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Forecasting in technical facility control systems

Abstract

The paper presents a methodology for designing forecasting systems for control systems for technical facilities. The topicality of the selected topic is justified by the specific requirements for forecasting systems, intended for use in control systems of technical facilities.

The methodology proposes to design a forecasting system appropriate to the described stages with the use of a number of parameters characterising the forecasting process. The work analyses the peculiarities of the forecasting method, which are determined by a series of characteristics. An example of such a characteristic is the commensurability of the interacting parameters in the process of interaction of the parameters characterising the process of negative influence on the control process and the parameters counteracting this influence. An example of a parameter characterised by an increase in the accuracy of forecasting is the parameter of increasing the determinism measure, which is secured by separate, additional components in the forecasting system. An example of additional components may be the implementation component of the process of counteracting the negative impact, the component supporting the adoption of decisions in relation to the implementation of counteracting the negative impact of accidental events on the controlled object.

The use of the developed design methodology allowed the accuracy of the forecasted data to be increased, which leads to an increase in the efficiency of using the forecasting system.

Key words: forecasting system, negative impact, forecasting time interval, accidental event, forecasting efficiency, control object.

Prognozowanie w systemach sterowania technicznymi obiektami

Streszczenie

W artykule przedstawiono metodykę projektowania systemów prognozowania dla systemów sterowania obiektami technicznymi. Aktualność wybranego tematu uzasadniona jest specyficznymi wymaganiami stawianymi systemom prognozowania, przeznaczonym do stosowania w systemach sterowania obiektami technicznymi.

Metodologia proponuje zaprojektowanie odpowiedniego dla opisanych etapów systemu prognozowania z wykorzystaniem szeregu parametrów charakteryzujących proces prognozowania. W pracy przeanalizowano specyfikę metody prognozowania, którą determinuje szereg cech. Przykładem takiej cechy jest współmierność parametrów oddziałujących w procesie interakcji parametrów charakteryzujących proces negatywnego wpływu na proces sterowania i parametrów przeciwdziałających temu wpływowi. Przykładem parametru charakteryzującego się wzrostem trafności prognozowania jest parametr zwiększania miary determinizmu, który jest zabezpieczony odrębnymi, dodatkowymi składowymi w systemie prognozowania. Przykładem dodatkowych komponentów może być komponent realizacyjny procesu przeciwdziałania negatywnemu wpływowi, komponent wspomagający podejmowanie decyzji w związku z realizacją przeciwdziałania negatywnemu wpływowi zdarzeń losowych na kontrolowany obiekt.

Zastosowanie opracowanej metodologii projektowania pozwoliło na zwiększenie dokładności prognozowanych danych, co prowadzi do zwiększenia efektywności wykorzystania systemu prognostycznego.

Słowa kluczowe: system prognozowania, negatywny wpływ, przedział czasowy prognozowania, zdarzenie losowe, skuteczność prognozowania, negatywny wpływ, obiekt kontrolny.

1. Introduction

Forecasting systems are widely used in various scientific and technical fields. Each industry requires the use of specific methods of implementation of tools or forecasting systems that are specific to their respective industries. There are possible different interpretations of forecasting, which depend on the following factors:

– ideas about forecasting goals and their description;
– methods of implementing prediction tools in accordance with the purpose of forecasting;
– the use of additional functional components that interact with the prediction tools and provide the necessary efficiency in forecasting processes and other factors that are directly related to the specifics of the selected subject area.

Forecasting systems which, in addition to prediction tools, use a number of selected functionally-oriented tools and thus provide a higher level of efficiency in their forecast results, are commonly called hybrid forecasting systems.

This paper considers the problems of creating forecasting tools for technical object control systems and ways to solve them. An important difference between the implementation of forecasting in the control systems of technical facilities, in relation to forecasting, for example, in economic, social and other fields, are the requirements for use, small volumes of memory, use of microprocessors and other tools. The work is focused on the creation of methods for designing forecasting tools for control systems of technical facilities.

2. Problems that arise when building forecasting systems

Assume that the predicted events (Vp_i) may affect the management process $[Pr_i(Op_i)]$ of the object Op_i. Forecasting is implemented in accordance with the goal (CP_i), which consists of at least two components. The first component of the goal (CP_i^{If}) determines the need to predict the occurrence of the event, which provides an opportunity to obtain information about the random event $I_f(Vp_i)$. This event is associated with the selected synchronisation parameter, which characterises the process of functioning of an object $Pr_i(Op_i)$. The expected event Vp_i is determined by using methods implemented by the corresponding prediction system (SPB_i). The prediction corresponding to the first component of the goal (CP_i^{If}) can be described by the relation:

$$Da[Pr_i(Vp_i)] \rightarrow SPB_i \rightarrow I_f(Vp_i),$$

where $Da[Pr_i(Vp_i)]$ – data that can cause Vp_i, $Pr_i(Vp_i)$ – the process that generates Vp_i.

