PREDICTION OF NO – FAILURE SYSTEM OPERATION

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Abstract: The paper is focused on analytical approach to prediction of ability and resources of simulation. It deals with simulation experiments with static approach except using time and selection decisive event.

Keywords: reliability, life cycle, reliability block diagram, faultlessness, probability, static simulation, stochastic, element, failure - free operation

1. INTRODUCTION

Systematic attention in all stages of the product's life cycle is supposed in order to assure the technique reliability security.

The reliability bases are forming in the first periods of the technique creation. The rational determination of qualitative and quantitative demands on the reliability so called *specific demand on the reliability* is the decisive task.

It includes the set of the activities realised in the stage of the conception and demands determination and the stage of the design and development, which aim is the specification of the demands of product reliability as the unit and also the reliability of single parts.

Predictive analyses of the reliability of faultlessness indicators observing and prediction, preparedness, maintainability and safety of the system are applied.

The reliability analyses are realised also in the stage of the usage, operation and the maintenance for the evaluation and determination or specifying the indicators of the reliability and for the assessment whether the specified demands were fulfilled.

The analysis of the system reliability is the process, which is usually realised on the system model. The set of information about the properties of the system model is the final product of this process. The model can be modified during the analysis.

Analysis has to have clearly determined rules and processes so as the process of the analysis to be repeatable and in order to always lead to the same results.

For the concrete case we have to choose a suitable analytical method, which enables to (F):

- ➢ model and evaluate the reliability problems in the required range,
- ➢ make direct, systematic qualitative and quantitative analysis,
- ➢ predict numeral values of the reliability indicators.

In the present practise the most often used methods of reliability analysis are:

- o Reliability Block Diagrams,
- o Fault Tree Analysis,
- o Markov analysis,
- o Failure mode and effects analysis, FMEA,
- o Simulation methods.

The simulation modelling is suitably applied within the frame of the separation (allocation) of the demands on single parts of the product (or parts of the process of maintenance providing). The aim is to determine the demands on the critical reliability or of each product part in such a way so that the product as the complex fulfils the determined demands.

The allocation of the demands on the reliability is closely associated with the process of the design and evaluation of the product and its steps can be repeated in connection with the changes of the design or on the basis of optimising studies, feedback from the operation.

The indicators of the reliability on the lower levels of the product structure can differ from those, which were defined in the product specification. For example, the repaired product can be built up from the parts, which had been never repaired.

2. RELIABILITY BLOCK DIAGRAMME

Prior estimations of the reliability indicators are obtained above all by calculation in the stage of projection. They can be received also by following of the critical elements reliability in the period of evaluation and testing and specified as the result of the feed-back information form the statistic plotting of operation failures and the degradation of elements plotted during the repair actions.

At the specification of demands on the reliability generally the numerical values of partial reliability properties for the technique as the unit are defined.

The reliability of the technique as a unit is the reflection of the reliability level of single groups, subgroups, functional pairs and components, from which the technique consist of. That's why also in the case of reliability prediction the decomposition of reliability demands is necessary.

From the whole level of the reliability the demands of the lower levels of constructional elements are defined. The effort is to get to the level of the elements in the serial or parallel structure.

Due to it, the transformation of the complicate structure to the simple one is sometimes made in order to be able to express the mathematical level of the reliability.

On the contrary, at the well-known values of the reliability of the decisive elements, it is possible to determine the final level of the system reliability.

The probability reliability analysis - also called the reliability block diagram (RBD - Reliability Block Diagram), whose bases are the Bool algebra of events, logical, oriented and undirected graphs, calculus of probabilities, is the basic tool of reliability observation.

The probability reliability analysis is the method of taking into account the probabilities of events occurring in complicate systems, which represent various arranged structures formed with elements.

The structure of the system can be expressed by the equation:

$$M_k = \{ E_1, E_2, \ldots .. E_k \} \qquad (1)$$

Single symbols indicate:

M_k – mechanical system with „k“ elements,

E_i – i element of the system.

