PREDICTION OF THE SYSTEM AVAILABILITY USING SIMULATION MODELING

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Abstrakt: The article deals with the possibility of system availability prediction using the simulation modelling. The system availability determined with system faultlessness and system maintainability is expressed by various parameters of mean time between the failures and the mean time of single elements repair. The system simulations are carried out with more parameters MTBF and MTTR, the results of the simulation course gives a real idea about the system behaviour in time and about changes of the values of asymptotic system availability factor.

Keywords: sampling size, fault time, interval between failure, normal distribution, financial costs, simulation experiment, optimisation process, probability density, optimal maintenance interval

1. INTRODUCTION

At the design of mechanical system consisting of several subsystems or elements we must generally predict the final reliability level characterised by the system availability. The estimation, which arises from the well-known, eventually estimated availability level of single subsystems is one of the possible ways.

The aim is to determine the system availability from the understanding of the factors of faultlessness partial properties, maintainability and arranging of single components maintenance.
The so-called states analysis, in which the system can occur, is the base for the design of the system availability model. The system can be in many and various states, whereas each of them is determined by a specific combination of single elements states.

Similarly, each system elements can occur in various states, which are randomly changing. The process, when the states of the studied objects are randomly changing in the time, is called Markov random process.

The most often the states in mechanical systems are expressed by a two - state model. The system, depending on the state of single elements, can occur either in function or in non-functional state. If the transition between these states is randomly changing and they can occur in arbitrary time, then this random process is usually called **common process of recovery** (1).

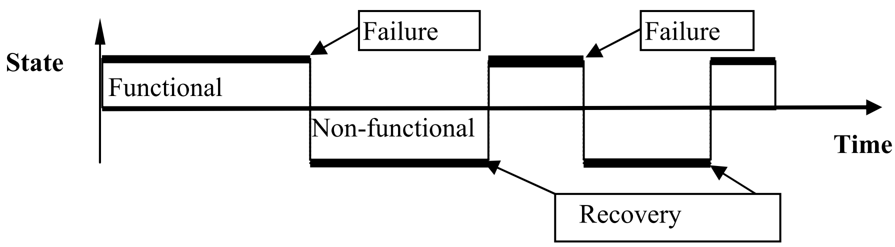

Fig.1.1 Common process of recovery

2. MECHANICAL SYSTEMS AVAILABILITY

The reliability of the objects being repairing is characterised above all by the availability indicators, which completely describe their faultlessness and maintainability.

The availability indicator is a function or numerical value used for the description of the probability distribution of a concrete studied (random) quantity, which characterises the object availability. The state of the object, which is randomly changing in time, is generally such a quantity.

The probability, in which state the object (element, system) occurs in the certain time, is described for the operation state by the **function of immediate availability *A(t)*** or for the non-functional (disable to operate) state by the function of immediate unavailability *U(t)*.
The functions *A(t)* and *U(t)* are inter-complementary, the sum of their values is in the certain time equal with 1 (the probability that the object will occur in the one state or in another one is equal with the certainty).

The function of the immediate availability *A(t)* expresses the probability that the object is in the state when it is able to perform the requested function in the given conditions and in given time providing that the requested outer conditions are ensured.

This indicator is not very often used in the practice because not the immediate level of object availability but the level of its availability detached to a certain time interval is usually the subject of the interest.

For the availability description the following indicator are used:

a) **Mean availability coefficient**, which expresses the mean value of the immediate availability in the certain time interval (t_1, t_2):

$$\overline{A}(t_1, t_2) = \frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} A(t) \cdot \mathrm{d}t \,. \qquad (1)$$

b) **Asymptotic (stabilized) availability coefficient** represents the limit of the immediate function of the availability for t → ∞.

$$A = \lim_{t \to \infty} A(t) \,. \qquad (2)$$

Asymptotic availability coefficient *A* can be expressed by equation:

$$A = \frac{MTBF}{MTTR + MTBF} \,, \qquad (3)$$

where: *MTBF* – mean time between failures, *MTTR* – mean time to repair.

