Using the Direct Determined Fully Probabilistic Method (DDFPM) for determination of failure

A.P. Janas, M. Krejsa & V. Krejsa

VSB – Technical University Ostrava, Czech Republic

ABSTRACT: DDFPM has been developed as an alternative for Monte Carlo in the assessment of structural reliability in probabilistic calculations (Marek et al. 1995). Input random quantities (such as the load, geometry, material properties, or imperfections) are expressed as histograms in the calculations. In the probabilistic calculations, all input random variables are combined with each other. The number of possible combinations is equal to the product of classes (intervals) of all input variables. With rather many input random variables, the number of combination is very high. Only a small portion of possible combinations results, typically, in failures. When DDFPM is used, the calculation takes too much time, because combinations are taken into account that does not contribute to the failure. Efforts to reduce the number of calculation operations have resulted into the development of algorithms that provide the numerical solution of the integral that defines formally the failure probability with rather many random variables:

\[ p_f = \int f(X_1, X_2, \ldots, X_n) dX_1, dX_2, \ldots, dX_n, \]

where \( D_f \) represents a failure area where \( g(X) \leq 0 \) for the function of the combined density of probabilities of random quantities. The algorithms are implemented into ProbCalc - features of the software will be presented here. Parts of the calculation can be carried out simultaneously. The random input variables can be expressed by means of histograms with parametric and non-parametric distribution created from sets of random quantities that have been measured or observed.

1 INTRODUCTION

Direct Determined Fully Probabilistic Method can be used now to solve a number of probabilistic computations and is based on general terms and procedures used in probabilistic theories. The random nature of quantities entering the probabilistic calculation is often expressed by the histogram created on the basis of monitoring and, frequently long-lasting measurements. The individual random variables are multiplied, divided, added, or subtracted. Sometimes, more complicated operations are needed. The needed random variable operations are expressed in bounded parametric or non-parametric histograms (empirical distributions). If general principles of the probabilistic theory are taken into account, the operations can be carried out directly and deterministically. It is possible to use any histogram expressing any random variable that enters the calculation (Fig.1). Those histograms are used then to assess the reliability of structures by the probability of failure \( P_f \).

A failure probability for two input random variables \( f_S(x) \) and \( f_R(x) \), characterize and specifies the area where a failure may appear and enables the failure probability to be calculated. That area is hatched separately for both the density \( f_S(x) \) and \( f_R(x) \).

The failure occurs, when the following condition is fulfilled:

\[ Z < 0, \text{ where } Z = R - S \]  \hspace{1cm} (1)

![Figure 1. Structure resistance and load response – probability density curves.](image-url)
this means the structure resistance will be lower than the structure load response. If points of intersections exist for the \( f_R(x) \) density with the \( x \)-axis, where the point of intersection is \( x = r_{\text{min}} \), and points of intersections exist for the \( f_S(x) \) density with the \( x \)-axis, where the point of intersection is \( x = s_{\text{max}} \), then

- the failure will not occur, if \( r > s_{\text{max}} (p_f = 0) \),
- might, but need not necessarily, occur if \( r_{\text{min}} \leq s \) and \( s \leq s_{\text{max}} \), where the failure probability for all possible \( s \) values is \( p_f (0 \leq p_f \leq 1) \),
- occurs always, if \( r_{\text{max}} < s_{\text{min}} \) \( (p_f = 1) \).

Note: Theoretically, the points of intersection may exist in infinitude, this being for instance the case of a parametric normal distribution.

The failure probability can be analytically calculated using the well-know formula (Králík 2006; Teplý & Novák 1999):

\[
p_f = \int_{-\infty}^{\infty} dp_f = \int_{-\infty}^{\infty} f_S(x) \cdot \varphi_R(x) \cdot dx
\]  

where \( \varphi_R \) is a distribution function of a structure resistance. It is very complicated to solve the integral above directly analytically. Various calculation methods are employed for the calculation. The Direct Determined Fully Probabilistic Method ("DDFPM") uses fundamentals of probabilistic calculations to solve the integral numerically.