The structure of the system elements can be serial, parallel or combined.

2.1 SYSTEMS WITH SERIAL CONNECTION OF ELEMENTS

The elements of the set are arranged one after another and they are each other independent. The failure of unique element causes the loss of operational capability of the whole system. The system is functional if all elements are in the state of operational capability.

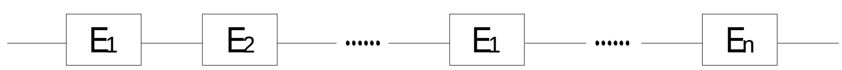


Fig. 2.1 Scheme of the system with the serial connection of the elements

If we mark the faultlessness of i-element E_i as R_i, then the faultlessness of the system is the product of the faultlessnesses of all elements:

$$\boldsymbol{R_S} = \boldsymbol{R}_1 \times \boldsymbol{R}_2 \times \boldsymbol{R}_3 \cdots \boldsymbol{R}_n = \prod_{i=1}^{n} \boldsymbol{R_i} \qquad (2)$$

The faultlessness of the serial system is lower than that of the most faultless element of the system. The reliability of the failure-free operation of the serial system with the number of elements decreases and the probability of the failure creation increases.

2.2 SYSTEMS WITH PARALLEL CONNECTION OF THE ELEMENTS

The increase of the reliability of the elements and the systems is ensured with the use of parallel (advance, reserve, redundant) elements. The failure occurs only in the case all elements of the system, basic and also advance, are damaged. The system is serviceable if at least one of the equal, independent elements is functional.

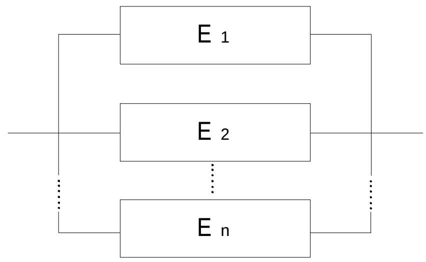


Fig. 2.2 Scheme of the system with parallel connection of the elements

The faultlessness of the parallel system can be calculated from the expression:

$$\boldsymbol{Rp} = 1 - \boldsymbol{F_S} = 1 - (1 - \boldsymbol{R}_1)(1 - \boldsymbol{R}_2)...(1 - \boldsymbol{R_n}) = 1 - \prod_{\boldsymbol{i}=1}^{\boldsymbol{n}} (1 - \boldsymbol{R_i}) \qquad (3)$$

If all elements have the same faultlessness R, then:

$$\boldsymbol{R_S} = 1 - (1 - \boldsymbol{R})^{\boldsymbol{n}} \qquad (4)$$

Also some specific cases of backup exist, for example if K elements are enough from N elements with same faultlessness for the security of the operational capability of the system.

Such a system is marked as k from n and the faultlessness of such a system can be calculated according to:

$$\boldsymbol{R_S}(\boldsymbol{k}, \boldsymbol{n}, \boldsymbol{R}) = \sum_{\boldsymbol{r}=\boldsymbol{k}}^{\boldsymbol{n}} \binom{\boldsymbol{n}}{\boldsymbol{r}} \boldsymbol{R}^{\boldsymbol{r}} (1 - \boldsymbol{R})^{\boldsymbol{n}-\boldsymbol{r}} \qquad (5)$$

If the elements have various faultlessness, we will use the equation:

$$\boldsymbol{R_S} = \boldsymbol{R}_1 \boldsymbol{R}_2 + \boldsymbol{R}_2 \boldsymbol{R}_3 + \boldsymbol{R}_1 \boldsymbol{R}_3 - 2\boldsymbol{R}_1 \boldsymbol{R}_2 \boldsymbol{R}_3 \qquad (6)$$

2.3 SYSTEMS WITH SERIAL-PARALLEL CONNECTION OF ELEMENTS

The majority of real systems consists of serial and parallel connected subsystems, which are called combined. The final faultlessness of the whole system is calculated from the previous mentioned equations by the suitable dividing of the system to serial or parallel subsystems.