It expresses the probability that the object, which is in the stabilized operation regime "operation – recovery", will be in the arbitrary time in state of operation capability (apart from the planned time during which the usage of the object is not planned, for example the planned prevention repair).

c) **operation availability coefficient** expresses the ratio of the total operation time in the usable state and the total time including the downtimes (4).

$$A_o = \frac{MUT}{MUT + MDT} \,, \qquad (4)$$

where: *MUT*- mean uptime, *MDT*- mean downtime.

d) **achieved availability coefficient** is expressed with the help of the mean time between maintenance MTBM and the mean time of maintenance downtime $\overline{M}$:

$$A_A = \frac{MTBM}{MTBM + \overline{\overline{M}}} \,. \qquad (5)$$

In the technical practice the asymptotic availability coefficient is used for the stabilized recovery process. It is very often used on condition that:

- logistic, administration and technical delays are neglected,
- the distributions of the random variable for the faultlessness with parameter λ and the maintainability with parameter μ are exponential.

If the distribution of periods between the faults and periods to the recovery has exponential character, we can express the asymptotic availability coefficient of the object as (3):

$$A = \frac{\mu}{\lambda + \mu} \,, \qquad (6)$$

where: λ - intensity of faults, μ - intensity of repair.

The asymptotic availability coefficient, which characterises a certain stabilized availability level, which the object is successively approaching with the increased operation time, is the most suitable from the mentioned indicators for the complete description of the object availability. All other statistical models created on the base of stochastic principles always lead to non-constant availability function A_i, i.e. to the availability function dependent on the operation time *t*.

3. SIMULATION APPROACH TO AVAILABILITY MODELLING

The concept of deterministic availability models arises from the idea that time functions to the fault and time necessary for fault removal at the element failure Ei are same distributions of parameters probabilities like those, which appear in them.

They most often lead to exponential, eventually Weibull probabilities distribution. The time curves of fault rate and reparations, eventually other stochastic influences during the reliability of complicated systems ensuring in real operation (3), are not taken into account in these models.

In the real case the operation reliability, respectively its partial properties are connected with processes, which are necessary for the failure removal (control process, supplying system, repairing process, etc.). That's why also the model may have several states and distributions of random variables.

These facts can be expressed by simulation modelling.

We utilise the fact that the probabilities of the components time of fault occurrence and the time of fault removal are quantities with significantly stochastic character, which can appear in wide range of values.

The proposed solution can be expressed like this:

a) System $M_{k\Psi}$ is decomposed into subsystems or elements

$$M_{k1\Psi} = \{ m_1, \Psi_1, m_2, \Psi_2, ... m_k, \Psi_k, ... m_s, \Psi_s \}_\Psi$$

The partial systems are analysed separately and the results are utilised for the final valuation of the system.

b) Statistic rules of model subsystems (elements) can be described by:
   - probability distribution of fault occurrence intervals,
   - probability distribution of active repair time,
   - eventually probability distribution of other downtimes.

c) We determine, which states are important for the system analysis and which we want to express by the simulation. Some states can be united.

d) We determine the outputs, which we can statistically elaborate and visualize by means of the graph.

e) We construct the computation simulation model and realise the experiments, which are then evaluated.

Tab. 3.1 Maintenance periods, which can represent model states with its own probability distribution of random variable

<table>
<tr><td colspan="7">Maintenance time</td></tr>
<tr><td colspan="2">Prevention maintenance time</td><td colspan="5">Maintenance time after failure</td></tr>
<tr><td rowspan="2">Logistic downtime delay</td><td rowspan="2">Active Prevention maintenance time</td><td colspan="4">Active maintenance time after failure</td><td rowspan="2">Logistic downtime delay</td></tr>
<tr><td>Technical downtime delay</td><td>Fault localisation time</td><td>Active repair time</td><td>Checkin g time</td></tr>
<tr><td></td><td colspan="5">Active maintenance time</td><td></td></tr>
</table>

4. MODELLING OF SYSTEM AVAILABILITY BY DISCRETE SIMULATION WITH VARIABLE TIME STEP

The formation of discrete simulation model with variable time step and the realisation of simulation experiment predict the execution of the following activities.

