THE LIMITED LIABILITY PARTNERSHIP «TST-16»

SSG program for the project "Stimulation of productive innovations"

TECHNICAL REPORT
on the work done and the results obtained, therefore, a subproject:
"Automated on-line monitoring system of incoming ore flows for mining and processing plants"
in the first half of 2017

Almaty, 2017

1. General information

This report is planned and compiled in accordance with the reporting regulations approved by the International Council for the Commercialization of Innovative Developments for World Bank Borrowers, and, in accordance with the fiduciary guidelines and other regulatory documents of this organization.

The report includes information on all the main works and organizational and technical measures carried out to implement the concept of commercialization of innovation: "Automated system for the operational monitoring of the quality of incoming ore-flows of the ore mining and processing enterprise", defined by the application No.APP-SSG-16/0330P and financed in accordance with the agreement On Grant No. 46 of November 30, 2016.

A brief summary of all the works and activities is given in the table below in the text of this section.

In the following sections of the report, the main results of engineering developments made in the first half of 2017 are given. A detailed description of the total volume of work performed and the results obtained, which are mentioned in this report, can be found on the website aosyst.kz. By the link "tst-16".

Table 1 - Summary of engineering developments, organizational and technical measures performed to LLP "TST-16" as of June 26, 2017

№	period	Name of events / works	results	performance
1	Aug 16	Elaboration and Harmonization of the Preliminary Application for the SSG Grant (Phase 1) with the ISCB	The application was developed. Sent to the portal www.fpip.kz. ISCB was reviewed and approved	Done. See Annex 4 (detailed material on the website aosyst.kz in the section tst-16)
2	Oct-16	Preparation of the full application in accordance with the requirements	Submitted for consideration by ISCB (on the portal www.fpip.kz.)	Done. See Annex 4 (detailed material on the website aosyst.kz in the section tst-16)

№	period	Name of events / works	results	performance
3	Nov-16 March-17	Carrying out of actions on creation of the enterprise in the form of partnership with limited responsibility, including: • Creation of a system of documents regulating the duties of the staff and the duties and rights of the enterprise in relation to personnel in accordance with the regulatory requirements in force in the Republic of Kazakhstan. • • Creation of a system of documents regulating the execution of works in accordance with the requirements of the international quality system (ISO-2000) and its Kazakhstan localization: 1. QMS (quality management system). "Quality quide". 2. The instruction on quality at performance of design works. 3. The instruction on quality at performance of starting-up and adjustment works (building and assembly works)	Created LLP "TST-16" Established job descriptions and regulations for each employee, internal regulations, collective agreements, employment contracts. The documentation was developed and signed in accordance with the established procedure	Done. See Annex 4 (detailed material on the website aosyst.kz in the section tst-16)
4	Apr-May-17	The implementation of activities in connection with the "Additional Agreement No. 1" to the "Grant Agreement No. 46 of November 30, 2016"	1. Completion of staffing in accordance with the approved staffing table. 2. Employment contracts with new employees included in the staff list from 01.05.17 3. Official regulations on labor protection, fire safety and electrical safety have been developed and approved. 4. 4. Documents were developed and approved • «"QMS Quality Manual" • • "Quality control instructions" 6. The contract on accounting services of the enterprise is concluded from 01/05/17	Done. See Annex 4 (detailed material on the website aosyst.kz in the section tst-16)
5	March-17-Apr-17	Carrying out of questions of the questions connected with rent of premises	A lease agreement was signed with LLP "AVA-Stroysistema" - a firm that granted LLP "TST-16" permission to the legal address when registering with the justice bodies.	Done. See Annex 4 (detailed material on the website aosyst.kz in the section tst-16)

№	period	Name of events / works	results	performance
6	Apr-May-17	Works and arrangements for the organization of a tender for the procurement of consulting services for the sub-project of the Automated System for the Automated on-line monitoring system of incoming ore flows for mining and processing plants (AS OMIOQ)	1. Development of the Terms of Reference for consulting in accordance with the requirements 2. 2. Publication of TK on the portal www.fpip.kz . Together with a letter requesting the expression of interest. 3. 3. Carrying out a tender for rendering consulting services for LLP "TST-16" for designing the "Automated on-line monitoring system of incoming ore flows for mining and processing plants" (AS OMIOQ) 4. Publication of the results of the competition on the portal www.fpip.kz .	Done. See Annex 4 (detailed material on the website aosyst.kz in the section tst-16)
7	May-17	A draft of the "Supplementary Agreement No. 2" to the Grant Agreement was developed.	The project was sent for approval to the PMU	By the time the report was compiled for the first half of the year, no reconciliation was received
8	May-17	A new version of the document "The Strategy of Commercialization" was developed. The document was compiled at the request of the PMU.	Document on the given form in Russian and English	By the time the report was compiled for the first half of 2017, no agreement was obtained from the ISCB. See Annex 3 (detailed material on the website aosyst.kz in the section tst-16)
9		Development of the document "Specification of methodological and scientific and technical solutions for the establishment of the AS OMIOQ"	A document has been developed on methodological and scientific and technical solutions for the creation of the AS OMIOQ "	Implemented in accordance with the work plan of the Grant Agreement. See Annex 1 (detailed material on the website aosyst.kz in the section tst-16)
10		Development of a working draft document for the AS OMIOQ "System-wide solutions"	The document of the working draft on the AS OMIOQ "System-wide solutions" was developed	Implemented in accordance with the work plan of the Grant Agreement. See Annex 5 (detailed

№	period	Name of events / works	results	performance
				material on the website aosyst.kz in the section tst-16)
11		Development of the document of the working draft on the AS OMIOQ "technical support" (TS)	The sections of the TS document of the working draft at the AS OMIOQ were developed. The document is under development under the subproject implementation plan.	The development is carried out on the basis of the working documentation for the TS AS OMIOQ submitted by the sub-project consultant.
12		Development of the document of the working draft on the AS OMIOQ "mathematical support" (MS)	The sections of the MS document of the working draft at the AS OMIOQ were developed	The document is under development under the subproject implementation plan.
13		Development of the document "information support" (IS) at the AS OMVRC	The document of the IS of the working draft on the AS OMCDR	Implemented in accordance with the work plan of the Grant Agreement
14		Development of application software (software)	The sections of the document "Software" of the working draft for the AS OMCDR have been developed. The document is under development under the subproject implementation plan.	The development is carried out on the basis of the working documentation for the TS AS OMIOQ submitted by the sub-project consultant.
15		Correction of system-wide solutions in terms of the structure and functionality of an automated system for the operational monitoring of the quality of input ore-flows at the dressing plant	Adjusted document "System-wide solutions"	Implemented in accordance with the work plan of the Grant Agreement
16		Substantiation of the selection of specialized measuring equipment for measuring the quality of ore in ore-flows at the inlet of the concentrator	Analytical report on the selection of instrumentation for the AS OMCDR	Implemented in accordance with the work plan of the Grant Agreement. See Annex 2 (detailed material on the website aosyst.kz in the section tst-

№	period	Name of events / works	results	performance
				16)
17	June-17	Formation of the documents "Technical Report", "Evaluation report of subproject monitoring under the GTOS and GNI grants program for the half year to 26 June 2017	Documents in Russian and English languages, including sections: 1.Executed scientific research work for the reporting period; 2. Expenditure Variance Report 3Financial report of co-financing funds (from 30.11.16 to 01.06.17).	Implemented in accordance with reporting to ISCB

1.2. In accordance with the plan for the implementation of the AS OMCDR sub-project, along with the organizational and technical measures outlined in Table 1 of this document, in the first half of 2017, two main stages of engineering work were carried out, the information of which is the subject of the contents of the subsequent sections of this technical report, namely:

1) Specification of methodological and scientific and technical solutions for the creation of an automated system for the operational monitoring of the quality of incoming ore flows at the dressing plant.

2) Development of a techno-working project for the development of an automated system for the operational monitoring of the quality of incoming ore-flows of a mining and processing enterprise, which includes the following components:

- Development of system-wide solutions.
- Development of technical support.
- Development of mathematical support.
- Development of Informational support.
- Development of application software.
- Correction of system-wide solutions in terms of the structure and functionality of an automated system for the operational monitoring of the quality of input ore-flows at the dressing plant.
- Substantiation of the selection of specialized measuring equipment for measuring the quality of ore in ore-flows at the inlet of the concentrator.

1.3. In conclusion of this section of the current document, it is appropriate to note:

- The works on specification of methodical and scientific and technical solutions for the creation of an automated system for the operational monitoring of the quality of incoming ore-flow at the dressing plant are being completed in the first half of 2017.
- The development of design solutions for the creation of an automated system for the operational monitoring of the quality of the ore-bearing ore in the mining and processing enterprise will continue in accordance with the plan for the implementation of the subproject and this phase will be completed in the fourth quarter of 2017.

2. Clarification of methodical and scientific-technical solutions for creation of automated system for real-time monitoring of incoming ore flows quality at dressing plant (DP)

In accordance with adopted commercialization strategy, clarification of methodological and scientific-technical solutions for creation of AS OMIOQ is the basic for commercialization products created under given subproject. Such products are: project documentation for automated system of real-time monitoring of incoming ore flows quality at dressing plants; protected intellectual property which determines the technology for real-time monitoring of ore flows characteristics entering enrichment.

2.1. At description of monitoring object, the following terms will be used under corresponding definitions:

Oreflow – transfer of ore during processing using any types of transport and conveyors.

Process stage – technological process which changes the quality or properties of processed material or product. Process stages discussed in this technical report are: extraction, coarse crushing, grinding.

Warehouse –reloading unit at open-pit represented by excavator pit which has railway line on one side and dumping body of warehouse.

Coarse crushing - first stage of ore processing intended for processing of lump material up to 1200 mm.

Monitoring - systematic spatial-temporal observation, analysis and assessment of state of controlled objects and processes and forecast of their changes under influence of various factors.

Ore pile - is a rock mass formed as a result of blasting operations in a quarry. Body of warehouse consists of it.

Ore quality - here it means content of that useful component of ore that is extracted from it during enrichment process.

Train - freight train for transportation of ore with permanent route between two points.

Dump-car - is a freight wagon for transportation and automated unloading of ore.

In modern conditions of ore processing, with multi-flow ore supply to processing stage of dressing plant, the given object has the form shown in Figure 2.1.

Primary raw material in form of gross extraction ore with pieces size not more than 1200 mm from various mines and quarries transported by railway trains to ore unloading zone of dressing plant. Train, as a rule, consists of a locomotive and, on average, 10 dump cars, with carrying capacity of 75 to 105 tons, depending on type. Each arrived train shall have passport data, including train loading point and its weight.

For example, there are two railway entrances to unloading site of ore mining and dressing enterprise SSGPO JSC (hopper car lines No.3 and No.7) after traffic light sign. Traffic lights are installed separately for each railway track.

