Package ‘SPREDA’

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Type Package

Title Statistical Package for Reliability Data Analysis

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Description The Statistical Package for REliability Data Analysis (SPREDA) implements recently-developed statistical methods for the analysis of reliability data. Modern technological developments, such as sensors and smart chips, allow us to dynamically track product/system usage as well as other environmental variables, such as temperature and humidity. We refer to these variables as dynamic covariates. The package contains functions for the analysis of time-to-event data with dynamic covariates and degradation data with dynamic covariates. The package also contains functions that can be used for analyzing time-to-event data with right censoring, and with left truncation and right censoring. Financial support from NSF and DuPont are acknowledged.

License GPL-2

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Contents

SPREDA-package *Statistical Package for Reliability Data Analysis*

Description

The Statistical Package for REliability Data Analysis (SPREDA) implements recently-developed statistical methods for the analysis of reliability data. Modern technological developments, such as sensors and smart chips, allow us to dynamically track product/system usage as well as other environmental variables, such as temperature and humidity. We refer to these variables as dynamic covariates. The package contains functions for the analysis of time-to-event data with dynamic covariates and degradation data with dynamic covariates. The package also contains functions that can be used for analyzing time-to-event data with right censoring, and with left truncation and right censoring. Financial support from NSF and DuPont are acknowledged.

Details

Package:	SPREDA
Type:	Package
Version:	1.2
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Contains functions that are useful for the analysis of reliability data.

Author(s)

Yili Hong, Yimeng Xie, and Zhibing Xu

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References

Hong, Y., W. Q. Meeker, and J. D. McCalley (2009). Prediction of Remaining Life of Power Transformers Based on Left Truncated and Right Censored Lifetime Data. *The Annals of Applied Statistics*, Vol. 3, pp. 857-879.

Hong, Y. and Meeker, W. Q. (2010), Field-Failure and Warranty Prediction Using Auxiliary Use-rate Data. *Technometrics*, Vol. 52, pp. 148-159.

Hong, Y. and Meeker, W. Q. (2013), Field-Failure Predictions Based on Failure-time Data with Dynamic Covariate Information, *Technometrics*, Vol. 55, pp. 135-149.

Hong, Y. (2013), On Computing the Distribution Function for the Poisson Binomial Distribution, *Computational Statistics and Data Analysis*, Vol. 59, pp. 41-51.

Hong. Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

Meeker, W. Q. and L. A. Escobar (1998). Statistical Methods for Reliability Data. *John Wiley & Sons*.

Meeker, W. Q. and L. A. Escobar (2014). RSplida. http://www.public.iastate.edu/~stat533/.

Xu, Z., Y. Hong, and R. Jin (2014), Nonlinear General Path Models for Degradation Data with Dynamic Covariates, submitted.

`ce.dat.prep` *Create an object for cumulative exposure*

Description

Create a dataset with format that is suitable for analysis in the cumulative exposure model.

Usage

```
ce.dat.prep(xt.dat, failure.dat, ref_time = NULL)
```

Arguments

`xt.dat` "data.frame" format object. The first and second columns are sample id and time, respectively. Other columns are dynamic covariates.

`failure.dat` A "Surv" object. See Surv.

`ref_time` Reference time for each sample. If not specified, ref_time is a vector of 0's.

Value

A list of failure.dat, xt.obj and aux.inf.

`cls` *Mixed primal-dual bases algorithm for estimation of parameters with restriction.*

Description

It is used to estimate the parameters which have restrictions on the domain based on mixed primal-dual bases algorithm.

Usage

```
cls(y, X)
```

Arguments

`y`	A vector for responses.
`X`	Matrix of covariates.

Value

`y`	A vector for responses;
`x`	Matrix of covariates;
`betahat`	Estimates of parameters;
`yhat`	Estimates of responses.

Author(s)

Yili Hong

References

Fraser, D. A. S. and H. Massam (1989), A mixed primal-dual bases algorithm for regression under inequality constraints. Application to concave regression. *Scandinavian Journal of Statistics*, Vol. 16, pp. 65-74.

See Also

clme and deglmx

Examples

```
y<-sort(rnorm(100, 10, 2))
x<-cbind(runif(100, 1, 3), sort(rnorm(100, 3, 1)))
res<-cls(y, x)
```

Coatingenv *Dynamic covariates for the coating data.*

Description

A data frame with 36 observations and 9 variables.

Usage

```
data(Coatingenv)
```

Format

`SPEC_NUM` Observation id.

`TIME` Observation time for each id.

`UVB` a dynamic covariate.

`UVA` a dynamic covariate.

`VIS` a dynamic covariate.

