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RELIABILITY
CONSULTING
PROGRAMS

STRUREL System of Programs for Probabilistic Reliability Analysis

STRUREL is a set of programs for the reliability analysis of structural, operational and other systems employing state-of-the-art techniques.

- **STATREL -** A program for reliability oriented statistical analysis and simulation
- **COMREL -** A program for time-invariant and time-variant component reliability analysis
- **SYSREL -** A program for system reliability analysis including reliability updating
- **COSTREL -** A program for reliability oriented optimization
- **PERMAS-RA -** A multipurpose FE-Program (by INTES) coupled with **Comrel** & **Costrel**

The **STRUREL** software covers the preparatory steps, all computational tasks and many post processing options in technical reliability, decision making under uncertainty and statistical analysis. The programs have applications in structural engineering and code making, in the nuclear power plant, offshore, ship and aerospace industry, in hydrology, operations research, financial planning and statistics.

The **STRUREL** package is implemented under Windows providing user friendliness, graphical pre- and post-processing and rich on-line help. All **STRUREL** programs are genuine 32-Bit Windows applications. They will run on PC's with Windows 9x or Windows Me, Windows NT-4, Windows 2000 and Windows XP.

STATREL is a program with many special features for statistical reliability-oriented data analysis but also covers standard statistical analyses. It provides a useful set of illustrative menu-driven tools to perform basic descriptive statistics with many graphical facilities.

For all models included in other **STRUREL** modules **STATREL** performs parameter estimation by different methods, confidence interval and quantile estimation as well as hypothesis testing including tests for sample validity, distribution functions and parameters. Simple analysis of variance and regression is also included. Several Bayesian methods are implemented.

Results are made visible in terms of numerous graphical representations such as histograms, cumulative frequencies, bivariate plots, bar charts, probability paper plots. Import of data from spreadsheet programs like Excel and export of stochastic models to COMREL, SYSREL and COSTREL is possible.

Schemes for simulation of random numbers, random vectors and random time series (stationary, non-stationary, Gaussian, Hermite) allow numerical experiments. Different generation techniques such as ARMA or by simple and fast Fourier transforms can be used. Many predefined spectra can be selected and various forms of non-stationarities can be defined.

The implemented features for time series analysis provides rich tools for setting up and testing models. The features include numerous graphical representations of the time series such as histograms, probability paper plots, scatter diagrams, moving averages, Husid functions, mean value crossings and periodograms. Many transformation and filter

techniques including trend removals, smoothing, differentiation and integration, amplitude and frequency modulation are provided. Non-parametric spectral estimation and ARMA modeling as well as amplitude and frequency trend estimation are available.

COMREL comprises the modules COMREL-TI for time-invariant and COMREL-TV for time-variant reliability analysis of individual failure modes based on advanced FORM/SORM methodology. Several algorithms to find the most likely failure point (β-point) are implemented including a gradient free algorithm for non-differentiable failure criteria (state functions). Complementary or alternative computational options are Mean Value First Order (MVFO), Monte Carlo simulation, Adaptive Sampling, Spherical Sampling and several Importance Sampling schemes.

FORM/SORM techniques allow to compute a rich set of sensitivity measures showing the impact on reliability of individual basic random variables, of distribution parameters and of other constant parameters. Provided characteristic values are specified partial safety factors for all basic variables are another straightforward result.

COMREL can deal with arbitrary dependence structures in the stochastic model (Rosenblatt, Hermite and Nataf-models). The full set of stochastic models offered by STATREL is supported (44 models at present) and can be inputted either in parameter form or in terms of the first two moments and additional parameters if necessary. The models can be truncated and new user defined models can be added. You can make distribution parameters dependent on other variables, parameters and even functions. Dependencies can also be described in terms of correlations when this is theoretically admissible. The increased versatility in stochastic modeling certainly is one of the strength of COMREL/SYSREL.

Time-variant reliability is computed by the outcrossing approach also based on FORM/SORM methodology for stationary or non-stationary cases. Available random process models are regular or intermittent rectangular wave processes and differentiable Gaussian and non-Gaussian translation processes (Hermite or Nataf processes). Both models can be scalar processes and vector processes. All random process types can be combined with each other including the possibility to combine intermittent and non-intermittent processes. Sensitivity measures and partial safety factors are provided similar to time-invariant analysis. In addition, various other exceedance measures like excursion time, hazard rate, point-in-time non-availability are evaluated.

In **COMREL** several failure criteria can be defined in one job. Alternatively one may use “Archives” of stochastic models and state functions connected to predefined "Reliability Processors".

Two versions with identical capabilities are available, one for the professional user requiring the state functions to be written in Fortran 90 and subsequent compiling and linking, and the other having a powerful ***Symbolic Processor*** with many predefined functions.