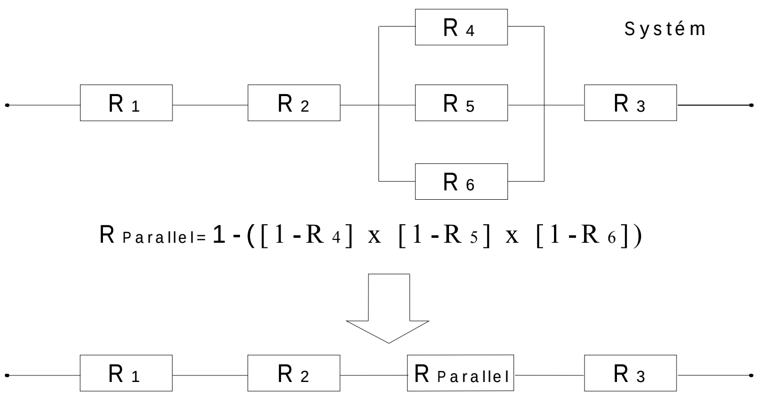


Fig. 2.3 Scheme of combined configuration of elements calculation

3. SIMULATION MODELLING OF FAULTLESSNESS

We can be express the static approach of the creation of simulation model of the probability reliability analysis by the following notional model:

- Serial – parallel sequenced system is characterized by the number of serial subsystems and number of the subsystems sequenced parallel.
- Each subsystem is defined by the number of elements and each element by the value of the probability of the failure-free operation.
- In the state vector of the system $X_{Mk(t)} = (X_{1(t)}, X_{2(t)}, \ldots, X_{k(t)})$ and its elements $X_{i(t)}$ the time of system activity t is constant, deterministically defined value. Simulation experiment is defined by the number of realisations representing constant time intervals between the failures.
- The elements of the system are characterized by two basic states:
  - failure-free – serviceable state P_A,
  - failure state P_B.

  The basic states create the whole group of events and it is given $P_A + P_B = 1$

  The states of the elements can be expressed by logical nil or by one depending whether the case occurred or did not occur, for example:

  $P_A = 1$ - the element is in failure state,
  $P_B = 0$ - the element is in failure-free state.

  The generally causal change of nil and one in the system is the state quantity $X_{Ei(t)}$ expressed by the expression:

$$\{X_1(t) : t \geq 0\} \rightarrow E_1,$$
$$\{X_2(t) : t \geq 0\} \rightarrow E_2,$$
$$\vdots$$
$$\{X_k(t) : t \geq 0\} \rightarrow E_k.$$

- The probabilities of elements failure-free operation are constant in time. They can be taken for and modelled as causal values of equal separation of the probability of failure- free operation of elements E_i expressed by the mean value.
- The generation of the event "failure" can be generated from the equal division in the range 0 - 1.

  $P_A + P_B = 1$ - the whole group of events
  $P_A = 0{,}97$ - probability of failure-free operation
  $P_B = 0{,}03$ - probability of failure generation

