COST OPTIMIZATION FOR REALISATION OF MAINTENANCE COST

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Abstract: This paper deals with optimal control interval determination using minimization the financial costs. It clears conceptual, mathematical and simulation model of the problem solution. It enumerates and evaluates results of the simulation.

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

1. INTRODUCTION

In the stage of the technique usage some precautions of dependability support are realised at the technique user, expressed in the Complex care program, which determines:

- strategy of approaches to the realisation of the complex care control,
- methods of the activities in the realisation precautions,
- organisation work forms of executive workers,
- types and technological limitations of complex care tasks.

The non-operating state and maintenance costs minimizing, but also optimising of:

- ➢ dependability,
- ➢ safety,
- ➢ production quality,
- ➢ profit.

The optimal determination of time periods for maintenance making is important task of the maintenance systems control. The maintenance interval represents the maintenance period between single maintenance levels (the period for realisation of the maintenance of respective level).

At the optimisation of maintenance intervals we need the verified and usable data, which can be acquired from one or more sources, for example:

- Previous knowledge from similar systems, if the maintenance actions can be suitable also for the new designed product. The maintenance programs of similar products can provide after the critical analysis suitable base.
- The data from all kinds of tests at the producer can provide information about the efficiency, usefulness and the effectiveness of designed maintenance programs of the new product and its components.
- If no previous verified knowledge about the fault rate of other systems exist or if the previous and new systems are not similar enough, the maintenance interval can be determined by estimation (expert method). The experiences of producer, user specialists are utilised and it is progressing in accordance with the knowledge in the dependability, operation, operation conditions etc.

- If verified data about the failure rates of single system components exist, it is possible to use calculations in accordance with the restoration theory and rules of complicate systems dependability for determination of the maintenance intervals.

2. COST OPTIMISING PRINCIPLE

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- If no previous verified knowledge about the fault rate of other systems exist or if the previous and new systems are not similar enough, the maintenance interval can be determined by estimation (expert method). The experiences of producer, user specialists are utilised and it is progressing in accordance with the knowledge in the dependability, operation, operation conditions etc.
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Determination of maintenance action interval thus so that the total unit costs of the object's life cycle should be minimized is the aim of the optimisation.

The total unit costs N_c at vanishing the costs components, which are not suggestible by the maintenance actions, consist of three components:

1. Supplying costs of the object (N_o), which are constant (independent on the maintenance interval time),
2. Costs of preventive maintenance (N_p),
3. Costs of the corrective maintenance (N_n) of the object (their amount depend on the maintenance interval)

The expression of total unit costs:

$$Nc_{(t)} = 1/t\ (N_o + N_{p(t)} + N_{n(t)}) \qquad (1)$$

where: t – is the maintenance interval, which we are looking for.

The expression is rearranged into the form, where each term on the right side expresses the relative costs:

$$Nc_{(t)} = N_o /t+ N_{p(t)} /t+ N_{n(t)} /t) \qquad (2)$$

The relative costs for the preventive maintenance are constant in time and that's why we directly replace them by symbol N_p :

$$Nc_{(t)} = N_o /t+ N_p+ N_{n(t)}/t) \qquad (3)$$

The optimising task lies in finding such a maintenance interval t, which ensures that the total unit costs expressed by the previous equation will be minimal.

The suitable (convex) form of the curve $Nc_{(t)}$ and sufficiently sharp and expressive minimum in point $D(t_{opt};\ Nc_{(t)\ min})$, which enables relatively exact identification of the optimum point position, are the conditions of the application successfulness of the optimising method.

If the function minimum $Nc_{(t)}$ is flat and inexpressive, the determination of the optimal maintenance interval is more difficult, but it enables easier combination of maintenance actions without negative impact in economical field.

All variants of economical optimising of the technique life cycle or maintenance intervals are based on a similar principle.