It is recommended to use histograms instead of probability density curves for the calculation (Fig. 3). The Probability density, \( f(x) \), is described as follows:

\[
f(x) = \lim_{\Delta x \to 0} \frac{\Delta P(x)}{\Delta x} = \lim_{\Delta x \to 0} \frac{p(x)}{\Delta x}
\]  

where \( \Delta x \) is a class/interval of the histogram, \( \Delta P(x) \) is a number of values in the \( \Delta x \) interval, \( P \) is the number of all values in the histogram, and \( p(x) \) is the probability of \( x (0 \leq p(x) \leq 1) \).

To solve the integral (2) numerically, the relation can be modified as follows:

\[
p_f = \int_{-\infty}^{\infty} dp_f = \int_{-\infty}^{\infty} f_S(x) \cdot \varphi_R(x) \cdot dx = \sum_{i=1}^{n} f_{R,i} \cdot \varphi_R \cdot \Delta x
\]  

The load probability density, \( f_S(i) \), is given as follows:

\[
f_S(i) = \int_{-\infty}^{\infty} f_S(x) \cdot dx = \sum_{i=1}^{n} f_{R,i} \cdot \Delta x = \frac{\Delta P_{S,i}}{\Delta x}
\]  

and the distribution function, \( \varphi_R(x) \), is given as follows:

\[
\varphi_R(x) = \int_{-\infty}^{x} f_S(x) \cdot dx = \sum_{i=1}^{n} f_{R,i} \cdot \Delta x = \frac{\Delta P_{S,i}}{\Delta x} = \sum_{i=1}^{n} f_{S,i} \cdot \Delta x
\]

In the formulae (5) and (6) above, \( i \) is an index (serial number) of the histogram class/interval, \( \Delta(x) \) is the size of the class/interval for the histogram, \( \Delta P_{S,i}, \Delta P_{R,i} \) are the number of values in the \( i \)-th class/interval of the \( S, R \) histograms, \( P_S, P_R \) are the number of all values in the \( S, R \) histograms; \( p_{S,i}, p_{R,i} \) is the probability of \( S, R \) values in \( i \).

After substitution into (4):

\[
p_f = \sum_{i=1}^{n} f_{S,i} \cdot \varphi_R \cdot \Delta x = \sum_{i=1}^{n} \left( \frac{P_{S,i}}{\Delta x} \cdot \sum_{i=1}^{n} p_{R,i} \right) \cdot \Delta x
\]

In the formula (7) and in the formulae above, the number of classes/intervals is \( n \). It is necessary to define the number correctly. It is possible to choose the number of intervals that is same for the both histograms. The number is given as follows

\[
m = \frac{r_{\text{max}} - s_{\text{min}}}{\Delta x}
\]

The failure will be numerically calculated as follows: for each \( i \)-class of the both histograms, the probabilities \( p_{R,i} \) and \( p_{S,i} \) will be calculated. Then, \( p_f \) as the failure probability pursuant to (7) will be calculated. The number of probability values for each
histogram will be \( m \). When the calculation is carried out pursuant to (7), the algorithm can be modified in such a way so that the number of operations could be directly proportional to \( m \). It is clear from Figure 2 and 3 that the series of the probability values will be zero. For instance, for all \( R \) histogram classes/intervals where \( x < r_{\text{min}} \): \( p_{R,i} = 0 \). Te situation is similar for the \( S \) histogram where \( s_{\text{max}} < x \): \( p_{S,i} = 0 \).