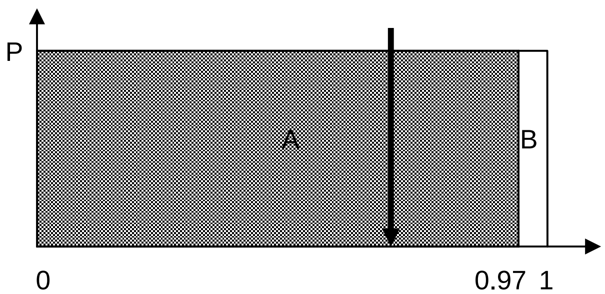
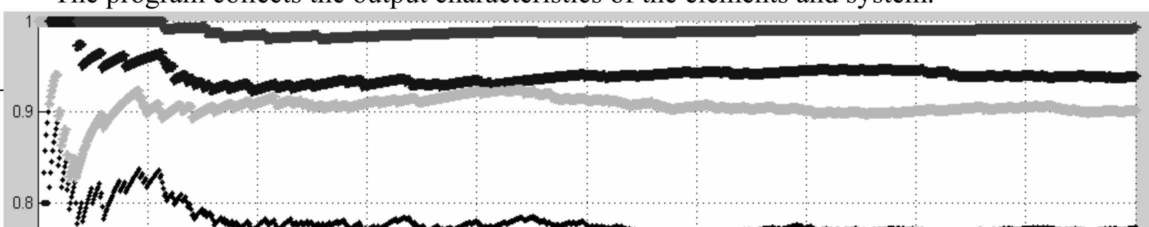


Fig. 3.1 The figuration of events occurring generation

- If the generated value exceeds the determined value of the failure-free operation probability, then the failure of the element occurs and vice - versa.
- At the parallel subsystem, one function element is enough so as the subsystem to be function, at the serial subsystem, all elements have to be function.
- The system is functional if all subsystems are functional.
- The number of events, which represents the failure - free operation of the element or of the system is marked n.
- If we simulate the generation of the element or system failure N-times then the final probability of the failure-free operation is defined by the expression R=N/n.
- The program collects the output characteristics of the elements and system.