`TEMP` a dynamic covariate.

`RH` a dynamic covariate.

`UV` a dynamic covariate.

`GROUP` Group for each id.

Source

Hong. Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

Coatingout *Dynamic covariates for coating data*

Description

A data frame with 36 observations and 4 variables.

Usage

```
data(Coatingout)
```

Format

`SPEC_NUM` Observation id.

`TIME` Observation time for each id.

`DAMAGE_Y` Response for each id.

`GROUP` Group for each id.

Source

Hong. Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

`deglmx` *Functions for estimating parameters in the linear/nonlinear mixed models with dynamic covariates.*

Description

Functions for estimating parameters in the linear/nonlinear mixed models with dynamic covariates. Those dynamic covariates will have restricted-shape effects such as monotonic increasing, decreasing or quadratic shape.

Usage

```
deglmx(fixed, data, dyn.data, id, time, random = NULL, linear = TRUE, ytrend,
splinetrend = NULL, splinetype = NULL, degree = NULL, knots = NULL,
weights = NULL, subset = NULL, start, maxiter = 10, method = "BFGS", ...)
```

Arguments

`fixed` Formula with fixed effect.

`data` Data with id, time, response, and fixed covariates.

`dyn.data` Dynamic data with id, time, dynamic covariates.

`id` The name of the id which is characters or string.

`time` The name of time in the data or dyn.data which is characters or string.

`random` The formula for random parts which should condition on the id.

`linear` The index of linear or nonlinear.

`ytrend` If ytrend=1 indicates the increasing trend of the response, if ytrend=-1 indicates the decreasing trend of the response.

`splinetrend` They are a vector of trends of dynamic covariate effects. Define 1 as increasing trend and -1 as decreasing trend.

`splinetype` They are a vector of the spline basis type which can be chosen among "Ms", "Is", and "Cs".

`degree`	The degree of the spline functions.
`knots`	The number of knots in the spline functions.
`weights`	Weights of the observation.
`subset`	Subset of the data.
`start`	The initial values for covariance and variance matrix.
`maxiter`	The maximum number of iteration in the optimization.
`method`	The method of optim function with "BFGS" as default. More details in optim.
`...`	Other items.

Value

The returned outputs belong to class of "deglmx". list(type = type, fit = fit, dat = dat.obj, dyn.mat = cov.mat.tmp, ytrend = ytrend, dyncovnames = dyncovnames, dyn.data = dyn.data, beta.index = beta.index, call = mfun)

`type`	Type of the model either linear mixed or nonlinear mixed models.
`fit`	The fitting results in the model including estimates, residuals, loglikelihood, and so on.
`dat`	The modified data.
`dyn.mat`	The spline basis functions.
`ytrend`	The indication of response trend either increasing (1) or decreasing (-1).
`dyncovnames`	Names of dynamic covariates in the model.
`dyn.data`	The modified dynamic data.
`beta.index`	Indications of parameters in the dyanmic covariates.
`call`	The call function in the model.

Note

For the nonlinear model, we currently only implement one specific nonlinear relationship.

Author(s)

Yili Hong

References

Hong. Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

Examples

```
data(Coatingenv)
data(Coatingout)


fit=deglmx(DAMAGE_Y~UV+RH+TEMP, data=Coatingout, dyn.data=Coatingenv,
          id="SPEC_NUM", time="TIME", random=~TIME|SPEC_NUM, linear=TRUE, ytrend=-1,
         splinetrend=c(-1, -1, -1), splinetype=c("Is", "Cs", "Is"), degree=c( 3, 3, 3),
        knots=c(4, 4, 4), weights=NULL, subset=NULL,start=c(0.017,0.0013,-0.404,0.0176),
          maxiter=10, method='BFGS')

fit=deglmx(DAMAGE_Y~G/(1+exp(-log(UV+RH+TEMP)/H)), data=Coatingout, dyn.data=Coatingenv,
          id="SPEC_NUM", time="TIME", random=~G+H|SPEC_NUM, linear=FALSE, ytrend=-1,
          splinetrend=c(1, 1, 1), splinetype=c("Is", "Cs", "Is"), degree=c( 3, 3, 3),
          knots=c(4, 4, 4), weights=NULL, subset=NULL, start=c(0.1, 0.1, -0.5, 0.01),
          maxiter=4)
```

---

i.spline.x *i_spline basis*

Description

Create the i_th splines basis for I_splines basis or C_splines basis

Usage

```
i.spline.x(xx, tt, i, k, delta = 1e-04, Cs = F)
```

Arguments

xx	values of of covariate
tt	values of knot sequence of the covariate
i	I_th splines basis
k	degree of the spline
delta	the length of the spans to split the range of covariate
Cs	indicator of whether the creation of C_splines basis is needed