The most common are the processes $Pr_i(Op_i)$, for which the synchronising parameter is the time T. Predictions can be focused on transmitting their results to the appropriate users or individual systems (Su_i). Based on the analysis of prediction data and possible data on the current state of the process $Pr_i(Vp_i)$, it is possible to obtain additional information about changes that may arise in this process. In this case, the previous ratio can be written as:

$$\{Da[Pr_i(Vp_i)] \rightarrow SPB_i \rightarrow I_f(Vp_i)\} \rightarrow \{Su_i = f[I_f(Vp_i), Pr_i(Op_i)]\}, \quad (1)$$

where $f[I_f(Vp_i), Pr_i(Op_i)]$ is a function that describes a certain way of interaction Vp_i with $Pr_i(Op_i)$, based on information $I_f(Vp_i)$ and current state data $Pr_i(Op_i)$, the results of which can be transmitted to the subject Su_i.

The second component of the prediction goal (CP_i^d) determines the requirements for methods of counteracting the system of influence (SWP_i) of the expected event Vp_i on the process $Pr_i(Op_i)$. To extend the functionality of SWP_i, a decision-making system (SPR_i) can be used. The process of achieving this component of the forecasting goal can be described by the following relationship:

$$\{[SWP_i(CP_i^d) \& I_f(Vp_i)] \rightarrow [SPR_i, SUP_i]\} \rightarrow Dz(Pr_i(Op_i)), \quad (2)$$

where $Dz(Pr_i(Op_i))$ – a solution implemented in accordance with the goal of the process of influencing $Pr_i(Op_i)$, which is formed by the system SWP_i, there is a possibility to use the decision-making system, SUP_i – control system $Pr_i(Op_i)$.

It can be affirmed that the first component of the goal $CP_i^{I_f}$ determines the need to predict a certain event, and the second component of the goal CP_i^d determines how desirable it is to respond to the occurrence of the expected event.

If the Cp_i is only the first component in CP_i then such a prediction is called passive, because the obtained information $I_f(Vp_i)$ is not directly used. In most cases, the processes of event prediction Vp_i are implemented when there is a need to analyse the information $I_f(Vp_i)$, based on which decisions are made to implement the impact of SWP_i on the process $Pr_i(Op_i)$.

The forecasting system (SPG) will include interconnected components, the first of which is the prediction system SPB_i events Vp_i. The main element of the system SPB_i implements a function that calculates the possible parameters Vp_i, the values of which determine the possibility of a corresponding event. Such a system, based on the provided data, can to some extent expand the description of the interpretation of the goals of the prediction and the description of the interpretation of the input data.

The second component is the SWP_i system, which on the basis of current state data $Pr_i(Op_i)$, and prediction result information $I_f(Vp_i)$, using, if necessary, the decision-making system SPR_i, forms a method of influence and activates its implementation on the process $Pr_i(Op_i)$ (Rebizon, 2015). This impact should be in line with the forecasting goals of CP_i and can be implemented using the SUP_i management system. This can be written as:

$$SPG = F[SPB_i, SWP_i, SPR_i] \rightarrow SUP_i[Pr_i(Op_i)], \quad (3)$$

where F is a function that describes the overall organization of the operation of the SPG. Assume that the predicted events Vp_i, if they occur, will have a negative impact on $Pr_i(Op_i)$.

The SUP_i control system is an important component related to the operation of the SPG. This system can provide the ability to implement the impact on the process $Pr_i(Op_i)$, which is formed by the system SWP_i.