Many operations are not needed when calculating the failure probability, \( p_f \), using the method above. Only those classes that are common for the both histograms will be involved in the failure. Other classes do not need to be taken into consideration. The number of classes involved in a creation of a failure can be determined as follows (9):

\[
n = \frac{s_{\text{max}} - r_{\text{min}}}{\Delta x}
\]

In that case, only non-zero probability values in individual histogram classes are taken into account for the calculation of the failure probability. Then, the calculation is considerably shorter, because typically \( n \ll m \). The results are identical for the both methods.

When employing the numerical calculation, it is necessary to choose correctly the size of the class/interval: \( \Delta(x) \). It is clear that the lower the value is, the more accurate the result should be. This is however at expense of an increasing number of operations. With a certain quality of input data, the number of histogram classes should be generally such so that another increase would not influence considerably the result. The number of the classes/intervals may significantly influence the data group used for creation of the histogram.

Each histogram used in the calculation has typically other features (another dispersion, other number of data...). Then, it might not be a good and feasible solution to divide the histogram into same classes/intervals. Each histogram can have a different value, \( (\Delta x)_h \), and a different number of classes, \( n_h \).

Let us take \( (\Delta x)_S \) for the \( S \) histogram. Then, the number of classes for the entire histogram is:

\[
m_S = \frac{s_{\text{max}} - r_{\text{min}}}{(\Delta x)_S}
\]

And similarly, let us take \( (\Delta x)_R \) for the \( R \) histogram. Then, the number of classes for the entire histogram is:

\[
m_R = \frac{r_{\text{max}} - r_{\text{min}}}{(\Delta x)_R}
\]

The failure probability can be calculated after the formula (7) is modified to (12):

\[
p_f = \sum_{i=1}^{i_p} (p_{S,i} \cdot \sum_{j=1}^{j_p} p_{R,j})
\]

Only the overlapping intervals/classes of the both histograms are taken into account. In the \( S \) and \( R \) histograms, the number of intervals is as follows:

\[
n_S = \frac{s_{\text{max}} - r_{\text{min}}}{(\Delta x)_S}
\]

\[
n_R = \frac{r_{\text{max}} - r_{\text{min}}}{(\Delta x)_R}
\]

When using (12) for the calculation, \( i \) increases from \( i = 1 \) to \( n_S \). \( j \) needs to be chosen from \( j = 1 \) to \( j \) pursuant to (15), where \( j \) is an integer or rounded up in line with (16).

\[
j \leq \frac{i \cdot (\Delta x)_S}{(\Delta x)_R}
\]

\[
n_R \geq \frac{j \cdot (\Delta x)_S}{(\Delta x)_R}
\]

It is clear that the calculation of the failure probability, \( p_f \), is different if the number of classes is chosen pursuant to (15) or (16). The real value will be in the range of \( j \) calculated pursuant to (15) and (16). If the intervals \( (\Delta x)_S \) and \( (\Delta x)_R \) are small enough, the difference of the calculated value of \( p_f \) should not be significant. It is however optimum, if \( (\Delta x)_S = (\Delta x)_R \).

2 USING DDFPM TO CALCULATE THE FAILURE PROBABILITY FOR TWO RANDOM VARIABLES

Several methods can be used to calculate the probability of failure \( p_f \) using DDFPM. The original and simplest method (Janas & Krejsa 2002) consists in calculating the histogram as follows:

\[
Z = R - S
\]

Then, the failure probability, \( p_f \), is calculated based on fulfillment of the condition (1), i.e. \( Z < 0 \), Figure 4. Then:

\[
p_f = \frac{\sum_{i=1}^{i_p} \Delta p_{Z,i}}{p_Z} = \sum_{i=1}^{i_p} p_{Z,i}
\]

where in (18): \( \Delta p_{Z,i} \) is the number of values in the \( i \) class of the \( Z \) histogram, \( p_Z \) is the number of all values in the \( Z \) histogram, \( n \) is the total number of classes in the \( Z \) histogram, \( i_p \) is the total number of classes in the \( Z \) histogram where \( Z \leq 0 \), and \( p_{Z,i} \) is the failure probability in the \( i \) class. Then:

\[
p = \frac{\sum_{i=1}^{i_p} \Delta p_{Z,i}}{p_Z} = \sum_{i=1}^{i_p} p_{Z,i} = 1
\]
The probability $p_{Z,i}$ in the $i$-class is the sum of products of the $p_{S,i}$ probabilities for $s_i$ in $i$-classes of the $S$ histogram and $p_{R,i}$ probability of $r_i$ in $i$ classes for the $S$ histogram (Fig. 4). The difference between the values $z_i = r_i - s_i$ is located for all pairs, $r_i$ and $s_i$, in the $i$ class of the $Z$ histogram. In that case, it is advisable to choose $\Delta z = \Delta x$.

$$p_{Z,i} = \sum p_{s,i} p_{r,i}$$  \hspace{1cm} (20)

The method above is similar to the Monte Carlo method used for calculation of the failure probability: first, the $Z$ histogram is created and then the failure probability, $p_f$, is determined for the fulfillment of the condition (1). This approach was originally used for DDFPM (Janas & Krejsa 2002). The $Z$ histogram was not however created using a Monte Carlo based simulation method.

DDFPM methods offer considerably more opportunities. Rather less time is needed when the intervals out of the hatched area in Figure 2 are not taken into account – they are unnecessary. If the values in the $R$ histogram or $S$ histogram are out of the area, the failure may never appear. If $R$ and $S$ are in the hatched area, the failure may, but not necessarily, occur for certain combinations of $s_i$ and $r_i$. In that case, the failure occurs if $s_i > r_i$. In DDPFM, the standard method can be used. The histogram is calculated from (17) using only the values from the overlapping intervals, this means $1 \leq i \leq n_S$ for the $S$ histogram and $1 \leq j \leq n_R$ for the $R$ histogram, where the failure probability is determined again upon fulfillment of the condition (1). In the standard method, the number of operation used for the calculation of the $Z$ histogram is directly proportional to the product $M = m_S \cdot m_R$, where $m_S$ and $m_R$ are the total number of classes in the $S$ and $R$ histograms, respectively.

When calculated the shortened $Z^*$ histogram only from intervals that might, but not always, be involved in occurrence of the failure, the number of operations is proportional to the product $N = n_S \cdot n_R$. Typically, $N \ll M$. Therefore, it is reasonable to use that piece of knowledge when calculating the failure. The $Z^*$ is determined using the relation (21), where the values from the $R$ histogram are taken into consideration only for $r$ from the interval being $r_{min} \leq r \leq r_{max}$. Similarly, the values from the $S$ histogram are taken into consideration only for $s$ values from the interval being $s_{min} \leq s \leq s_{max}$. In the relation (20), they identified as $R^*$ and $S^*$:

$$Z^* = R^* - S^*$$  \hspace{1cm} (21)

It is clear that the $Z^*$ histogram contains only some values of the $Z$ histogram (Fig. 5). However, for $Z \leq 0$ and $Z \leq 0$, the values of the both histograms are identical. This means:

$$p_f = \frac{\sum \Delta P_{Z^*,i}}{\sum \Delta P_{Z,i}} = \frac{\sum \Delta P_{Z^*,i}}{P_Z} = \sum p_{Z^*,i}$$  \hspace{1cm} (22)

In the formula (22) above, all $z$ values are from the $Z$ histogram. In case of the shortened $Z^*$ histogram, the failure probability is smaller than 1 (23), Figure 5.

$$p_{Z^*} = \frac{\sum \Delta P_{Z^*,i}}{\sum \Delta P_{Z,i}} = \frac{\sum \Delta P_{Z^*,i}}{P_Z} < 1$$  \hspace{1cm} (23)

This method can be optimised, or better to say, rationalised. In order to calculate the failure probability, $p_f$, for the shortened $Z^*$ histogram, those failures probabilities where $Z^* \geq 0$ will be deducted from the sum of the failure probabilities for all combinations. It is possible to express this as follows:

$$p_f = \sum p_{S,j} \left( \sum p_{R,i} \right) - \sum p_{S,j} \left( \sum p_{R,i} \right) = p_{Z^*} - p_{Z^* > 0}$$  \hspace{1cm} (24)

Figure 4. Calculation of the $Z$ histogram.