Each railway track has semaphores to maneuver train at unloading. Semaphore is controlled by operator of coarse-crushing unit (CCU) with help of control panel. By switching on appropriate light of semaphore, the operator instructs the train driver to move forward, backward or stop within hopper car track. While doing this, operator visually assesses the position of dump carregarding the first or second bunker and from control panel gives signal to unload (command to dump). This signal is reflected in unload semaphore: unloading is allowed - green light of semaphore, unloading is prohibited - red light of semaphore. According to operator's decision, unloading can be done in "checkerboard order", alternately from two tracks.

Dump cars unloading is carried out automatically from locomotive driver's cab or his assistant (in place).

At dumping, tilt sensor above bunker triggers, thereby signaling the execution of dump command. After verifying that unloading is completed, operator cancels command to dump, red light of semaphore lights up.

Real-time operational information on full situation and parameters of CCU ore flows along the entire technological chain (from ore supply from various mines and warehouses in railway wagons to ore preparation stage and product exit from crushing unit on conveyors to dressing unit) is provided to all interested services of dressing plant.

Figure 2.1- The monitoring object

2.2 Despite the available examples of developed ore flows monitoring systems for separate production unit there is no wide practice of creating above-mentioned systems of necessary reliability, high efficiency and analytical competence. This is especially evident in multi-flow scheme of ores supply from various mines for processing. Under these conditions, it is practically impossible to obtain estimates of qualitative-quantitative characteristics of ore flows from direct measurements at the input of ore preparation complex in real-time. This is due, first of all, to difficulties of conducting real time reliable and correct measurements of quality and volume-weight characteristics of large-lump ore mass flow (size of a piece up to 1200 mm) entering the dressing plant. Using laboratory data of QC department for and surveying measurements made in the quarry is also of little use because of long intervals between measurements and differences in ore quality assessment of ore mining and processing units.

Selection of points for ore flow quality control and the timing of ore masses supply and reception process for proposed method of input ore quality assessing is given in flow chart on Figure 2.2.

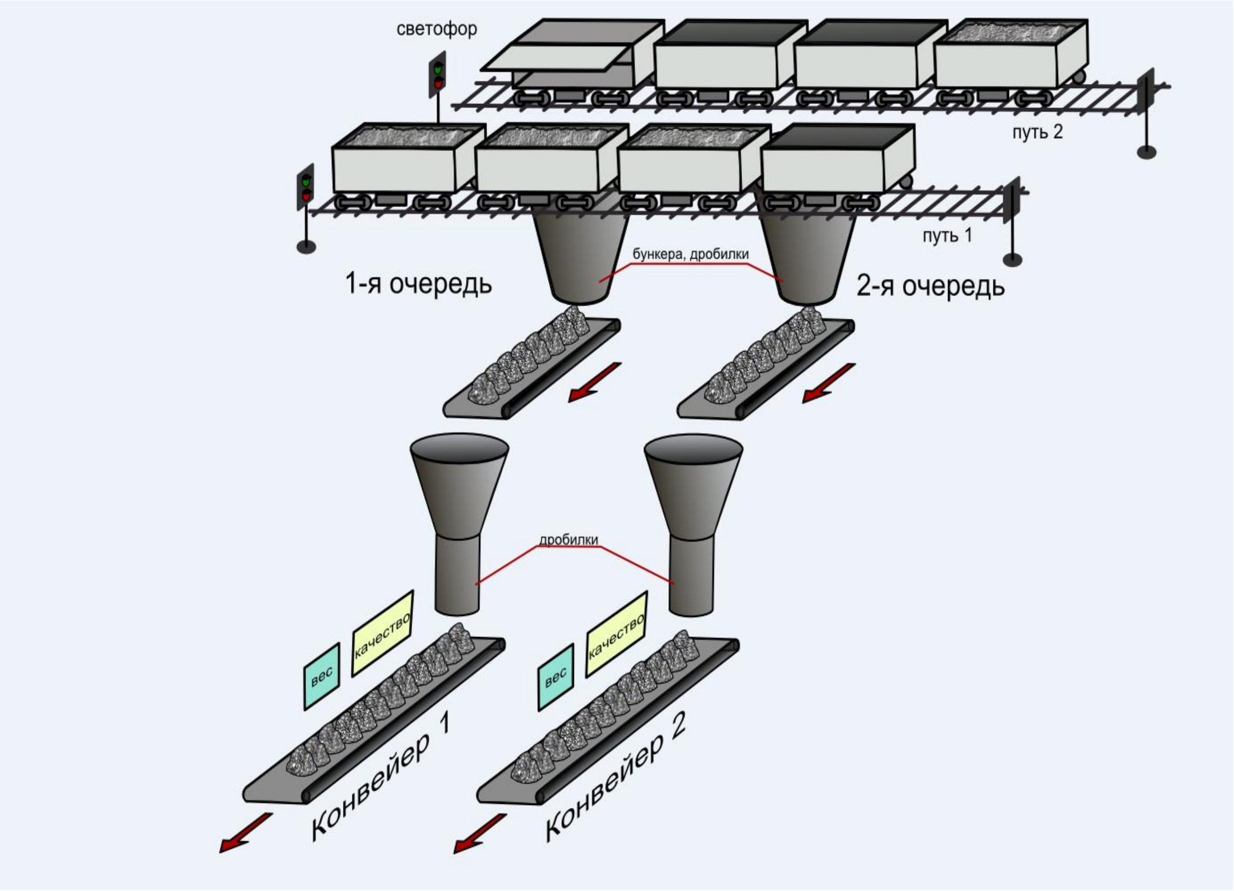

Figure 2.2 - An example of a technological scheme for receiving ore at the ore preparation complex

Measurement of volume-weight and quality characteristics of ore flows is carried out by sensors installed on output conveyors of coarse-crushing unit where ore from separate ore carriers is collected. At the output the ore flow already has characteristics that allow weighing and measurement of quality values. To perform these measurements each conveyor has tensometric scales and magnetic susceptibility sensors.

2.3. Under these conditions, the proposed method is based on evaluation of characteristics of input ore-flows based on direct measurements of appropriate characteristics of integrated output stream which includes ore of various types (deposits) and temporal information about arrival and maneuvering of transport units at discharge zone into receiving bunkers of course-crushing unit.

Proposed analysis method and the algorithm for conveyor flows estimation based on chronology of ore train maneuvering at unloading zone make it possible to reduce solution of task of input ore flows monitoring the projection of unloaded wagons at sections of output flow.

It results in division of output flow into time intervals, each of which is compared to one of unloaded wagons. This allows to determine a train, warehouse (or mine)from which ore arrived since it is necessary to calculate content of useful component in it also to form reporting documentation.

To solve the monitoring task, a set of the following related tasks shall be solved:

- identification of input / output of train for unloading,
- identification of dumping of car,
- modeling of ore passing through processing stages and calculation of expected wagon borders in the output flow,
- analyzes of signal from weight sensor at output flow and defining wagons borders in it.

2.4. Temporal description of ore preparation at input to DP

2.4.1 To increase efficiency of assessing qualitative and quantitative characteristics of input ore flows in proposed methodology it is offered to use the paradigm of temporal model for ore processing at course-crushing unit, which is based on chronology of unloading process of mobile units as well as chronology and magnitude of measurements of qualitative-quantitative indicators of exit ore flow after course- crushing.

The logic is based on reasoning rules considering time factor. Temporal logics are a powerful means of describing events and have great expressive capabilities in representing real time structures. As temporary primitives are used moments (in point logic) or intervals (in interval logics) of time. If time moments are taken as basis, then time intervals can be represented as ordered pair of moments corresponding to beginning and end of time interval. If time intervals are taken as basis, then a moment can be considered as interval of zero length. Main elements of such logics are discussed in [*4, 5, 6, 7*].

2.4.2. With regard to assessment of volume and quality of ore flows, assessment of temporal features of ore input and processing stage allows restoring characteristics of these ore-flows based on chronology of unloading process of mobile units, and also based on chronology and measurements of qualitative-quantitative values of output ore flow after course-crushing. Moreover, temporal model consider peculiarities of solution of such task under current monitoring system, namely:

- necessity to obtain a solution in time constraints of real controlled process;
- necessity to record time factor (dependencies) in describing the problem situation and in process of finding a solution;
- impossibility of obtaining all objective information necessary for decision, and, in this connection, use of subjective, expert information;
- necessity to apply plausible methods of output and active participation in the process of searching for decision-makers;
- necessity to use significant amount of data that change over time (readings of sensor, control parameters values, operator’s actions, etc.)

As noted above, it is quite problematic to perform direct reliable measurements of qualitative-quantitative characteristics of input ore flow in real-

time mode and with accuracy necessary for practice. In this connection, these characteristics can be obtained by calculating by appropriate measurements of output flow. It is clear that without additional information on moments of initiation of flows at inlet of processing stage, dynamics of their motion along crushing complex and chronology of measurements of integral output flow after crushing, this task does not have unambiguous solution. Its solution is possible only in presence of temporal information on dynamics of ore preparation process at input to dressing unit, which allows, according to certain logical rules, to correlate ore mass of transport unit k of unloaded at time t_k and weight of virtual segment of output flow measured on interval$\{t_{ri} ; t_{ri+1}\}$.
Content of such temporal information ensuring uniqueness of solution of task of input ore mass volume and quality control is determined by technological crushing scheme. For most dressing plants, it corresponds to the scheme shown in Figure 2.2. In accordance with this scheme, gross production ore with pieces size not more than 1200 mm, supplied by railway (dump trucks with capacity of 105 tons) from various quarries is fed into receiving hopper of course-crushing unit. Ore from each receiving hopper is crushed up to the size of 350-400 mm, and then fed to second stage of crushing (not shown in diagram), where it is crushed to not more than 22 mm size. Product of second crushing stage is fed to belt conveyors for further processing. Thus, during time ΔT, discrete flows of ore wagons from different quarries after course-crushing are converted to integrated continuous flow of ore for which instantaneous weight and quality parameters can be measured with sufficient accuracy and reliability. Time interval ΔT includes various events characterizing the ore mass move rate to place of measurement of its qualitative and quantitative characteristics, which finally, could serve to determining correspondence between real discrete units input ore flows and virtual segments of output integral flow.

Results of analysis of possible measurements of ore flows dynamics corresponding to mentioned technological scheme, as basic variables that could serve as bases for setting structure forming corresponding logical rules of temporal model, the following events and time intervals are selected:

- moment of car dump,
- time interval when ore car occurs on conveyor before conveyor scales,
- expected time for beginning of ore car flow through scales,
- time interval for ore processing before leaving the crusher of 1st stage,
- time for railway train arrive for unloading,
- flow duration from 1^{st} stage crusher exit to quality control sensors

2.5. Formalization of ore preparation model

2.5.1.To construct temporal model of ore preparation and determine belonging of ore segment output to certain wagon of one of input discrete ore flows at dressing plant entrance, we will use Timed Interval Calculus (TIC) device [2, 3].

