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Precedent approach to the formation of programs for cyclic objects control

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Abstract. The idea and procedure for formalizing the precedent method of formation of complex control solutions (complex control programs) is discussed with respect to technological or organizational objects, the operation of which is organized cyclically. A typical functional structure of the system of precedent control by complex technological unit is developed, including a subsystem of retrospective optimization of actually implemented control programs. As an example, the problem of constructing replaceable planograms for the operation of the link of a heading-and-winning machine on the basis of precedents is considered.

1. Introduction

The functioning of a large number of objects (mechanisms, machines, vehicles, technological units, man-machine complexes of different scale and purpose) as well as the work of small and large groups of people is organized cyclically. The latter implies the repetition, with some accuracy, of a certain set of actions, controls, operations, the implementation of which allows the desired result to be obtained at the end of each work cycle. Multiple playback and control of cycles for a certain period of time (shift, day, month) allows the data on control programs, conditions and results of their implementation, on the trajectories of change in controlled variables to be accumulated. These data should be used to form effective programs for controlling the upcoming work cycles of the facility in conditions of change in the properties of disturbing influences and control channels, as well as the diversity of cyclic assignments (orders) for the products received.

The paper presents: the task of creating and implementing cyclic programs for controlling a complex technological object (CTO) or a production complex, a new structure of a program control system, a procedure (algorithm) for the formation of a program for each upcoming work cycle of an object. A distinctive feature of the proposed system and procedure is a new interpretation and concretization of the well-known in the international legal practice method of decision-making based on precedents [1], as well as a similar method of selecting regular (recurring) decisions in intelligent control systems based on precedents [2-5], which are combined with the idea of retrospective optimization and control prediction [6, 7].

2. The precedent method of decision-making

Before presenting the essence and specifics of the proposed precedent approach to program control of cyclic objects, we need to turn to the terminology and content of the well-known method of judicial decision-making based on precedents and to the methods of reasoning based on precedents relating to the theory of intellectual systems.

Precedent (*praecedens*, lat. – going ahead) is a case that had an earlier place and serves as an example or justification of cases of this kind [8].

Legal precedent is the decision of a certain court or executive authority on a specific judicial or administrative case, which has become a model for solving similar cases in the future [9].

Case law – the legal system (England, the United States, Canada, and other countries), in which the main source of law is the *judicial precedent*. In the absence of clear definitions of the law, judges have the power and duty to create the law by setting a precedent on the basis of "similar cases". The decision on the particular case in question will be applied in the future to other similar cases.

According to [2, 8, 9] reasoning methods based on precedents include 4 main stages of decision making, which constitute a *precedent cycle*:

- Retrieve [*ri'triv*] – extract from the case library a similar precedent or a subset of precedents, corresponding to the situation in which another (new) decision is need to be made.
- Reuse [*ri:'ju:z*] – reuse of the extracted precedent (precedents) for making the next decision.
- Revise [*ri'vaiz*] – revision (correction), if necessary, of a precedent decision in accordance with the considered (next) task (problem).
- Retain [*ri'tain*] – saving the newly adopted solution as part of a new precedent (for future similar situations).

The structure of the precedent cycle is shown in figure 1.