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3. OPTIMISING MODEL OF PERIODIC CONTROLS INTERVAL

The device Z is formed by elements $P_1, P_2, \ldots\ldots P_K$, which are in operable or failure state.

The diagnostic operations with costs per hour C_1 are made for the detection of failure state occurrence in periodical times $t_{K1}, t_{K2}, \ldots t_{KN}$. During the diagnostic inspection all or several elements can be diagnosed.

In the case of failure occurrence until the closest control of the operability the device causes with its operation the loss per hour C_2.

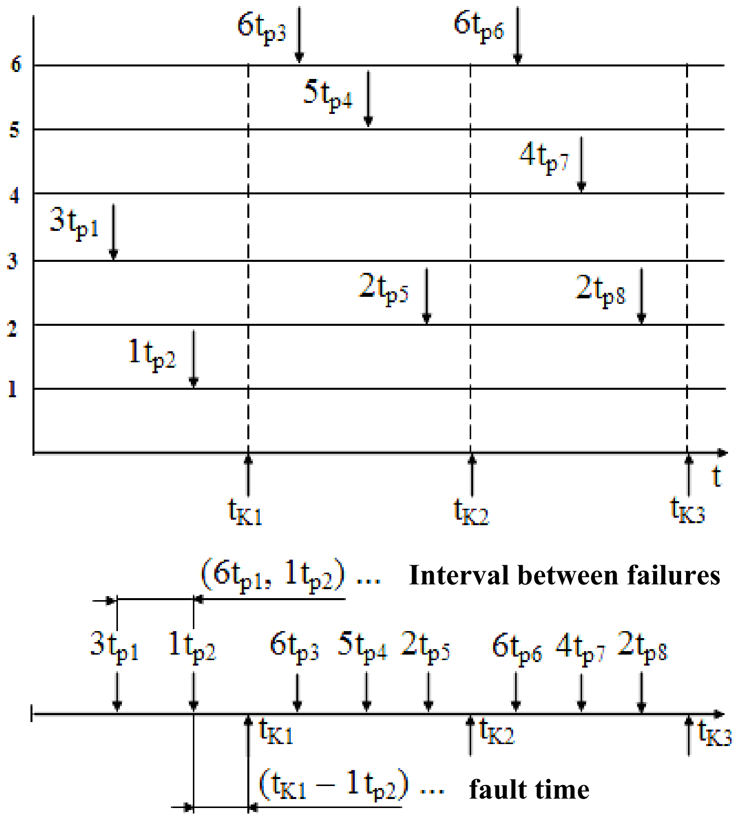


Fig. 3.1 Scheme of failures moments and diagnostic controls
t_{Ki} – control time, I t_{pi} – time of failure occurrence on the I – element

Operation times to the failure occurrence of single elements have the probability distribution of continuous type with distribution function:

$$F_{(t)} = P\,(\,T \leq t\,) \tag{4}$$

and with probability density $f_{(t)} = \dfrac{d}{dt}\,F\,(t)$.

Due to the failures, which appear in times $t_{P1}, t_{P2}, \ldots . t_{PM}$, due to the work in unsatisfactory conditions or due to non operating state, losses rise up to the closest diagnostic control.

$$N_P = \sum C_2\,.\,(\,t_{Ki} - t_{Pi}\,) \tag{5}$$

If no failure occurs, losses rise from the unavailing usage of the diagnostic device C_1.

The sum of costs of planned diagnostic controls and losses from the device operation in the fault state

$$N_C = \sum C_1 + C_2 \, . \, (t_{Ki} - t_{Pj}) \qquad (6)$$

must be minimal and so also the mean costs of one cycle of periodic control.

4. SIMULATION MODEL OF MAINTENANCE INTERVALS OPTIMIZATION

In the case of knowledge of the mean time values of failures occurrence, deterministic calculation for various control intervals is made according to previous relations and the minimal value of test function is being searched.

If we have an elaborated statistical set of data and information about failures in the form of type and distribution parameters of times between failures in the operation units, we can utilise the simulation approach.