1. Input of the starting conditions and specification of variables values in the initial simulation time TIME = 0, input of the simulation period TEND. Elements state $L_{(i)} = 0$, system state $S = 0$.
2. Generating of intervals of failure occurrence of single elements of the system from the probabilities distributions of periods between the failures $x_{(i)}$ (i = 1,2,......N).
3. Sequencing of faults occurrence and choosing of the first event by searching the minimum from values $x_{(i)}$ for i = 1, 2,..., N.
4. Element state $L_{(i)}$ change to $L_{(j)} = 1$ the element is defective and the repair is realised. System state S change to S = 1 system is non-functional.
5. Shift the time axis by the interval of the first fault CAS=CAS+ $x_{(i)}$.
6. Generate element maintenance realisation period from the probability distribution of maintenance time $y_{(i)}$ (i = 1,2,......, K).
7. Shift the time axis by the maintenance time CAS=CAS+ $y_{(i)}$. Element state $L_{(i)}$ change to $L_{(j)} = 0$ the element is serviceable. System state S change to S = 0 system is non-functional.
8. Generate new interval $x_{(i)}$ of element *I* failure, which was returned to the serviceable state.
9. Calculations of the elements and system availability.
10. Condition testing of the simulation process finishing, if the value of the simulated time reaches the predefined value TEND, otherwise repeat points 3-10
11. Collect and elaborate by statistical methods the data of input and output quantities.
12. The results outputs on the display and printer. End of the simulation experiment.

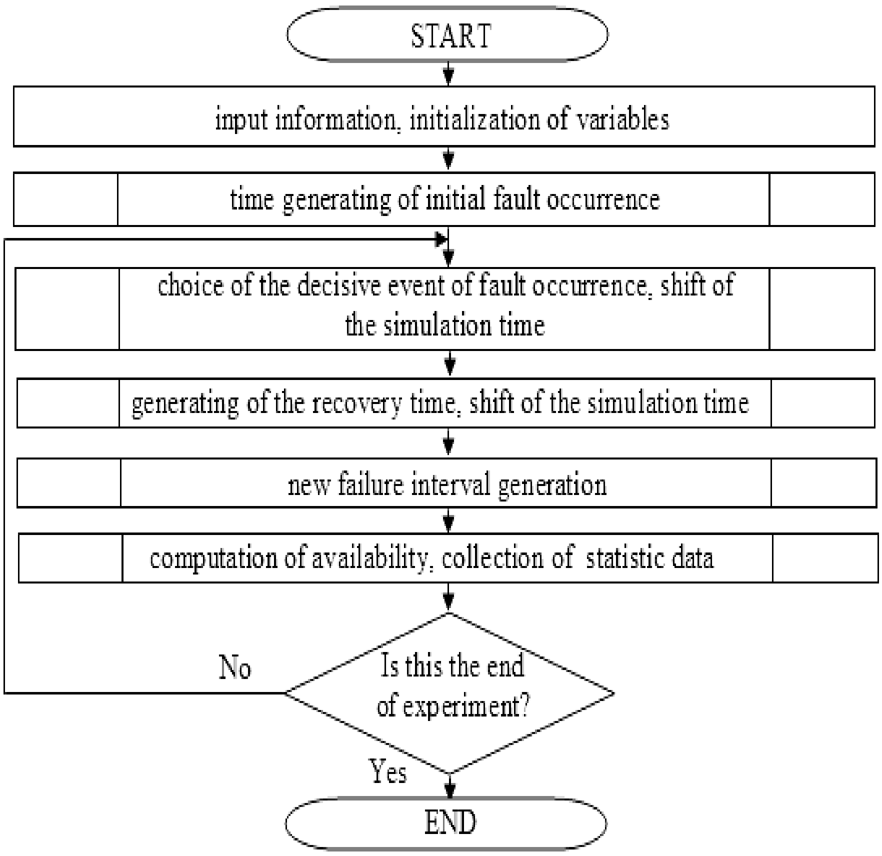

Fig.4.1 Flow diagram

Simulation model is constructed for easy observation of the dynamic maintenance states of the elements and system from the simulation results

The intervals of maintenance are limited by red rectangles *fig.4.2,f ig.4.3*.