Details

Creation of the i_th splines basis for I_splines basis or C_splines basis

Value

`i.spline.x` returns a vector of i_th splines basis for covariate values xx in knots i and degree k

Author(s)

Yili Hong

References

Hong. Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

See Also

m.spline.x

Examples

```
i.spline.x(xx=runif(20), tt=c(0, 0, 0, 0.3, 0.6, 0.8, 1, 1, 1 ), i=3, k=3,
delta = 1e-04, Cs = FALSE)
i.spline.x(xx=runif(20), tt=c(0, 0, 0, 0.3, 0.6, 0.8, 1, 1, 1 ), i=3, k=3,
delta = 1e-04, Cs = TRUE)
```

---

kaplan.meier.location *Kaplan-Meier Location*

Description

Calculate the location of Kaplan-Meier estimator.

Usage

```
kaplan.meier.location(fit)
```

Arguments

fit	survfit object.

Value

xloc, yloc	x, y locations.

Author(s)

Yili Hong

Examples

```
require(survival)
fit <- survfit(Surv(time, status) ~ x, data = aml)
kaplan.meier.location(fit)
```

Lifedata.MLE *Parametric Fitting for Lifetime Data*

Description

Fit parametric models (based on log-location-scale family of distributions) to right censored and/or left truncated data, with (dynamic) covariates.

Usage

```
Lifedata.MLE(formula, data, xt.dat = NULL, dist, method = "BFGS",
subset, truncation, na.action, weights, ref_time = NULL, starts = NULL, ...)
```

Arguments

`formula` A formula object, which has a `Surv` object on the left of ~ and covariates on the right.

`data` A data frame used to evaluate variables in the `formula`, `subset` and `weights` arguments.

`xt.dat` A data frame contains dynamic covariates. The first and second columns must be sample id and time. If specified, cumulative exposure model will be used to fit the data.

`dist` Distribution used in the model. Can be "weibull", "lognormal", "loglogistic", "frechet".

`method` Default is "BFGS". This function calls optim to do optimization. Other options can be found in optim.

`subset` This is an optional argument that specifies the subset of observations to be used in the fitting procedure.

`truncation` An optional data frame contains truncation time and indicators.

`na.action` Indicates what to be done when data contain missing values.

`weights` An optional vector of weights for each observation.

`ref_time` An optional vector of reference time (start time) of dynamic covariates. If it is `NULL`, `ref_time` is a vector of 0's.

`starts` Initial values for parameters.

`...` Further arguments can be passed to optim.

Details

The default method for choosing start values can sometimes failed, the user may need to try several start values to make the function work.

Value

This function returns an object of class "Lifedata.MLE". An "Lifedata.MLE" object is a list of

`call`	Called function.
`formula`	Formula argument in the input.
`coef`	Vector of coefficients.
`vov`	Variance-covariance matrix of `coef`.
`min`	`-loglikelihood` evaluated at `coef`.
`surv`	Survival probabilities.
`dat`	Dataset used to fit the model.

Author(s)

Yili Hong

References

Yili Hong and William Q. Meeker. Field-Failure Predictions Based on Failure-Time Data With Dynamic Covariate Information. *Technometrics*, **55**(2), 135–149, 2013.

See Also

Surv, optim, summary.Lifedata.MLE. See methods(class="Lifedata.MLE") for all the functions related to "Lifedata.MLE" object.

Examples

```
#####################################################################
### right censored data
data(shock)
res1=Lifedata.MLE(Surv(Distance, Censor)~1, data=shock, dist="weibull")
res1
summary(res1)

res2=Lifedata.MLE(Surv(Distance, Censor)~1, data=shock, dist="lognormal")
res2
summary(res2)

#####################################################################
### left truncated right censoring data
data(testdata)
test=Lifedata.MLE(Surv(truncation.age, age, failure)~1, data=testdata,dist="weibull",
method="Nelder-Mead", subset=(group=="MC_Old"))
summary(test)


#####################################################################
### dynamix covariates
data(Prod2.xt.dat)
data(Prod2.fai.dat)


test=Lifedata.MLE(Surv(failure.time, delta)~1, data=Prod2.fai.dat,xt.dat=Prod2.xt.dat,
starts=c(12, 3.5, log(2)), dist="weibull")
summary(test)
```

lifetime.mle *Calculate MLE for Lifetime Distribution*

Description

Calculate MLE for samples from lifetime distribution, e.g., Weibull distribution. The observations can be complete or censored.