Flow diagram *fig. 4.4.* shows the process described below.

1. Insertion of input data (elements number, unit controlling costs C_1, unit costs - losses C_2, time of simulation end in operation units, distribution parameters of periods between failures of elements, set-up of initial values of variables).
2. We generate the size of intervals between failures. We determine the smallest and the biggest interval between failures and the step of tested cycle.
3. We realise the cycle of optimisation experiment and change the step (increase or decrease of the control interval).
4. We determine the number of controls. We calculate the prevention controlling activity costs Np. We calculate the operation times in fault state and the loss size Nn. We calculate the total costs Nc.
5. We process the output data.
6. We verify the conditions of experiment continuation.
7. We diagrammatise the size of costs depending on the size of control intervals.

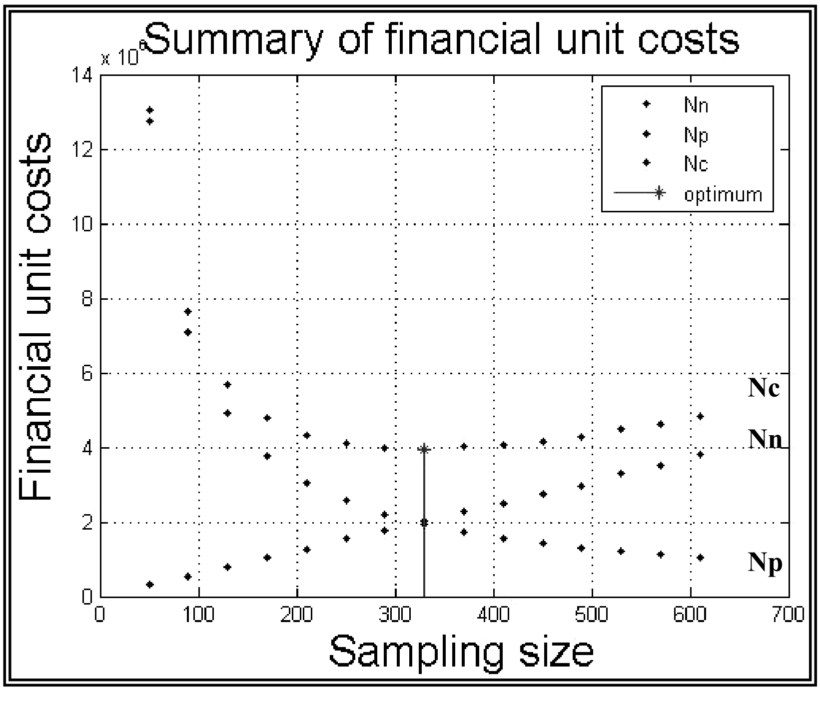


Fig. 4.1 Diagram *of optimal size of control interval for the simulation experiment 1 (input parameters tab.5.1)*