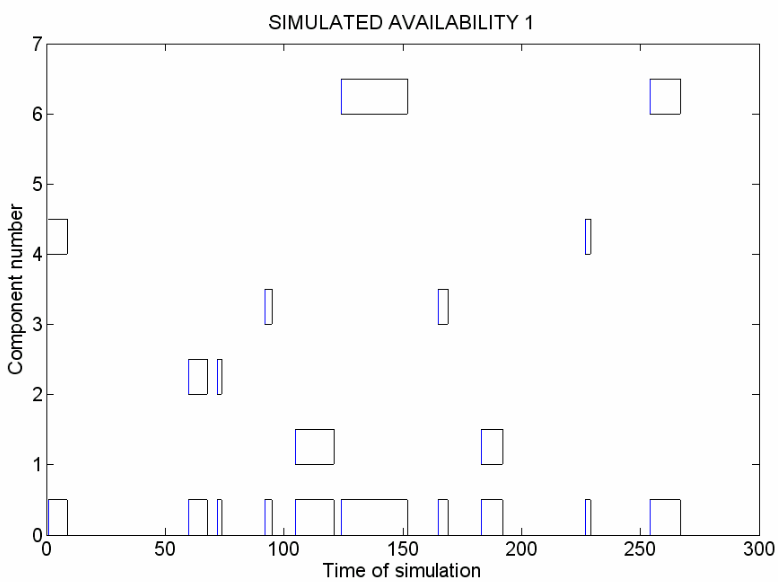

Fig. 4.2 The process of experiment with the simulation duration of 267 hours with indication of elements and system maintenance time

cud	T	S	E1	E2	E3	E4	E5	E6
1	1	0	1	1	1	0	1	1
2	9	1	1	1	1	1	1	1
3	60	0	1	0	1	1	1	1
4	68	1	1	1	1	1	1	1
5	72	0	1	0	1	1	1	1
6	74	1	1	1	1	1	1	1
7	92	0	1	1	0	1	1	1
8	95	1	1	1	1	1	1	1
9	105	0	0	1	1	1	1	1
10	121	1	1	1	1	1	1	1
11	124	0	1	1	1	1	1	0
12	152	1	1	1	1	1	1	1
13	165	0	1	1	0	1	1	1
14	169	1	1	1	1	1	1	1
15	183	0	0	1	1	1	1	1
16	192	1	1	1	1	1	1	1
17	227	0	1	1	1	0	1	1
18	229	1	1	1	1	1	1	1
19	254	0	1	1	1	1	1	0
20	267	1	1	1	1	1	1	1

Fig. 4.3 Process of the experiment with output statement of events, time and states of elements and system

In the case of simulations with longer simulation time the intervals with low predicative value are indicated *fig. 4.4* and that's why we further evaluate the graphs shown below.

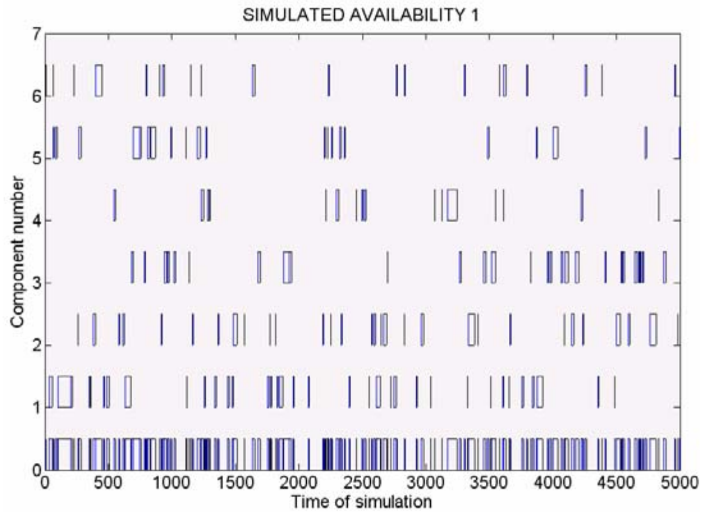

Fig. 4.4 The process of experiment with simulation duration of 5000 hours

It is possible to follow graphically the value of the asymptotic availability coefficient in dependence on time *fig.4.5*.