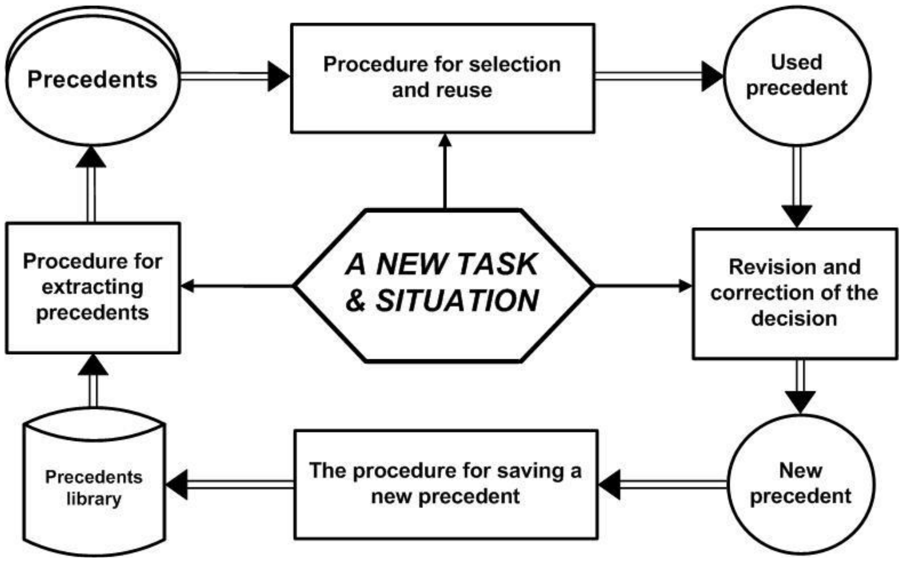

Figure 1. General presentation of the precedent decision-making cycle in similar situations.

The model of each precedent includes the description of three main components: the situation, the solution of the problem, the result of applying the solution. In the cases when such description is not sufficient for the implementation of the precedent cycle, the ontology (formal description) of the subject area, to which the decision problem belongs, is used. Ontology, in turn, includes: a finite set of concepts (notions, terms), a finite set of relations between concepts, a finite set of interpretation functions defined on concepts and relationships.

The tasks of operational control and scheduling of complex technological units and cyclic-class complexes are usually formulated and solved on the basis of functional, physico-chemical, balance and other models of control objects. The examples of such systems are modern automatic control systems of technological processes (ACS TP) for steelmaking units (converters, arc furnaces), chamber heating and thermal furnaces, coke batteries, rolling mills, production of tank structures, complex machine tools and vehicles, coal mining complexes in mines, etc. Their disadvantage is the presence of significant errors in control actions, which are due to the inaccuracy of the models used, incompleteness of information about changes in the properties of the control object and multivariate perturbation effects. Such ACS TP do not take into account the fact that each cycle of the object operation generates not only material products (technical products, materials, energy), but also data sets that represent the information model of a particular technological cycle.

3. The task of precedent control of a complex technological object

The above precedent approach to the selection of control decisions (effects), in the form of a control program for each upcoming technological cycle, allows the operational information about the operation of the object and the control system to be fully used and, as a result, the number of control errors to be reduced (its efficiency to be increased). Next, let's look at how the functional-algorithmic structure of the control system of a cyclic action unit should look, which is based on the precedent approach to the development of control programs for regular (repeated) cycles.

When developing automated control procedures for CTO, it is important to consider that each technological cycle is often not an exact repetition of previously implemented cycles. The latter are more or less different: the goals of control (the properties and characteristics of the product), the changing properties and parameters of the process unit (because of its aging, the use of different materials and regimes, load changes), the experience and control techniques of different operators – technologists, properties of external (disturbing) effects. The precedent cycle of the formation and implementation of control programs for such objects, presented in figure 1, should be changed and supplemented to take into account the named features and distinctive features.

The task of precedent control of CTO can be formulated as follows.

Given: a) A meaningful description of the existing complex technological object in accordance with figure 2.

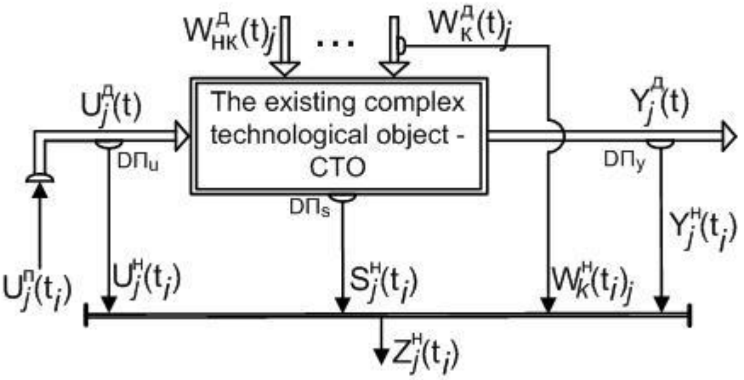

Figure 2. General representation of the control object – a complex technological unit (a complex).