Usage

```
lifetime.mle(dat, minusloglik, starts, method = "BFGS", hessian = TRUE,...)
```

Arguments

dat	First column contains event times, second column contains event indicators.
minusloglik	-loglikelihood.
starts	Initial values for parameters.
method	Default is "BFGS". This function call optim to do optimation. Other options can be found in optim.
hessian	A logical value. If TRUE, hessian matrix will be returned. Default is TRUE.
...	Further arguments can be passed to optim.

Value

A list of

call	Called function.
coef	The best minimizer found.
vov	Variance-covariance matrix of coef.
min	-loglikelihood evaluated at coef.
dat	Dataset used.
minusloglik	-loglikelihood function.

Author(s)

Yili Hong

See Also

`optim`

Examples

```
#censored samples from Weibull distribution
dat=cbind(c(1.1,2,3.6,4,5.3,7,7,7), c(1,1,1,1,1,0,0,0))
res=lifetime.mle(dat, minusloglik=miniusloglik.sev, starts=c(0,1))
res$coef  #return \eqn{u, log(\sigma)}
```

m.spline.x *M_splines basis*

Description

Creation of M_splines basis

Usage

```
m.spline.x(x, tt, i, k)
```

Arguments

`x`	a value of the covariate
`tt`	values of knot sequence of the covariate
`i`	the i_th M_spline function
`k`	degree of the spline

Value

`m.spline.x` returns a value of M_spline basis value for x in i_th spline degree of k

Author(s)

Yili Hong

References

Hong. Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

See Also

`i.spline.x`

Examples

```
m.spline.x(x=0.3, tt=c(0, 0, 0, 0.3, 0.6, 0.8, 1, 1, 1 ), i=2, k=3)
```

`MIC.splines.basis` *Splines basis functions*

Description

Creation splines basis for M_splines, I_splines and C_splines

Usage

```
MIC.splines.basis(x, df = NULL, knots = NULL, boundary.knots = NULL,
type = "Ms", degree = 3, delta = 0.01, eq.alloc = F)
```

Arguments

`x`	values of covariate
`df`	number of splines needed which is equal to knots+degree
`knots`	number of knots needed which does not include the number of knots at the beginning
`boundary.knots`	the values of boundary knots, which are usually the minimum and maximum of covariate
`type`	types of splines basis needed, which can be Ms Is or Cs
`degree`	degree of the splines function
`delta`	the length of the spans to split the range of covariate
`eq.alloc`	indicators of whether the knots are equally allocated

Value

list(mat=mat,x=x, df=df, knots=knots,boundary.knots=boundary.knots, type=type,degree=degree,delta=delta)

`mat`	it is a matrix of splines basis
`x`	the input of covariate
`df`	the input of number of splines needed
`knots`	the input of number of knots needed not including the boundary
`boundary.knots`	the values of boundary knots
`type`	type of splines function which can be MS IS or Cs
`degree`	degree of the splines functions
`delta`	the length of the spans to split the range of covariate

Author(s)

Yili Hong

References

Hong. Y., Y. Duan, W. Q. Meeker, D. L. Stanley, and X. Gu (2014), Statistical Methods for Degradation Data with Dynamic Covariates Information and an Application to Outdoor Weathering Data, *Technometrics*, DOI: 10.1080/00401706.2014.915891.

See Also

i.spline.x, m.spline.x

Examples

```
MIC.splines.basis(x=runif(20), df = NULL, knots = 3, boundary.knots = NULL,
    type = "Ms", degree = 4, delta = 0.01, eq.alloc = FALSE)
```

plev *The Standard Largest Extreme Value Distribution*

Description

The cdf, pdf, quantile function, and random number generation for the standard largest extreme value distribution.

Usage

```
plev(z)
dlev(z)
qlev(p)
rlev(n)
```

Arguments

z	Vector of values where the cdf or pdf to be evaluated.
p	Vector of probabilities where the quantile function to be evaluated.
n	Number of random samples. If input is a vector, then the number generated is the length of it.

Value

plev returns cdf, dlev returns pdf, qlev returns quantiles, and rlev returns random samples.

Author(s)

Yili Hong

See Also

psev, dsev, qsev, rsev.

Examples

```
plev(c(2,3))
dlev(c(2,3))
qlev(0.1)
rlev(10)
```

---

plotdeglmx *Plot function for the class of "deglmx".*

Description

Plots of dynamic covariates and fitting of the model in the class of "deglmx".

Usage

```
plotdeglmx(x, type)
```

Arguments

`x`	The fitting results of class "deglmx".
`type`	If type=1, plot the spline effect plot. If type=2, plot the fitting plots. If type is missing, plot all of them.