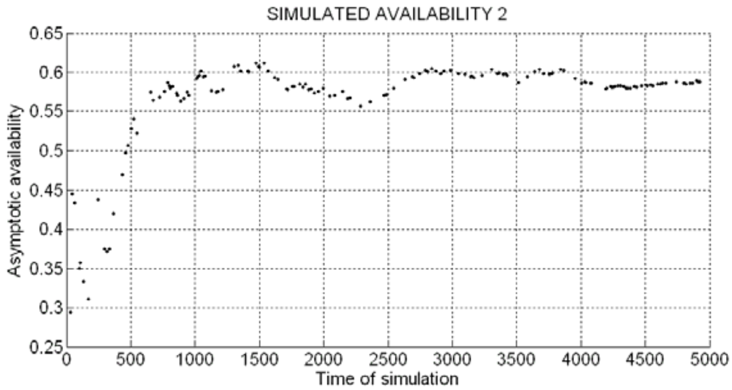

Fig.4.5 Rise and stabilisation of asymptotic availability coefficient

The rise of the asymptotic availability coefficient value is very interesting. In comparison to the published statements (3) the rise time to the stabilized state is quite long. After using same input values, experiments give results with same dissipation, so is necessary to realize more number of the simulations.

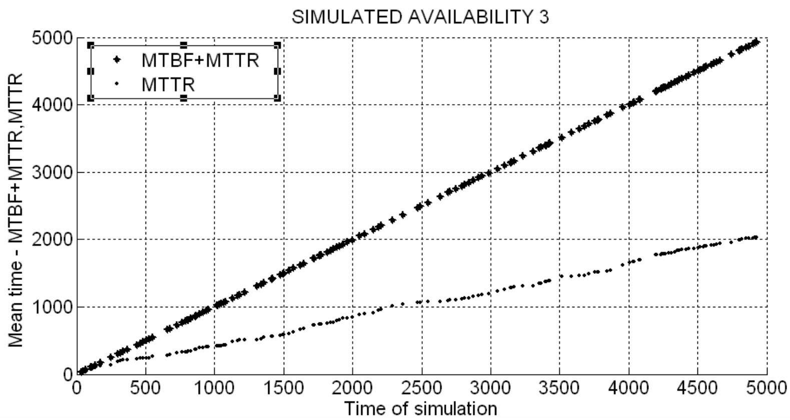

Fig.4.6 Participation of MTBF and MTTR during system observation time

Graph in *fig.4.6* shows the time period of the system use MTBF+MTTR, quotient of the no-failure state and quotient of the maintenance MTTR realisation.

The limitation of the areas under the curves evaluated from the bottom to the top shows the quotient of the maintenance time and the quotient of the system's serviceable state from the total time of study. The quotient of the maintenance lower, the reliability is higher.

5. RESULTS AND CONCLUSIONS FROM SIMULATION EXPERIMENTS

The simulation experiments are made for the serial mechanical system with six elements. The mean time between the faults and the mean time to repair is of exponential probability distribution.

Experiments are realized with parameter values depicted in tab. 1.

- Mean time between the failures is expressed by exponential distribution with parameter MTBF,
- Mean time to repair is expressed by the exponential distribution with parameter MTTR.

In experiments 1 - 4 the mean time to repair parameter was decreasing.

Tab. 5.1 Input parameters of simulation experiments

Parameter In hours	Element of the system					
	E1	E2	E3	E4	E5	E6
MTBF	100	140	110	160	120	150
MTTR 1	15	12	16	11	14	10
MTTR 2	7.5	6	8	5.5	7	5
MTTR 3	3.75	3	4	2.75	3.5	2.5
MTTR 4	1.5	1.2	1.6	1.1	1.4	1

Results from the first experiment are shown in *fig. 4.5, fig. 4.6*. Quotient of the maintenance time is high and asymptotic availability coefficient doesn't reach a value 0.6.