$Y_j^R(t), U_j^R(t), W_C^R(t)_j, W_{NC}^R(t)_j$ – the real CTO output actions on the external environment in the *j*-th technological cycle at time t, the real control actions on the CTO, the real controllable external actions on the CTO, the real non-controllable external action on the CTO, respectively; $Y_j^{FS}(t_i), U_j^{FS}(t_i), W_C^{FS}(t_i)_j, S_j^{FS}(t_i)$ – a vector of full-scale measuring signals (data) about the output actions of the object related to the j-th technological cycle and the discrete moment ⤒ ⤓ of time t_i, the vector of signals about the full-scale control actions on the object, the vector of full-scale signals of controlled external actions (disturbances), the vector of full-scale signals characterizing state of the object in the j-th cycle at the time t_i ; $Z_j^{FS}(t_i)$ – generalized vector of full-scale signals received from sensors-converters; SC_U, SC_S, SC_Y, SC_W – conventional designation of actuators (A) and sensor-converters (SC).

b) Retrospective information model of the functioning of the existing control system in the form of a database on the parameters $\{Z^N_{j-m}(t_i); m=1,2,...,M; t_i(j-m) \in T_{j-m}\}$ of the actual realized technological cycles.

c) Difference (recalculation) mathematical models of the influence of increments $\Delta u_p(t_i) = u^{FS}_p(t_i) - u_p(t_i)$ of control actions $u_p(t_i) \in U_j(t_i), p \in P_j$ and controllable disturbances $\Delta w_{cr}(t_i) = w^{FS}_{cr}(t_i) - w_{cr}(t_i)$ on changes in output variables $\Delta y^A_n(T_j)$ and states $\Delta s^A_m(T_j)$ of the object at the end of the technological cycle.

d) Criterion of optimality of technological cycle control T_j, for example, the total costs $Q(T_j)$ on the cycle realization.

e) Limitations on control actions of $U_j(t_i) \in \Omega(U, T_j)$ type, where $\Omega(U, T_j)$ is the range of admissible values of the control vector components in the cycle T_j.

f) Information on the starting state $\tilde{S}(t_0)_{j+1}$ of the control object at the time t_0 of the beginning of the next (j+1)-th period (cycle) of its operation, as well as on controllable disturbances $\tilde{W}_C(t_0)_{j+1}$.

Required: to modify the method of decision-making on the basis of precedents applied to the control of CTO of cyclic action, to specify it in the form of a procedure (algorithm) for the formation and implementation of control programs and the functional structure of the precedent control system.

The effectiveness of the precedent method with regard to the control of the CTO of a cyclic action largely depends on the number of high-quality and relevant precedents (corresponding to the current state of the object, external influences and the task of the upcoming technological cycle, as well as error-free solutions, operators – technologists in the immediate past cycles). With a considerable variety of tasks for production output (for example, more than 400 grades of steel can be smelted in a modern steel smelting shop), as well as with a large capacity of many situations for external actions and measurement errors, it is very difficult to select at least 5 faultless precedents for each type of a product. Therefore, it is advisable, at the end of each technological cycle, not to reject erroneous decisions, but to correct them, solving the problem of retrospective optimization. It is possible to rely on this optimization in the method of restorative-predictive automatic control described in [6, 7] and protected by a number of patents for inventions.

The selection of precedents from the set of past technological cycles in relation to the forthcoming cycle can be carried out on the basis of coincidence of goals and constraints, the proximity of the quality parameters of the products received, the proximity of the duration of the completed and forthcoming cycles, the closeness of the initial conditions, and the lowest costs for output of the unit of production.