The degree of influence of Vp_i on $Pr_i(Op_i)$ may be different, because the results of forecasting Vp_i , which are determined by the nature of the prediction process, may be such that $I_f(Vp_i)$ does not provide the ability for SWP_i to fully influence $Pr_i(Op_i)$ in accordance with CP_i. The expansion of functional tools aimed at improving the efficiency of forecasting processes is based, inter alia, on the use of analysis of fragments of textual description of the interpretation of the processes of these tools (interpretation of their parameters and algorithms). The SWP_i system can operate in different modes, which are characterised by different degrees of influence Vp_i on $Pr_i(Op_i)$, for example, in the mode of providing partial influence on the process $Pr_i(Op_i)$. The need for possible restrictions on the impact on $Pr_i(Op_i)$ on the part of SWP_i, may be due to the fact that CP_i, in some cases, describes the result of the prediction as not accurate enough. The expediency of the mode of partial influence on $Pr_i(Op_i)$ is also due to the fact that the prediction processes are less determined in relation to the requirements formulated for control systems $Pr_i(Op_i)$.

The study of methods for solving forecasting problems, in many cases, is being implemented to determine the possibilities of ensuring the required accuracy of forecasting, which leads to difficulties in solving these problems (Rosienkiewicz, 2019; Haipeng, Hua, 2020). Quite often the ways to overcome these difficulties are to formulate requirements for the use of more initial data and other requirements for them. A possible approach to avoid these difficulties is to solve the problem of determining the degree of consistency of the methods used in the implementation of predictions with the characteristics of the data that can be used in this case. Such coordination of prediction methods is also realised in relation to the methods of forming counteraction to the negative impact of Vp_i on the system $Pr_i(Op_i)$.

Since the parameter T, in most forecasting problems, is synchronising, we consider the relationship between the components of the SPG in terms of synchronisation of their work. The parameter T provides the ability to set the ability of the SPG system, within the set time, to provide an opportunity for the implementation of processes to counteract the negative impact of Vp_i on the process $Pr_i(Op_i)$.

The synchronising parameter for the SPG system can be a parameter other than the time parameter, but then it must be key and determine the main stages of the functioning of the system $SUP_i[Pr_i(Op_i)]$. For example, a parameter such as temperature can determine the stages of the technological process depending on the change in its value, in relation to which control actions are performed.

An important condition for mutual cooperation between SPG and SUP_i, when it is possible to set common synchronisation parameters, is the affinity between their key parameters. The need for this condition stems from the fact that the systems SPG and SUP_i may differ from each other. For example, the system $SUP_i[Pr_i(Op_i)]$ is preferably as close as possible to the model of the process itself $Pr_i(Op_i)$. This approximation provides high process control implementation efficiency $Pr_i(Op_i)$. The SPG system, by its nature, differs from the $SUP_i[Pr_i(Op_i)]$ and, moreover, from the $Pr_i(Op_i)$ process. This is due to the fact that forecasting tools are primarily focused on detecting adverse events that occur mainly in the external environment (En_i), surrounding $Pr_i(Op_i)$. Diagnostic systems deal with the detection of negative events that occur in the environment of $Pr_i(Op_i)$ (Blata, Chair, 2013; Dwojak, Rzepiela, 2005).

To build a system SPB_i, you need information about the environment En_i, in which $Pr_i(Op_i)$ operates. Such information should make it possible to predict the occurrence of the event Vp_i, which may have a direct impact on $Pr_i(Op_i)$. Therefore, the SPG system must use process information from En_i to successfully predict random adverse events. To do this, use it close to the object part of the environment. Its closeness is determined by the ability of random negative events in this environment to affect $Pr_i(Op_i)$. The object Op_i is designed to function in a certain En_i, in this case, the model $SUP_i[Pr_i(Op_i)]$ can use not only the general parameters that characterize En_i, but information about individual fragments of processes occurring in this environment. Therefore, the individual data used in $SUP_i[Pr_i(Op_i)]$ and in SPG must be related.

3. Analysis of the peculiarities of the implementation of forecasting methods

To expand the possibilities of the analysis of various aspects of the operation of the forecasting system, tools are needed to use textual descriptions of the interpretation of data and processes activated in the SPG to conduct such an analysis. One of the basic components used for semantic analysis is the semantic dictionary Sc_i.

Within the SPG, the semantic dictionary Sc_i can be used to form textual descriptions of the interpretation of elements, components and processes used in the forecasting system. The element Sc_i is a phrase that has its own semantic meaning in the relevant subject area. All textual descriptions of the interpretations used in the SPG are formed based on the use of the dictionary Sc_i. If it is necessary to expand or modify individual text descriptions, text transformation methods are used, and if necessary, Sc_i can be extended (Korostil, Afanasyewa, Korostil, 2021; Korostil, Korostil, 2012).

