# D3.1 Report on Work Done and Results

# SAKURA-APM

## Asset Performance Management System for grain processing industry

## PaaS SAKURA-IIoT based


DIH PIAP

Centre 4.0 KPI DIH

INNOVINNPROM LLC

Vinnytsia Automation and Instrument Making Cluster

Vinnytsia National Technical University


Vinnytsia - 2023

# Prerequisites

SAKURA-APM system deployment started in 2020
The main task is to increase the energy efficiency of the grain elevator, thanks to the use of IoT technologies without upgrading the elevator equipment.

### Characteristics of the object of implementation:

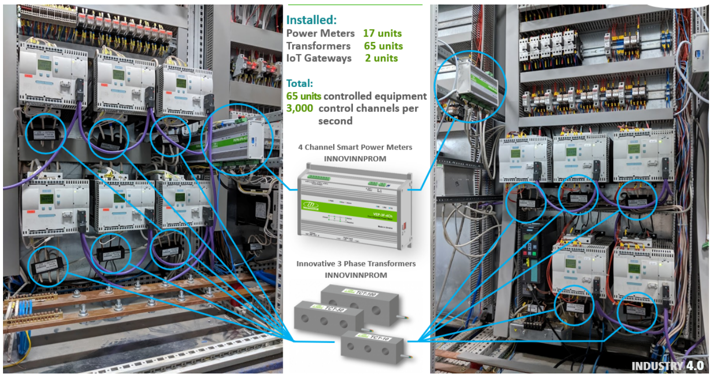
The volume of fully loaded grain storage is 100,000 tons
SCADA - Automated design system "Route" INNOVINNPROM
PLC – Siemens S7-1500, 1500 DI/DO/AI/AO

### Installed:

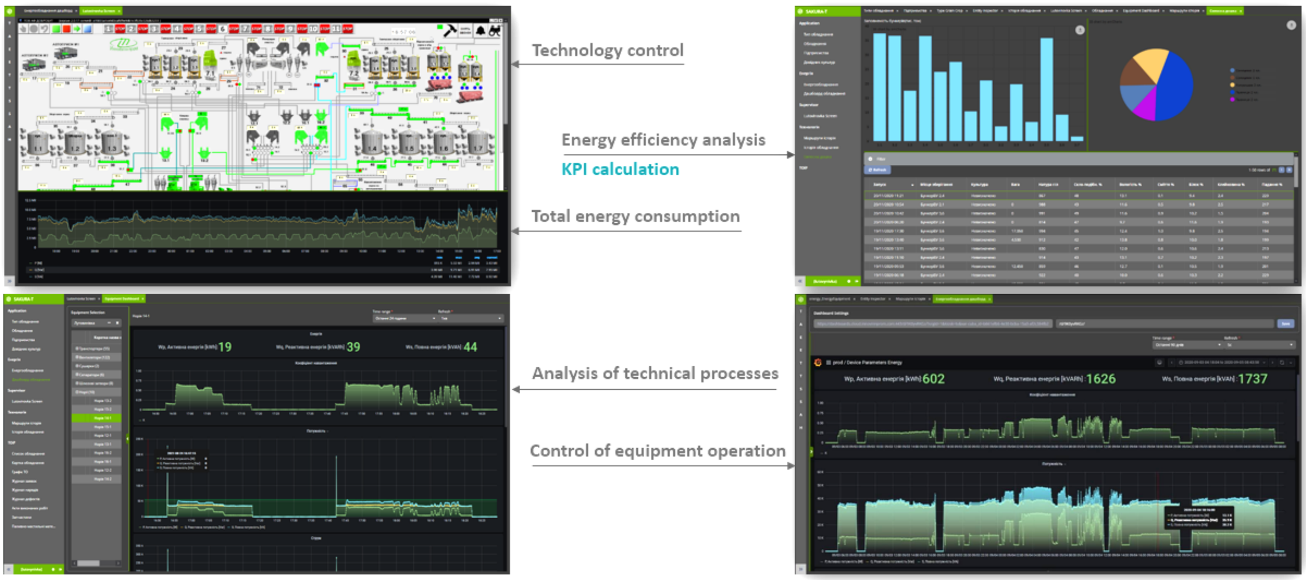
Power Meters INNOVINNPROM 17 units
Transformers INNOVINNPROM 65 units
IoT Gateways TELTONIKA RUT-955 2 units

### Total:

65 units controlled equipment
3,000 control channels per second



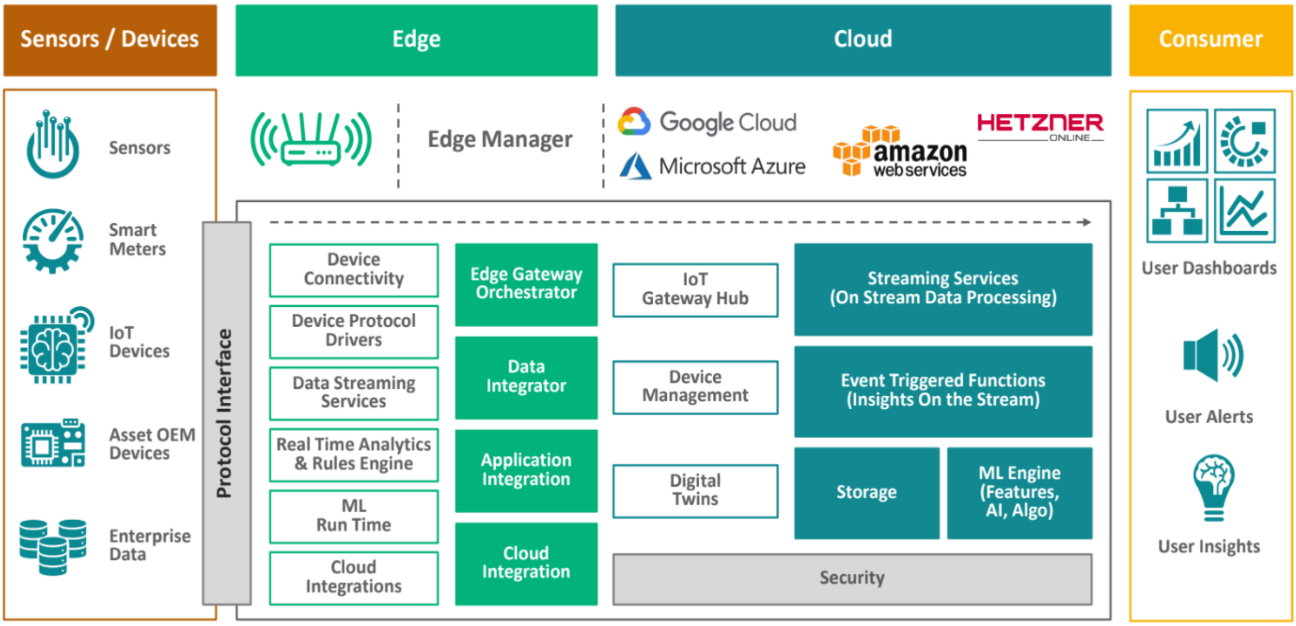

As part of the work, SAKURA-IIoT cloud platform (PaaS) and SAKURA-T cloud software (SaaS) based on it were developed and deployed:




Visualization and analysis of the operation of the elevator equipment made it possible to reduce the energy consumption of the elevator equipment by 8..10% due to the application of administrative and technical measures (optimization of SCADA settings of production management). Of course, the lack of automatic intelligent control and analysis of elevator operation did not ensure the achievement of the maximum effect from the use of IoT technologies.

# General Structure and Deployment of the SAKURA-APM

The Architecture in a Typical Manufacturing Scenario of the SAKURA-APM is shown in the figure:




## Software specification

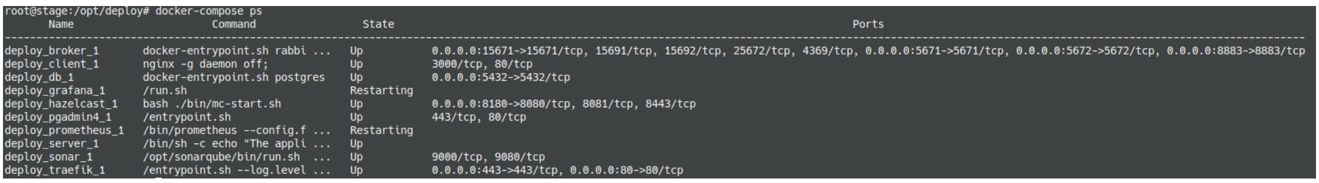
| № | Component | Amount |
|---|---|---|
| 1 | **CAD Route InnoVinnprom 2.0.17/2.0.18** | **1 lic** |
| 2 | **Java 11.0.15** | **1 lic** |
| 3 | **NodeJS 16.15.1** | **1 lic** |
| 4 | **React 16.13.1** | **1 lic** |
| 5 | **Bootstrap 4.6** | **1 lic** |
| 6 | **Grafana 7.1.15** | **1 lic** |
| 7 | **Guacamole 1.1.0 or MeshCentral 0.9.61** | **1 lic** |
| 8 | **PostgreSQL 14.4 with TimescaleDB 2.7** | **1 lic** |
| 9 | **Spring boot 2.6** | **1 lic** |
| 10 | **Python 3** | **1 lic** |
| 11 | **Google Collab** | **1 lic** |
| 12 | **PyTorch 1.11.0** | **1 lic** |
| 13 | **Traefik 2.7** | **1 lic** |
| 14 | **Rabbitmq 3.8** | **1 lic** |
| 15 | **Hazelcast 5.1.4** | **1 lic** |
| 16 | **Sonarqube 9.6.0** | **1 lic** |
| 17 | **Prometheus 2.38.0** | **1 lic** |

The project is deployed on the server capacities of HETZNER hosting.

Docker-compose was used for automatic deployment and node management. The main components are client (client application implemented on React) and server (server application implemented on Spring Boot).

Grafana was used as a visualization of client data, which has integration with database, server and client nodes.

Postgresql with the Timescale Db extension is used as a database, which allows manipulation of time series.



```
root@stage:/opt/deploy# docker-compose ps
       Name                     Command               State                                                                  Ports
-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
deploy_broker_1       docker-entrypoint.sh rabbi ...   Up           0.0.0.0:15671->15671/tcp, 15691/tcp, 15692/tcp, 25672/tcp, 4369/tcp, 0.0.0.0:5671->5671/tcp, 0.0.0.0:5672->5672/tcp, 0.0.0.0:8883->8883/tcp
deploy_client_1       nginx -g daemon off;             Up           3000/tcp, 80/tcp
deploy_db_1           docker-entrypoint.sh postgres    Up           0.0.0.0:5432->5432/tcp
deploy_grafana_1      /run.sh                          Restarting
deploy_hazelcast_1    bash ./bin/mc-start.sh           Up           0.0.0.0:8180->8080/tcp, 8081/tcp, 8443/tcp
deploy_pgadmin4_1     /entrypoint.sh                   Up           443/tcp, 80/tcp
deploy_prometheus_1   /bin/prometheus --config.f ...   Restarting
deploy_server_1       /bin/sh -c echo "The appli ...   Up
deploy_sonar_1        /opt/sonarqube/bin/run.sh  ...   Up           9000/tcp, 9080/tcp
deploy_traefik_1      /entrypoint.sh --log.level ...   Up           0.0.0.0:443->443/tcp, 0.0.0.0:80->80/tcp
```

The screenshot shows all the main and auxiliary applications that have been deployed.

# Tasks, Problems and Limitations

The essence of TTE within the framework of the BOWI project is a study of the feasibility of using AI & ML, Big Data, Digital Twin technologies to achieve maximum energy efficiency and reduce grain elevator energy costs.

During the operation and development of SAKURA-APM, we received more than 100 GB of data per second on the operation of 76 units of grain elevator equipment (three-phase voltage, current & power factor (cos φ), active, reactive & full power, active, reactive & full energy, power time on/off, crop, …)

In addition, practical experiments and work with data were carried out within the following limitations:

- Seasonality of elevator operation - certain routes and equipment operate in a certain season.
- The problem of choosing a route from a deterministic list of 11 routes, each of which has from 85 to 435 options (a total of 2,795 variations), as well as the possibility of constructing unforeseen SCADA routes (tens of thousands of variations).
- Lack of possibility to work with closed commercial data on the type and weight of grain crops.
- The impossibility of achieving an instant result, and the need to conduct long-term research in several days, which is a consequence of the need to move large volumes of grain.
- Impossibility to interrupt or adjust the scheduled business processes of the elevator.
- The cost of one experiment on moving grain is measured in tens of thousands of euros, the cost of an unsuccessful experiment, which can lead to a loss of grain quality or a long stoppage of the elevator, for example, due to an overflow of the noria and a break of the noria belt, can exceed the cost of grant funding.