4. Stages of formation of control programs based on precedents

The procedure for solving the above problem on the basis of the precedent method includes the following components:

1. Control of parameters $Z^{FS}_j(t_i) = \{Y^{FS}_j(t_i), S^{FS}_j(t_i), W^{FS}_C(t_i)_j, U^{FS}_j(t_i), t_i \in [0, T_j]\}$ and calculate the estimates of the performance indicators $Q_m(T_j) = F_m\{Z^{FS}_j(t_i), t_i \in [0, T_j]\}, m \in M_E$ of the control system in the course and at the end of the j-th time interval $[0, T_j]$. In particular, the cost of implementing the j-th technological cycle can be used as the main indicator of efficiency. The components of the vector $Z^{FS}_j(\cdot)$ have the form:

$$Y_j^{FS}(t_i)=[y_1^{FS}(t_i),...,y_n^{FS}(t_i),...,y_N^{FS}(t_i)]_j; \qquad S_j^{FS}(t_i)=[s_1^{FS}(t_i),...,s_l^{FS}(t_i),...,s_L^{FS}(t_i)]_j$$
$$W_{Cj}^{FS}(t_i)=[w_{C1}^{FS}(t_i),...,w_{Cr}^{FS},....,w_{CR}^{FS}(t_i)]_j; \qquad U_j^{FS}(t_i)=[u_1^{FS}(t_i),...,u_p^{HS}(t_i),...,u_P^{FS}(t_i)]_j \quad (1)$$

All data on the measured values of the parameters, on the actually implemented control program $PR(j,t_i)$, as well as on estimates of the calculated indicators $\{Q_m^{FS}\cdot(T_j)\}$ are placed in a special database.

2. Retrospective optimization (at the end of the j-th technological cycle) of the actually implemented program:

$$PR^{FS}(j,t_i)=\{u_1^{FS}(t_{1i},\tau_1),....,u_p^{FS}(t_{pi},\tau_p),...,u_P^{FS}(t_i,\tau_P);Y_j^{FS}(t_i);S_j^{FS}(t_i);t_i,t_{pi}\in[0,T_j]\} \quad (2)$$

where $\{u_1^{FS}(\cdot),....,u_P^{FS}(\cdot);t_i\in[0,T_j]\}$ is the actual program of control actions; $Y_j^H(\cdot)$ – the actual program of output variables of the object; $S_j^{FS}(\cdot)$ – the actual program of variables of the object state; $\tau_1,...,\tau_p,....,\tau_P$ – application time of the 1,…,p,…P-th control actions; t_i – current (i-th) time point belonging to the cycle $[0,T_j]$; t_{pi} – the moment of the beginning of application of the p-th control action. Optimization is carried out in accordance with formula (3):

$$PR^O(j,t_i)=\begin{cases}PR^{FS}(j,t_i),\ if\ Y_j^{FS}(T_j)=Y_j^*(T_j);\ S_j^{FS}(T_j)=S_j^*(T_j);\\ Ag\{PR^{FS}(j,t_i);t_i,t_{pi}\in[0,T_j]\};\ if\ Y_j^{FS}(T_j)\neq Y_j^*(T_j);\ S_j^{FS}(T_j)\neq S_j^*(T_j)\end{cases} \quad (3)$$

where $PR^O(j,t_i)$ is the optimized control program for the j-th technological cycle; $Ag\{\cdot\}$ – the operator (algorithm) of retrospective optimization [6, 7] of the actual (full-scale) program $PR^{FS}(j,t_i)$ implemented in the period $[0,T_j];Y_j^*(T_j),S_j^*(T_j)$ – the specified values of the output variables and variables of the object state at the end of technological cycle, i.e. at the point of time $t_i=T_j$.

$$PR^O(j,t_i)=\{u_1^O(t_{1i},\tau_1),...,u_P^O(t_i,\tau_P);Y_j^O(t_i);S_j^O(t_i);W_C(j,t_i);t_i,t_{pi}\in[0,T_j]\} \quad (4)$$

The first line of formula (3) corresponds to the case when the actual and target values of the goal variables $Y_j^{FS}(T_j),S_j^{FS}(T_j),Y_j^*(T_j),S_j^*(T_j)$ (with a given accuracy) almost coincide, that is, the operator $Ag\{\cdot\}=1$. The second line is realized when the specified values of the goal variables are significantly different.