Features of the implementation of forecasting methods are determined by factors that characterise the relevant processes. Such factors can combine a number of parameters that describe the relevant features of the studied processes. One of these parameters describes the degree of determinism of the various components of the SPG and SUP_i systems and necessitates the determination of the difference between them. This difference should not be less than the specified value, because, otherwise, it makes no sense to implement predictions, but only to expand the system SUP_i.

The degree of dimension of different data and parameter values in different components is a very important characteristic. Analysis of the magnitude of the dimension of the input data and the corresponding parameters used in interconnected systems may be based on the study of scale size, or to determine the possibility of transitions from one scale (scale of one parameter class) to another scale (scale of another parameter class). This measure of dimension may be different for different selected pairs or groups of parameters.

The parameter that connects the SPG with the decision-making system is the degree of compliance of the data used in the decisions formulated in SPR_i, with the data of the result of predictions obtained by the system SPB_i. The system SPR_i which, along with the data, uses descriptions of the interpretation of this data, performs the function of supplementing the prediction data so that the result of predictions was more efficient when used by the control system SUP_i,

When random factors negatively affect the operation of the object $Pr_i(Op_i)$, and the components of the SPG system counteract the negative impact, the SPG may be characterised by the ability to provide a certain level of security for the object.

An important feature of the operation of the SPG system is the choice of the period of operation of the SPG system. If time is selected as the synchronising parameter, the period of operation of the SPG system is determined by the time interval ΔT_i. The interval ΔT_i cannot be larger than the set operating cycle $Pr_i(Op_i)$, but may coincide with the size of this cycle and may also be smaller than the latter.

When choosing ΔT_i it is important to determine the effective value of this interval. One of the key characteristics of forecasting is the measure of reliability of the forecast, which stipulated, among other things, to the fact that reducing the value of ΔT_i, it becomes possible to obtain more information about the processes that can cause Vp_i, if within such an interval Vp_i can occur. This factor can be defined as the of time inertia of processes that can cause Vp_i (time inertia of processes). Assume that the speed of functioning of processes is determined by the intensity of events on which the generation of processes are focused. The intensity of events activated by the process $Pr_i(Op_i)$ is much higher than the intensity of events Vp_i, and this feature can be interpreted as the of time inertia of the processes generating Vp_i with respect to $Pr_i(Op_i)$. The parameter of time inertia of the processes generating Vp_i can be used to determine ΔT_i. This parameter can be determined based on the analysis of the processes themselves $Pr_i(Vp_i)$.

The SPG system uses not only information about the initial data, but also uses certain hypotheses about the processes of occurrence Vp_i. Such hypotheses mainly concern information about the processes that generate the corresponding Vp_i. The hypothesis is integral, so we can talk in general about the possibility of Vp_i.

The event prediction function Vp_i, can use one or more parameters that characterise the event as independent variables. This function can be a relationship between the input data and the key parameters Vp_i. Common examples of such functions are linear or nonlinear regression functions, exponential functions and others that can be selected to calculate the parameters of the prediction event (Bronsztejn et al., 2022; Kołodziej, Żakowski, 2022). Hypotheses can be modified on different forecasting cycles, the use of which is possible when choosing prediction functions.

Another feature of SPG is that prediction systems can provide an iterative way to implement the prediction Vp_i in relation to the same process $Pr_i(Op_i)$. The results of each case of using SPG can be taken into account by the prediction algorithm at the next stage of forecasting. Due to this, it is possible to increase the reliability of the forecasting process implemented by the SPG system, if it turns out that the next iteration of the prediction results was more accurate.

4. Structural features of building forecasting systems.

The whole forecasting process, in a hybrid system, consists of separate stages.

The first stage is realised by the process of forming a hypothesis about the expected event Vp_i, or prerequisite events, (PE). The formation of the hypothesis is based on the use of linear functions, which can be written as:

$$h_i(Vp_i) = L_i^h(x_{i1}^p, \dots, x_{in}^p), (4)$$

where $h_i(Vp_i)$ is a hypothesis concerning the occurrence of the event Vp_i, L_i^h – the function describes the method of calculating the possibility of confirming the hypothesis, x_{ij}^p – variable parameters that determine the current value of the hypothesis $h_i(Vp_i)$.

Hypothesis, in accordance with the accepted interpretation, is a description of one of the possible forms of confirmation or denial of the possibility of achieving the goal of forecasting. Assume that the hypothesis is described as a logical quantity, and its definition can be described by the processes of logical inference of some hypothesis $h_i(Vp_i)$, which is carried out using logical transformations of input data for which their logical interpretation is formed and using appropriate logical statements (Widła, Zienkiewicz, 2018; Mordechaj, 2018). If $h_i(Vp_i)$ is equal to one, it means that the goal C_i^h presented at the logical level in the form of a hypothesis is possible and vice versa.