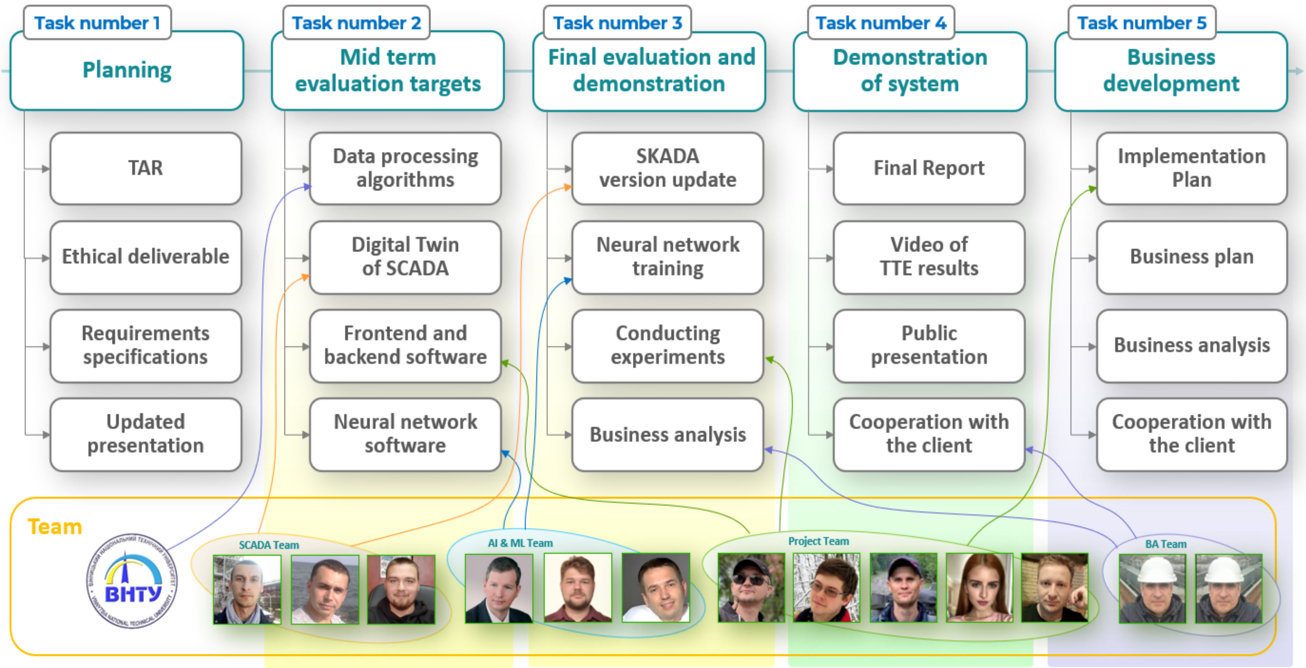
In addition to technical problems, from the start of the project we faced problems caused by the war with the Russian Federation:

- Mobilization of key programmers of our team.
- Mobilization of 50% of elevator workers.
- Staff optimization and reduction of 50% of the agricultural holding's management staff, including specialists with whom we cooperated within the project.
- Rejection of all software services that have Russian origin or funding, which led to the stoppage or incorrect operation of a number of services.

# Start of the Project

The project started with updating and expanding the team. Three teams were created:

1. The **Project Team** led by Andrii Lukhverchyk, which was engaged in solving the issues of updating and optimizing the software stack, obtaining and preparing for Big Data processing, creating a Digital Twin SCADA
2. The **AI & ML team** is headed by Doctor of Technical Sciences, professor of the Vinnytsia National Technical University Vitaly Mokin, who was involved in the implementation of AI & ML technologies.
3. The **SCADA team** consisting of engineers and programmers who solved issues of modernization and updating of system software, SCADA software, PLC firmware, microcontroller hardware, IoT devices.

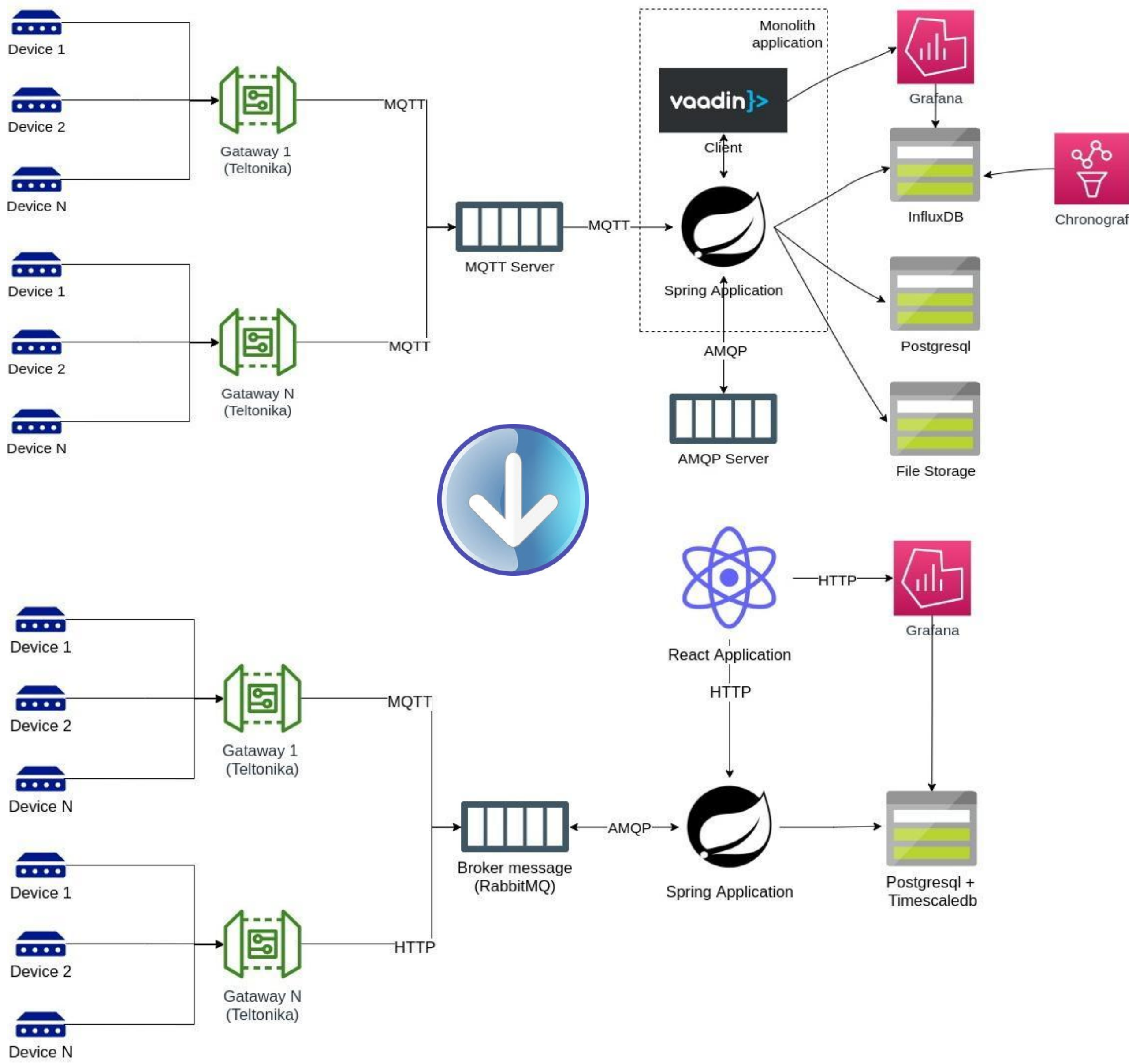



A road map was drawn up and each team received specific tasks.

# Works Performed by Project Team

## Project Team: Simplify and Optimize the Technology Stack

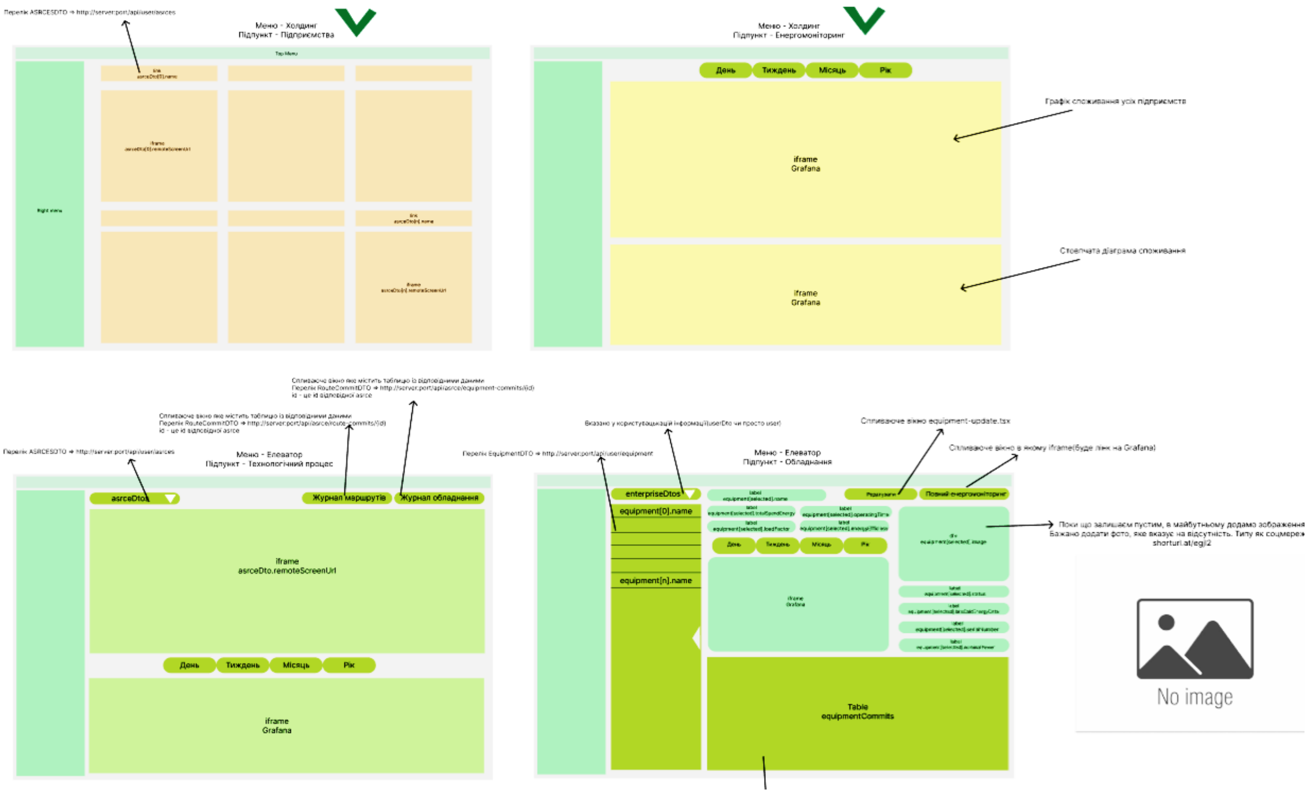
The team received an ambitious task - to simplify and optimize the technological stack of the project, reduce the number of databases and minimize their structure.



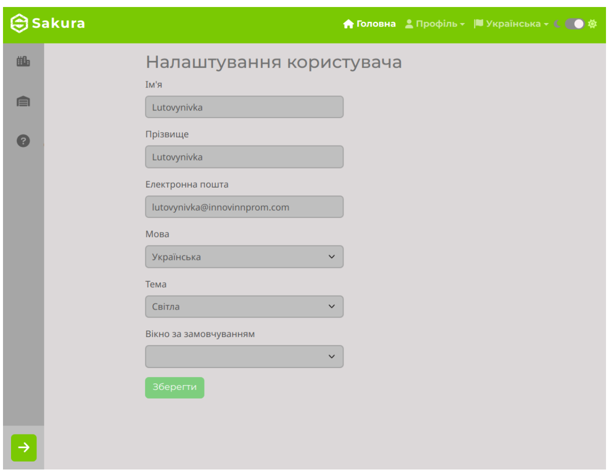

- ❖ The monolithic application was divided into a client and a server.
- ❖ Moved the client part from Vaadin to React. This provides more opportunities for development, simplifies maintenance, allows for easier configuration of horizontal scaling.
- ❖ Due to the TimescaleDB extension for PostgreSQL, we excluded the time series database (Influxdb) and the administration tool (Chronograf).
- ❖ Moved the Mqtt server to RabbitMQ, due to the Rabbit-MQTT plugin.
- ❖ PostgreSQL is used to store files.
- ❖ We increased the fault tolerance of the application due to the introduction of a two-way queue in RabbitMQ.

