derivatives. Dover. ISBN: 0-486-41998-3.

Yang, C. H., Zidek, J. V., & Wong, S. W. (2019). Bayesian analysis of accumulated damage models in lumber reliability. Technometrics, 61(2), 233-245.

Examples

```
# simulate data with constant load 4500 psi and test of duration 1Y (8760 hours)
simuConstLoad_4500_1Y = simu_failTime(default_param, 30, 4500, 8760, TRUE)

# simulate data for ramp load
simuRampLoad_Inf_1Y = simu_failTime(default_param, 30, Inf, 8760)
```

`solveCanADM` *Simulate the time-to-failures given θ (posterior samples) under load profile*

Description

Give the estimated probability of failure after 30 years (or can be set via `set_returnPeriod`) based on a large number of replications with given load profile. The θ's, where

$$\theta = (\mu_a, \sigma_a, \mu_b, \sigma_b, \mu_c, \sigma_c, \mu_n, \sigma_n, \mu_{\sigma_0}, \sigma_{\sigma_0}),$$

will then be used to solve the Canadian ADM for time-to-failure T_f and probability of failure P_f with and without duration of load (DOL) effect.

Usage

```
solveCanADM(inputTheta, inputPhi, verbose = FALSE)
```

Arguments

`inputTheta`	a matrix where each row is θ
`inputPhi`	performance factor ϕ of the load
`verbose`	displays the index, the number of failure of the current θ, and the number of failure of the current θ with no DOL effect to console if TRUE

Details

The equation of the Canadian model is:

$$\frac{d}{dt}\alpha(t) = [(a\tau_s)(\tau(t)/\tau_s - \sigma_0)_+]^b + [(c\tau_s)(\tau(t)/\tau_s - \sigma_0)_+]^n \alpha(t),$$

where

* (a, b, c, n, η) are piece-specific random effects, and

- $a|\mu_a, \sigma_a \sim Log-Normal(\mu_a, \sigma_a)$;

- $b|\mu_b, \sigma_b \sim Log-Normal(\mu_b, \sigma_b)$;

- $c|\mu_c, \sigma_c \sim Log-Normal(\mu_c, \sigma_c)$;

- $n|\mu_n, \sigma_n \sim Log-Normal(\mu_n, \sigma_n)$;

- $\eta|\mu_{\sigma_0}, \sigma_{\sigma_0} \sim Log-Normal(\mu_{\sigma_0}, \sigma_{\sigma_0})$ and set $\sigma_0 = \frac{\eta}{1+\eta}$.

* $(x)_+ = max(x, 0)$.

* σ_0 serves as the stress ratio threshold in that damage starts to accumulate only when $\tau(t)/\tau_s > \sigma_0$.

* The performance factor ϕ comes from the load $\tau(t) = \phi R_o \frac{\gamma D_d + D_s(t) + D_e(t)}{\gamma \alpha_d + \alpha_l}$.

* The default time step when solving the Canadian model numerically is 100 hours. It can be set via `set_timeStep`.

* The probability is calculated as (number of failed samples / total number of simulation samples). Total number of simulation samples can be set via `set_simuSampleSize`.

Value

Returns a list of three elements. The first element of the list is the time-to-failure T_f. The second element is the probability of failture P_f. The third element is the probability of failure P_f without DOL effect. The index of θ, the number of failure of the current θ, and the number of failure of the current θ with no DOL effect will be printed in this order along the way if `verbose` is TRUE.

References

Yang, C. H., Zidek, J. V., & Wong, S. W. (2019). Bayesian analysis of accumulated damage models in lumber reliability. Technometrics, 61(2), 233-245.

Wong, S. W., & Zidek, J. V. (2018). Dimensional and statistical foundations for accumulated damage models. Wood science and technology, 52(1), 45-65.

Examples

```
# This is a small demo with 50 simulated failure times
set_simuSampleSize(50)
# simulate the time-to-failures given theta under the residential loads
resList = solveCanADM(default_param, 1, TRUE)

# Below is a more realistic example, using 1000 simulated failure times
# for each posterior draw of theta
set_simuSampleSize(1000)
resTheta = abcMCMC(100, 100, 10, 0.4, c("constLoad_4500_1Y"))
resList = solveCanADM(resTheta, 1, TRUE)
```

Index