To form a hypothesis, we use information concerning $Pr_i(Op_i)$, information about possible $Pr_i(Vp_i)$, and about initial data $\{x_{i1}^p, x_{i2}^p \dots, x_{in}^p\}$, which can cause the occurrence of Vp_i. Information about $Pr_i(Op_i)$, SUP_i, CP_i is known, data from the En environment are also to some extent known. On the basis of these data, it is possible to form a set of parameters x_{ij}^p, corresponding approximations of their values $\{x_{i1}^p, x_{i2}^p \dots, x_{in}^p\}$ and their textual interpretation. Based on the transformation and analysis of these data and reducing their values to a logical interpretation on the set {0,1} and using separate textual interpretive descriptions, we can construct relations (4).

The next step in the forecasting process is the stipulation event (SE). At this stage, the requirements for the input data that will be used in the prediction process are formed. Relevant requirements can be formed based on the use of various methods of analysis and conversion of initial data, which include:

- formation of input data from the initial data based on the use of information about the latest and other additional information;
- the choice of the method of transformation of input data for the implementation of prediction processes;
- preparation of initial data in order to take into account the forecast data obtained in the previous forecasting cycle.

As part of the SE step, an analysis of the feedback data generated in the SWP_i can be performed if it is to be used. Conversion of initial data into input data can be as follows:

- in the implementation of the processes of filtering the initial data, which blocks the transmission to the system SPB_i data, the value of which has a low probability of their relation to the prediction processes;
- in determining input data that can cause the occurrence of Vp_i, which can be based on the use of cluster analysis methods.

When choosing the input data conversion method for SPB_i, the analysis of the textual description of the interpretation of the data related to the processes $Pr_i(En)$ and the analysis of the textual description of the interpretation of the forecasting goal can also be used.

The next stage of the forecasting process is called a conditionality event (CE). At this stage, the requirements for describing the purpose of forecasting are being clarified. It is obvious that such adjustments can be made to reduce the information on the forecast results and reduce the requirements for the amount and accuracy of forecast data. Limiting the requirements for the results of the prediction is possible only to the extent that the information obtained provides an opportunity to exercise adequate, in relation to the goal, impact of the SWP_i system on $Pr_i(Op_i)$.

The next step is direct prediction or (EP). The need to allocate this function in a separate stage is due to the fact that the information obtained at the output of the system SPB_i cannot be directly transmitted to SUP_i. This situation is typical of most prediction systems, as the prediction result must be transformed so that it is consistent with $Pr_i(Op_i)$.

At this stage of the forecasting system, the criterion for forecasting efficiency is selected. The choice of this criterion is based on the results of the analysis of the originally formulated goal CP_i and the goal modified at the CE stage. Since the forecasting system is expanded with a number of functionalities, and the goal of forecasting is a priority requirement, when choosing the criterion for forecasting efficiency, the results of all transformations implemented within the SPG processes are taken into account.

The SWP_i system is focused on the implementation of SPG cooperation with $SUP_i[Pr_i(Op_i)]$, so SWP_i can be interpreted as an interface between these systems. Such an interface can be adapted to different technical objects, depending on $Pr_i(Op_i)$. It is advisable to coordinate the SWP_i interface with the diagnostic system SD_i, because Vp_i, as well as faults that may occur in $Pr_i(Op_i)$, has a negative impact on $Pr_i(Op_i)$.

The predicted events have a negative impact on the processes $Pr_i(Op_i)$ and such an impact, in some cases, can be interpreted as an event equivalent to the occurrence of a fault in the object. In this case, counteraction to such influence can appear similar to counteractions caused by emergence of the corresponding malfunctions and can be realised by means of system SD_i.

5. Practical aspects of using the forecasting system.

The first practical aspect of using the SPG concerns the conversion of the initial data into the input data Da_i, which is implemented as part of the SE conditionality step. Due to the lack of complete information about $Pr_i(En_i)$ it is quite difficult to determine Vp_i only on the basis of available data on $Pr_i(En_i)$. This is one of the reasons for the need to use methods for predicting the occurrence of Vp_i. Among the possible cases of Vp_i, we are interested only in those events that affect $Pr_i(Op_i)$.