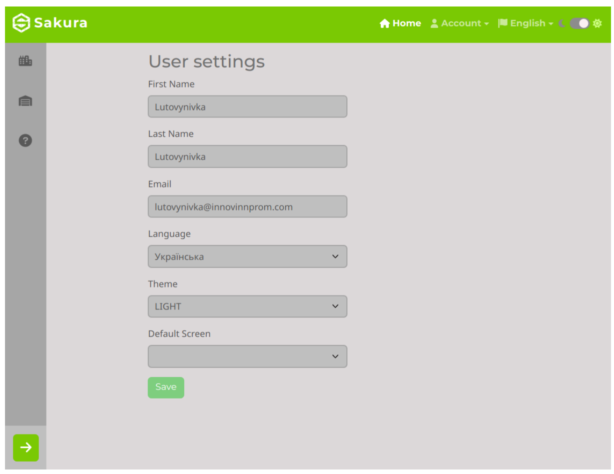
## Project Team: Updating the Interface of the Project Software

The team received an ambitious task - to simplify and optimize the technological stack of the project, reduce the number of databases and minimize their structure.

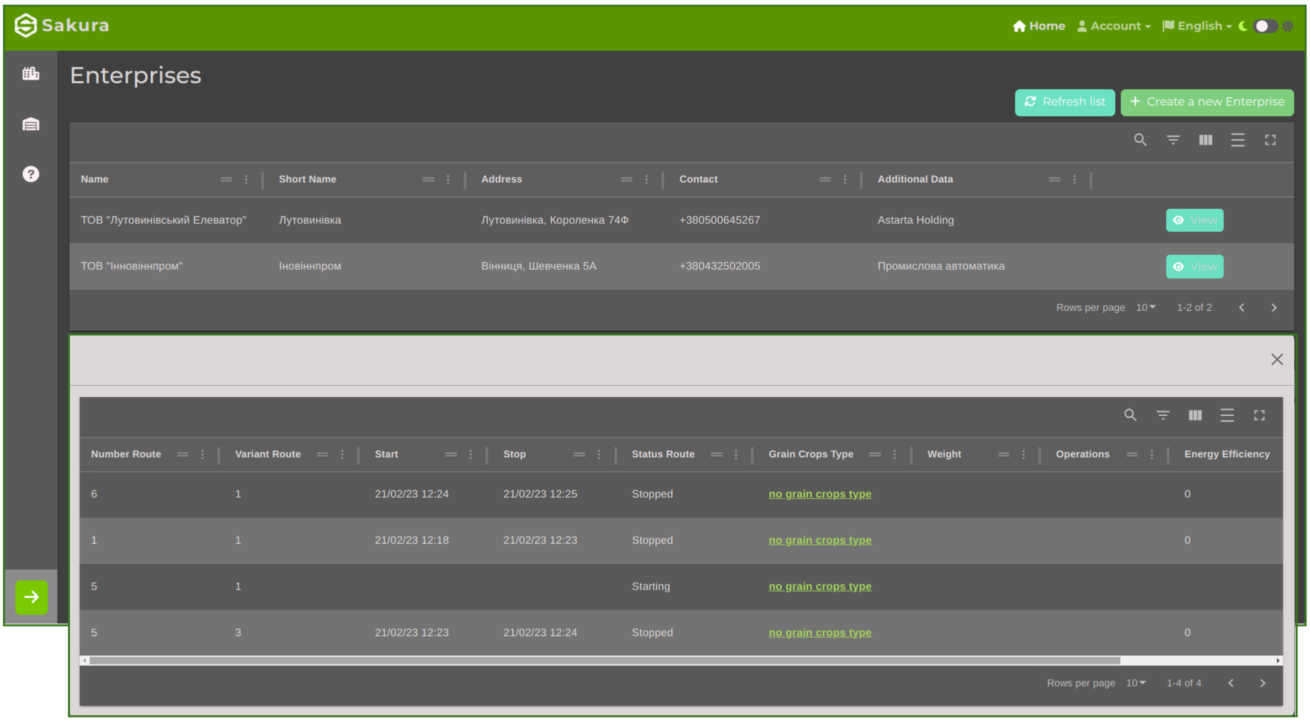


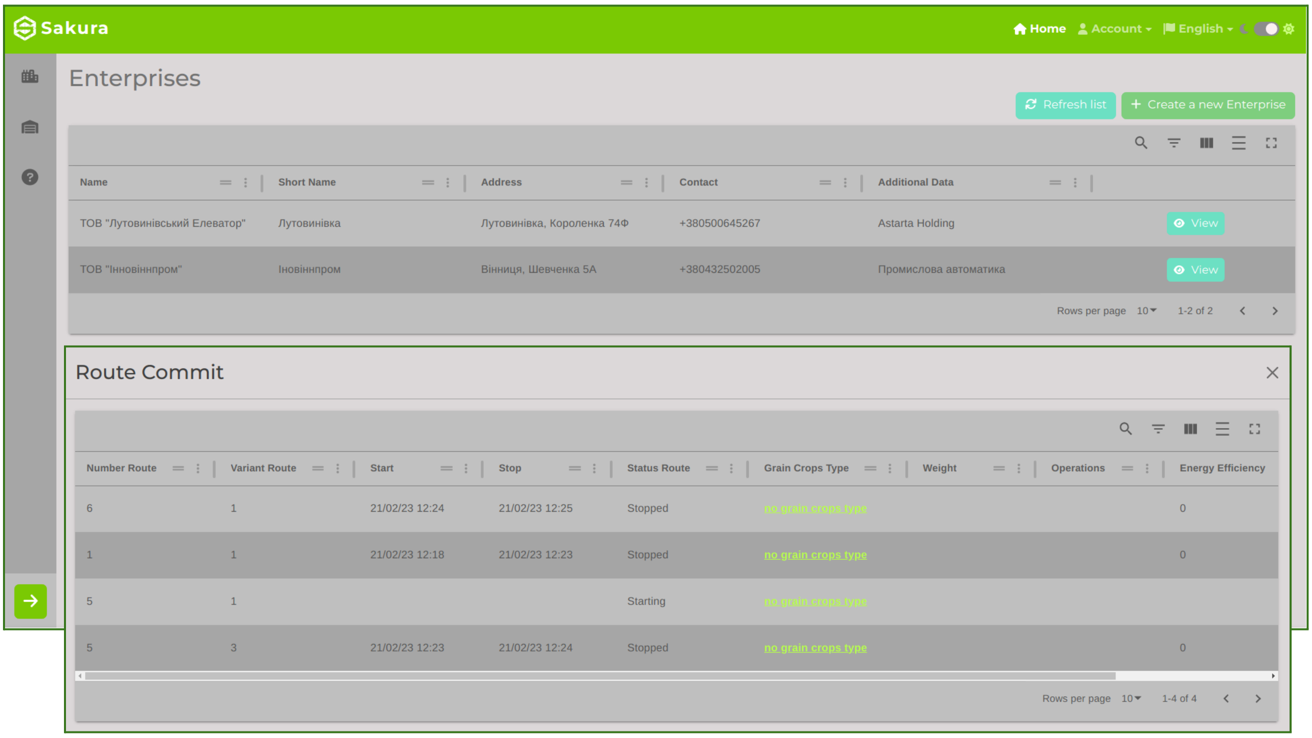

### Added multilingual localization



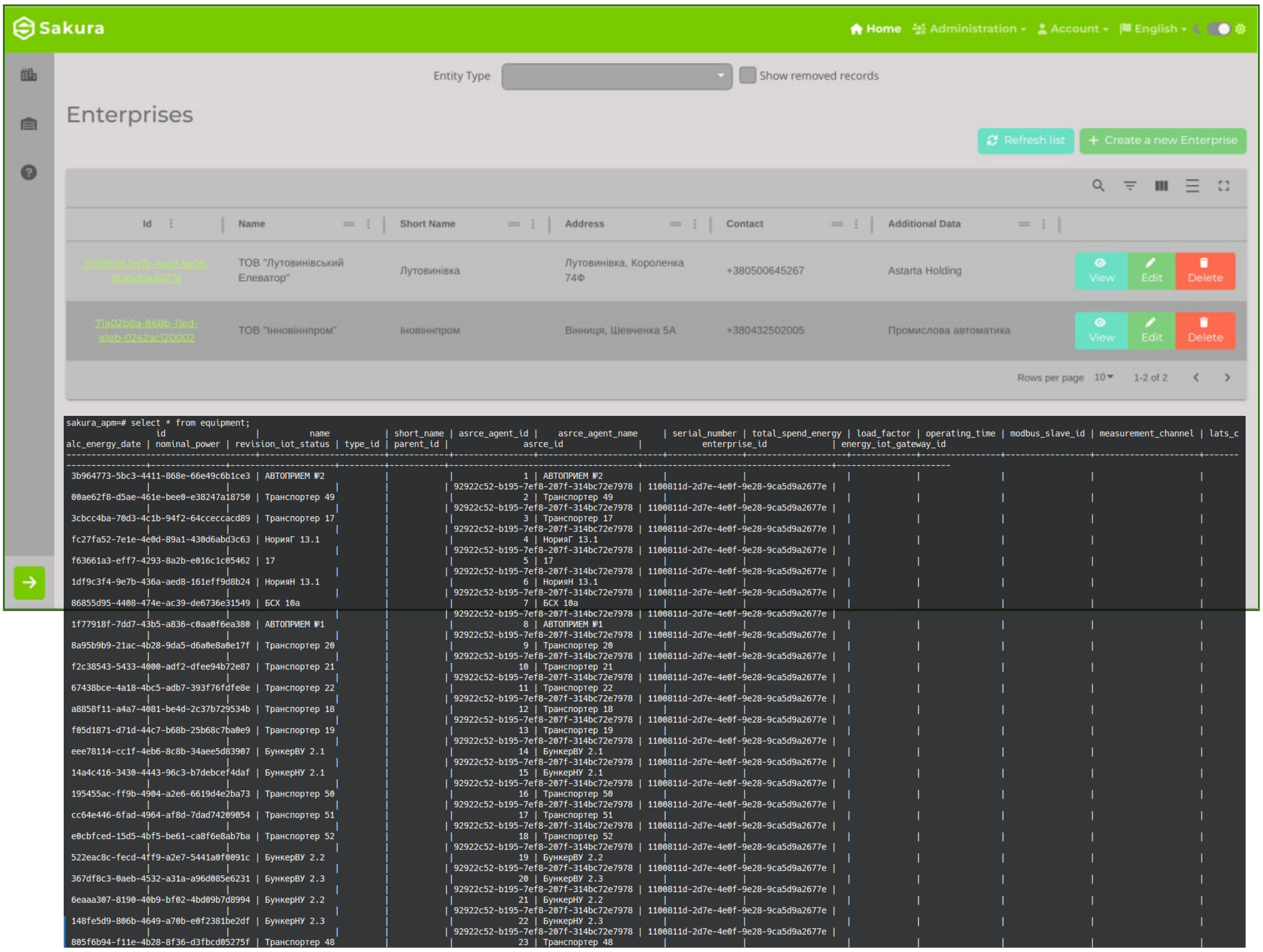



## Project Team: Add Dark Theme to Web Interface of the System

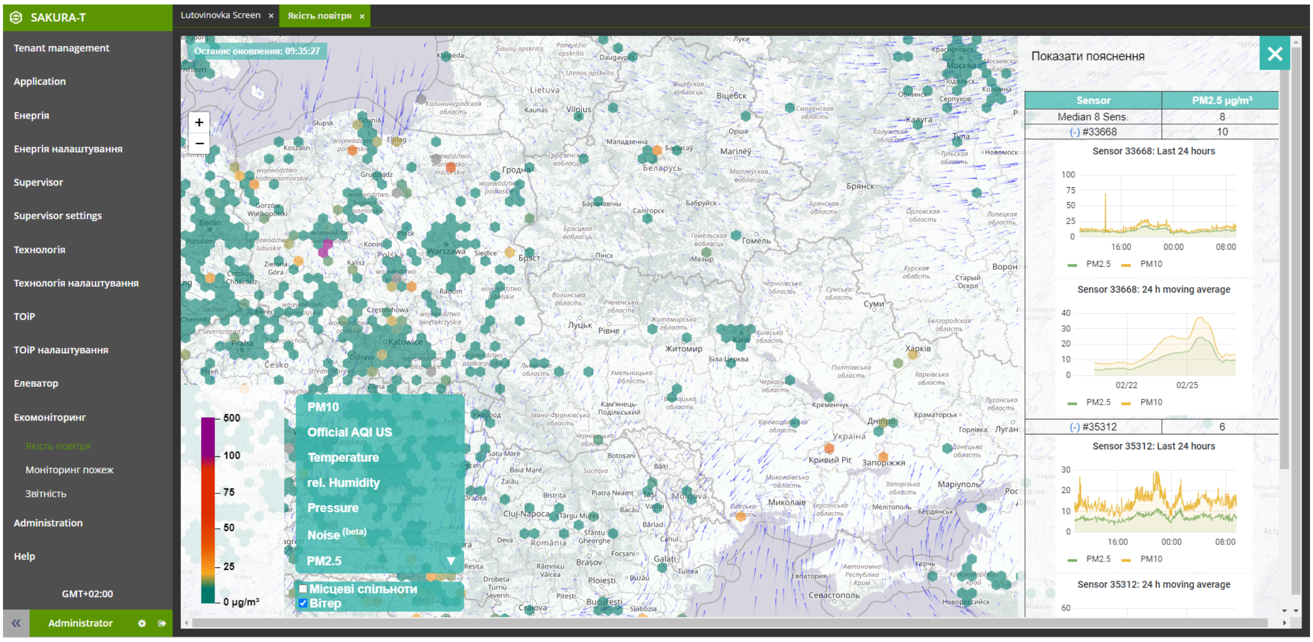


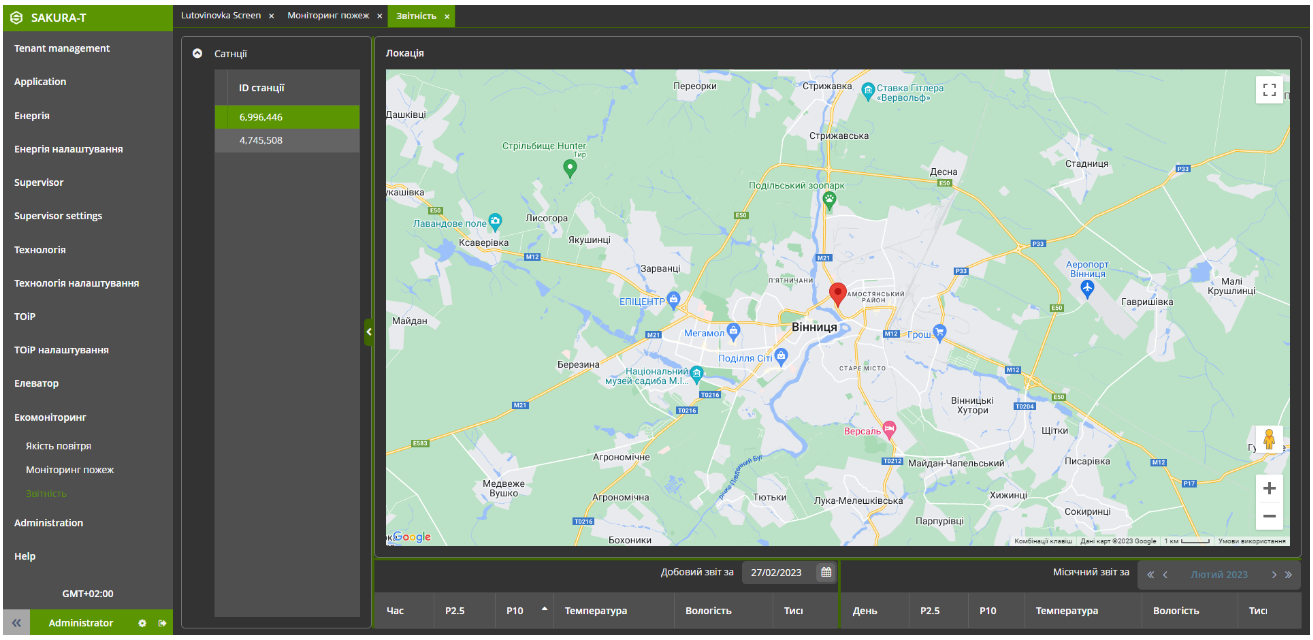



## Project Team: Added Support for Importing Data from SCADA to Create a Digital Twin



## **Project Team:** An environmental monitoring module has been added



## Project Team: Formation and Preparation of Data for the Operation of the AI & ML Module

### The data format is developed and presented in the form of formalized tables

**1. Real-time table of energy parameters energy_20xx_xx.zip**

| name | time | equipment _id | Ua | Ub | Uc | Wp | Wq | Ws | Pp | Pq | Ps | cosA | cosB | cosC | Ia | Ib | Ic | Umax | Imax |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| name | time | equipment_id | | | | | | Ws | | | Ps | | | | | | | | |