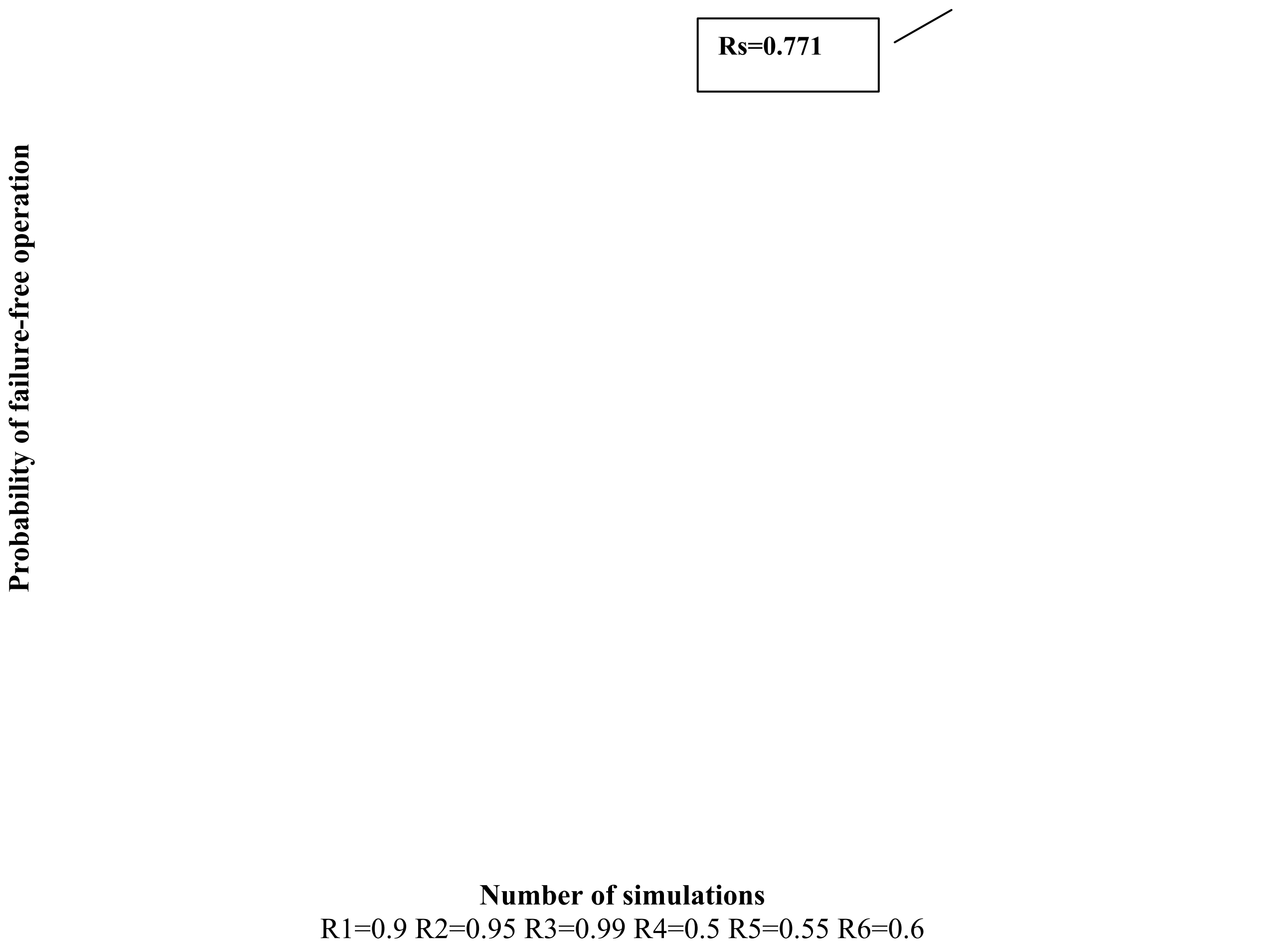


Fig. 3.2 Input data, function development and results of simulation experiments from static simulation model with structure according to fig. 2.3

The static approach does not enable to determine the final level of the reliability at various dividing rules of elements probability and it does not give any real idea about the failure creation in time.

Analytical ways of calculations of probability reliability analysis have restricted usage for the same statistic divisions of the probability of elements failure-free operation, which can be mathematically expressed. It is most often the case of exponential or normal probability separation.

We are not able to solve analytically the more complicated structures, other various rules of probability dividing, due to the lack and the complexity of the mathematical apparatus.

The stochastic approach of the probability of the reliability analysis modelling can remove the above-mentioned drawbacks.

If we can express the probability of the elements failure-free operation by the parameters of the division of causal variable intervals between the failures, the total probability of the failure-free operation can be expressed by the summary statistic parameters determined from the values of the total amount of generated data.