Main elements of TIC, used further at formalization of temporal model of ore preparation, define the following concepts:

- Time determining domain (T) is a non-negative real number and interval is sequence of time points, for example, time interval [x ... y] is defined as:
  $\forall x,y: R* [x \ldots y] = \{z: T | x \leq z \leq y\}$
- *Constants.*ForexampleMaxWeightmaybedescribedasrealnumberMax Weight; R, where Ris real number).
- *Temporal dynamics* (trace) is a function of time domain of determining variable. For example, ore weight on conveyor can be represented by time dynamics (Weight) of variable real number domain. So, Weight: T→R.
- *Interval operators*. There are three primitives of interval operators: α, ω, σ having type I → T (where I denotes all intervals and they return the starting point, end point and length of given interval.
- *Interval brackets.* Pair of interval brackets returns all intervals that are defined by predicate inside brackets. Predicate is usually a first-order predicate. For example, for the following TIC expression, [Weight(α)≤ Weight], indicating that value of Weight variable is not less than the value obtained at beginning of interval.
- *Rules.* Rules define temporal properties of intervals and their connections.

All listed elements of TIC-model, except the last one, are intuitively understandable and can be numerically identified for technological object of ore preparation at input to a certain DP.

2.5.2. Rules of TIC-model of belonging of output flow ore segment to a particular wagon of one of input discrete flows, and hence determining belonging of ore to a quarry we will discuss in more detail.

Rule 1. Binding events to the timeline.

If S_i^{sv}=true **then** $T_i^{sv} = t$,

where: S_i^{sv} – sign of the dump of the i-th wagon, T_i^{sv} - dump time of the i-th wagon, t – current time.

This rule means that if an accident occurred in the wagon, the time for the wagon is equal to the current time.

Rule 2. Determination of the time interval for crushing ore in a bunker.

If $⟦ W_i^{oj} - P^{bunk} \neq 0 ⟧ = \{x,y: T \mid \forall t : [x \ldots y] * (W_i(\alpha([x \ldots y])) = W_i^{oj} \wedge W_i(\omega([x \ldots y]))=0 \wedge W_i = W_i - P^{bunk})\}$

then $t^{bunk} = \sigma([x \ldots y])$, where: W_i^{oj} – estimated weight of the ore of the i-th wagon; P^{bunk} - Hopper capacity per second; W_i – Current weight of the ore of the i-th wagon,

t^{bunk} - The time interval for crushing the ore of the bunker.

This rule means that in each cycle (1 second) of the total weight of the ore in the bunker, the quantity equal to the productivity of the hopper per second is subtracted. This rule allows you to calculate the time spent by the bunker on crushing the dumped car and fix the expected moment of the end of the wagon exit from the bunker..

Rule 3. Determination of the time interval from the moment of appearance of the ore of the wagon on the conveyor until the moment of measurement on the conveyor scales.

$$t_i^{konv}=L^{konv}/V^{konv},$$

где L^{konv} – Conveyor length to conveyor weights;

V^{konv} – Conveyor speed.

Rule 4. Determination of the expected time of the beginning of the flow of ore in the wagon through the balance..

$$T_i^{ojnach} = T_i^{sv} + t^{bunk} + t_i^{konv}.$$

This rule means that the expected time for the beginning of the flow of ore in the wagon through the scale is determined by the sum of the time of the dump of the wagon with the time interval for crushing the ore of the hopper and the time interval when the appearance of the ore of the wagon on the conveyor.

Rule 5. Calculation of the length of the time interval of the wagon's flow.

If $[\![S_i^{sv}=true \ \& \ t \geq T_i^{ojnach}]\!] = \{x,y : T \mid \forall t : [x \ldots y] * (S_i^{sv}=true \wedge t \geq T_i^{ojnach})\}$

then { $W_i^{\Sigma}=0$;

while ($W_i^{\Sigma} \leq W_i^{oj}$)

$W_i^{\Sigma} = W_i^{\Sigma} + W_i$;

t=t+1;

end

$\{T_i^{int} = t - T_i^{ojnach}; \ T_i^{ojkon} = T_i^{ojnach} + T_i^{int}\}$

}.

This rule means that if the wagon wreck event occurred and the current time is greater than or equal to the time of the expected start of the wagon unloading, then the condition is checked whether the total weight of the wagon wagon is less than the expected weight of the wagon and, as soon as this condition is not fulfilled, calculated the interval of ore flow of wagon and time of the end of the wagon flow.

Rule 6. Correction rule of the time beginning of the flow of the wagon.

If ⟦W(t)-W(α)≥0,05W(α)⟧ ={ x,y : T | ∀t : [x…y] ∗ (W(t)-W(α([x…y]))) ≥0,05 W(α([x…y]))⋀σ[x…y]≥5}

then $t_i^{nachpot}$=α([x…y]).

This rule means that as the start time of the flow, the system captures a significant (more than 5 seconds) and stable (more than 5%) increase in the signal from the weight sensor.

Rule 7. The rule for adjusting the end time of the wagon's flow**.**

If ⟦W(t)-W(α) ≤0,03W(α)⟧ ={ x,y : T | ∀t : [x…y] ∗ (W(t)-W(α([x…y]))) ≤

0,03W(α([x…y])) ⋀ σ[x…y]≥5}

then t_i^{konpot} = w([x…y]).

This rule means that as the end-of-flow time the system fixes a stable (more than 5 seconds), close to zero (not more than 3%) value of the signal from the weight sensor.

2.6. Implementation of monitoring system using temporal ore-preparation model at input to DP.

2.6.1. The rules of temporal logic was practically used in development of ore flows monitoring system for iron ore. Monitoring system was implemented considering canons of hard real-time systems on duplicated Siemens controller in the form of functionally complete program blocks united by a common algorithm of operating environment of controller. Functional description of these blocks is given further in the text

2.6.2Fixing the time of entry / exit of wagon

Ore is fed to crushing unit along railway tracks. Track occupancy sensors are installed to fix the time of entry and exit of wagons on the tracks. When receiving signal from occupancy sensor, the system records the time when wagon enters the unit. Stability of signal is considered during fixing of time. If signal appears for a short time and disappears, the system identifies the event as a false signal and does not fix the input of train wagons. Exit time is recorded when track occupance signal is removed.

2.6.3. Determination of number of dumped wagons

The task is to identify the moment of car dumping into bunker and counting such dumps for wagon chain on tracks. System uses the following discrete signals to identify the moment of dump:

- track occupancy,
- train movement on track,
- operator's command to dump a wagon,
- signal of wagon dump,

Signal of wagon dump should most accurately reflect the moment of dump. But because of highly noisy environment (dust), sensor does not always provide accurate information. Therefore, system provides for additional algorithmic processing, which allows filtering appearance of false alarms of sensor, as well as identify the dump even in absence of "Dump" signal.

To filter false signals, algorithm takes into account the context facility situation. Wagon dump should be preceded by train entrance (signal of track occupancy), signal of movement on track long enough to locate wagon above the bunker and operator's command to dump. At dumping moment the movement signal should be already absent, i.e. train should be stopped. If dump signal contradicts the context, then such signal is rejected and ignored by the system. For example, if dump signal comes in absence of track occupancy signal, the system considers the dump impossible in absence of train.

On the contrary, if facility situation indicates that wagon should be dumped (train entered, wagon is positioned, operator instructed to dump), but the signal does not come up, the system waits for its occurrence, but even it is absent, records dump if time was sufficient for its unloading. In this case, dump signal stoping moment is considered to be a dump moment.

Train can be unloaded simultaneously to bunker of 1st and 2nd line. Each hopper has its own signals of operator and dump.

2.6.4 Record of weight and quality of ore

Conveyors feeding ore from bunkers on line have scales and magnetic ore susceptibility sensors. Iron content in ore is calculated based on signal from magnetic susceptibility sensor according to the formula:

$$Fe = A*X + B$$

where:

Fe – iron content,

X – magnetic ore susceptibility,

A, B – regression model coefficients for mine that supplied the ore.

A and B coefficients are obtained as a result of statistical processing of ore samples taken from mine. Obtaining these coefficients is not included in the tasks that the system solves. System provides interfaces for entering them and uses the entered values in calculations. Ore comes for processing stage from several mines. Coefficients are given for each of them. In order to calculate the iron content in ore as precisely as possible, the system identifies the ore passing through conveyor for belonging to a particular mine and uses the corresponding coefficients.

2.6.5.Identification of ore passing along conveyor for belonging to a mine

Unloading into bunker can be done simultaneously from two tracks. The unloading trains could come from different warehouses. Therefore, the task is to identify belonging of ore on conveyor to one of dumped wagons. Task becomes nontrivial if unloading is done in dense time schedule and ore is conveyed by a continuous flow. System determines the time limits of wagons in line relative to weights. That is, system determines what wagon ore passed by weight at which certain time. Knowing transport lag value between weights and magnetic susceptibility sensor, the system determines the time boundaries of wagons in line relative to magnetic susceptibility sensor. Wagon time limits in line are determined relating to weights in 4 stages:

1. determination of time when wagon begins passing weights,
2. determination of time when wagon ends passing weights,
3. correction of wagon boundaries in line considering total ore weight in line,
4. secondary correction of wagon boundaries in line considering extremes of signal from weight sensor.

2.7. Determination of time when wagon begins passing weights

At this stage, system determines the expected time when ore from unloaded wagon reaches weights. This time is calculated according to rule 4.

Calculated T_i^{ojnach} is accepted by system as first (approximate) approach of wagon border and further is subject to confirmation considering actual situation on facility. If at occurrence of T_i^{ojnach} no ore is onweights(opening), then as wagon beginning will be considered the nearest ore occurrence on weights. Other cases of correction of wagon beginning moment are closely connected with determining moment of end of previous wagon.

2.8. Determination of time when wagon ends passing weights

2.8.1. At determining the time when wagon ends passing weights, the system relies on expected (known a priori) weight of wagon. Algorithm for determining of time when wagon ends passing weights is carried out according to rule 5. Algorithm sums the weight of ore that passed weights from movement of wagon beginning and at reaching the expected wagon weight fixes the moment of wagon end.

If the expected wagon weight is already met, then for the next wagon the inequality is not valid:

$$T_i^{ojnach} \leq t,$$

where t - current moment,

then the system continues to count weight for the current wagon until the following condition is satisfied for the next wagon. In this case, as end of wagon will be accepted T_i^{ojnach} of next wagon.