Figure 5. Shortened $Z^*$ histogram.
In the formula (24), \( p_{Z^*} \) represents a quantile of a shortened \( Z^* \) histogram and \( p_{Z^*\geq 0} \) is a positive part of the \( Z^* \) histogram. The failure probability is affected only by the negative part of the \( Z^* \) histogram.

The failure probability can be calculated after the formula (24) is modified:

\[
p_f = \sum_{i=1}^{n} p_{s,j} \left( \sum_{j=1}^{\frac{ny}{2}} \sum_{j=1}^{\frac{ny}{2}} p_{R,j} \right)
\]

(25)

The \( j \) index in the formulae (24) and (25) should be an integer as explained above. For \( \Delta \alpha \delta = \Delta \alpha \delta_R = \Delta \alpha \delta \), the formula (25) needs to be modified to (26) that is identical with (7):

\[
p_f = \sum_{i=1}^{n} p_{s,j} \left( \sum_{j=1}^{\frac{ny}{2}} \sum_{j=1}^{\frac{ny}{2}} p_{R,j} \right)
\]

(26)

It is evident that the rational calculation of the \( p_f \) failure probability using DDFPM for two independent variables is identical with the numerical calculation of the known analytical formula (2).

The calculation of the failure probability pursuant to (26) can be characterized using the flow diagram in Figure 7. For two independent quantizes, the number of operations is

\[
p_f = \int f(X_1,x_2,\ldots,x_n)dx_1,dx_2,\ldots,dx_n
\]

approximately a half of operations needed for the calculation of the failure probability from the shortened \( Z^* \) diagram if all possible combinations are taken into account.

The method used for calculation of two independent variables (see Fig. 7) results from the formula (26). For more variables, the procedures might not be so clear and simple. When calculating a value from a part of the \( Z^{**} \) histogram, it is necessary to choose the direction/trend of variables used in the calculation of the failure probability. When all variables are chosen, changes are made gradually in one of them – either for all values or only until \( z > 0 \). If it is clear then that \( z > 0 \) is always true for the chosen direction of changes of the variable, it is not necessary to calculate the failure probability for that variable anymore. It is very important to determine the correct direction/trend of the changes. If another approach would be used to calculate the failure probability for two independent variables without employing the formula (26) and without following the chart in Figure 7, the number of operations might be much higher.

In order to calculate successfully a part of the histogram that is marked as \( Z^{**} \), it is necessary to determine the correct trend/direction of all possible changes in the variables used in the calculation. The term “trend optimizing” has been introduced for the described method of optimizing of DDFPM calculation of failures.

There are, in fact, three methods that can be used to calculate the failure probability, \( p_f \), by means of DDFPM for two histograms: \( R \) and \( S \). The result of the calculation must be identical:

1. Determination of the histogram \( Z = R - S \) and probability quantile of the histogram for \( p_f \) where \( Z < 0 \).
2. Determination of the shortened histogram \( Z^* = R^* - S^* \) and probability quantile of the histogram for \( p_f \) where \( Z^* < 0 \).
3. Determination of the failure probability pursuant to (25) and (26), this means creation of only the negative part of the \( Z \) that is marked as \( Z^{**} \).
When DDFPM is used for the above mentioned calculations of the failure probability, it is necessary to master:

Ad 1) necessary computational operations with histograms (deduction, it this case) and the probabilistic quantile that meets the set condition.