While the ***Professional*** version may be necessary for complicated iterative state functions or when external programs have to be linked to the state functions application of the ***Symbolic*** version is very easy. State functions can be specified in normal mathematical notation. Names for variables and parameters can be chosen freely and are automatically transferred into the stochastic model and vice versa. Important constants are predefined. Built-in functions include all elementary, trigonometric, hyperbolic, logarithmic and some special functions like the Gaussian distribution function and its inverse, Bessel and Gamma functions. Several alternatives for numerical integration, differentiation and root finding are available as well as comparative operators and test functions. Auxiliary user defined functions and reference functions can be defined and used similar to subroutines in the professional version.

SYSREL covers system reliability evaluation including event updating. The graphical user interface has the same comfort and capabilities regarding stochastic modeling as in COMREL. The logical model in **SYSREL** is connected with the failure criteria and the stochastic model (basic random variables) for a fully interactive control. System modeling includes not only the representation by a (minimal) set of parallel systems in series but also the important case of conditional events (observations, event updating).

For the FORM/SORM methods **SYSREL** is based on, you have access to several efficient and reliable algorithms searching for the β-point (most likely failure point) with special solution strategies. An alternative computational option is Monte Carlo simulation.

Also SYSREL is available in the professional version for Fortran 90 and for the ***Symbolic*** specification of state functions.

COSTREL is the first integrated solution for reliability-oriented optimization available on PC`s. It combines the rich features of stochastic modeling as implemented in COMREL with an efficient one-level optimizer. **COSTREL** can perform performance- (cost-, weight-, volume-) optimization under a reliability constraint as well as reliability optimization under a performance constraint. For both types of problems an arbitrary number of additional constraints (stress or deformation constraints etc.) can be included. Like the other STRUREL programs also **COSTREL** computes a rich set of sensitivity measures for better interpretation of results. The approach is based on FORM/SORM techniques and is restricted to time-invariant problems at present. An extension to stationary, time-variant problems will be available soon.

PERMAS-RA is a powerful multipurpose FE-Program with a long and successful history. This program was coupled to COMREL and COSTREL in several steps, the last being the *ASRA-HPC* project. PERMAS covers all features of modern FE-Software. Most of its features co-work with COMREL and COSTREL. This includes non-linear analysis and access to non-differentiable state functions by means of response surfaces. Further information can be obtained from INTES GmbH in Stuttgart, see http://www.intes.de. You will also find a link to the *ASRA-HPC* website there.

Post processing

The programs provide short and clear result files but in case of problems a detailed error traceback can be generated. From parameter studies you can compute and plot failure probability, reliability, partial safety factors, hazard functions, expected cost and, of course, various sensitivity measures.

Availability of programs

The ***Symbolic*** versions of **COMREL, COSTREL** and **SYSREL** come to you as stand-alone executables. An interactive and context sensitive help system is included (*.hlp format).

Educational versions of **COMREL-TI** and **SYSREL** are available for students.

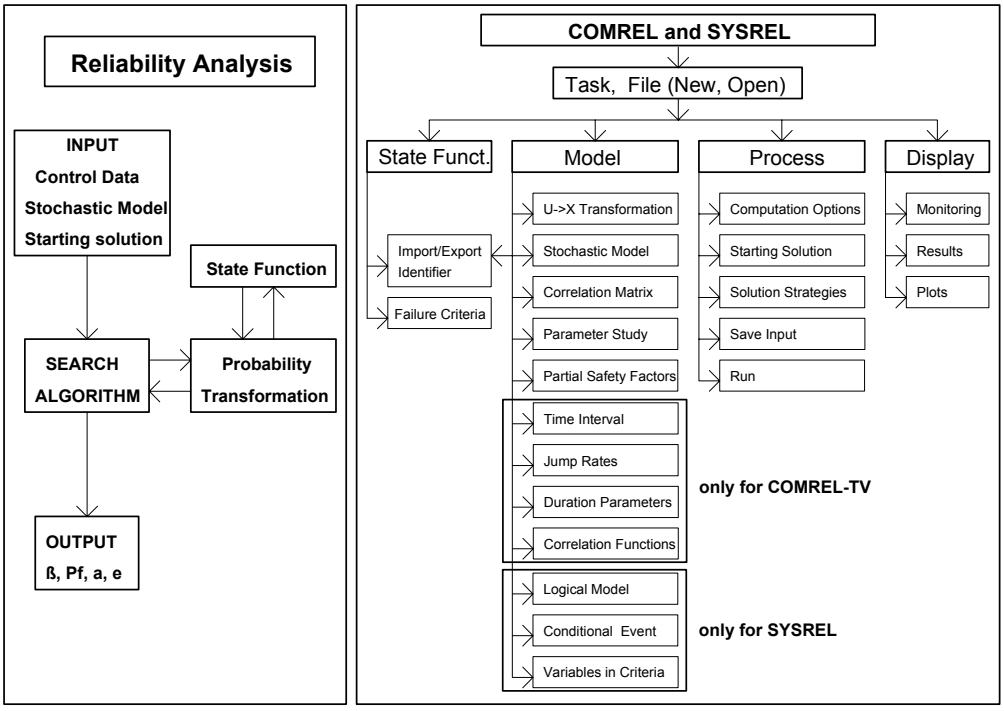
The computational kernels of the ***Professional*** versions of **COMREL, COSTREL** and **SYSREL** are collected in object-libraries. By default, these libraries are delivered for 32-Bit Compaq Visual Fortran compiler v. 6.x but other compilers are also possible. A development toolkit including interface descriptions of essential modules and parts as source code can be made available under special conditions.