2.8.2. If the expected weight of wagon is not reached, but ore flow on conveyor ended (opening), the system fixes the end of wagon but makes additional analysis. If recorded weight is much less than expected (less than 70%), then the system analyzes the moment of end of bunker exit of previous wagon and the moment of beginning of the current one. If difference between these moments makes up a time interval sufficient for appearance of opening on weights, then flow end point is registered as end of previous wagon passing weights. If the time interval is too small or absent, then flow end point is registered as end of the current wagon.

2.9. Correction of wagon boundaries in line considering total ore weight in line

As flow is understood the time interval from moment of ore flow occurrence on weights until the moment of its termination. Wagon boundaries are determined according to rule 6. When fixing the end of flow, system corrects boundaries of wagons inside the flow defined at previous stages. System determines the total weight of ore in flow and number of wagons in it. Next, for each car in the flow, system summarizes its expected weight. Result of this operation is the expected weight of flow. Further, expected flow weight is compared with actual one and the discrepancy coefficient is determined:

$$k_{determined} = \frac{W_{exp.} - W_{act.}}{W_{act.}}$$

where:

$k_{determined}$ - coefficient is determined,

$W_{exp.}$ - expected flow weight,

$W_{act.}$ - actual flow weight.

For each car in the flow, the actual weight is calculated by formula:

$$W_{wag.act.} = W_{wag.exp.} * (1 - k_{невяз.})$$

where:

$W_{wag.act.}$ - actual wagon weight,

$W_{wag.exp.}$ - expected wagon weight.

System then sets wagon boundaries in line so each wagon weight corresponds to calculated for it weight $W_{wag.act.}$

2.10. Secondary correction of wagon boundaries in line considering extremes of signal from weight sensor

2.10.1. When ore appears on weight it does not cause instantabrupt change in signal from weight sensor. Signal has some inertia. This is due to inertia of crusher, which, when receiving ore switches to full capacity with a little delay, as well as damping of the signal itself in order to suppress noise. Similar inertia is observed at the end of flow (Figure 2.3.).

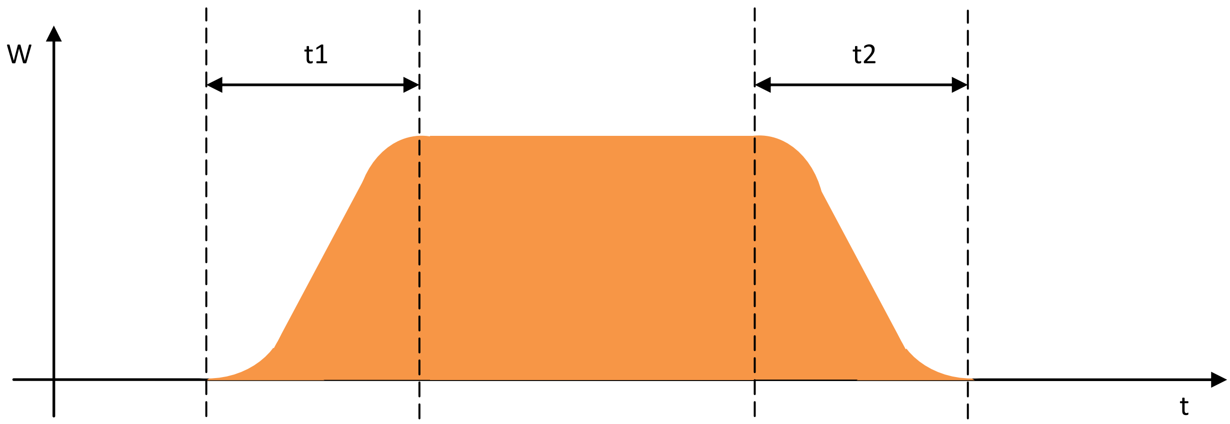

Figure 2.3 - Inertia at the beginning and end of the ore flow on the belt

where: t1 – inertia at the beginning of flow, t2 – inertia at the end of flow

2.10.2. At certain relative duration of dumps it leads to situations where ore flow for wagon is declining and here ore from the next wagon begins to enter weights. Here is extremum in signal from weight sensor (Figure 2.4.):

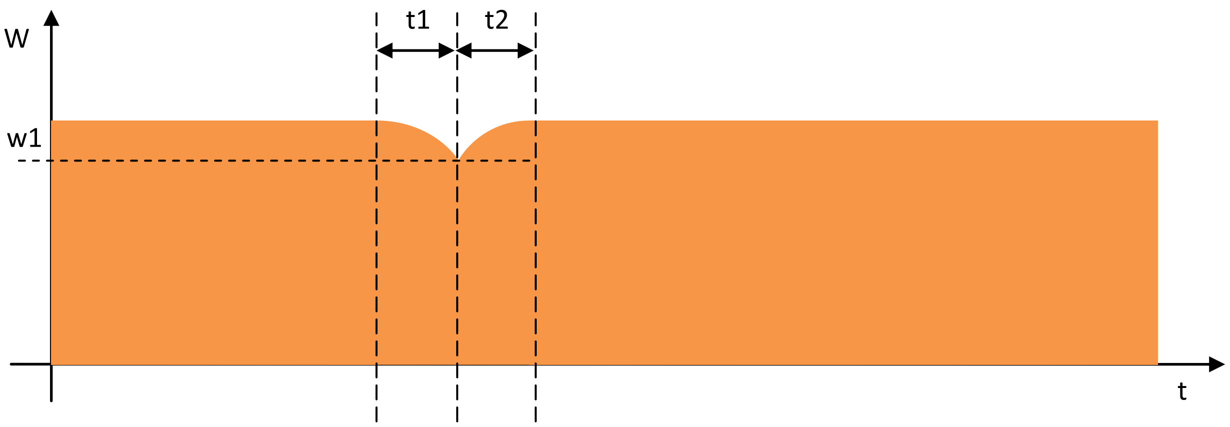

Figure 2.4 - The presence of an extremum in the indication of the weight of the ore flow

where: t1 – end of ore flow from the first wagon, t2 – beginning of ore flow from the next wagon, w1 – Minimum signal from the weight sensor, characterizing the border between the cars.

Processing of such extremes allows more accurate determination of wagon boundaries in flow. Algorithm of secondary correction searches for extremums in the analyzed flow. In finding those, system analyzes the extremum for proximity to wagon boundaries obtained at the previous stage. If found extremum is near one of boundaries, system corrects the boundary taking the extremum moment as a new boundary. If extremum is at a considerable distance from boundaries obtained at the previous stage, system accepts it as change of orevolume on conveyor, possibly due to a failure of ore feed from crusher, and ignores it.

2.11. Joining of train wagons

System provides operator with interface to perform joining of two consecutive wagon trains into one train. This operation might be needed at failure in track occupancy sensor after which signal disappears for a while. When occupancy signal disappears the system registers exit of train, and at next signal registers entrance of a new train. If actually there was only one train on track, operator unifies trains recorded by system. To merge, operator specifies the number of first and the following train and confirms the operation. As a result, system refers train wagons registered as second train to the first train and deletes the second train. To change wagons, iron content shall be recalculated considering parameters of first train warehouse.

2.12. Separation of trains

Similarly, combining operation allows the system to separate trains. It might be needed at failure of track occupancy sensor where track occupancy sensor does not respond to exit of train and occupancy signal remains unchanged. In this case, system does not register exit of train and entrance of the next, and as a result, wagons from the second train are referred by system to the first train. To correct this erroneous situation, operator performs splitting operation. To do that, operator enters the number of train under splitting, number of wagons that shall be left in the train and time of entrance of the next train. As a result, system registers entrance of a new train with time of entrance set by operator and re-ties to it wagons indicated by operator. Iron content is recalculated for re-tied wagons, considering parameters of warehouse of second train.

Proposed methodology aimed at application of temporal model for determining the ore belonging to a quarry during crushing technological process of DP, allows to conduct realtime control of input ore flows and effective management of quality of enrichment process, provide feedback to ore supplying quarries.

2.13. Methodical solutions on effective functioning of Automated system for real-time monitoring of incoming ore flows quality of dressing plant

2.13.1. Method of real-time and reliable monitoring of qualitative and quantitative characteristics of input ore-flows of dressing plant should ensure efficient and reliable functioning of AS being created, and therefore should be able to monitor operability of both the entire system as a whole and its components. In this case, control of AC functioning reliability provides the ability to monitor operability of the system's hardware at all its hierarchical levels, with assessment of operability of "hot standby" mode. Starting from field equipment and instrumentation, including instrumentation for obtaining initial weight data from from conveyor weights, sensors for control of ore useful component content (copper, iron, etc.), traffic light sensors (position of switches on operator panel for dumping of ore trains.) and state of metal detectors on conveyors, up to programmable logic controllers realizing the basic logic of operation of ore flows monitoring system ensuring functioning of “input control” subsystem, including monitoring of wagon movement on unload tracks, control of dumpcarsunloading, quality control and weight of ore flow after coarse-crushing based on qualitative analysis sensor and conveyor weights, up to level of production and dispatch control implemented under client-server architecture on the basis of automated workstations and technologies for application servers and databases.

2.13.2. Proposed methodology for creation of AS considers necessity to assess operability and quality of functional tasks performed by subsystems of AS under creation. In this case, functioning mode of monitoring system should envisage possibility of performing diagnostic and test tasks under mentioned subsystems. These tasks include possibility to check AS operation in various contingencies, including:

- presence of fragments of unreliable data on state of object under control;
- simultaneoususe of AS by a large number of AS users;
- modeling situations when clients attempt to change data without authorization, etc.

2.13.3. Important part of methodology for creation of AS RMIOQof dressing plant is measures for adjustment of created AS at the site, testing it and putting it into pilot production.

Appendix 1 to this technical report contains document: "Clarification of methodological and scientific-technical solutions for creation of automated system for real-time monitoring of incoming ore flows quality at DP", which provides methodological support for development of AS.

3. Development of techno-working project for creation of Automated system for real-time monitoring of incoming ore flows quality of dressing plant(AS OMIOQ).

In accordance with adopted commercialization strategy, project documentation under development is the basic for hardware and software complexes subproject of AS OMIOQ and commercialization product: techno-working documentation for AS OMIOQ of dressing plants.

3.1. Development of system-wide solutions.

3.1.1. Issues of system-wide solutions adopted under development of AS OMIOQ reflect the following sections:

- automation concept,
- tasks of automated system (AS),
- preliminary functional structure of AS,
- main solutions on technical, informational, program and organizational support of AU,
- solutions in related parts of project,
- AS testing program.

3.1.2. Automation concept is based on proposed methodology of AS OMIOQ, technology of their control, set goals and main tasks to be solved at creation of AS.