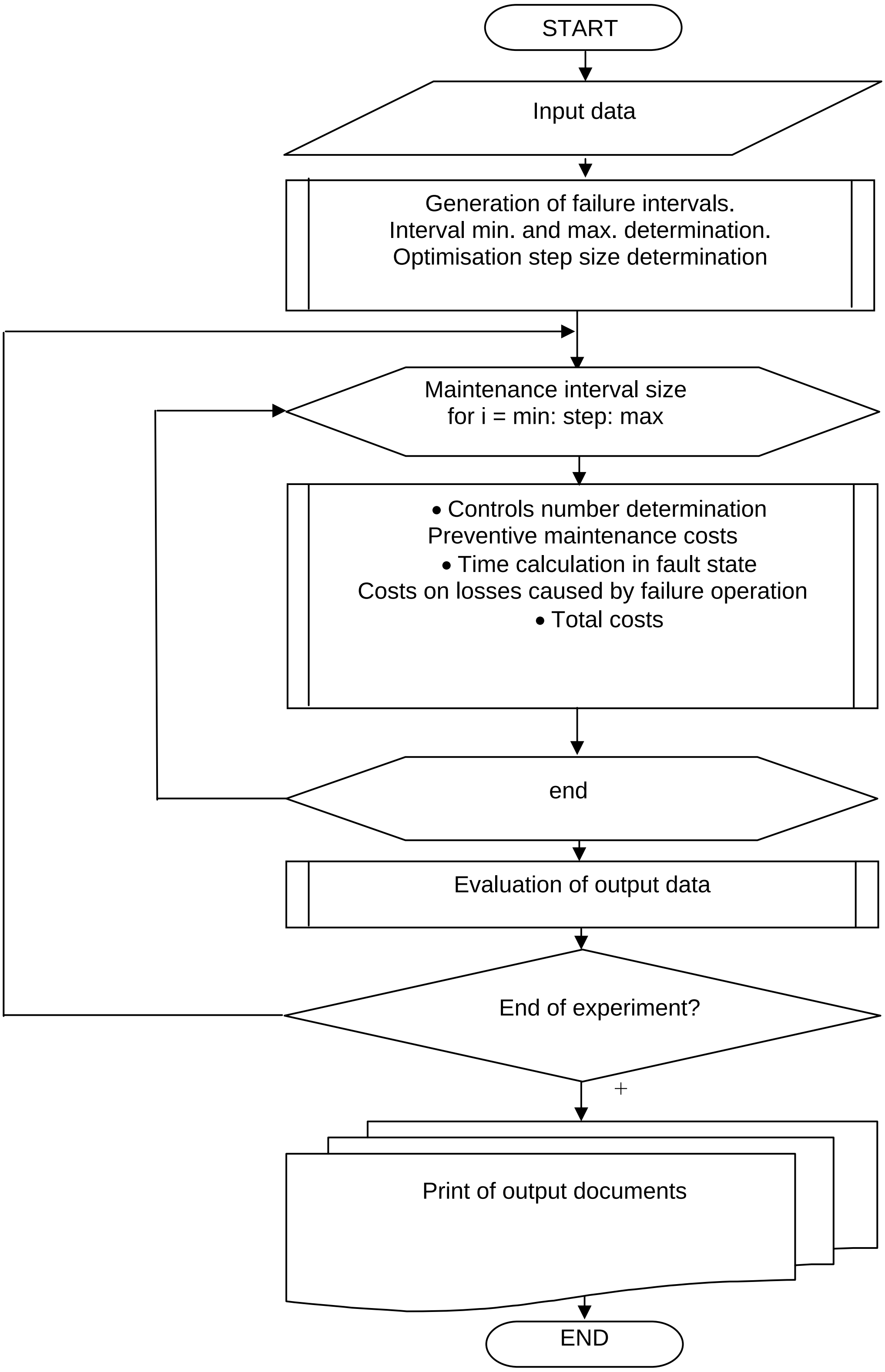


Fig. 4.2 Flow diagram

5. REALISATION AND EVALUATION OF RESULTS OF SIMULATION EXPERIMENTS

The simulation experiments enable to follow the changes of the output parameters values depending on the change of input parameters.

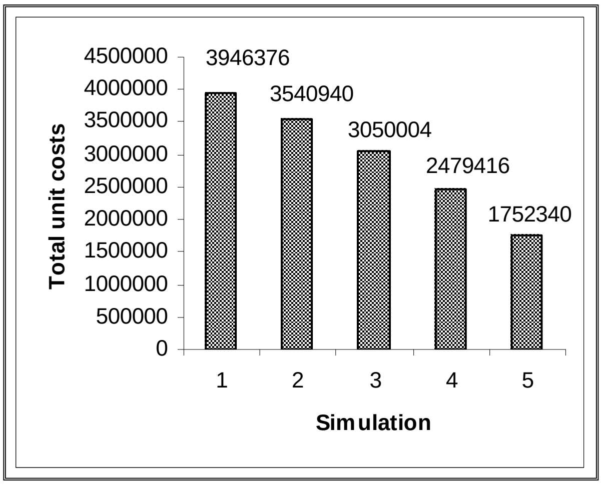
Which is the change of total costs and size of control interval in dependence on the change of unit costs values on control operations at constant costs of losses from the failure operation?