The computational kernels can be used on any system providing a modern Fortran compiler, if the user is prepared to communicate with the programs on an ASCII file basis.

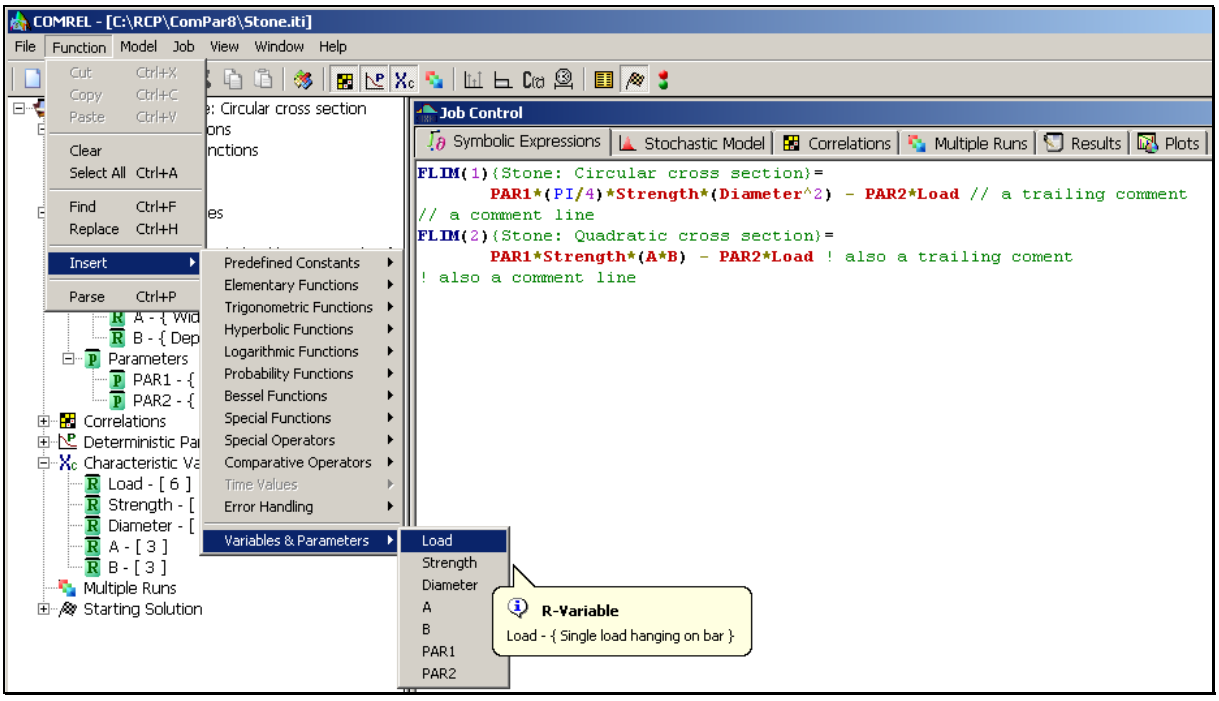
Help and documentation

We have made operations easy and direct by a modern desktop using many icons and shortcuts. A help-bar provides first useful information for all features. More and detailed help on both theoretical concepts and techniques can be activated. More theory and technical details of the programs are documented in manuals. The manuals provide several well described standard examples to study operation of the programs and to help interpreting the results. A rich set of additional representative examples is provided illustrating most of the capabilities and helping the user to formulate and model his problem.