The operator $Ag\{\cdot\}$ uses the difference mathematical model of the control object of the following form:

$$\begin{cases}\Delta y_n^A(T_j)=\Phi_n\{[u_P^{FS}(t_i)-u_P(t_i)]_j;p\in[1,P];n\in[1,N];u_P^{FS},u_P\in U_j^{FS}\},\\ \Delta S_m^A(T_j)=F_m\{[u_P^{FS}(t_i)-u_p(t_i)]_j;m\in[1,M];p\in[1,P];u_p^{FS},u_p\in U_j^{FS}\},\end{cases} \quad (5)$$

where $\Phi_n\{\cdot\},F_m\{\cdot\}$ the operators of the recalculation (difference) type, which in the simplest form represent the tables of recalculation coefficient:

$$\Delta u_p \to \Delta y_n; \qquad \Delta u_p \to \Delta s_m \tag{6}$$

The optimized control programs $\{PR^O(j,t_i); j \in J; t_i \in [0,T_j]\}$ are placed in a special database of optimal (rational) programs, which are considered as precedents at the stage of forming control programs for the upcoming technological cycles.

3. Formation of a subset of actual precedents for the forthcoming (j+1)-th period of the object's operation.

$$\{P\hat{R}(j-m), m \in [0,M]\} \Leftarrow B\{[Y^o_{j-m}(T), Y^*_{j+1}(T), m=\overline{0,M}];[S^O_{j-m}(T), S^*_{j+1}, m=\overline{0,M}]\}, \tag{7}$$

where $B\{\cdot\}$ – an algorithm for selecting precedents that correspond to given values of the target variables $Y^*_{j+1}(T), S^*_{j+1}(T)$ of the upcoming (j+1)-th cycle.

Selection of programs $\{P\hat{R}(j-m)\}$ is carried out by the criterion of maximum closeness of values to the given values $y^O_{j-m}(T), s^O_{j-m}(T)$. Elements of the set $\{P\hat{R}(j-m), m \in [0,M]\}$ are ordered in descending order of proximity criterion.

4. Interactive selection by the operator – technologist of the retrospective-optimal program $PR^*(j+1,t_i)$ from an ordered set $\{P\hat{R}(j-m)\}$ that corresponds to his preferences $PR^*(j+1,t_i) \in \{P\hat{R}(j-m), m \in [0,M]\}$.

5. Adjustment of the selected program-precedent $PR^*(j+1,t_i)$ in the presence of significant deviations in the parameters of disturbances $W_C^{FS}(j+1,t_i)$, the upcoming cycle of operation of the technological control object from the corresponding parameters $W_C(j+1,t_i)$ of the selected program. In this case, a difference mathematical model (5) is used, which is supplemented by a difference model of the effect of controlled perturbations.

5. Functional structure of the precedent control system

Figure 3 shows a functional diagram of the control system that implements the above described procedure for formation of programs controlling the complex object based on the precedent approach.

An important question in relation to this scheme is the question of the differences and advantages of this method of CTO control from other methods, in particular a method based on type representatives [12] or a method using a retrospective analysis of analogues and prototypes [13, 14]. We believe that the main difference (and advantage) is the use, in real time, of data on the functioning of the current control system, operational accumulation and selection of the best control practices [15]. In this case, it is not necessary to build and continuously update the mathematical model of a complex control object. It is possible to confine oneself to recalculation coefficients in relation to actually implemented controls and controlled disturbances.

As a concrete example of the use of the presented precedent approach, let us consider the task of constructing a planogram of the work of the heading-and-winning combine KM138 (with CGS 13 combine) during the shift [16,17,18]. The planogram is carried out by a replacement link, which includes 10-11 people (combine operator, 7 miners, 2-3 electricians). Parameters of the coal seam: thickness – 1.8 m, face length –180 m. Operating width of the coal combine – 0.63 meters. The standard speed of advancement of the combine is 5 m/min. The standard maintenance time (for one operating cycle) is 30 minutes.