Tab. 4.1 represents the input and output parameters of simulations. Each experiment provides the determination visualisation of the control interval optimal size in the studied range of possible control interval. The optimisation process and its range for the simulation experiment 1 are shown in *fig. 4.3.*

Tab. 5.1 Input and output parameters of simulations

INPUT:					
Generation of failure times:	MU=1200				
Normal distribution:	SIGMA=200				
Simulation:	**1.**	**2.**	**3.**	**4.**	**5.**
Control operation unit costs	5000	4000	3000	2000	1000
Losses caused by failure operation	120				

OUTPUT:					
Simulation:	**1.**	**2.**	**3.**	**4.**	**5.**
Interval between controls	330	290	250	210	130
Total unit costs	3946376	3540940	3050004	2479416	1752340



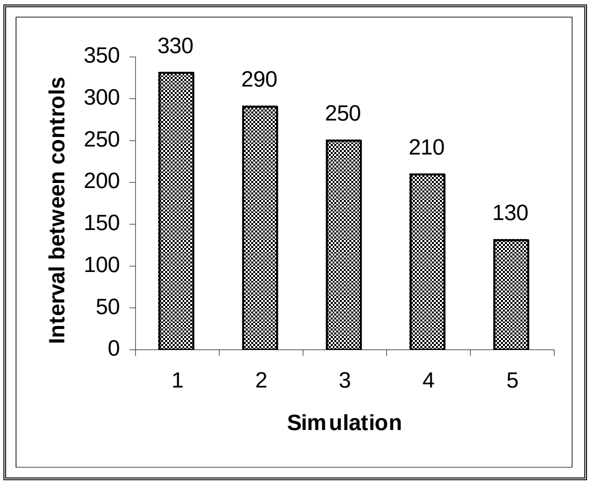


Fig. 5.1 Reduction of total costs and size of optimal control interval at decreasing of control operations costs according to tab. 5.1

Which is the change of total costs and control interval size depending on the change of unit costs values occurring due to the failure operation at constant costs of control operations?

Input and output parameters, optimisation process, increase of total costs and reduction of optimal control interval size at costs increase due to the failure operation is shown in tables and graphs below.

Tab. 5.2 Input and output parameters of simulations

INPUT:					
Generation of failure times: Normal distribution:	MU=1200				
	SIGMA=200				
Simulation:	**1.**	**2.**	**3.**	**4.**	**5.**
Losses caused by failure operation	120	220	320	420	520
Control operation unit costs	5000				

OUTPUT:					
Simulation:	**1.**	**2.**	**3.**	**4.**	**5.**
Interval between controls	330	250	210	170	160
Total unit costs	3936012	5327617	6408536	7411640	8174268

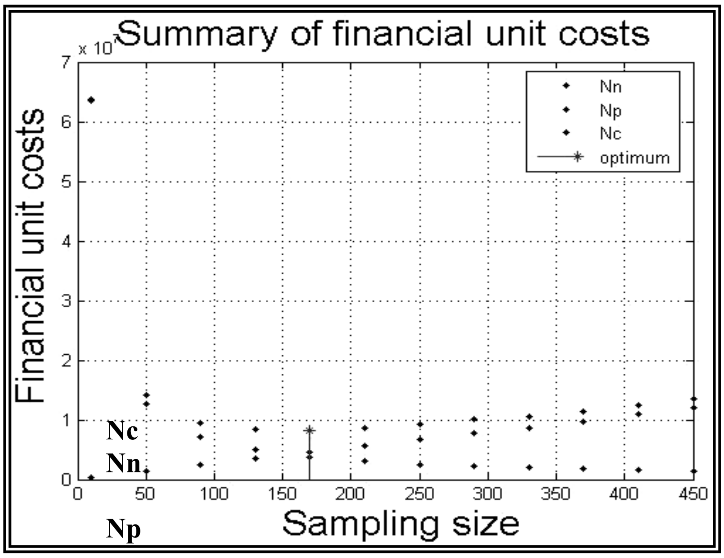


Fig. 5.2 Diagram of optimal size of control interval
for simulation experiment 5 (input parameters tab. 5.2)