Ad 2) definitions of those parts/zones of the histograms with variables that will never participate in the failure probability (zone 3), that might, but not necessarily, participate in the failure probability (zone 2), similarly as in ad 1) necessary computational operations with histograms (the deduction, in this case), and determination of the probabilistic quantile that meets the set conditions.

Ad 3) definitions of those parts/zones of the histograms with variables that might, but not necessarily, participate in the failure probability and performance only of those probabilistic calculations mentioned in ad 2) where \( Z < 0 \).

The first method is the simplest one, it however needs most operations. (Note: The number is not decisive for two histograms, but seems to be a limiting factor if several input random variables are involved in the calculation, because the number of operation increases enormously).

The second method is slightly more complicated because it is necessary to define only those parts of the histogram that never participate in the failure and those that that might, but not always, be involved in occurrence of the failure. With two histograms, the definition is simple. It is however more complicated in calculations of failure probabilities with more random variables where in some histograms, the zone 1 (that is always involved in the occurrence of the failure) might be present. In individual histograms, it is necessary to define clearly the areas depending on their participations in occurrence of the failure. The method used for defining the zones in the histograms is referred to as a zonal analysis (Janas & Krejsa 2002).

The third method is connected with the zonal analysis. It defines trends of changes of the variables and is referred to a trend analysis. As already mentioned above, the process is rather simple with two variables, but considerably more complicated with more variables. If a suitable numerical approach is introduced, the method is, however, feasible.

3 USING DDFPM TO CALCULATE THE FAILURE PROBABILITY FOR SEVERAL RANDOM VARIABLES

With more random variables, the probability failure is formally defined in the formula (27) (Teplý & Novák 1999):

\[
p_f = \int_{D_f} f(X_1, X_2, \ldots, X_n) \, dX_1 \, dX_2 \ldots dX_n
\]  

where \( D_f \) represents a failure area where \( g(X) \leq 0, f(X_1, X_2, \ldots, X_n) \) for the function of the combined density of probabilities of random quantities.

As mentioned in (Teplý & Novák 1999), it is generally impossible to calculate the integral of the failure probability (27) in a closed form. A number of efficient stochastic methods have been and is being developed for that purpose.

DDFPM can be used to calculate the integral (27) numerically. The possibilities are same as those for the calculation of the two histograms. In the first phase of development of the method, the action ad1) only was used. This means, the histograms \( X_1, X_2, \ldots, X_n \) and the function dependence \( F \) were known and the \( Z \) histogram was calculated. For \( Z \), the following applies:

\[
Z = F(X_1, X_2, \ldots, X_n)
\]

Only then, the probability failure was calculated from the \( Z \) histogram

\[
p_f = P(Z \leq 0)
\]

With many random variables, the calculation takes much time, because in the \( X_i \) histogram, there are \( n_i \) intervals/classes, the number of operations in the calculation of the \( Z \) histogram is proportional to the product.

\[
N = n_1 \cdot n_2 \cdot \ldots \cdot n_n
\]

Then, methods were looked for in order to rationalize the calculation and maintain still the correctness (Janas & Krejsa & Krejsa 2006a,b). First, attention was paid to reduction of a number of intervals/classes of the input quantities for the histograms, while maintaining the entire range of each input random variable, and to the grouping of input quantities and to introduction of such groups of quantities jointly into the calculation where a joint histogram could be prepared (such pre-treatment needs to be correct and needs to ensure that the joint histogram used for calculation will provide same result as each histograms being introduced separately). The mentioned methods were also combined. In order to minimize the complicated solutions it was also decided not to introduce the statistically dependant or functionally dependant input random variables into the calculation separately, but to use a joint histogram or histograms (cross-section characteristics), if possible. Ways for using that method are however limited.

The methods mentioned in ad2) have been employed too: the number of classes/intervals of the input variables for each histogram involved in the calculation was decreased, keeping at the same time the total number of classes for each histogram. In that case, only the classes involved in the failure, enter the calculation.