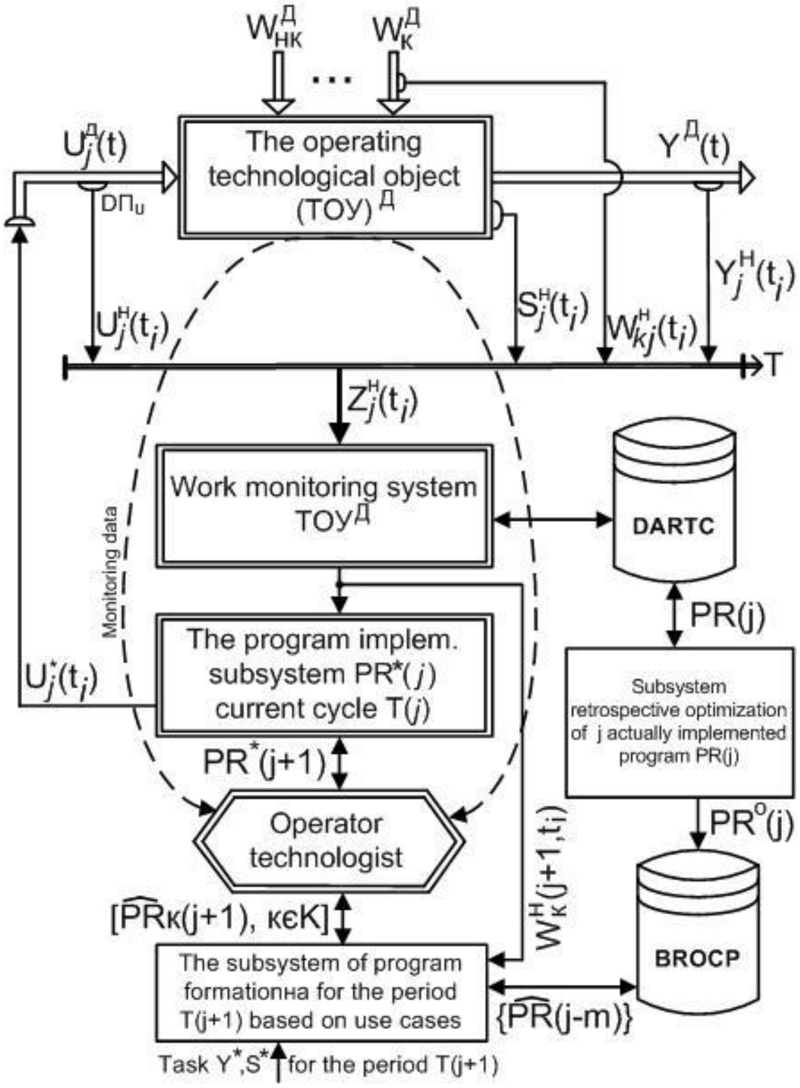

Figure 3. Scheme of formation and implementation of control programs for complex technological objects on the basis of precedents.

(DARTC – database of actually realized technological cycles; BROCP – the base of retrospective-optimal control programs; $PR(j), PR^o(j)$ – actually realized and optimized work program of the object in the period T_j, respectively; $PR^*(j+1)$ – a specified work program for the period T (j + 1); $\{\widehat{PR}(j-m)\}$ – programs from the database of etrospective-optimal control programs for periods $\{T(j), T(j-1), ..., T(j-m)\}$.

In each working cycle, the link performs the following typical operations: preparatory and final, cutting of the combine, combine control during coal extraction, auxiliary operations, movement of the support sections, cleaning of the support base, preparation of the combine for hauling, combine control during the hauling, manual cleaning of the coal not loaded with a combine, preparation for moving the conveyor, moving the conveyor, connection of the face with the belt road, connection of the face with the ventilation drift.

As a planogram – precedent, the schedule shown in figure 4 is selected, which is characterized by accident-free operation during the shift. Its time characteristics are shown in the 1st line of table 1 (a and b).

Table 1. Calculated parameters of the shift cycle.