The choice of the corresponding Vp_i is made on the basis of the analysis of the degree of proximity $Pr_i(En_i)$ to $Pr_i(Op_i)$ and the features that characterise the relationship between Vp_i and $Pr_i(Op_i)$, the first of which is the relationship between their parameters of affinity, the second is the dimension of the current values of related parameters and the third is the size between the parameters of these processes. The affinity of the parameters means their same nature, and dimension means that the values of related parameters can be measured in the same units, and size means that the values of the parameter values are within agreed limits.

Regarding the lack of information about $Pr_i(En_i)$, we can speak only in relation to the data that may relate to the following points in time, starting from t_i and continuing to $t_{i+1,} t_{i+2,}..., t_{i+m}$. Past parameter values, if required, must be recorded. If the parameter P_i^{En} is affinity to the parameter P_i^{OP} and characterises Vp_i, then we can construct an extrapolation function using the previous data P_i^{En} from time points $\{t_{i-r}, \dots, t_i\}$ (Fortuna, Mąsowski, 2005). Based on the use of this function, it is possible to obtain its values or moments of time $\{t_{i+1,}..., t_{i+m})\} \in \Delta T_j$. We write this function as:

$$P_i^{En*} = f^{En*}[p_i^{En}(t_i), \dots, p_{i+m}^{En}(t_{i+m})].$$

This function can be used to calculate the values of the parameters Vp_i during ΔT_i. Since $Pr_i(Op_i)$ functions within successive cycles, the input parameters P_i^{OP} are those values that correspond to the period ΔT_{i-1}. Since the parameters P_i^{En} and P_i^{OP} are affinity, dimension and size, when their value changes, the total value is determined by the relation: $P_i^{EO} = F(p_i^{En}, p_i^{OP})$, where F is the function that determines the corresponding the value of the parameter P_i^{EO}, which characterises the event Vp_i. If the obtained value of the parameter P_i^{EO} exceeds the permissible limits, then this fact is registered in SPB_i, as the possibility of Vp_i in the current time interval ΔT_i. The number of calculated parameters characterising Vp_i may be greater than one parameter.

The next practical aspect concerns the stage of conditionality of the event, or determining the factors that are relevant to the expected event and may be closely related to the description of the goals of forecasting. The goals of forecasting, in most cases, describe not only the event Vp_i, but also the conditions that can provide opportunities for the functioning and activation of processes that counteract the negative impact of Vp_i on $Pr_i(Op_i)$. In contrast to the conditionality, which refers exclusively to the factors associated with the occurrence of Vp_i, the conditionality refers to the factors that provide the possibility of a reaction that determines the goal. This means that within the SPG forecasting system there must be some information or incomplete data on expected events Vp_i. Prediction, as a non-deterministic process of definition of certain data that should be relevant to Vp_i, is possible only if there is some information about Vp_i. Moreover, it can be affirmed that predicting the event Vp_i is not possible if there is no information about the event. In this case, the problem arises of determining how the amount of initial information about Vp_i affects the accuracy of forecasting. Assume that the prediction accuracy can influence the possible degree of counteraction of the SWP_i, component to negative processes in $Pr_i(Op_i)$ caused by the events Vp_i. In order to prevent the processes of counteracting the influence of Vp_i on $Pr_i(Op_i)$ to prevent negative changes in $Pr_i(Op_i)$, they must be to some extent predictable in the SWP_i, system. Within the SPG, there must be some information $I_f^*(Vp_i)$, to create an initial version of the tools that implement the processes of counteraction to the corresponding Vp_i. The process of anticipation of the influence of Vp_i on $Pr_i(Op_i)$ by the SWP_i system is activated on the basis of prediction data Vp_i, which are formed by the process SPB_i. It may turn out that the means of blocking the influence of Vp_i are not effective due to differences in the values of the parameters of the event Vp_i received at the stage of its forecasting and at the stage of occurrence of the event Vp_i. Then, SWP_i implements the correction of the means of preventing the influence Vp_i, using information about the above-mentioned difference between the parameters Vp_i which occurred, and the expected event Vp_i^*. In this case, forecasting allows you to identify the type of process required in $Pr_i(SWP_i)$ and, if necessary, expand it. Based on this, we can determine what should be predicted about Vp_i and how to react to its occurrence.