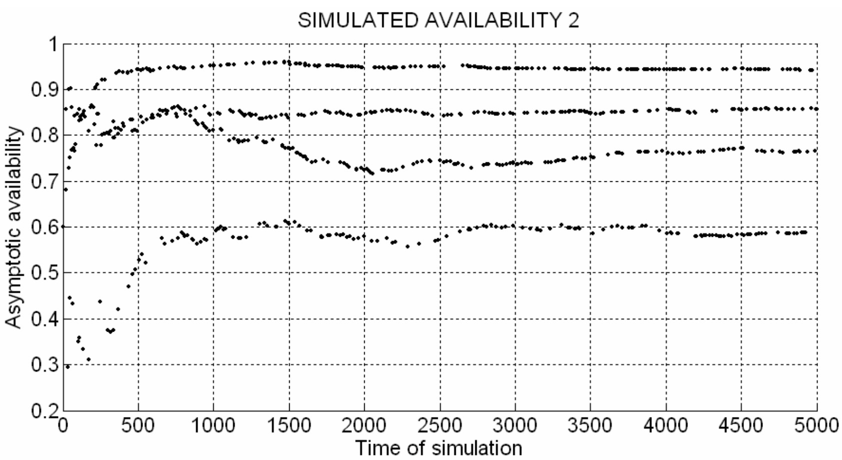

Fig. 5.1 Asymptotic availability coefficient developments

Other experiments shows rising of asymptotic availability coefficient up to value 0.95, while lowering MTTR of elements *fig.5.1.*

From the shown experiment results the confirmation of the mathematical expression base of availability coefficients is clear that the reached availability level is determined by two components – by faultlessness and maintenance.

The relationship between faultlessness, maintenance and availability is shown in table 5.2.

Tab. 5.2 Relationship between faultlessness, maintenance and availability

Faultlessness	**Maintenance**	**Availability**
Expressed by parameter MTBF	Expressed by parameter MTTR	Expressed by parameter A
MTBF - Constant	MTTR - Decreases	A - Increases
MTBF - Constant	MTTR - Increases	A - Decreases
MTBF – Increases	MTTR - Constant	A - Increases
MTBF - Decreases	MTTR - Constant	A - Decreases

6. CONCLUSION

It expresses the possibilities of availability increase of constructed and operating devices. It is possible to increase the availability practically only by shortening of intervals of the device maintenance components.

Simulation modelling of availability prediction is advantageous for it's possibility to watch dynamic process using graphical outputs. This outputs gives more illustrative image about random processes. Output values can be easily compared. Parameters of the system can be tunable according this comparison, so the system response will be appropriate.

References

4. Holub, R., Vintr, Z.: Aplikované techniky spolehlivosti. Část 1: Specifikace požadavků na spolehlivost. [Skripta] Brno: Vojenská akademie 2002.
5. Holub, R., Vintr, Z.: Základy spolehlivosti. [Skripta] Brno: Vojenská akademie 2002.
6. Vintr, Z.: Možnosti predikce pohotovosti technických systémů. In: TD 2004 – DIAGON 2004 – Sborník přednášek 27. mezinárodní konference. Zlín: Academia centrum UTB, 2004, str. 85 – 90. ISBN 80-7318-195-6.
7. US Army TM 5-698-3 Reliability primer for command, control, communications, computer, intelligence, surveillance, and reconnaisance (C4ISR) facilities, 2003
8. Crowe, D., Feinberg, A.: Design for reliability. CRC Press. New York. 2001
9. Chovanec, A.: Modelovanie a simulácia diskrétnych stochastických procesov, TNU AD v Trenčíne v spolupráci s vydavateľstvom GERŠI. Trenčín 2004, ISBN 80-8075-009-2.
10. Leitner, B. : Optimum design of Track Maintenance machine Frames by Matlab. In: Zborník medzinárodnej konferencie "TRANSPORT 2003, VTU Todora Kableshkova, Sofia 2003, str. 157 - 160.
11. Balog, J.: Diagnostikovanie a prognózovanie stavov pri údržbách strojov. SM3 – 1, Prípadová studia, Slovenská poľnohospodárska univerzita v Nitre. Nitra 2002.

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