3.1.3. Initial structural and functional requirements are determined by technical solutions adopted in AS OMIOQ project that correspond to basic principles of modern concept of building automated information-management systems that include the following main provisions:

- System structure should be hierarchical with clear, reliable, inter-level interaction based on standardized industrial data exchange protocols;
- Flexible centralized, hierarchical control and management of automation object;
- Open architecture of information interaction of various components of system;
- Minimum recovery time of system;
- Self-diagnosis;
- Convenient, simple maintenance and intuitively understandable interactive interfaces, together with a high degree of readiness of software and hardware;
- Compatibility with standard software based on DNO technology.
- Process control system and all types of support should be adapted to modernization and expansion. Volume of necessary physical devices and modules should be sufficient to process additional signals in volume of at least 15% (by inputs and outputs) and have a minimum reserve of

memory capacity for control, signaling, programming and further modernization of control process of at least 20%.

3.1.4 AS OMIOQ is a three-level, clearly structured system assessed from functional, algorithmic and technical points of view. Structural diagram of system is shown in Figure 3.1.

3.1.5 Solutions inadjacent parts of project cover the following sections:
- Construction solutions;
- Power supply;
- Solutions on health and safety;
- Solutions for environmental protection;
- Solutions for fire prevention measures;
- Solutions for equipping of operator premises.

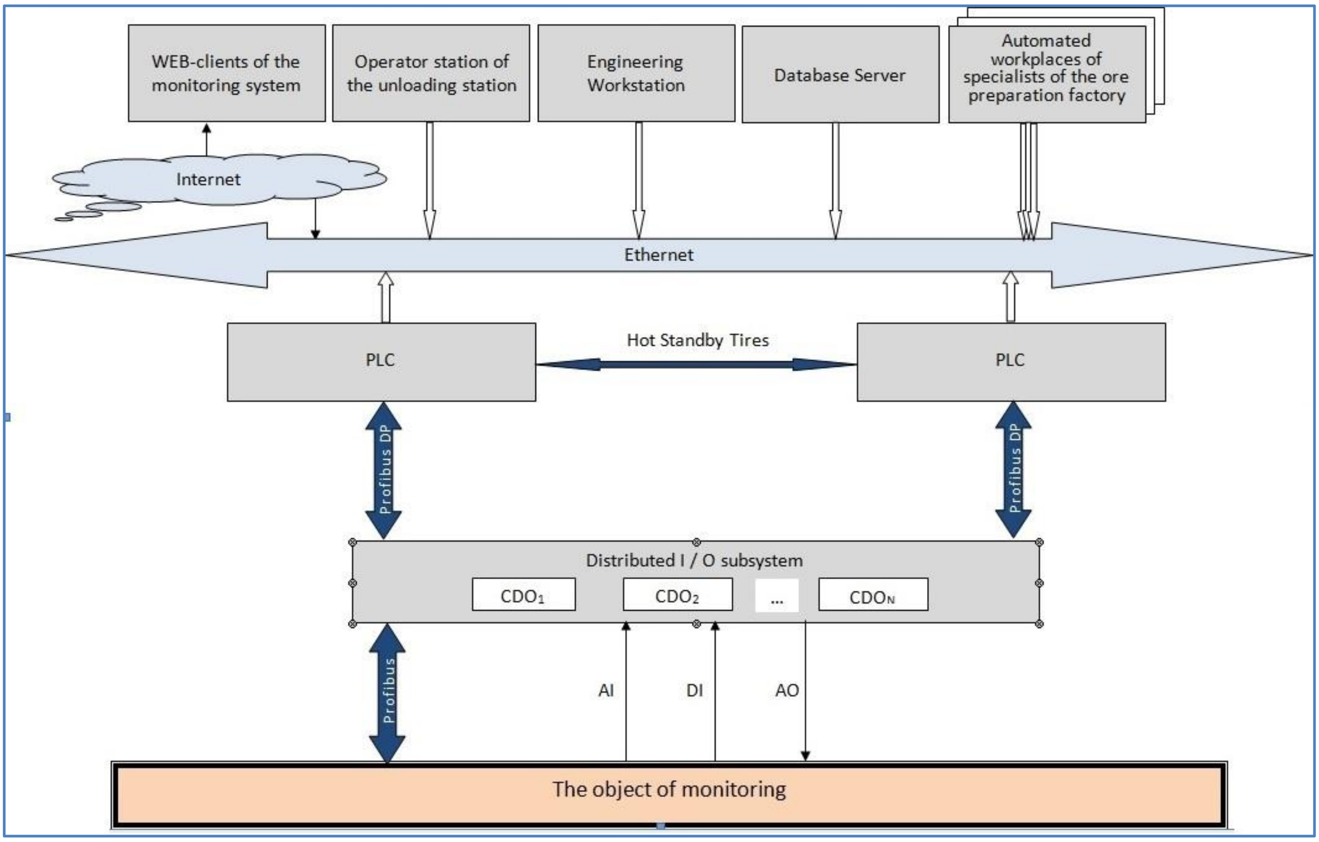

Figure 3.1 - The structural scheme of the AS OMIOQ

Annex 2 to this technical report provides more detailed documentation on system-wide solutions for creation of AS OMIOQ.

3.2. Development of technical support.

This section of AS OMIOQ project, which defines its system hardware and software platform and technical solutions for creation of AS, in accordance with subproject implementation plan, is currently under development.

3.2.1.Structure of automation system. Technical specification for the system as a whole, its functioning, reliability, accuracy, structure of technical equipment complex require the system to satisfy a large number of technical and economic indicators, hardware reliability, accuracy, high reaction speed, convenience of modification and maintainability.

AS OMIOQ is a three-level system with hot redundancy of hardware, with fast automatic non-shock switching from working controllers to standby.

Level I (basic automation) - is based on programmable logic controllers of Siemens. Open architecture allows to supplement the system or apply new technical means providing expansion and modernization of system in the future.

As technical basis of controller equipment, two control systems are used on base CPU Simatic S7 417-5H with hot redundant on "master-slave" principle, ET 200M remote I / O stations.

Controller ensures implementation of the following control functions:

• control of technological parameters:
• data exchange between I / O CPI and control network;
• preventive and emergency alarms.

Use of H-system ensures:

• High reliability;
• Scaling in a wide range;
• Reducing operating costs;
• Minimum demand for cable products;
• Reduced installation costs.

Level II (HMI/SCADA). Top level II has installed servers and workstations of CCU operator, "Crusher" and others connected by local Industrial Ethernet networks with 100Mb data transfer rate and possibility to access in the dispatching system enterprises.

Industrial Ethernet network on SCALANCE X208 switch base, installed in CPU cabinet. SCALANCE X208 module has 8 ports for connecting copper network cables with RJ45 plug. Users connection is suggested to perform with standard TP-cord.

As workstations of operators APM 1,2 and database server are used specialized personal computers SIMATIC IPC847C with RAM of at least 8 GB optical discs with capacity of at least 1TB.

Workstation of unloading operator has specialized embedded personal computer SIMATIC IPC627D with at least 8GB RAM, optical disk capacity of at least 500GB.

At operator control level there is interface of:

• Information display on mnemonic diagrams workstations;

• light signals of process failures and failures
• technical means of system;
• changes in control settings and monitored parameters;
• source of information for archiving process parameters;
• authorizing access to system functions with use of passwords.

3.2.2.Software and hardware platform of AS OMIOQ. Siemens and Microsoft tools are planned to be used as hardware and software platforms.

Industrial servers and computers are used as technological servers of computers for workstations. Network equipment of Siemens.

Reliable, uninterrupted, non-stop operation of system is provided by the following solutions:

• Optimal architecture system, rational decoupling of subsystems;
• use of hot backup (duplication) of controllers;
• use of uninterruptible power supplies for all devices;
• development of enhanced subsystem for diagnostics of system elements.

Proposed solutions will allow replacing the failed units on the move without stopping the system and technological mechanisms.

3.2.3. Hardware platform

Intellectual hardware base of automation is made up of programmable logic controllers of Siemens company. Siemens controller based on CPU Simatic S7 417-5H with hot redundant "master-slave" operation with ET 200M remote I / O stations is offered as technical basis for controller equipment for "incoming quality control" subsystem. Use of H-system ensures:

• High reliability;
• Scaling in a wide range;
• Reducing operating costs;
• Minimum demand for cable products;
• Reduced installation costs.

Stations ET200M are assembled from signal modules of Simatic S7 400 series. They are connected to controllers via IM-153-2 interface modules via Profibus-DP network. To replace I / O modules on the move without disconnecting power in I / O stations, active bus modules are used.

To connect to Industrial Ethernet network, controllers that conduct functions of "Input Quality Control" system are equipped with communication modules CP 443-1.

All controller equipment and ET200M stations are mounted in metal cabinets of IP 55 version (manufactured by Rittal) and connected to the industrial network 220V.

Input-output stations are arranged on the basis of the following signal modules:

- Digital input module SM321;

- Digital output smodule SM322;
- Analog input module SM331;

3.2.4 Software of AS OMIOQ.

Project uses the following software:

- SIMATIC PCS 7, engineering environment system development package V8.2 floating license for 1 user.
- SIMATIC WINCC V7.3, RT 2048 (2048 external variables), System software SCADA-systems, executable software, single license;
- for workstations, there is OC Windows 7 64-bit SP1.

At present, significant part of working drawings of main complex of AS OMIOQ, according to schedule, has been developed, and is given below, contains twenty positions. The remaining engineering design work will be completed in the third quarter of 2017 according to execution plan for subproject of grant agreement.

Table 3.1 - Sheet of working drawings of the main AS complex OMIOQ

Sheet	Name	Note
1	List of project documents	Elaborated
2	**General information**	
3	Structural scheme of a complex of technical means	Elaborated
4	Diagram of interface connections	Elaborated
5	PC cabinet. Power supply scheme	Elaborated
6	PC cabinet. Connection scheme for external postings	Elaborated
7	PLC cabinet Power supply circuit diagram	Elaborated
8	The PLC cabinet. Connection scheme for external postings	Elaborated
9	Cabinet of the Device for communication with the object (CDO). Power supply scheme	Under development
10	Cabinet of the CDO. Input of analog signals	Under development
	Electric schematic diagram	
11.1-11.3	Cabinet of the CDO. Entering binary signals	Under development
	Electric schematic diagram	
12	Cabinet of the CDO. Output of analog signals	Under development
	Electric schematic diagram	
13	Cabinet of the CDO. Output of discrete signals	Under development
	Electric schematic diagram	
14	Cabinet of the CDO. Connection scheme for external postings	Under development
15	Cabinet CDO MV-5. Power supply scheme	Under development
16	Cabinet CDO MV-5. Output of analog signals	Under

Sheet	Name	Note
		development
17	Cabinet UCO MV-5. Connection scheme for external postings	Under development
18	Connection scheme for external postings	Under development
19	Layout of optical cables Profibus	Under development
20.1-20.4	Cable magazine	Under development

3.2.5 Structural-functional diagram of AS OMIOQ of dressing plant and options of analytical monitoring devices to use for such system are shown in Fig. 3.2.