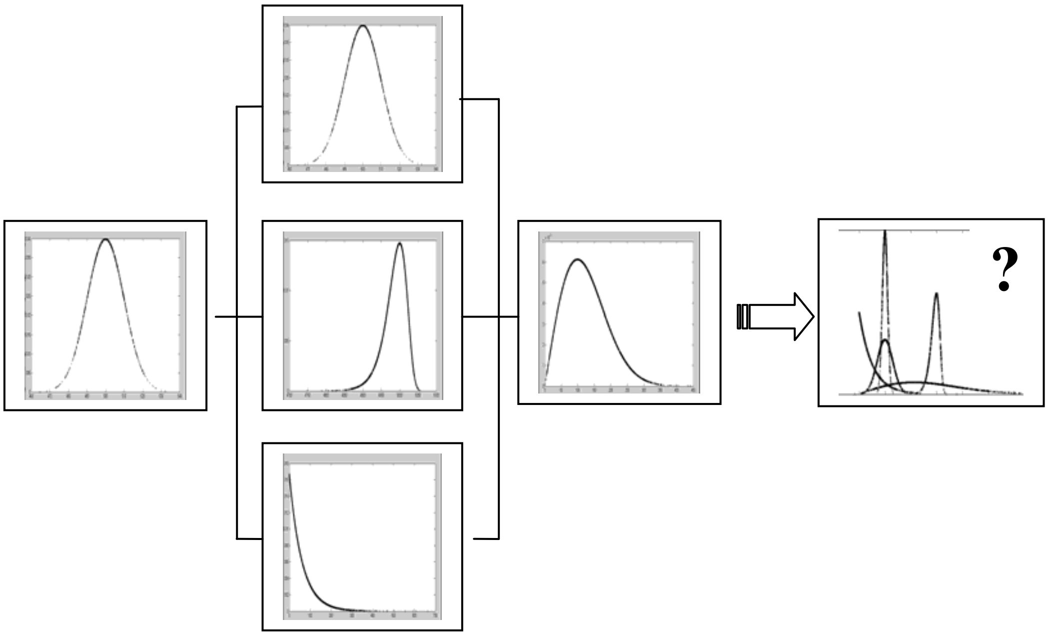


Fig. 3.3 The figure of the stochastic philosophy of modelling

3.1 STOCHASTIC SIMULATION MODEL OF FAULTLESSNESS WITH THE CHOICE OF DECISIVE EVENT MÔŽEME VYJADRIŤ NASLEDOVNÝM POJMOVÝM MODELOM

- The system is divided into subsystems with serial and parallel structures. The values of the periods between single elements failures are generated.
- The highest values of failure generation times are chosen from the times of failure creation of the subsystem from the parallel elements and they are used for the integration into the serial structure of the system.
- The lowest value of the failure generation time is chosen from the times of failure creation of the serial connected subsystems.
- The process of generating of events choice is repeated until the end of the realization number.
- Statistic data are collected about operation time, total number of elements failure and other necessary data

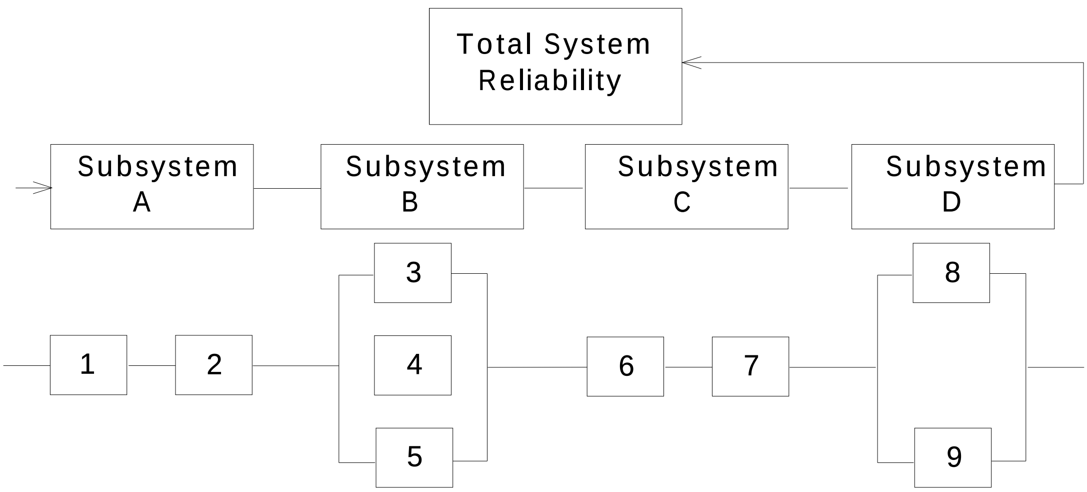


Fig. 3.4 System decay with combined structure

System is made of 6 elements with series-parallel structure according to *fig.2.3*.
Elements are decribed with time to failure distributions according to computer language MATLAB:

R1=exprnd(260); R2=normrnd(80,18);
R3=wblrnd(90,2); R4=exprnd(50);
R5=normrnd(50,10); R6=wblrnd(20,1.5);

Simulation experiment was made for 10000 simulations. During simulation cycle, maximum event was chosen from parallel structure. This event was used in series structure and minimal event was chosen for system failure.

Computed times to failure of elements 2,4,6 are depicted with probability density function and cumulative density function on *fig.3.5* and *fig.3.6*.