(a)

No.	Shift starting point t_0	Shift hand-over, min	Start / end of technological cycles, mines				Working speed of the combine, m/min			
			r_1	r_2	r_3	r_4	V_1^*	V_2^*	V_3^*	V_4^*
1	0	38	38 / 125	125 / 210.5	201.5 / 297.5	297.5 / 384.5	5.4	5.0	5.0	5.0
2	0	19.5	19.5 / 104.5	104.5 / 190.0	190.0 / 275	275 / 360	5.5	5.9	5.0	5.0

(b)

Speed of the combine by cycles, m/min				Pauses between cycles, min			Programs
v_1^n	v_2^n	v_3^n	v_4^n	τ_1	τ_2	τ_3	
5.4	5.0	5.0	5.0	7.5x4	7.5x4	6x3	$P\hat{R}_j$
5.5	5.9	5.0	5.0	6.8x4	6.8x4	5.9x4	PR_j^o

The drawback of the precedent is the incomplete completion of the last (4th) cycle of work at the shift end. The lost time was 24.5 minutes. The optimization of the planogram can be performed by reducing time from 38 to 19.5 minutes for reception – shift handover and by 0.1-0.2 minutes of pauses between cycles. The parameters of the optimized planogram are given in the second line of table 1.

It should be noted that the above example of the formation of planograms is illustrative (simplified). A real task of this kind requires the full registration of all processes and actions of the work link during each shift, detailed retrospective analysis and optimization of the planogram, not only by performance criterion, but also by the safety criterion, as well as by other indicators.

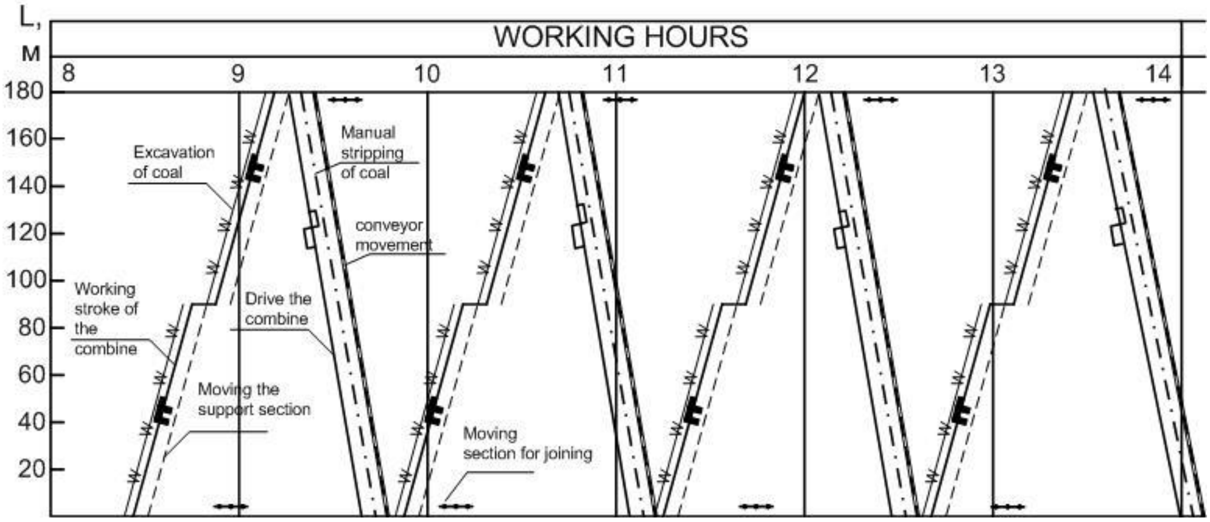

Figure 4. The planogram of the link work, chosen as a precedent.

6. Conclusion

The article considers the problem of applying the precedent approach to decision-making with respect to the construction of management programs for complex technological object of cyclic action. Information on control decisions (control programs) of the operator – technologist, related to the previous technological cycles, is accumulated in the DARTC database. Then, the procedure for retrospective optimization of past decisions that in the BROCP database and, in the future, are used as precedents for choosing a management program for the upcoming technology cycle.

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