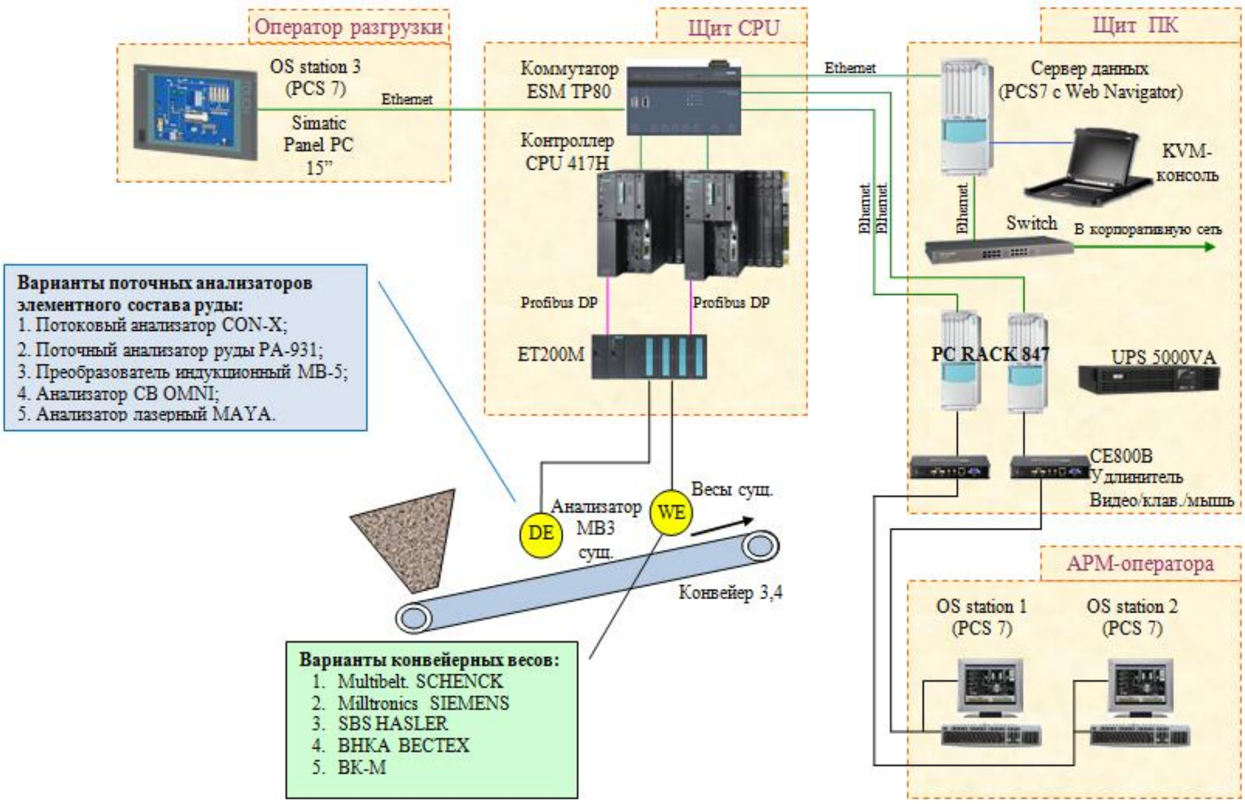

Figure 3.2 - Structural - functional scheme of the system of incoming quality control of ore flow to the dressing plant

Works on recommendations and selection of specialized measuring equipment for measuring the ore quality in ore flows at input to dressing plant show that, according to conducted review of type of excitation source of test substance, all flow analyzers can be divided into 4 types:

1) Instruments with X-ray tube;
2) radioisotope;
3) laser;
4) neutron.

Below, Table 3.1 contains comparative table of characteristics of flow analyzers, depending on type of excitation source. Selection of type of excitation source is individual and depends on the task that needs to be addressed at a particular enterprise.

Table 3.2. - Comparative table of the characteristics of stream analyzers depending on the type of excitation source

Parameters	Instruments with X-ray tube	Radioisotope	Laser	Neutron	Optical
Analyzed elements	From Al to U	From Mg to U	From C to U	From C to U	From H to Mt
Value Range Ambient temperature Air, oC	-20 to +45	-30 to +50	-20 to +45	-30 to +50	
Dimensions, mm	890x275x240	Sensor 150x140x300 Power cabinet 300x250x170	1500x800x1300	2103x1690x1575	Lighting unit 2000x2000x1000 Cabinet with electronics 1300x800x200
Weight, kg	45	Sensor 5 Power cabinet 6,5	450	from 2721 to 4081	180
Area / volume of analysis	Surface	Scope	Surface	Scope	Surface
Limits of detection and accuracy	For all stream analyzers - up to 100ppm (0.01%), vary depending on the elements				
Danger to health Of staff	there is	Unlikely	no	there is	no
Frequency of analysis, samples / min	Continuously	Continuously	3-20	1, Possibly continuously	20

In accordance with the analysis of technical and operational characteristics of stream analyzers, the laser-plasma analyzer MAYA and the magnetic induction converter MV-5 possess indisputable advantages over the others. However, in some cases, for example, when there are already existing streaming analyzers that are acceptable in terms of accuracy and performance, mining equipment can also be recommended for use in monitoring and management systems of ore flow.

In more detail, the possible options for analytical instruments for use in the developing automation system are given in Table 3.3.

Table 3.3. - Brief description of the ore quality analyzers for the proposed monitoring system of input ore flows

Conveyor X-ray fluorescence analyzer of CON-X substance composition	Conveyor flow analyzer of element composition CB OMNI	Induction conveyor converter MV-5	Conveyor analyzers MAYA	ACP-1C streaming digital analyzer
			 	
Conveyor on-line analyzer CON-X is used to identify and measure the concentration of elements and minerals in the ore on a conveyor belt. The analyzer is able to analyze elements beginning with Al (Z = 13) and up to U (Z = 92)	Conducting a continuous analysis of the composition of ore and concentrates. Reliable and accurate analysis of bulk raw materials. The device operates on the principle of gamma-neutron activation analysis.	Inductive conveyor converter MV-5 is used for continuous non-contact measurement of magnetic characteristics of ore flows, with subsequent determination of the mass fraction of magnetite and general iron in ore and its processing products.	Laser Optical Emission (LIBS) analyzer of elemental composition of mineral materials on the conveyor.	Analyzers digital X-ray radiometric technological products in the flow AKP-1C are designed for quantitative determination of mass fractions of chemical elements from calcium to uranium in the range from 0.05 to 70.00% in technological products of processing of mineral raw materials, rocks, ores, pulp, liquid, solid And bulk materials in the flow

This section of the project works is carried out in accordance with the plan for the implementation of the grant subproject and is under development and will be completed in the third quarter of 2017.

3.3. Development of mathematical support.

3.3.1. The documentation on the mathematical support of the OMVRS established by the AC regulates a set of mathematical methods, models and algorithms used in an automated system for incoming quality control of ores entering enrichment. This section of the project is under development in accordance with the implementation plan for the grant subproject. The document is developed in accordance with the requirements for the content of documents including the solutions for mathematical support described in Section 7 of RD 50-34.698-90 and includes a general (consolidated) and block (detailed) description of algorithms for solving the problem of operative monitoring of the quality of input ore flows.

3.3.2. The mathematical support of the AS OMIOQ is a set of formalizations describing the functional of data acquisition subsystems, situational analysis and calculation of qualitative and quantitative characteristics of ore flows from incoming warehousing transport from various warehouses of the mining complex. From a constructive point of view, all formalizations are built on a modular principle and materialize in the form of specialized algorithmic blocks. The composition and functional specificity of the algorithmic base are chosen based on the technological completeness of the operations of the input ore control process, and also taking into account the ideas and positions of the object-oriented approach for constructing the corresponding software on this algorithmic basis.

3.3.3. In general, the algorithm for solving the input control problem allows you to determine the weight of the selected ore flow passing through the conveyor scales for each large crushing stage and identify the point (warehouse) where this ore was submerged. In addition, based on these results and the readings of the magnetic susceptibility sensor, the algorithm makes it possible to calculate the iron content in the ore according to the regression models predetermined for each warehouse and to calculate the performance of the queues.

3.3.4. The result of decomposition of the model into algorithmic blocks of a given functional orientation and their interaction are presented on the structural diagram (Figure 3.3). Below we consider only the classification of elements from the point of view of their implementation by means of object-oriented programming in the form of program modules.

The list of tasks implemented by functional blocks includes the following:

1) Collection and primary processing of signals from the object.
2) 2) Determination of the weight of the ore to be supplied in each train (turntables) and for each loading place of the ore.
3) 3) Determination of iron content in medium-crushed ore from the beginning of the shift, control of the weight of the accepted ore from the beginning of the shift.
4) 4) Information generation for output to the corporate network for monitoring the operation of the 3rd receiving hopper by operational personnel.

The list of functional units of the AS OMIOQ and a description of their main functions is presented below in the text:

1 1 Function block (FB) "RailWay":
- Identification of the input of the train.
- Identification of the output of the train.
- Enter information on the specified train.

- Combining train.
- Separation of train.

3. Functional block (FB) "Identifier of unloading the wagon":
   - Determination of the moment of unloading the wagon.
   - Creation of a new data block "Wagon".
4. Functional block (FB) "Bunker":
   - Calculation of the current mass in the hopper.
   - Calculation of productivity on the output of the crusher.
   - Determination of the time of the beginning of the output of the ore of the wagon from the bunker.
   - Determination of the time ending of the output of the ore of wagon from the bunker.
   - Determination of the data block of the first wagon in the bunker.
5. Functional block (FB) "Scales":
   - Calculation of the "zero" of the weights.
   - Identification of the beginning and end of the flow.
   - Calculation of the total weight of the current flow.
   - Archiving of weight and magnetic susceptibility values in cyclic archives.
   - Identification of the passage of ore of wagon through a weight sensor.
   - Handling of the contingency situation "Uncertain ore"

6 Function block (FB) "Flow processing":
   - Function call (FC) "Determination of the number of wagons in the flow".
   - Calling the function (FC) " Primary correction of the wagon boundaries in the flow".
   - Call of the function block (FB) "Search for extremes".
   - Calling the function (FC) " Secondary correction of the wagon boundaries in the flow".

7. Function (FC) "Determination of the number of wagons in the stream":
   - Determination of the number of wagons in the flow.
   - Calculation of the "discrepancy" coefficient.
   - Determination of the actual last wagon in the flow.
8. Function (FC) "Primary correction of wagon boundaries in the flow":
   - Correction of the expected mass of wagons, the coefficient of "discrepancy".
   - Recalculation of the end time of the passage of the scales by the wagon (and the start time of the passage of the weights of the next wagon) in accordance with the received wagon mass on the basis of an array of weight values.
9. Function block (FB) "Search for extremes":

- Determination in the array of values of the weight of extreme values, that is, the boundary values for wagons.
- Formation of an array of indices of extreme weight values.