Author(s)

Yili Hong

See Also

deglmx

Examples

```
 data(Coatingenv)
 data(Coatingout)


 fit=deglmx(DAMAGE_Y~UV+RH+TEMP, data=Coatingout, dyn.data=Coatingenv,
           id="SPEC_NUM", time="TIME", random=~TIME|SPEC_NUM, linear=TRUE, ytrend=-1,
          splinetrend=c(-1, -1, -1), splinetype=c("Is", "Cs", "Is"), degree=c( 3, 3, 3),
         knots=c(4, 4, 4),weights=NULL, subset=NULL,start=c(0.017,0.0013,-0.404,0.0176),
           maxiter=10, method='BFGS')
 plotdeglmx(x=fit)
 plotdeglmx(x=fit, type=1)
 plotdeglmx(x=fit, type=1)
```

`Prod2.fai.dat` *Dataset of failure information of Product 2.*

Description

A data frame with 1800 observations and 3 variables.

Usage

```
data(Prod2.fai.dat)
```

Format

`failure.time` a numeric vector

`delta` a numeric vector

`ce` a numeric vector

Source

Hong, Y. and W. Q. Meeker (2013). Field-Failure Predictions Based on Failure-Time Data With Dynamic Covariate Information. *Technometrics*, **55**(2), 135–149.

`Prod2.xt.dat` *Dataset of covariate information of Produce 2.*

Description

A data frame with 80552 observations and 3 variables.

Usage

```
data(Prod2.xt.dat)
```

Format

`id` a numeric vector of sample ids.

`time` a numeric vector of time.

`x1` a numeric vector of dynamic covariate `x1`.

Source

Yili Hong and William Q. Meeker. Field-Failure Predictions Based on Failure-Time Data With Dynamic Covariate Information. *Technometrics*, **55**(2), 135–149, 2013.

psev *The Standard Smallest Extreme Value Distribution*

Description

The cdf, pdf, quantile function, and random number generation for the standard smallest extreme value distribution.

Usage

```
psev(z)
dsev(z)
qsev(p)
rsev(n)
```

Arguments

z	Vector of values where the cdf or pdf to be evaluated.
p	Vector of probabilities where the quantile function to be evaluated.
n	Number of random samples. If input is a vector, then the number generated is the length of it.

Value

`psev` returns cdf, `dsev` returns pdf, `qsev` returns quantiles, and `rsev` returns random samples.

Author(s)

Yili Hong

See Also

plev, dlev, qlev, rlev.

Examples

```
psev(c(2,3))
dsev(c(2,3))
qsev(0.1)
rsev(10)
```

`shock` *Shock Absorber Failure Data*

Description

A data frame with 38 observations and 3 variables.

Usage

```
data(shock)
```

Format

`Distance` a numeric vector

`Mode` a factor with levels `Censored` `Mode1` `Mode2`

`Censor` a numeric vector

Source

Meeker, W. Q. and L. A. Escobar. Statistical Methods for Reliability Data. *John Wiley & Sons*, 1998.

`summary.Lifedata.MLE` *Summaries of "Lifedata.MLE" Object*

Description

These functions summaries a "Lifedata.MLE" object.

Usage

```
## S3 method for class 'Lifedata.MLE'
summary(object, ...)
```

Arguments

`object`	A "Lifedata.MLE" object.
`...`	Additional arguments.

Value

summary.Lifedata.MLE returns an object of class "summary.Lifedata.MLE", which is a list of

call	Component from obj.
coef	Vector of coefficients.
vcov	Variance-covariance matrix of coef
coefmat	Matrix contains mean, sd, 95% lower CI and 95% upper CI of coefficients.
min	Component from obj.
surv	Component from obj.
dat	Component from obj.
ori.coef	coef component in obj.
ori.vcov	vcov component in obj.

See Also

Lifedata.MLE

---

testdata *Testdata*

Description

This dataset involves left truncation and right censoring.

Usage

```
data(testdata)
```

Format

A data frame with 710 observations on the following 9 variables.

age a numeric vector

failure a numeric vector

manufacture.year a numeric vector

manufacturer a factor with levels MA MB MC MD ME Other

cooling a factor with levels FIFE NIFE NINE Unknown

insulation a factor with levels d55 d65

truncation a numeric vector

truncation.age a numeric vector

group a factor with levels MA_New MB_Old MC.ME.Other_New MC_Old MD_Old ME_Old Other_Old

Source

Hong, Y., W. Q. Meeker, and J. D. McCalley. Prediction of Remaining Life of Power Transformers Based on Left Truncated and Right Censored Lifetime Data . *The Annals of Applied Statistics*, **3**(2), 857–879, 2009.

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