Basic Data Flow and Sequence of Tasks in a Reliability Analysis



State Function Window and Model Options



Several events must happen to cause failure: A parallel system for *SYSREL*

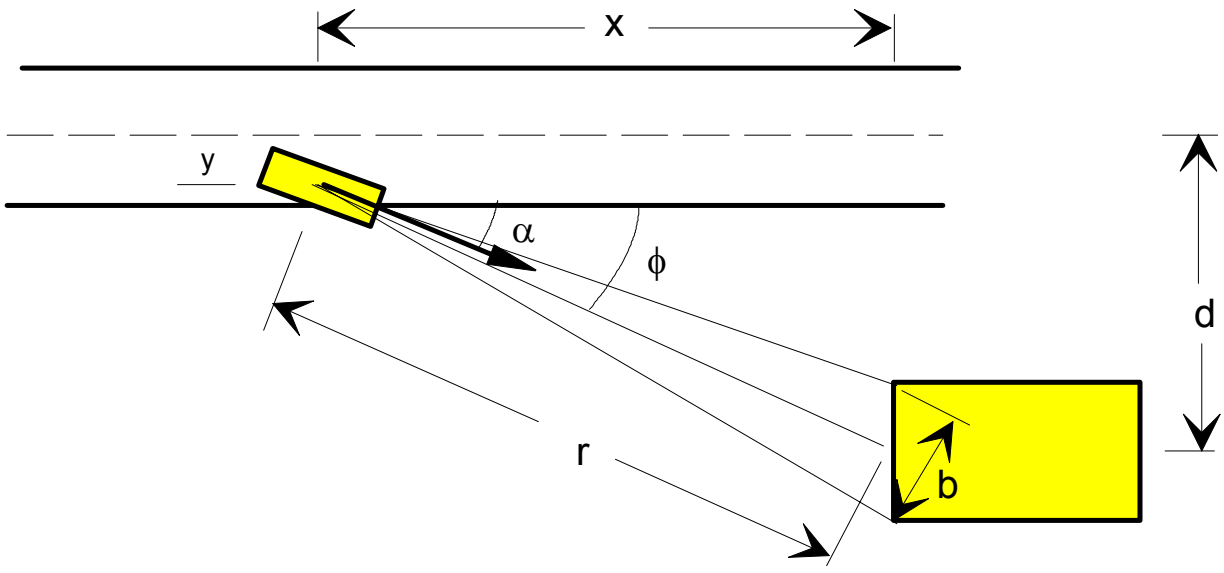
The failure probability of a structural element under truck impact can be determined by making use of the following simplified model. The impact force, based on energy balance, is:

$$F_i = \sqrt{k\,\kappa\,m\,(v_0^2 - \frac{2\,a\,d}{\sin(\phi)})} \qquad (\text{for } v_0^2 > \frac{2\,a\,d}{\sin(\phi)})$$

where:

- v_0: initial velocity
- κ: equivalent stiffness
- m: total mass
- a: deceleration
- κ: pay load factor ($0 \le \kappa \le 1$)
- ϕ: angle between collision course and track direction
- d: distance from the structural element to the road ($d \le \frac{v_0^2 \sin(\phi)}{2\,a}$)

Vehicle leaving a road and hitting an obstacle.



Stochastic Model

Basic variable	Distribution	Mean value	Standard deviation	C.o.V. (%)	Name of Variable or Constant
v_0 (m/s)	lognormal	22	2.2	10	*Speed0*
k (N/m)	lognormal	300 000	60 000	20	*Stiffness*
m (kg)	normal	10 000	5 500	55	*Mass*
κ (no dimension)	beta	0.7	0.1	14	*kappa*
a (m/ s^2)	lognormal	4	1.3	33	*Decelera*
ϕ (°)	Rayleigh	10	5.21	52	*Phi*
F_c(N)	lognormal	2.010 E+6	2.015 E+5	10	*Fc*
d (m)	constant	4.5(1.5)	-	-	*Dist*

Note: The resistance F_c is defined by distribution parameters median ξ=2.0E+6 and δ=0.100.

Events (Logical Model)

A)The event of failure of the structural element given that the truck reaches the structural element.

B)The event that the truck does not come to a stop before hitting the target

C)The event that a truck leaves the road.

Unconditional probability: $$\mathrm{P}\{F_c - \sqrt{k\kappa m(v_0^2 - \frac{2ad}{\sin(\phi)})} \le 0\} \qquad \text{(A)}$$

Hit probability given occurrence: $$\mathrm{P}\{\frac{2ad}{\sin(\phi)} - v_0^2 \le 0\} \qquad \text{(B)}$$

Occurrence probability: $$\mathrm{P}\{\mathrm{U} - \Phi^{-1}\left(\frac{\lambda n t b}{\sin(\phi)}\right) \le 0\} \qquad \text{(C)}$$

Hit probability: $$\mathrm{P}\{(\mathrm{B}) \cap (\mathrm{C})\}$$

Total probability: $$\mathbf{P\{(A) \cap (B) \cap (C)\}}$$

Definition of State Functions (Events) and some Results