Energy data is provided for each unit of equipment with a discreteness of 1s in real time. They provide a complete picture of the quality and efficiency of the equipment

**2. Route statistics table route_history.csv**

| route_id | start_date | stop_date | route | variant_route |
|---|---|---|---|---|

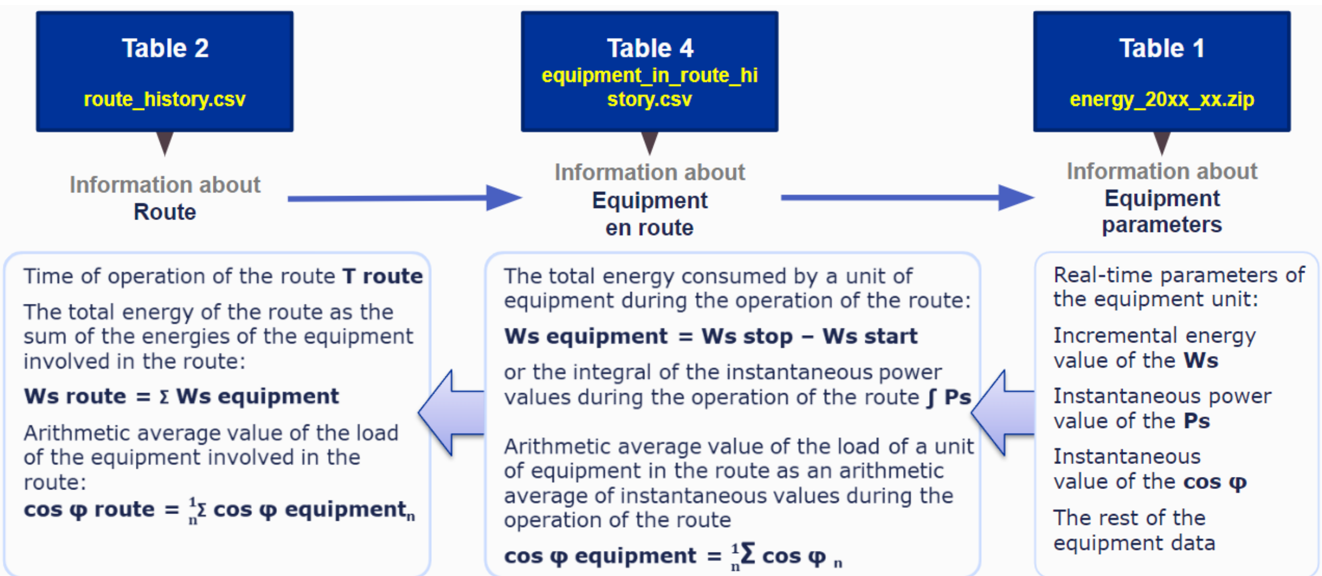
**3. Table of equipment parameters equipments.csv**

| equipment_id | full_name_equipment | short_name_equipment | name_equipment_type | nominal_power |
|---|---|---|---|---|

**4. Equipment statistics table in routes equipment_in_route_history.csv**

| equipment_id | route_id | postition |
|---|---|---|

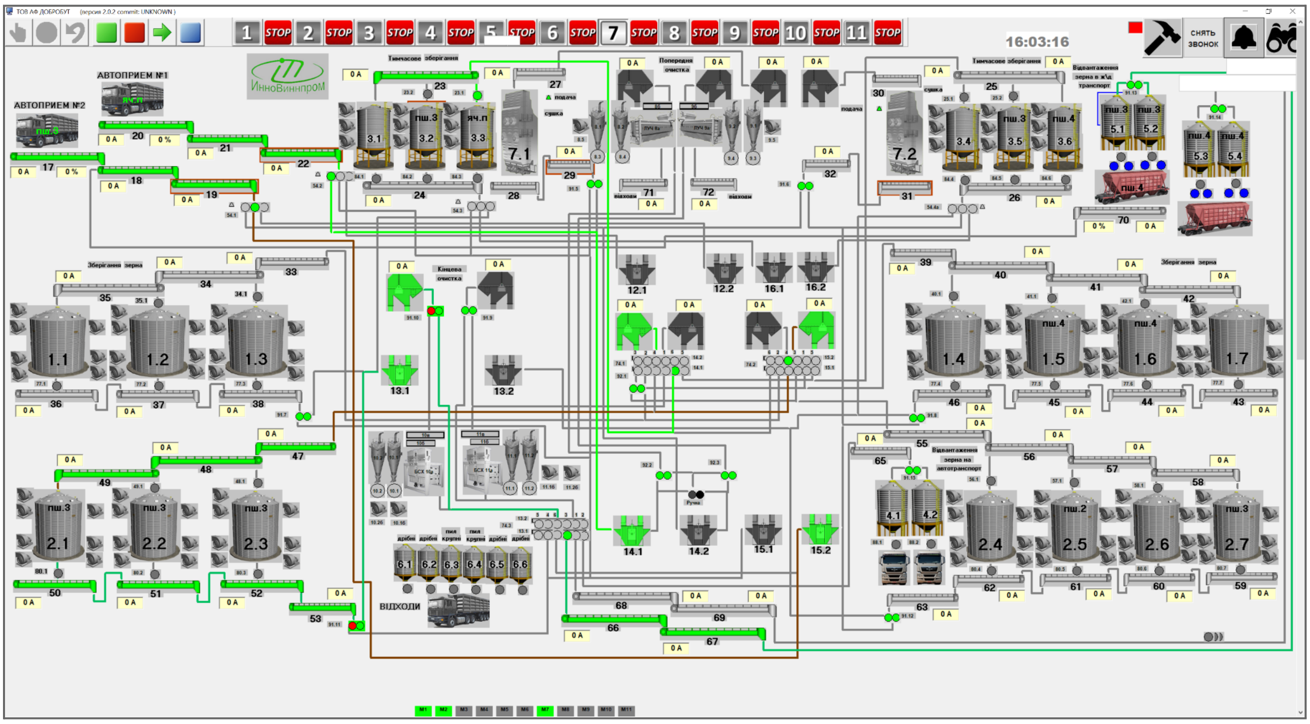
### Formalized algorithms for working with data




The data in table No. 3 are used to forecast the energy consumption of routes for which there are no statistical data

# Works Performed by SCADA Team

## SCADA Team: Development of a New Version of SKADA Software




A new version of **CAD Route InnoVinnprom 2.0.18** has been developed, tested and implemented, which contains the following advantages:

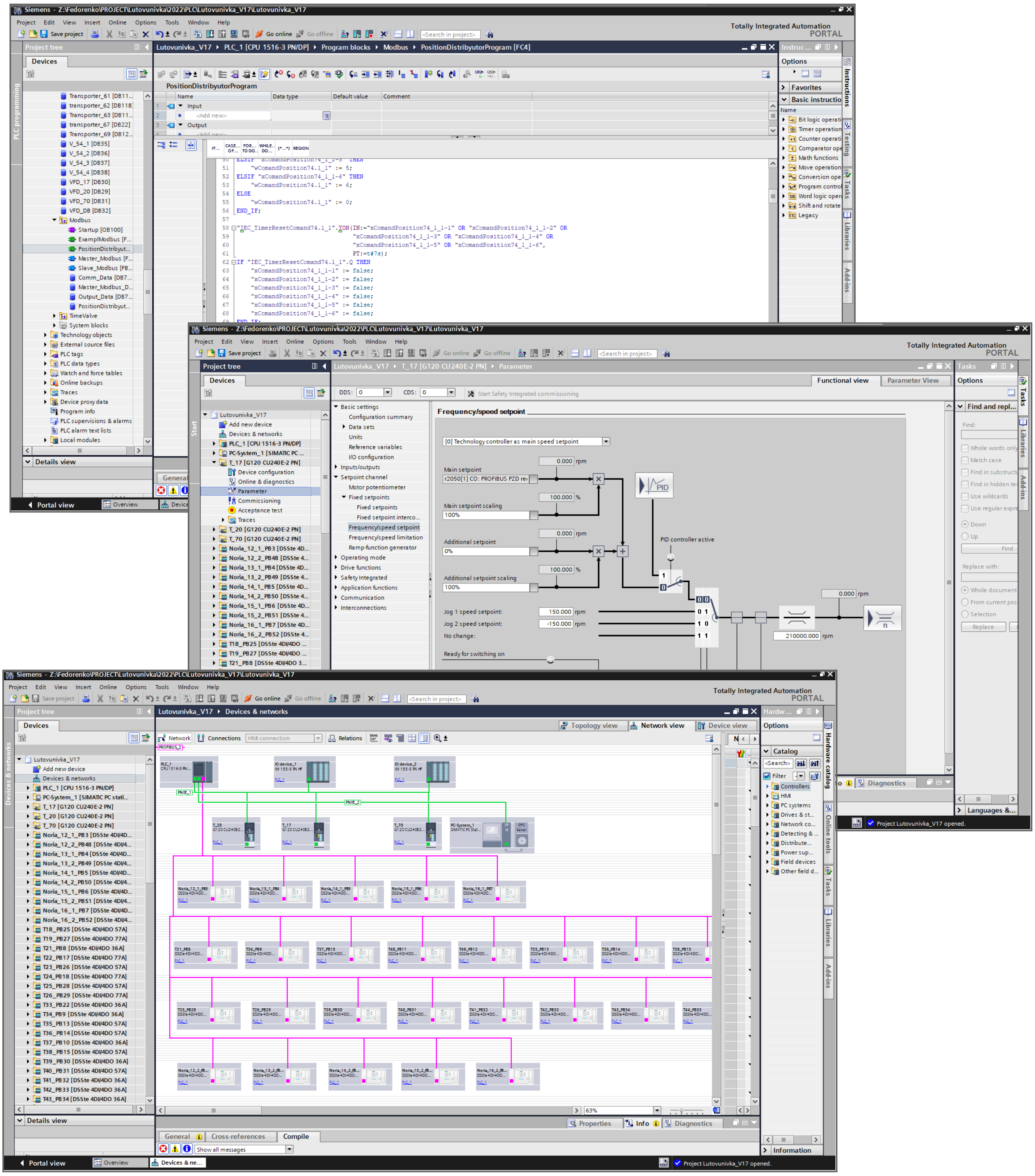
- Ukrainian-language interface.
- An extended set of communication functions that will ensure the output of an extended set of data.
- Additional me for working with routes have been created

For reference:

CAD Route InnoVinnprom is a licensed software developed by INNOVINNPROM for automating the development of SKADI elevator systems. It has more than 100 implementations on the territory of Ukraine, Kazakhstan, Moldova and Orkostan. These are Europe's largest port grain terminals and linear grain elevators with a capacity of 50,000 ... 300,000 tons of grain, as well as industrial mills, bread factories, oil presses plants and compound feed plants.

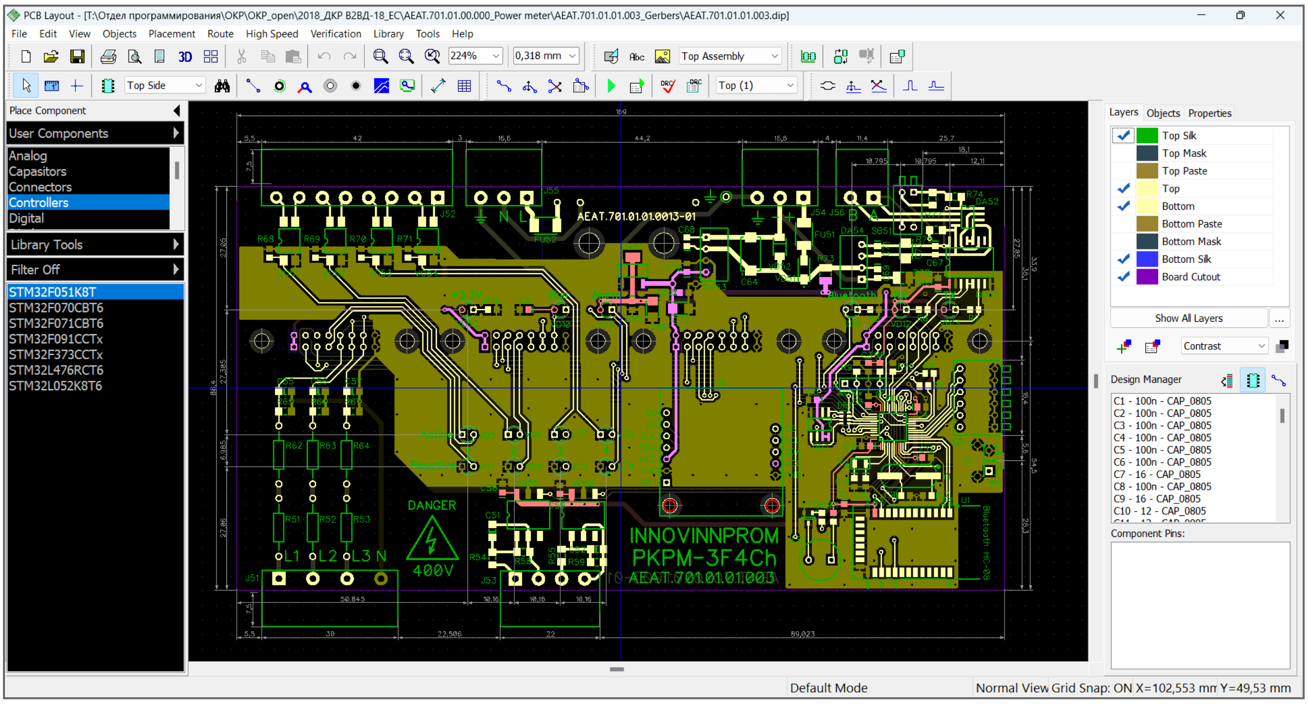
## SCADA Team: A New Version of the PLC Firmware Was Developed and Implemented

PLC – Siemens S7-1500, 1500 DI/DO/AI/AO



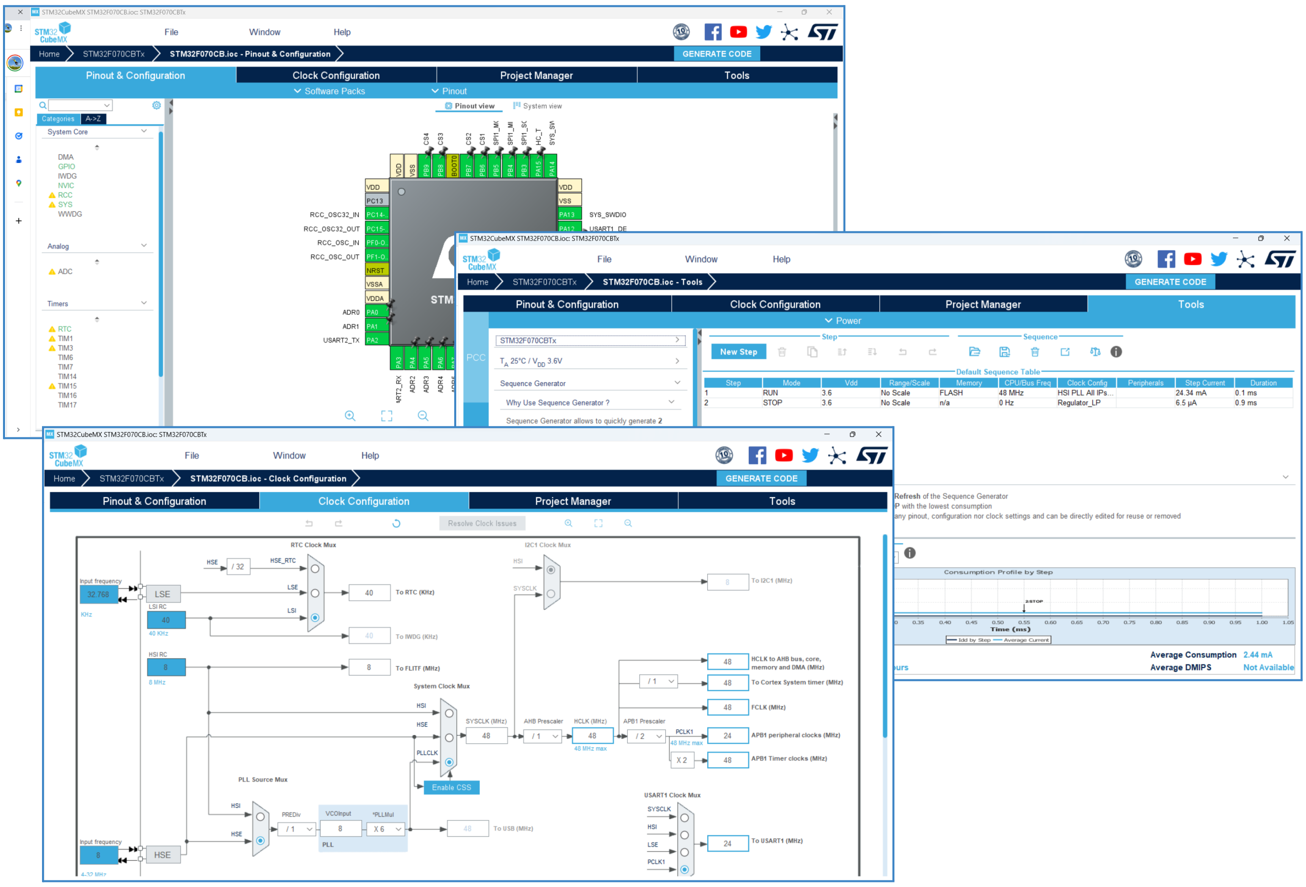

The firmware is developed in the [Siemens Simatic TIA Portal v17](#) software.

## SCADA Team: Manufacturing & Testing of Modernized Energy Meters




The new version of the [PKPM-3F4KM] electrical network parameter control device is equipped with a real-time clock.

## Hardware Development for a New Version of Energy Meters

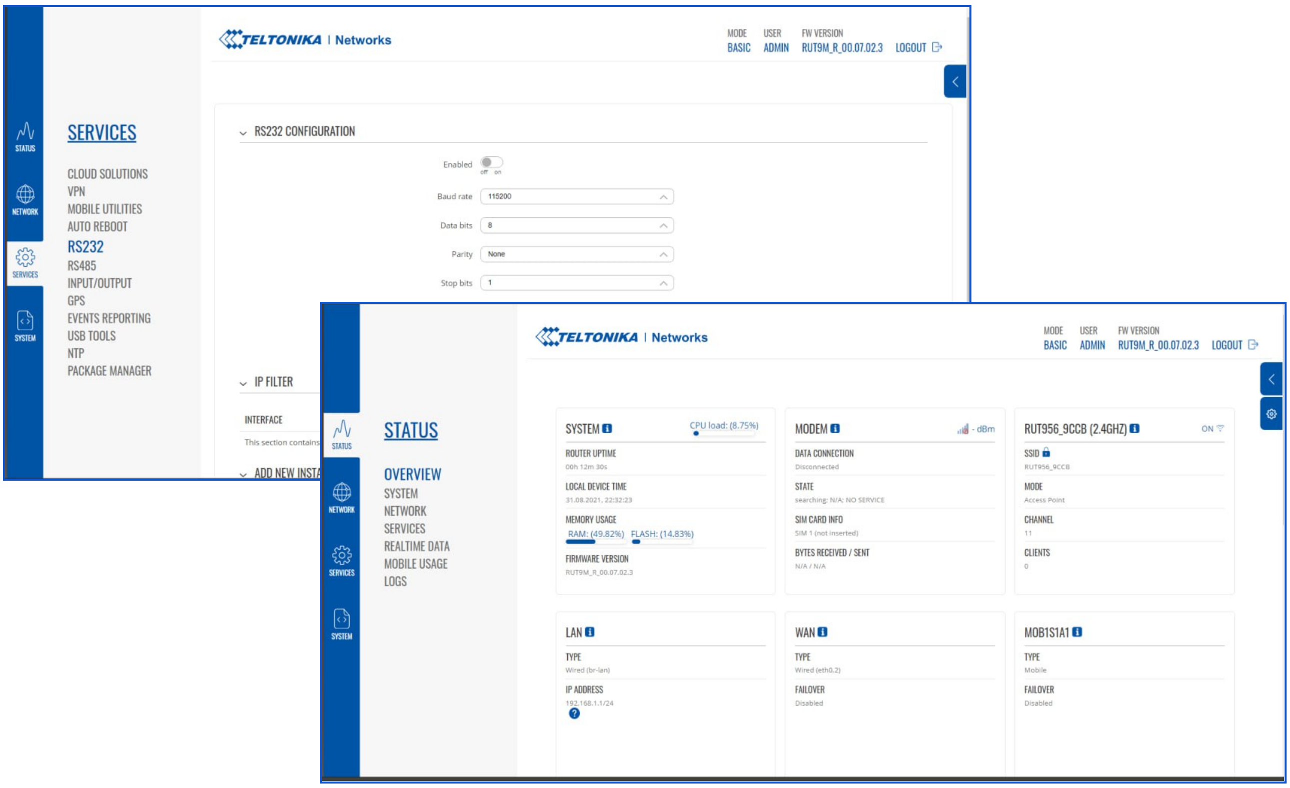


## SCADA Team: Purchase and Configuration of a New Model of the IoT Gateway

In accordance with the planned budget, an [industrial cellular router Teltonika RUT-966]() was purchased, which is used in the project as an IoT gateway.