Probability density function and cumulative distribution function of the decisive event – mean time to failure is depicted on *fig. 3.5* and *fig. 3.6*.

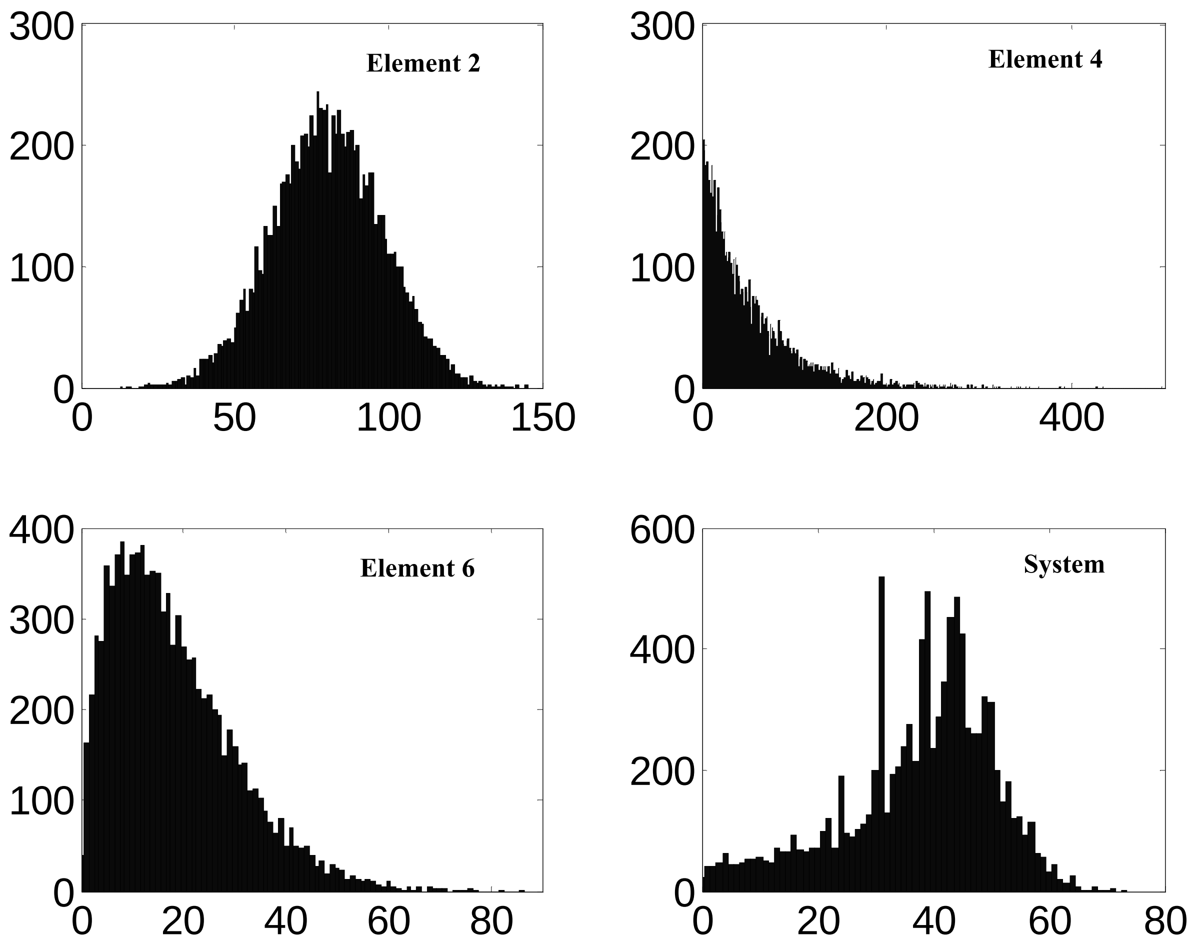


Fig. 3.5 Histogram of generated values of times between failures of elements 2,4,6 and value of system's time between failures