In order to use that method, it is essential (this being, in particular, the case of several random variables) to divide each histogram into areas (zones -
“the zonal optimizing) depending on their share in the failure. For some histograms, software has been developed that is able to make calculations. The zonal analysis makes it possible to define a shortened $Z^*$ histogram for several variables. If the trend analysis is employed, parts of the $Z^**$ histogram only are used (see Fig. 6) – the quantille represent the numerical solution of the integral (27). The character of the random quantities entering the calculation is different for purposes of the zonal analysis. In each histogram, one up to three types of zones can appear. If the variable is in

- zone 1: the failure occurs always, whatever are the values of the other variables that affect the occurrence and magnitude of the failure probability; the failure will not occur, if $r > s_{\text{max}} (p_f = 0)$,
- zone 2: the failure may occur depending on values of the other variables that affect the occurrence and magnitude of the failure probability,
- zone 3: the failure does not occur, whatever are the values of the other variables.

The nature of the variables can be either of following two types:

a) The variable is involved in the failure unidirectionally (monotonously), this means if it changes from the left or from the right and other input quantities remain unchanged, the failure probability increases or decreases monotonously (Fig. 8). In that case, the zones 1, 2 or 3 can be present in the histogram but each of them occurs there not more than once.

b) The variable is involved in the failure non-monotonously. If it changes in one direction, the failure probability decreases and then increases (Fig. 9). In that case, the zones 1, 2 or 3 can be present in the histogram but at least one of them occurs there at least twice. So far, not more than five zones have been taken into consideration for the histogram.

The magnitude and number of zones is given by the task and by all input quantities (both variable and discrete quantities) that enter the calculation of the failure probability.

In the trend analysis, the failure calculation in each histogram is made from the zone 1 to the zone 3. This means, the trend of changes of each variable respects the direction of numbering of the zones. The failure probability for several variables can be calculated as follows:

$$p_f = p_{f1} + p_{f2}$$

(31)

In (31), $p_{f1}$ represents the quantille of the zone 1 (or the sum of quantilles in the zone 1) in the histogram where the zone (or zones) is located. It is clear that not so many computational operations are needed in order to determine $p_{f1}$. The failure probability $p_{f2}$ is a part of the failure probability for a failure appearing in the zones 2 in all histograms of variables involved in the failure. This calculation is typically more extensive. Similarly as with two variables, a shortened histogram $Z^*$ can be introduced and a quantille can be calculated with the $p_{f2}$ probability for that part of the histogram where $Z^* < 0$. It is however recommended to use the trend analysis and create directly that part of the histogram $Z^*$ where the quantille is $p_{f2}$.

If the failure probability is calculated using (27) for several variables, the numerical method used for the calculation is identical with that used for two variables. In the first stage, zones are created in all histograms that participate through different weights
in the failure. The trend analysis makes it possible to restrict the calculation to those combinations only that are really involved in the occurrence of the failure.

4 CONCLUSIONS

The mentioned calculation methods based on DDFPM (the direct determined fully probabilistic method) have been implemented into ProbCalc (Janas & Krejsa & Krejsa 2006a, b; Janas 2008; Janas & Krejsa & Krejsa 2008a, b, c). A lite version of ProbCalc can be downloaded at http://www.fast.vsb.cz/pdvp.

The described method enables, for instance, properties of load-carrying structures to be analyzed and investigated into for certain loads. It is desirable both for theoretical science and practice to develop the probabilistic methods for the assessment of structure reliability and other probability tasks, because a number of input variables are random and it is not always a good solution to regard them as deterministic quantities.

ACKNOWLEDGEMENTS

This paper has been drafted within preparation of the project 105/07/1265 with the financial support of state funds through the Czech Republic Science Agency and with the financial contribution of the Czech Republic Ministry of Education and Sport, project No. 1M0579 within activities carried out by the Centre of Integrated Designing of Advanced Structures.

REFERENCES