By the way, we tested the previous [Teltonika RUT-955]() model as an industrial gateway in our project. In accordance with the bug report provided by us, Teltonica adjusted the firmware of this router model and fixed the bugs. In this way, we had an effective influence on the serial production of RUT-955.

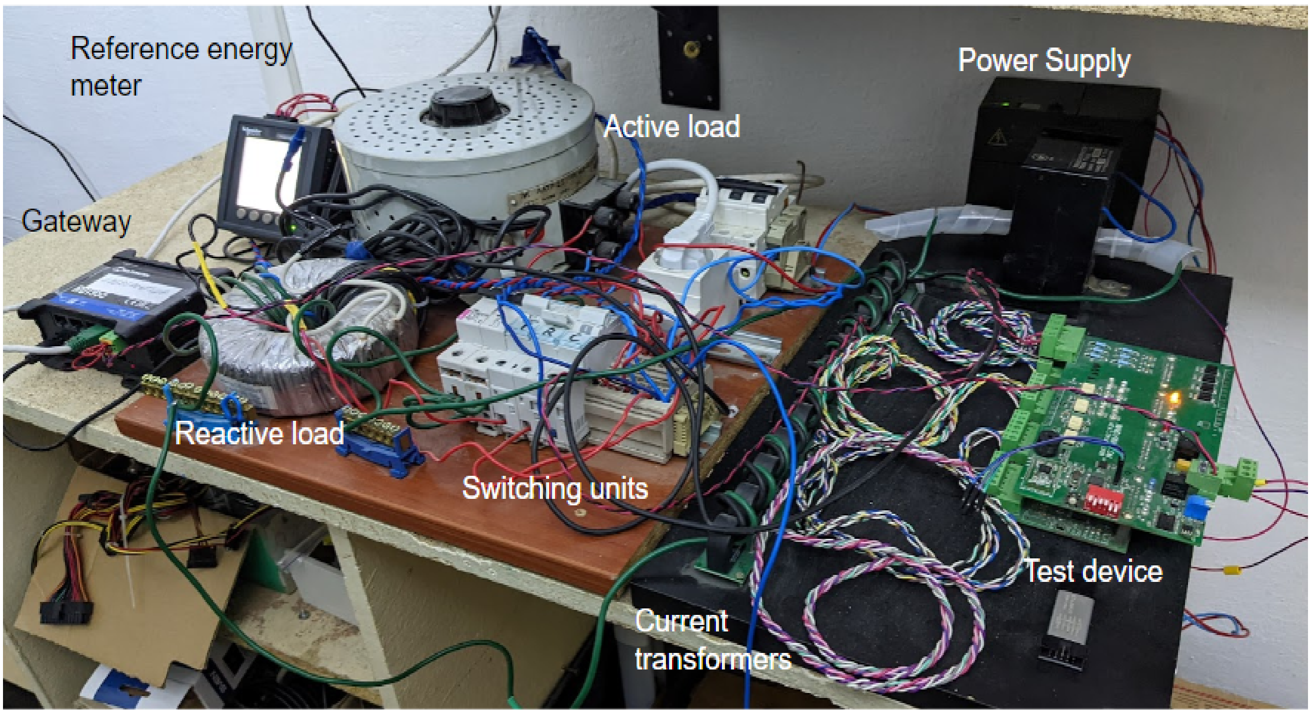
That is why we managed to get RUT-966 as an individual order with a significant discount.



## SCADA Team: Installation of a Test Bench for Checking and Adjusting Energy Meters

Engineers assembled a stand for testing new technologies, which includes the following equipment:

- The control board of the parameters of the power grid under test
- Reference certified serial device of accuracy class 0.1
- Teltonic's IoT gateway
- Active load of the power grid
- Reactive load of the power grid
- Power supply
- Start-up protection equipment



## Works Performed by AI & ML Team

The team received 100 GB of data on the operation of 65 units of equipment and 2,795 variants of technological routes of the grain elevator for almost three years of operation. These data included every second values of the electrical and technological parameters of the equipment.

Vinnytsia National Technical University

The data needed to be organized, as certain data packages may have been missing before the SCADA modernization. Therefore, the team identified two main directions of work - the selection of data on the operation of technological routes, which contain the maximum complete set of parameters, and the selection of algorithms, according to which the neural network could give the best forecasting result.

It was decided to concentrate efforts in two directions:

1. Analysis of the operation of technological routes and forecasting the choice of the most optimal technological route.
2. Analysis of the operation of elevator equipment and prediction of equipment failure.

**Routes are characterized by the following parameters:**

- Time of inclusion, time of exclusion, duration of work
- Total total (Ws), active (Wp) and reactive energy (Wq) consumed during route operation
- Power factor (cos φ) averaged during route operation
- Productivity of the route - kW of electricity / ton of product

**Basic equipment parameters:**

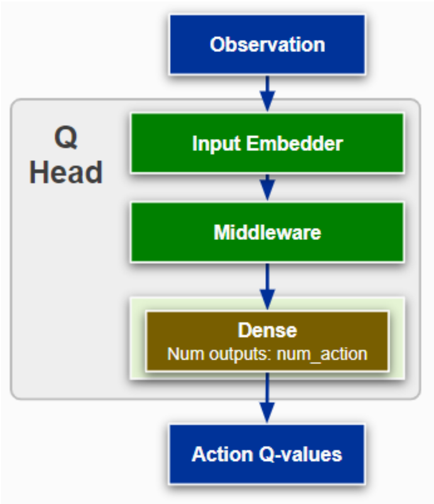
**Measured:**

- Instantaneous current values in three phases (I)
- Instantaneous voltage values in three phases (U)
- Time of inclusion and exclusion, duration of operation of the mechanism

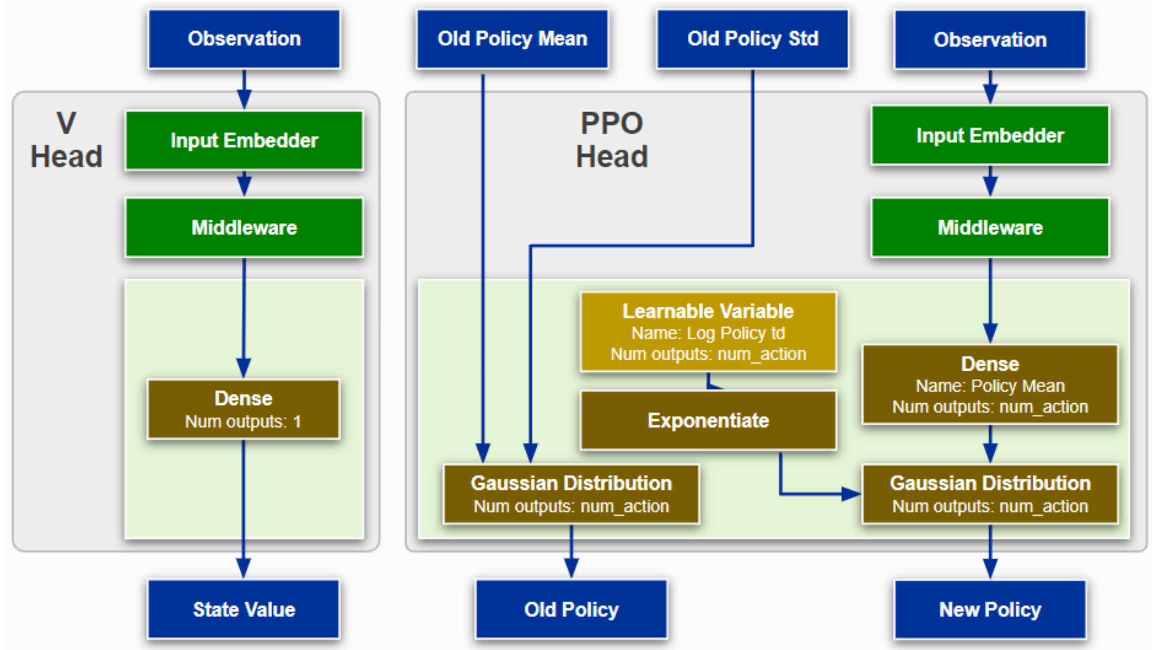
**Calculated:**

- Active (Pp), reactive (Pq), full power (Ps)
- The power factor (cos φ) which characterizes the level of grain loading of the mechanism
- Active (Wp), reactive (Wq), total (Ws) energy during the operation of the mechanism (in the route)

### Block diagram DQN




### Block diagram PPO

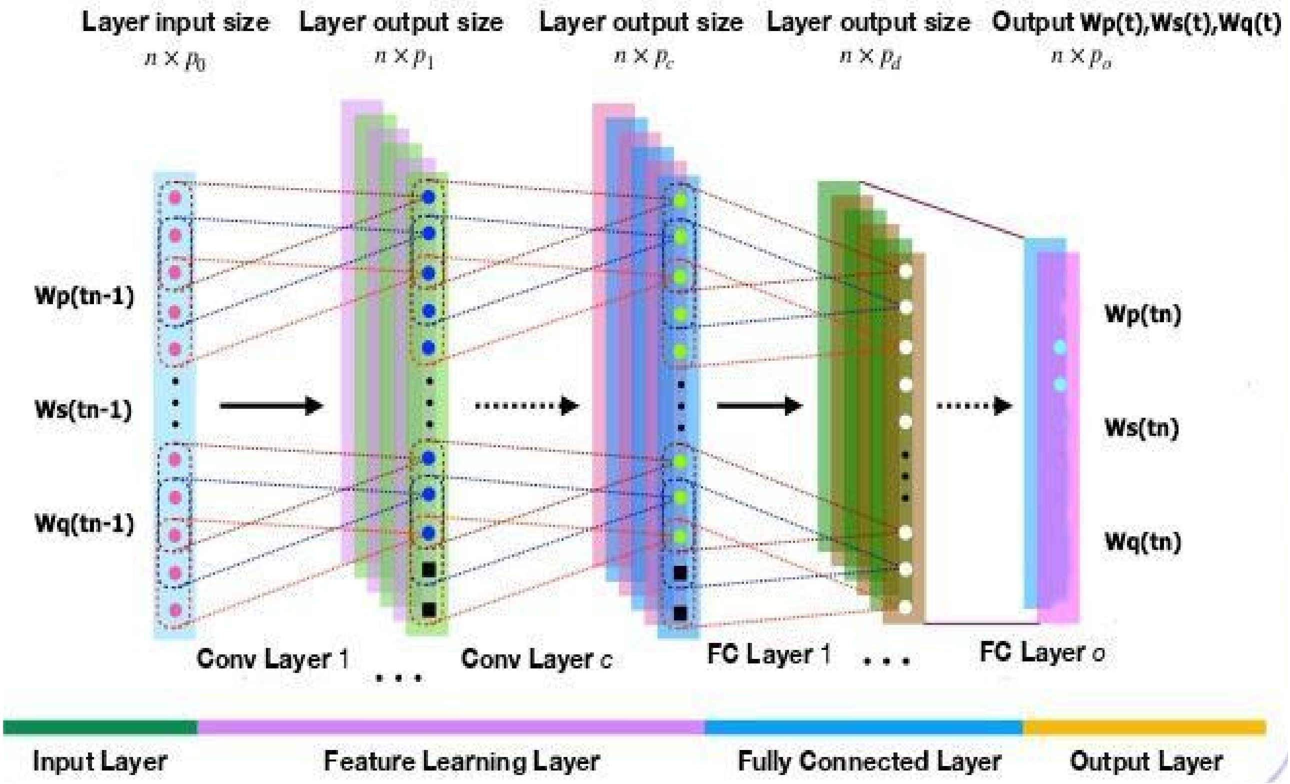



### Comparative  table of analogues for the optimization of the TP using intelligent information technology

| Parameter | DGN<br>Deep Q network | A2C<br>Advanage-Actor-Critic | PPO<br>Proximal Policy Optimization |
|---|---|---|---|
| **Recurrent politics** | No | Yes | No |
| **Multi Processing** | No | Yes | Yes |
| **Discrete** (Action Observation) | Yes/Yes | Yes/Yes | Yes/Yes |
| **Box** (Action Observation) | Yes/No | Yes/Yes | Yes/Yes |
| **Multi Discrete** (Action Observation) | Yes/No | Yes/Yes | Yes/Yes |
| **Multi Binary** (Action Observation) | Yes/No | Yes/Yes | Yes/Yes |