10. Function (FC) "Secondary Correction of Wagon Boundaries in Flow":

- The recalculation of the start or end time of passage of weights by the wagon in accordance with the array of indices of extreme values of weight.

11. Function block (FB) "Summary" - formation of summary lines:

- Filling in the fields: the declared weight of the railroad train , the time of entry of the train, the time of output, the number of wagons in the train, the number of the way, the number of the warehouse, the number of the locomotive.
- Calculation and filling of fields: the actual weight of the train, the average iron content in the train.

12. Functional block (FB) "Cleaner":

- Identify "extra" data blocks (DB).
- Delete "extra" data blocks (DB).

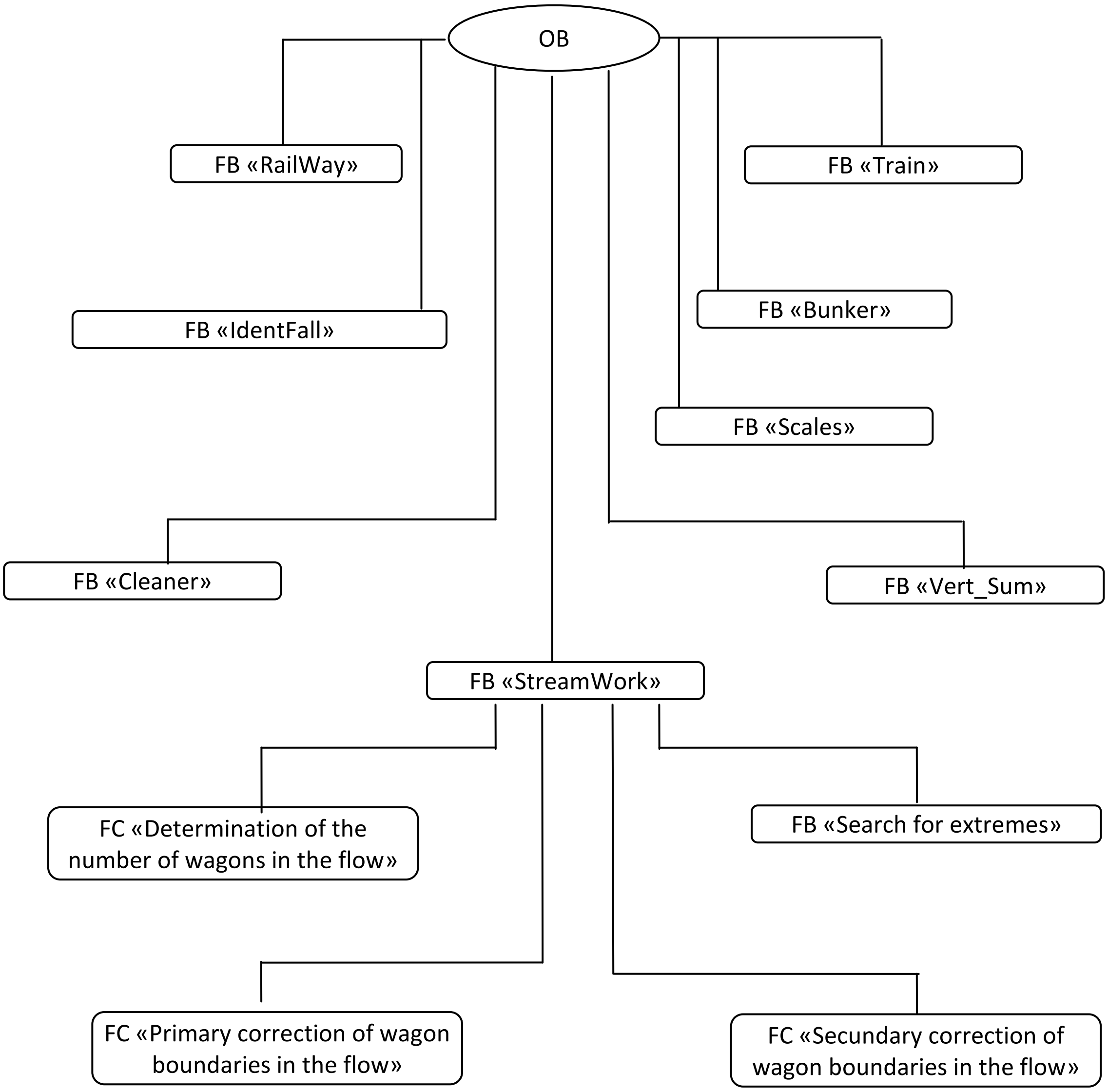

Figure 3.3 - Structure of the construction of the AS OMIOQ based on functional blocks

3.4. Development of information support (IO).

3.4.1. The information support of the AS OMIOQ is represented by sets, blocks, data structures that make up the information fund of the automated system of the AS. In the AS being developed, the AS OMIOQ Information Fund consists of:

– Information fund of the remote controller station AS OMIOQ,
– information fund of the station operator "OS".

The documentation on the Information Support of the AS OMIOQ provides a detailed description of the composition of the information fund of each subsystem, as well as a description of the information flows providing their interaction.

3.4.2 Information fund of the controller station AS OMIOQ

The tasks of the controller station of the AS OMIOQ, hereinafter referred to as the CS AS OMIOQ, are:

- collection and primary processing of information coming from the control object,
- Processing of information received from the facility and the formation of secondary and diagnostic information,
- Bringing complete information about the status of the control object to the form convenient for transfer to the station operator "OS".

Input information. The main information function of the AS OMIOQ is the collection, processing and presentation of information on the status of the automated control object, operational personnel or the transfer of this information for further processing.

The information on the state of the control object comes in the form of discrete input and analog signals to the cabinet "USO" and then through the "ProfiBus" network are transmitted for processing at the CS AS OMIOQ.

Output information. One of the tasks of the KS AS OMIOQ is issuing to the control facility analog signals resulting in the development and implementation of control actions. For example, to adjust the "Zero Weights".

Such signals are generated automatically based on the algorithm of the "FB Scales" function block and / or the value entered manually from the operator panel.

Control signals are output analog signals, the list of which is given in the table of documentation for the IO.

Information fund of the controller station (CS) AS OMIOQ is organized in the form of blocks of data having a specific structure and copies of which consolidate information images (descriptions) of processes and states of monitoring objects in real time. These informational descriptions have the following functional specifics:

- Secondary information about the state of the control object,
- tuning parameters of information processing algorithms,
- intermediate results of calculations,
- diagnostic information about the object and monitoring processes.

The following types of data block instances are specified and used in the CS AS OMIOQ:

1. 1. The type "ANALOG". Data blocks having the "DB ANALOG" type are instances of the "FB ANALOG" function blocks intended for processing and monitoring of analog signals included in the process control system.

   The structure of data blocks of this type is given in Table 5 of the document "Information Support of the AS OMIOQ ".

2. The type "DIGITAL". Data blocks having the "DB DIGITAL" type are instances of the "FB DIGITAL" function block implementing a mathematical algorithm for processing discrete signals.

The structure of data blocks of this type is given in Table 6 of the document "Information Support of the AS OMIOQ ".

3. The type "RailWay" - Way. Data blocks having the "RailWay" type are instances of the "FB RailWay" function block, a module describing the state of the railway bunker track and performing the functions of creating and processing data about the turntables, from the turntable entrance to the track of bunker and to the way out.

This unit has a PCS7 interface and allows the operator to interact with it to enter data on trains of the given path or to perform operations of uniting / separating trains.

The structure of data blocks of this type is given in Table 11 of the document "Information Support of the AS OMIOQ".

4. The type "Bunker". Data blocks of the "Bunker" type are instances of the "FB Bunker" function block, serve to simulate the passage of ore through the crusher and simulate the state of the receiving hopper. As a result of this simulation, the block places timestamps in the DB of the cars passing through it. Such marks correspond to the time of the beginning of the exit from the hopper and the time of the end of the exit of the car from the bunker.

The structure of data blocks of this type is given in Table 7 of the document "Information Support of the AS OMIOQ".

5. The type "IdentFall" - Identification of sites. Data blocks having the type "IdentFall" are instances of the function block "FB IdentFall", which implements an algorithm that during the unloading of the wagon cars into the bunker identifies the moment of the car's wreck ("FB IdentFall"), detects the moment of the pile, creates DBs of the wagons and fills fields The data block of the turntable: "DB number of the first car", "DB number of the last car".
   The structure of data blocks of this type is given in Table 9 of the document "Information Support of the AS OMIOQ"
6. The type "Vertushka" - Turntable. Data blocks having the "DB Vertushka" type are instances of the "FB Vertushka" function block, which are dynamically created for each turntable received for redistribution ("FB RailWay"). The function block "FB Vertushka" performs the recalculation of the number of wagons in the turntable when the fields of the DB number of the first car "," DB number of the last car "(" FB IdentFall ") are changed.

The structure of data blocks of this type is given in Table 8 of the document "Information Support of the AS OMIOQ".

7. The type "Scales" - Scales. Data blocks having the "DB Scales" type are instances of the "FB Scales" function block, serve for analysis and archiving of the weight values of the analog signal coming from the function block. As a result of the analysis, the block:
   - Identifies and fixes the start time of the "flow" and the end time of the "flow" of ore passing through the balance;
   - Preliminarily fixes the fields "Time of passing through the balance" and "Time of the passage of the weights" for objects of the "Wagon" type (further these fields are corrected by the functions of primary and secondary correction);
   - adjusts the "zero balance" and the current weight value, taking into account "zero scales";
   - Calculation of the total weight of ore in the "flow";
   - archiving of weight values in the cyclic archive of the controller station;
   - formation of objects "Wagon" and inserting them into the linked list in case of detection of " indeterminate ore".

The structure of data blocks of this type is given in the document "Information support of the AS OMIOQ".

8. The type StreamWork - Stream processing. Data blocks having the "DB StreamWork" type are instances of the "FB StreamWork" function block, the elements of which perform an analysis of the actual weight passing through the conveyor scales, compares the obtained data with the prospective data of the flow, then, based on the data obtained as a result of the analysis, performs stepwise correction of the wagon boundaries In the flow, bringing them closer to the real value.
   The structure of data blocks of this type is given in the document "Information support of the AS OMIOQ".
9. The type "Vert_sum" - Summary. A data block of type "DB Vert_sum" is an instance of the function block "FB Vert_sum", designed to generate and record the summary data in a data block.

3.4.3. Information fund of the operator's station "OS"

The tasks of the operator station are:

– - reception of information about the state of the object;

- transmission of operator commands, setting parameters and information on the status of acknowledgment of alarm messages to the object;
- Bringing the received information to a graphical view to provide it to the operator;
- providing the operator with an interface for managing the object, as well as an interface for configuring the algorithms for processing information;
- formation and archiving of alarm messages;
- archiving of operator actions;
- providing the operator with access to archived data.