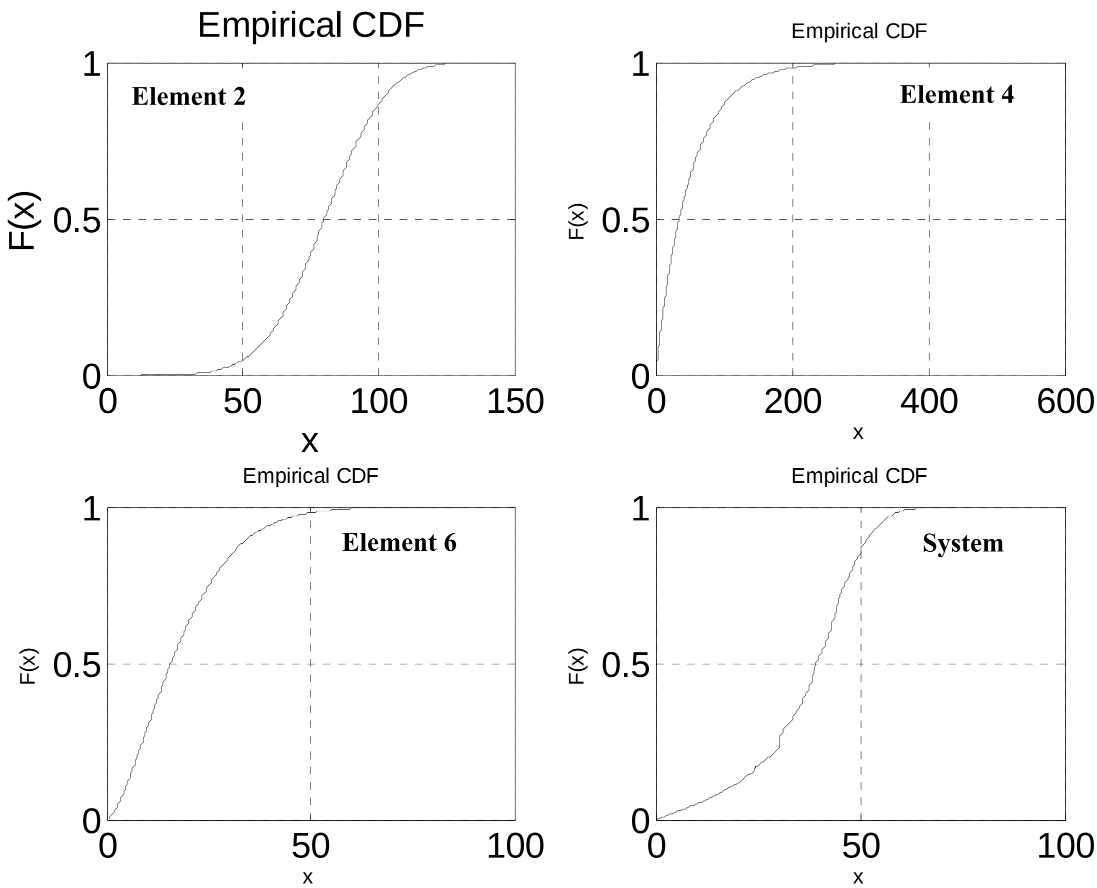


Fig. 3.6 Distribution functions of time between failures of elements 2,4,6 and mean time between failures of the system

4. CONCLUSION

Static a stochastic quantitative analysis ensures the calculation (estimation) of quantitative numerical values of chosen reliability indicators. The numerical value of the indicator is obtained by the experimentation with the model with the help of the computer technique, at the consideration of elementary effects, which structurally join the model into behaviour and analytical stages of the system.

The model and all inputs have stochastic character, also the result of the analysis is stochastic, loaded by a single rate of uncertainty, which is possible to decrease but not totally remove.

Calculation using analytical methods of probability intersection of several phenomena with different kinds of probability distributions is not possible.

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