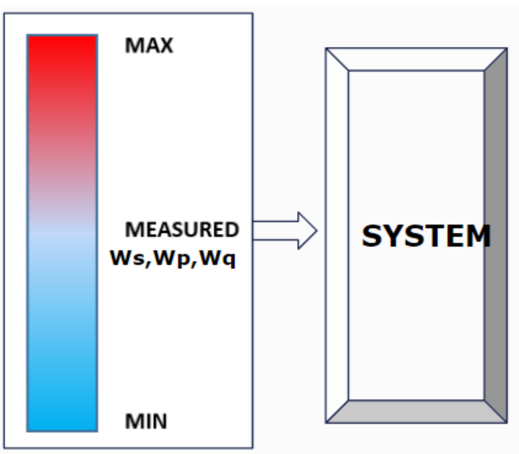
The best option is intellectual method **A2C with reinforcement learning**

## AI & ML Team: Architecture neural networks of typical nodes of grain elevator route devices has been developed



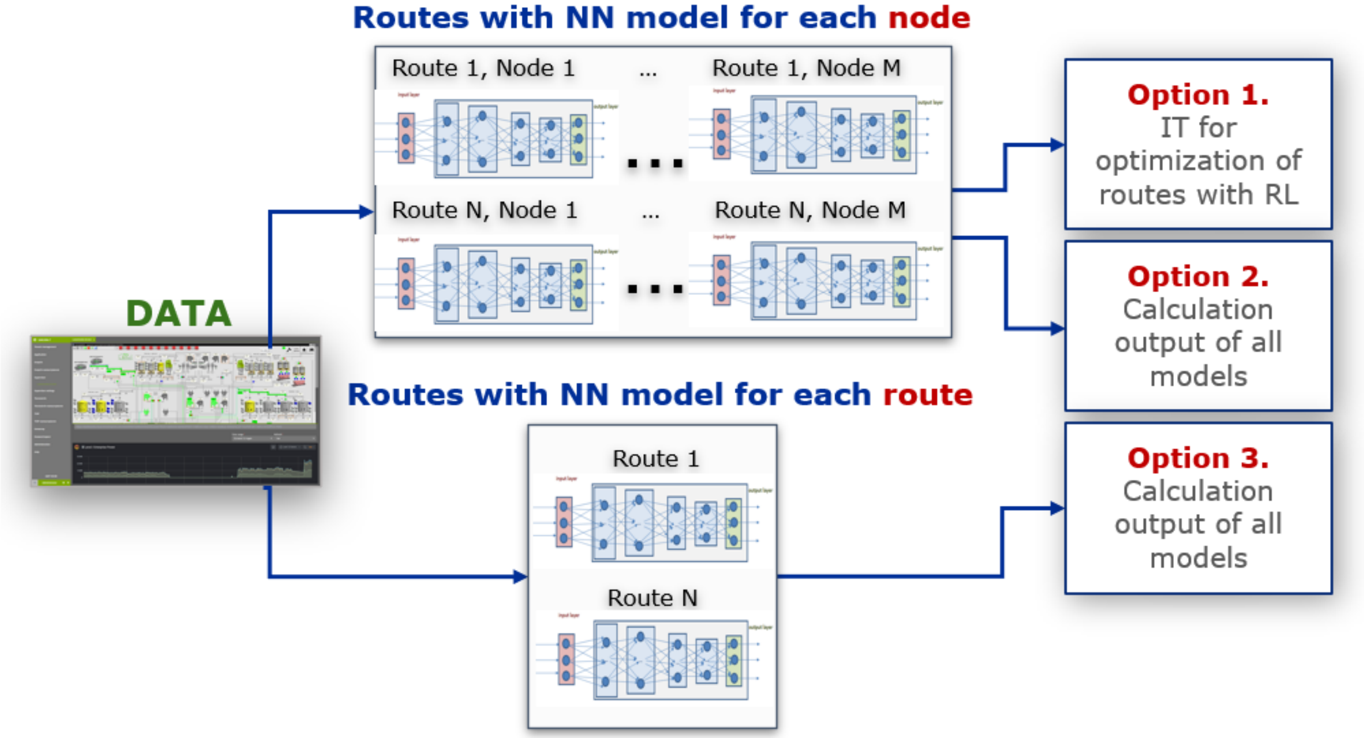

Prediction of three output parameters at once based on the same three input parameters, the same outputs of the previous node at the previous moment in time by one multilayer neural network (NN) or one convolutional neural network (CNN). But it is also worth checking the option when each parameter will be predicted separately using different types of neural networks (NN, CNN, RBF).

## AI & ML Team: Planning of experiments necessary for training of neural network models of nodal devices and system as a whole




**At the experimental stag**e, data from stage 1 of our intellectual technology will be taken and the implementation of stages 2 and 3 will be simulated - as if only the input parameters are known. The result will be compared with the measured values. The other 2 experiments will concern much larger and much smaller parameter values with a larger and smaller load (for example, **more moist and dense and vice versa**) to check how the algorithm will behave in extreme conditions.

## AI & ML Team: Choice of information technology for optimization of production at the grain elevator using neural network models and methods of training with reinforcement




| Option of IT | N | T |
|---|---|---|
| 1 | Small | Middle |
| 2 | Small | Big |
| 3 | Small | **Small - optimal** |
| 1 | Big | **Small - optimal** |
| 2 | Big | Big |
| 3 | Big | Middle |

N - number of routes
T - duration of calculations for optimization

Experiments showed that under real conditions, in most cases, the number of possible combinations of route variations between given input and output bunkers is small,

**so it was decided to implement option 2.**

It was option 2 that ensured the optimal duration of calculations, which is important for the operator.

## AI & ML Team: Comparison of examples of results of optimization of scenarios for choosing the optimal route of the grain elevator using intelligent technologies

| Version models | Relative error, % | R2_score |
|---|---|---|
| NN(4x1) for $W_p$ | 10,1% | 0.8 |
| NN(4x1) for $W_q$ | 9,8% | 0.78 |
| NN(4x1) for $W_s$ | 9,7% | 0.81 |
| NN(4x1) for cos φ | 23,1% | 0.45 |
| NN(4x3) for all W | 33,9% | -0.14 |
| NN(4x4) for all | 31,6% | -0,13 |
| CNN(4x3) for all W | 36,2% | -0.028 |
| CNN(4x4) for all | 36,4% | 0,004 |
| RBF(1x1) for $W_p$ | 36,1% | 0,58 |
| RBF(1x1) for $W_q$ | 36,1% | 0,60 |
| RBF(1x1) for $W_s$ | 36,1% | 0,58 |
| RBF(1x1) for cos φ | 20,1% | 0,57 |

The table shows the results of various methods of intelligent technologies for predicting the operation of elevator routes for choosing the optimal grain elevator route.

## AI & ML Team: Development of complexes of training, validation and test datasets suitable for training neural networks of nodal devices, taking into account real data from the grain elevator

### Training dataset:

A training dataset suitable for training neural networks of node devices, taking into account real data from the elevator

| route_id | time | Wp | Wq | Ws | cosF | time_n | Wp_n | Wq_n | Ws_n | cosF_n |
|---|---|---|---|---|---|---|---|---|---|---|
| 00049876-f98a-f65d-44f8-ed8824972c7b | 2021-08-01 09:26:56 | 0.0 | 0.0 | 0.0 | 0.843505 | 2021-08-01 09:26:53 | 0 | 0 | 0 | 0.592063 |
| 00049876-f98a-f65d-44f8-ed8824972c7b | 2021-08-01 09:26:58 | 6.0 | 5.0 | 6.0 | 0.844157 | 2021-08-01 09:26:54 | 12 | 9 | 15 | 0.590025 |
| 00049876-f98a-f65d-44f8-ed8824972c7b | 2021-08-01 09:27:00 | 11.0 | 8.0 | 13.0 | 0.843274 | 2021-08-01 09:26:55 | 18 | 27 | 30 | 0.586542 |
| 00049876-f98a-f65d-44f8-ed8824972c7b | 2021-08-01 09:27:03 | 20.0 | 14.0 | 24.0 | 0.843265 | 2021-08-01 09:26:56 | 27 | 36 | 48 | 0.589464 |
| 00049876-f98a-f65d-44f8-ed8824972c7b | 2021-08-01 09:27:11 | 40.0 | 28.0 | 48.0 | 0.839972 | 2021-08-01 09:26:57 | 36 | 51 | 63 | 0.588792 |

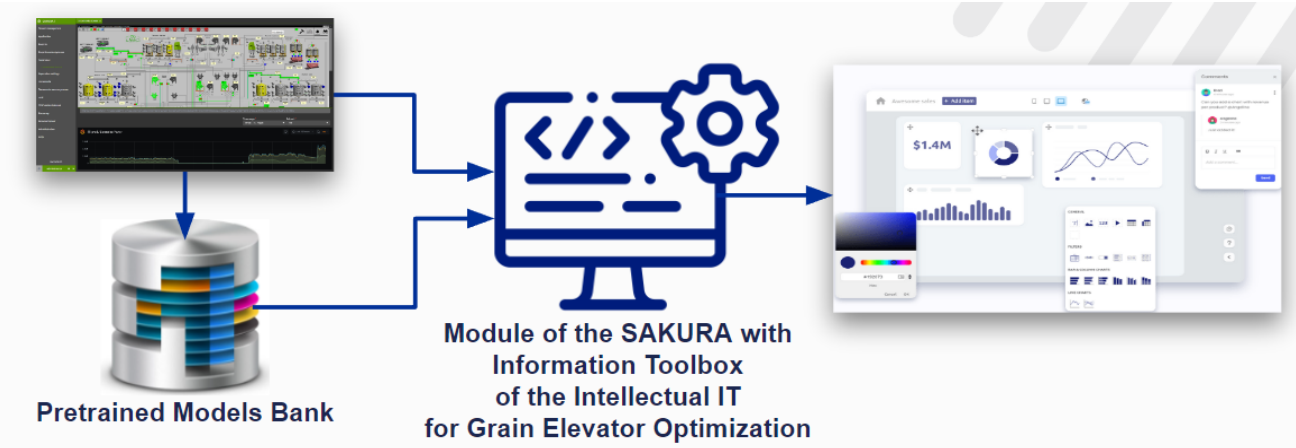
### Validation and test datasets:

Creation of validation and test data sets, suitable for training neural networks of node devices, taking into account real data from the elevator

```
Xvalid, Xtest, Yvalid, Ytest = train_test_split(X, Y, test_size=test_size_split)
print("Xvalid:", Xvalid.shape, "Yvalid:", Yvalid.shape)
print("Xtest:", Xtest.shape, "Ytest:", Ytest.shape)
```

```
Xvalid: (89173, 1) Yvalid: (89173, 1)
Xtest: (22294, 1) Ytest: (22294, 1)
```

## AI & ML Team: Construction of intelligent stimulator for simulation and visualization of the grain elevator technological cycle and optimization of its routes and equipment parameters




Based on data from the SAKURA system, a database of pre-trained neural networks of elevator route nodes has been created. According to information technology forecasting data, an information panel is created with optimal route data.