The next practical aspect concerns the EP prediction phase. In this case, it is necessary to choose the forecast time period ΔT_i. With the constant use of the forecasting process within the continuous operation of the *SPG* system, the problem of controlling the process of formation ΔT_i on individual cycles of operation $Pr_i(Op_i)$ arises. This is due to the fact that random events Vp_i can occur at any time, and the process of functioning Op_i can be a series of successive cycles, which are determined within the whole $Pr_i(Op_i)$.

In many cases, the required period of use of SPG is determined on the basis of the characteristics of the technological process, or the characteristics of the environment (Gundlach, 2021). An example of the first type can be cases when $Pr_i(Op_i)$ has fragments in which the operation of the process is under completely autonomous control, and the corresponding fragment Op_i is separated from the environment. In this case, the main threat to this time interval of operation $Pr_i(Op_i)$ may be the occurrence of faults, which deal with the diagnostic system. An example of the second type is a situation where the threat may be associated with dangerous changes in the external environment, such as periods of time when the parameters of the external environment take unpredictable values that negatively affect $Pr_i(Op_i)$.

6. Analysis of the value of the forecast period

Assume that Vp_i can occur during different cycles of operation $Pr_i(Op_i)$ and the establishment of the next prediction interval ΔT_i must be implemented in the established intervals of operation $Pr_i(Op_i)$.

The importance of choosing ΔT_i is due to the fact that during this interval a number of functions related to the prediction process must be implemented, and the size of this interval is related to the efficiency of forecasting. The functions implemented in the interval ΔT_i after activation of SPB_i include the processes of solving the following problems.

1. Determining the possibility of a dangerous event Vp_i.
2. Identification of the event Vp_i and determination of the parameters that characterise it.
3. The use of means to counteract the impact of Vp_i on $Pr_i(Op_i)$.

Requirements directly related to the definition of ΔT_i include:

- setting the start time of the interval $t_i^p \in \Delta T_i$,
- determination of the value of the interval ΔT_i.

The establishment of the moment t_i^p is closely related to the execution of the first stage *SE*, when a function is formed, which is used to calculate the parameters characterising Vp_i. The processes associated with the functioning of SPB_i are quite complex, so it is not advisable to continuously initiate them. In this case, it is necessary to use some integral parameters that characterise a certain level of probability of Vp_i. It can be assumed that all Vp_i arise due to anomalies in En_i, which are certain signs of the possibility of Vp_i, so it is necessary to analyse their occurrence within the *SPG*. Examples of such anomalies are changes in the values of key parameters of processes occurring in En_i, in which $Pr_i(Op_i)$ functions. Assume that any medium in which $Pr_i(Op_i)$ functions is inert. The inertia En_i means that the processes $Pr_i(En_i)$ are much slower than the processes $Pr_i(Op_i)$. Otherwise, in the processes $SUP[Pr_i(Op_i)]$ it would be necessary to create permanent means of protection $Pr_i(Op_i)$ from active processes in $Pr_i(En_i)$. Assume that at the *SE* stage, the detection of anomalies (An_i) is carried out which, in the simplest case, may be to verify whether the definition and calculation in $Pr_i(En_i)$ parameters do not exceed the established values. Assume that the moment of occurrence An_i in $Pr_i(En_i)$ can be taken as the initial moment t_i^p.

The next task is to determine the value of the interval ΔT_i, during which Vp_i can occur. Consider the successive moments of this interval. The first point in time that corresponds to the beginning of the interval ΔT_i is the moment $\delta t_i^{An} = t_i^p$, which corresponds to the detection by the system SPB_i of the anomaly $An_i(En_i)$. The second time point in the interval ΔT_i, is the moment of issuance by the system SPB_i of the prediction result Vp_i, which is denoted as δt_i^{IV}. The third moment of time in the interval ΔT_i corresponds to the moment of occurrence of the event Vp_i and means the time of registration of the event Vp_i and is denoted as δt_i^{RV}. The fourth moment of time is denoted as δt_i^{PV} and determines the moment of realisation of counteraction of the SWP_i system to the negative influence of Vp_i on $SUP[Pr_i(Op_i)]$ and the result of this counteraction. This moment determines the end point of the interval ΔT_i and the corresponding information is transmitted from SWP_i to SPB_i. The time axis of these moments and the whole forecast interval is shown in Figure 1.