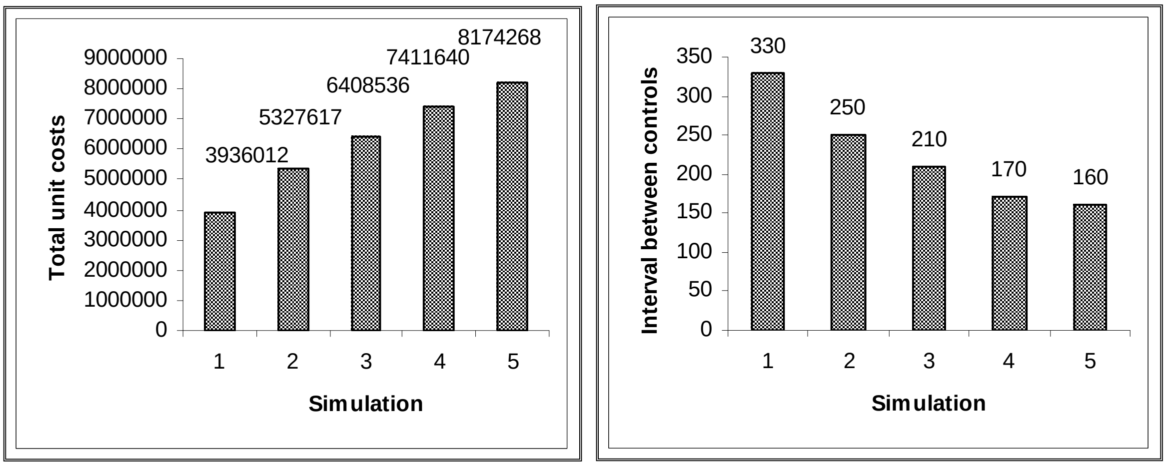


Fig. 5.3 Increase of total costs and the reduction of optimal control interval size at increase of costs due to failure operation according to tab. 5.2

The following result from the results of simulation experiments:

1. The total costs decrease with the decreasing values of unit control costs.
2. The size of optimal control interval decreases with the decreasing value of the unit control costs and the number of control activities intervals increases.
3. The total costs will increase and the size of the optimal control interval will decrease with the increasing value of the unit costs from losses caused by the failure activity.

6. CONCLUSION

The simulation model optimises the interval of maintenance action so that the total costs (on control and costs caused by failure) should be minimised.

The processing of simulation model arises from deterministic process of resolution of the mentioned problem. The simulation model was verified by processes of classical computer methods.

The algorithm representing the simulation model is drawn so that it could be easily modifiable. It enables to remove the lacks of classical computer methods and to get the required results in short time.

The obtained results can be applied to the determination of the number of control activities intervals and the size of control activities interval. They enable to gain an idea about the number of expended financial resources for the control operations, about the costs of the control operations and total financial costs.

The simulation model creates the bases for further development of problems resolution possibilities being connected with the determination of the optimal control interval size and minimising of total costs. It expands the range of application utilisation of simulation modelling for solution of problems related to the operation of specific technical systems. Generally it can be the mobile technique, elaboration device or constructional groups of technical devices, which during their operation get into the failure state.

The simulation model provides general graphical outputs of costs changes in dependence on the size of control interval and the number of control intervals. It can be used for the graphical and didactical support of the explanation of optimisation problems of maintenance intervals.

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