The operator station "OS" transmits the operator's commands, tuning parameters and alarm acknowledgment states to the UMVC's controller station. The list of transmitted data is given in the table of documentation for the IO

The information on the current state of the control object, received from the CS AS OMIOQ, is processed and provided to the operator in the form of mnemonic diagrams, the list of which is given in Table 3.4.

Table 3.4 - List of mnemonic stations of the operator «OS»

№ п.п.	Figure number of the mnemonic scheme	Mnemonic scheme name
1	figure 2	"Input quality control of ore"
2	figure 3	"Diagnostics"
3	figure 4	"Mnemonic schemes and transitions between them"
4	figure 5	"Password protection"
5	figure 6	"Analog parameter display"
6	figure 7	«Alarm signaling»
7	figure 8	"Messages in service windows"
8	figure 9	"Graphs of changing parameters"

3.5. Development of application software.

3.5.1. This section of the project works is carried out in accordance with the subproject implementation plan and will be completed in the 4th quarter of 2017.

3.5.2. The application software of data servers and workstations is designed for execution within the WinCC system integrated in PCS7.

The application software of the controller stations is implemented by the basic tools of STEP 7 software package of the PCS7 system in the SCL language being the extension of this tool.

As additional tools for software development of the controller and technological levels, a set of extensions for the PCS7 package and the Delphi V7 visual programming tool environment were used. Instrumental system Delphi V7 was used only for the implementation of individual utilities in the formation of original operational reports. In other cases, programming was carried out within the framework of the instrumental and language capabilities of the PCS7 package and its extensions.

In particular, programming of application logic at the technological (controller) level was carried out in the SCL language using the tools and libraries of Siemens' proprietary tool product STEP 7 integrated into the PCS-7 system. The software of the upper (dispatching) level is implemented within the principles and approaches of the client-server architecture on the basis of application server and database technologies. For programming, the instrumental capabilities of the WinCC product of the PCS-7 system and Delphi visual programming environment were used. At this level, the necessary functionality of the automated workstations (AWP) of specialists is implemented, including:

- interfaces for monitoring and control of "input control" processes,
- procedures for entering information on the weight, number and place of loading of the composition,
- service for storing and adjusting the coefficients of the regression equations for recalculating the signals of the MV-5 sensors into the values of the magnetic and total iron content, accumulating the archival information about the operation of the PTS,
- software for generating reports and summaries on the results of incoming control of the ore flow entering the DP, and also transferring data through the corporate network to the TSIT server of JSC SSGPO.

For the exchange of data between system components at the technological level, Industrial Ethernet and OPC technologies, as well as communications based on formats, interfaces and protocols adopted for Profibus and Profibus-DP networks are used.

3.6. Correction of system-wide solutions in terms of the structure and functionality of an automated system for the operational monitoring of the quality of incoming ore flows at the dressing plant.

3.6.1. Work to adjust the system-wide solutions include:

- specification of the specification of the technical structure of the AS OMIOQ;

- specification of equipment specifications;

- specification of the composition and formats of data blocks of the information support of the AS OMIOQ;

- specification of the interfaces of the system in the part of inter-level interaction and interaction with the operator;

- specification of the volume of tests of the AS OMIOQ at the facility and the strategy for implementing the system.

These improvements were carried out taking into account the results of the work done on the design and refinement of the methodology for the creation of the AS OMIOQ.

3.7. Substantiation of the selection of specialized measuring equipment for measuring the quality of ore in ore flows at the inlet of the concentrator.

3.7.1. The work on recommendations and selection of specialized measuring equipment for measuring the quality of ore in ore flows at the inlet of the concentrator show that in accordance with the review of the type of excitation source of the test substance, all stream analyzers can be divided into 4 types:

- instruments with an X-ray tube;
- radioisotope;
- laser;
- neutron.

In accordance with the analysis of technical and operational characteristics of stream analyzers, the laser-plasma analyzer MAYA and the magnetic induction converter MV-5 possess indisputable advantages over the others. However, in some cases, for example, when the ore mining enterprise already has streaming analyzers that are acceptable in terms of accuracy and performance, they can also be recommended for use in monitoring and control systems of ore flow.

For more information about this equipment, see Section 3.2.

Literature

1. V.A. Piven, A.V. Romanenko, V.V. Shepel, et al., Investigation of the influence of the variability of qualitative parameters of ore pit flows on the efficiency of iron ore enrichment, Metallurgical and Mining Industry. - 2007. - No. 2. - P. 64-68.
2. Fidge C.J., Hayes I.J., Martin A.P., and Wabenhorst A.K. A set-theoretic model for real-time specification and reasoning. In J.Jeuring, editor, *Mathematics of Program Construction (MPC'98)*, volume 1422 of*Lecture Notes in Computer Science*, pages 188-206. Springer, 1998.
3. Chen C., Dong J.S., Sun J. A Verification System for Timed Interval Calculus. http://www.comp.nus.edu.sg/~chenchun/TIC2PVS, 2007.
4. Prior A. N. Time and modality. Oxford, 1957.
5. Wright Georg H. von. “And next”. -Acta Philosophica Fennica 18, 1965, 293-304. The Georg Henrik von Wright Online Collection, Filosofia.fi
6. Ivin A.A. Temporal logic. In: Nonclassic logic.– M.: Nauka, 1970, p. 124-190. Ivin AA Temporal logics. In: Nonclassical Logic.-M. Science, 1970, pp. 124-190.
7. Karpov Yu.G. Model checking. Verification of parallel and distributed software systems. - SPb .: BHV-Petersburg, 2010.- 560 p.

ANNEX 1

Specification of methodical and scientific and technical solutions for the creation of an automated system for the operational monitoring of the quality of incoming ore-flows at the concentrating mill

ABSTRACT

Keywords: Ore flow, redistribution, storage, large crushing, ore pile, ore quality, train, railway carriage, monitoring, technique, temporal model, automated system.

This document is devoted to the methodology for assessing the qualitative and quantitative characteristics of the input ore flows entering the concentrator, increasing its efficiency by using the paradigm of the temporal model for processing ore raw materials at the large ore crushing section with different properties (from various quarries).

The document contains a description of the temporal model of ore preparation using the Timed Interval Calculus (TIC), which allows real-time identification of a segment of the output ore flow by the criterion of its delivery in a particular railway carriage, at the pace of the process.

The implementation of a monitoring system using the temporal ore-preparation model at the inlet of the concentrator is the basis for the Automated on-line monitoring system of incoming ore flows for mining and processing plants.

ANNEX 2

Justification of the choice of specialized measuring equipment for measuring the quality of ore in ore flows at the inlet of the concentrator

ABSTRACT

Keywords: measurements, equipment, ore flow, ore quality, magnetometry, fluorescence, analyzer, automated system.

The document is devoted to the review and selection of special measuring devices that allow to obtain data on the composition of ore raw materials in real time directly on conveyors, without sampling, which makes it possible to efficiently control the technological process.

The document contains descriptions of the purpose of special measuring devices for their characteristics and manufacturers' data. The data on comparison of measuring and operational characteristics of devices for the purposes of selection and application in the developed "Automated on-line monitoring system of incoming ore flows for mining and processing plants" are given.

The purpose of the document is to justify the choice of measuring devices and inform consumers of this information about the features of existing devices of the intended purpose.

ANNEX 3

TECHNOLOGY COMMERCIALIZATION STRATEGY OF SUB-PROJECT:

«Automated on-line monitoring system of incoming ore flows for mining and processing plants»

ABSTRACT

Keywords: Strategy, commercialization, technology, unmet need, innovation, competition, demand, market.

This document is devoted to the development of a strategy for the commercialization of scientific research results and the creation of an "Automated on-line monitoring system of incoming ore flows for mining and processing plants" (AS ICQO) as an object of commercialization.

The document contains information on the analysis of the market for such systems, describing the prerequisites and unmet customer needs, a brief description of the technology of ore preparation and methodological aspects of the creation of AS based on the use of modern solutions for managing similar objects. The information is specified taking into account the technological features of the control object, expressed in a complex situation in the unloading zone (the operation of the crushers and the degree of their loading), and also taking into account the data on the volume-weight and quality characteristics of the processed ore after large crushing, are restored, with a high degree Efficiency and accuracy, the characteristics of the input ore flows and the use in the AS of temporal ore preparation models. The issues of creation of an industrial prototype and its introduction at enterprises-customers of technology are also reflected.

The information objective of the document is the creation of consumers' of this information with an integral model of the subproject from the stage of creating the AS to its implementation.

ANNEX 4

Overview of organizational and technical activities and developments for the first half of 2017

ABSTRACT

This document is devoted to the review of organizational and technical activities carried out by the enterprise for the period from the submission of the grant application to June 2017.

The document contains structured data - tables - reflecting, not strictly, the sequence of documents and organizational and technical measures, the dates and period of their execution, their results, addressees, comments with links.

The first table "List of organizational and technical documents developed in LLP " TST-16 " as of June 26, 2017" contains a simple list of documents indicating the dates of their completion and the release of documentation.

The second table "The list of organizational and technical measures implemented in LLP" TST-16 "as of June 26, 2017" contains an expanded list of organizational and technical measures with the indication of the period, the date of commencement and completion of their execution and comments with references. Links can be submitted in two versions:

- for the presentation of materials on paper carriers, the links are addressed to the relevant information presented in the form of title pages (with multipage documents) or entirely to documents consisting of 2-3 pages;

- for submission of materials on electronic media, hyperlinks to the corresponding files are used which are in the same folder with the specified tables. The volume of reference information is more than 50 files with a total volume of about 150 mb.

The purpose of the document in question is to provide information for familiarization with the list of completed documents and completed organizational and technical measures for the reporting period.

ANNEX 5

Sub-project: «Automated on-line monitoring system of incoming ore flows for mining and processing plants»

GENERAL SYSTEMS SOLUTIONS

ABSTRACT

Keywords: General system solutions (GS), automated system (AS), functional structure of AS, technical support of AS, information support of AS, software of AS, organizational support of AS, techno-working project, test program for AS.

This document is devoted to the development of system-wide solutions for the creation of the project "Automated on-line monitoring system of incoming ore flows for mining and processing plants " (AS ICQO), which implements the concept of increasing the efficiency of mining and dressing production using modern hardware and software-mathematical solutions at the stage of ore preparation, Taking into account various characteristics of incoming ores.

The document contains materials on the concept and objectives of the AS, the functional structure and the main decisions on the technical, information, software and organizational support of the AS, the test program.

The information contained in the document regulates further detailed developments at various stages and phases of the creation of the " Automated on-line monitoring system of incoming ore flows for mining and processing plants " (AS ICQO).