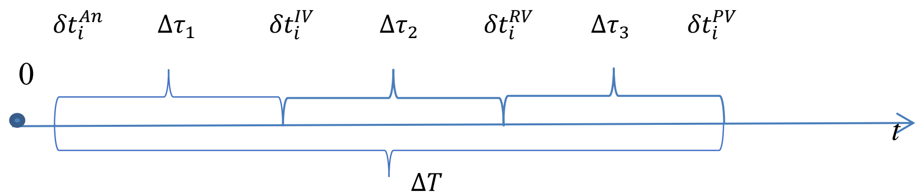

Figure 1. The time axis of these moments and the whole forecast interval

The intervals shown in Figure 1 are measured in seconds and mean the following. The interval $\Delta\tau_1$ determines the waiting time for information about a random event Vp_i from the moment the system detects SPB_i anomaly $An_i(En_i)$ until the system given SPB_i provides projected information about the possibility of an event Vp_i. The interval $\Delta\tau_2$ determines the waiting time for a random event Vp_i from the moment of providing information about the results of the prediction to the moment of occurrence of the predicted event. The interval $\Delta\tau_3$ determines the waiting time for information about the result of counteracting the negative impact of Vp_i on $SUP[Pr_i(Op_i)]$. This function is in contrast to other forecasting systems, relevant for technical objects, as the purpose of forecasting is to protect technical objects from the negative effects of Vp_i (Dutkiewicz, Wróblewski, Kozłowski, 2012; Giergiel, Hendziel, Zylski, 2013).

The practical aspects of using SPG include factors related to predictive processes. One such aspect of the use of SPG is based on the possibility of implementing an iterative forecasting process. The change in forecasting results in each cycle of the SPG system may be influenced by new factors that occur in $Pr_i(Op_i)$ and factors that occur in $Pr_i(En_i)$. The first factors relate to the processes of functioning of objects Op_i and can be considered within the framework of diagnostic tasks, reliability problems Op_i or other tasks.

Factors related to $Pr_i(En_i)$ that affect forecasting results can be considered independent of processes with $Pr_i(Op_i)$, and then they can be interpreted as factors characterising changes in environment En_i. Identifying the patterns of these changes, in an environment that is common to different objects Op_i, is very important. Based on the analysis of such changes, it is possible to identify the causes of their occurrence, which can be essential for solving problems, forecasting Vp_i.

Another practical aspect of using SPG is the possibility of establishing the need for modification of $SUP_i[Pr_i(Op_i)]$. If such a parameter as the degree of influence on the system $Pr_i(Op_i)$ in successive cycles of its operation increases, it may mean that the following factors occur. The first factor may be the approach of the end of the resource of the object. The second factor may be an increase in the frequency of response to the occurrence of Vp_i, which are similar to each other. This means that $SUP_i[Pr_i(Op_i)]$ does not adapt effectively enough to the environment En_i, which changes over time. In this case, there is a need to modify $SUP_i[Pr_i(Op_i)]$, which would allow, without the use of SPG, in the event of certain Vp_i, to counteract their impact on $Pr_i(Op_i)$.

7. Conclusions

The article presents methods of organising the forecasting system extended with additional functions that make it possible to increase the level of forecasting efficiency. Additional functions implemented in the form of separate components, aimed at improving the accuracy of forecasting results and improving their adequacy in relation to objects for which appropriate tools have been implemented.

A suitable extension of the forecasting system is the decision component, a component that presents the means of implementing the impact on the control object in the form of a system aimed at counteracting the negative impact of the forecasted event on the controlled object and other necessary extensions. Justification of the advisability of using possible additional functional components based on the analysis of the details of control objects, additional requirements that may arise when forming the description of the forecasting goal and other factors.

Building a forecasting system taking into account specific stages in the process and using various extensions allows you to increase the efficiency of using forecasting results. The introduction of additional functions related to forecasting processes and the analysis of forecast results makes it possible to relate such a system to hybrid forecasting systems.

It has been shown that it is possible to use a number of additional parameters characterising the forecasting process, which allows, if necessary, a more detailed analysis to be conducted of the processes under study. The implementation of the forecasting process as part of the proposed stages of this process allows for taking a number of features into account that are characteristic of separately selected controlled objects. This additionally allows you to use the results of previous forecasting cycles.

The proposed organisation of the forecasting system focuses on its use in technical facilities management systems. As part of this system, the functions of analysing the results of counteracting the negative impact of the anticipated event on the technical object are performed.

The forecasting system, which is extended with additional functions, apart from the prediction itself, allows the implementation of a number of possibilities, such as iterative organisation of the event forecasting process, which allows the previous results of forecasting random events to be taken into account.

The paper presents the development of a methodology for building forecasting systems, which is focused on the use in the design of control systems for technical facilities.

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