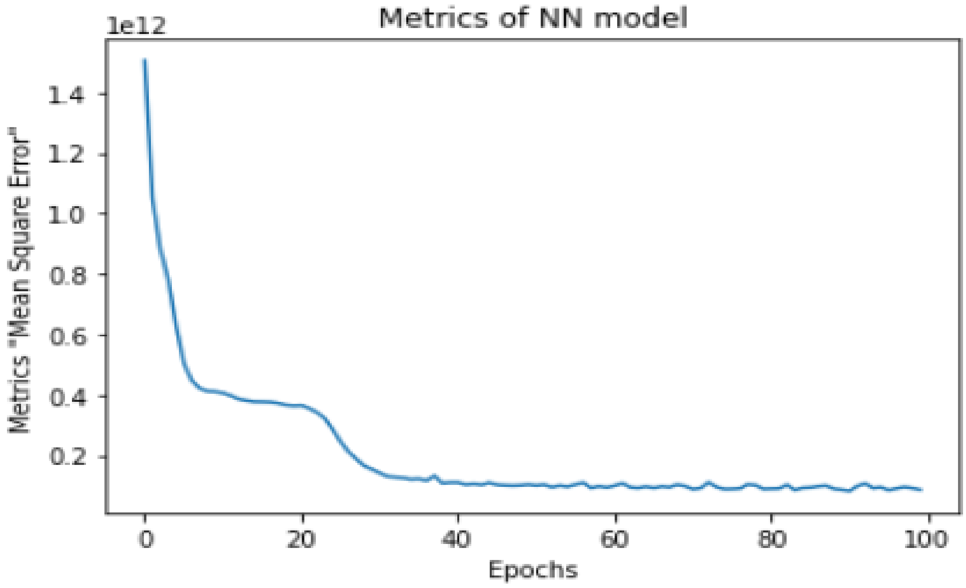
## AI & ML Team: Creating trained neural networks for grain elevator route nodes based on real data

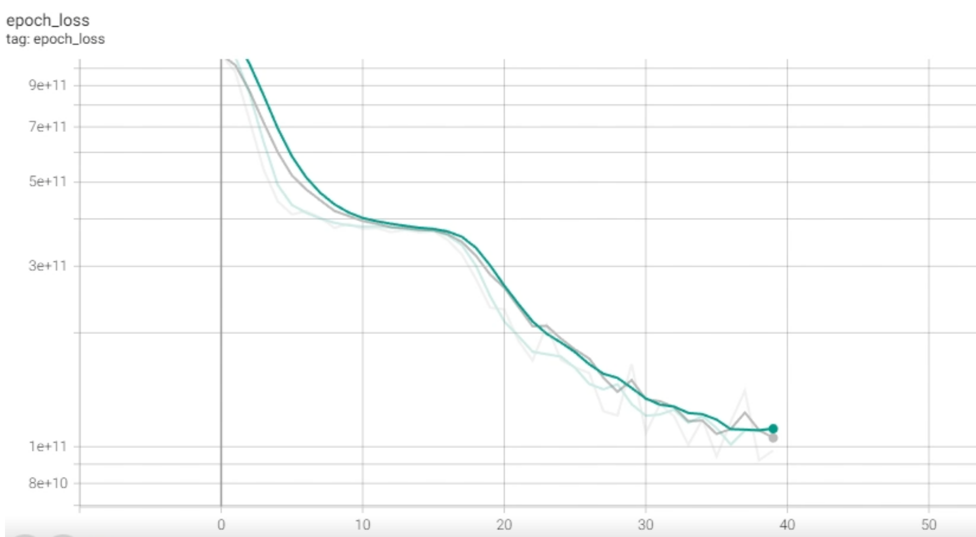
### ML of NN model:

| Layer (type) | Output Shape | Param # |
|---|---|---|
| dense (Dense) | (None, 256) | 1280 |
| dense_1 (Dense) | (None, 128) | 32896 |
| dense_2 (Dense) | (None, 64) | 8256 |
| dense_3 (Dense) | (None, 32) | 2080 |
| dense_4 (Dense) | (None, 3) | 99 |

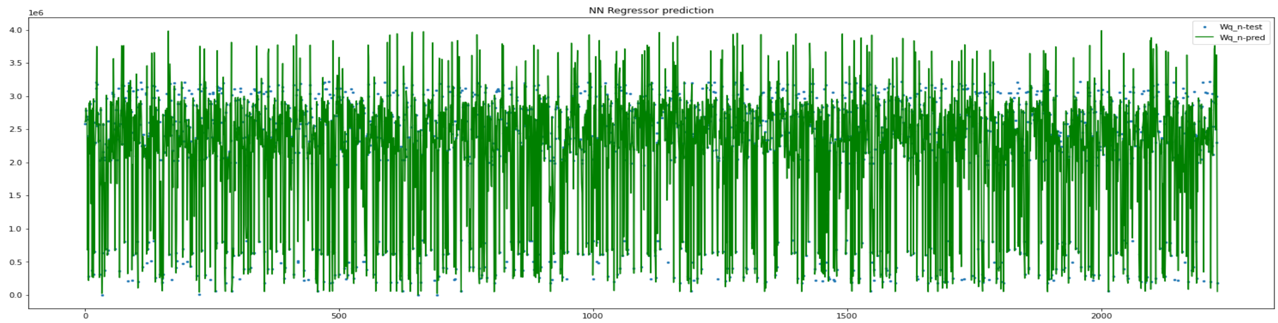
Total params: 44,611

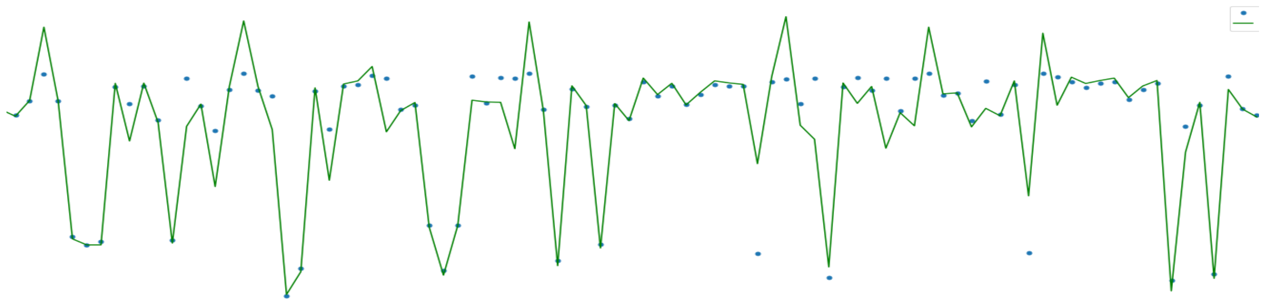
### Metrics of NN model:



## The obtained results of NN Regressor predicting:



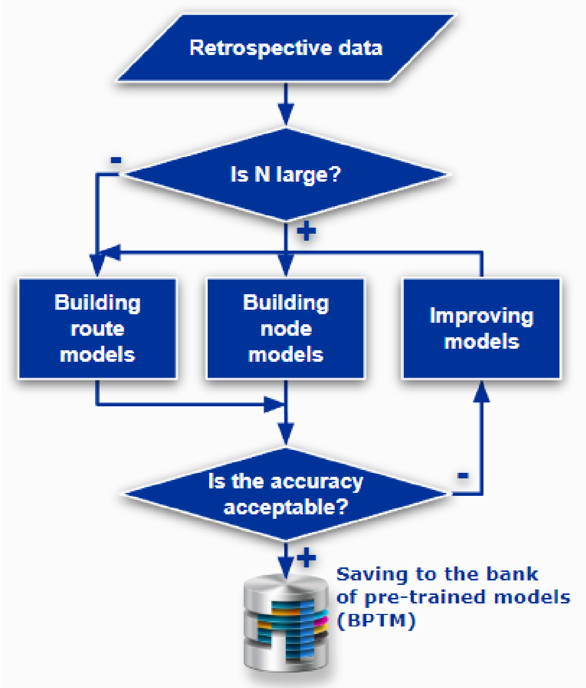



## Prediction accuracy is achieved:

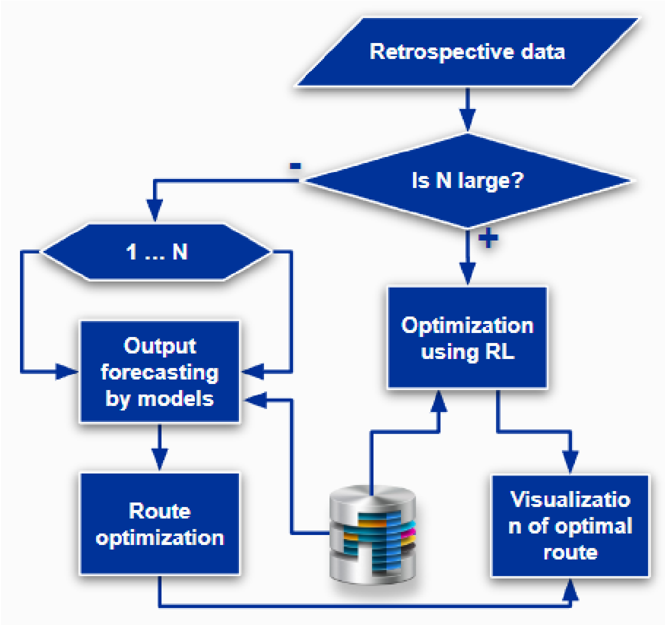
```
Route 0 prediction
Wp_n Relative error: 9.646%
Wp_n r2score : 0.8129453521752672
-----------------------------------------
Route 1 prediction
Wq_n Relative error: 9.425%
Wq_n r2score : 0.8476444593901902
-----------------------------------------
Route 2 prediction
Ws_n Relative error: 9.447%
Ws_n r2score : 0.8420825194985004
```

## AI & ML Team: Construction of algorithms for optimizing grain elevator routes based on new data using machine learning technologies with reinforcement

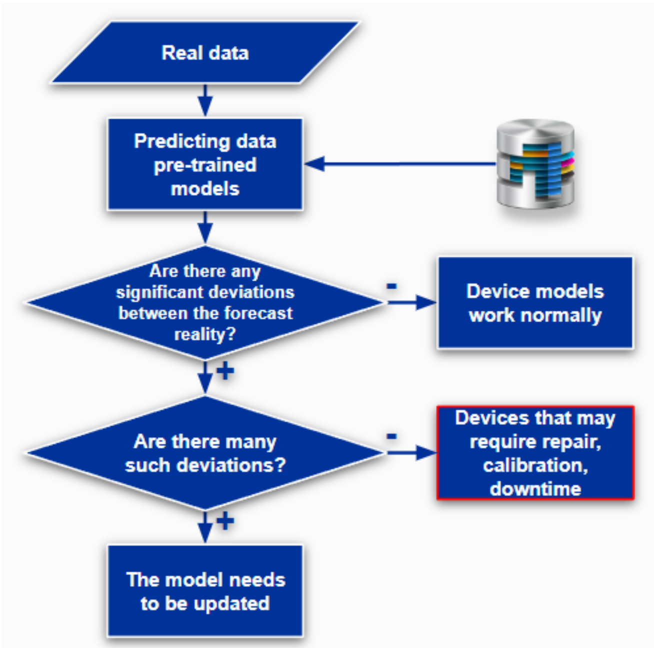
**Stage 1**
**Creation of the Pretrained Models Bank**




**Stage 2**
**The main stage of system operation**




## AI & ML Team: Implementation of algorithms for automatic detection of devices that may require repair, calibration, downtime, etc.




After each completion of the movement of the grain along the route, the forecast of the output data is compared with the same data at the output of the route that was selected.

Depending on the result of the comparison, a certain **algorithm** makes a conclusion about whether it is worth updating the models of the devices or the route and whether it is worth checking which devices of this route **may require repair, calibration, downtime.**

## Work results: Assessment of energy efficiency of work

We systematized and discarded false data and data that did not contain complete information about the operation of technological equipment and routes.

To evaluate the results, tables were created in csv format, which were transferred to xsl format for clarity. Taking into account the dependence of work on seasonality, we used data on the operation of elevators for three similar periods:

- ❖ October 2020 - January 2021
- ❖ October 2021 - January 2022
- ❖ October 2022 - January 2023

Data, including csv extracts from databases are placed in the D4.1.1_Operation statistics.xlsx:

| | Wp | | | Wq | | | Ws | | | Power factor (cos ϕ) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20-21 | 21-22 | 22-23 | 20-21 | 21-22 | 22-23 | 20-21 | 21-22 | 22-23 | 20-21 | 21-22 | 22-23 | |
| | 54 664,13 | 107 403,55 | 93 260,00 | 119 744,93 | 177 044,77 | 146 739,53 | 137 975,99 | 218 783,11 | 174 222,06 | 0,45 | 0,54 | 0,59 | |
| 1 | 258,06 | 397,93 | 78,59 | 230,36 | 427,93 | 94,61 | 349,39 | 590,26 | 125,36 | 0,74 | 0,67 | 0,63 | 1 |
| 2 | 1,56 | 52,50 | 1,27 | 3,27 | 66,94 | 1,73 | 4,54 | 87,36 | 2,77 | 0,34 | 0,60 | 0,46 | 2 |
| 3 | - | - | - | - | - | - | 1,22 | 0,97 | 0,79 | - | - | - | |
| 4 | 762,34 | 736,76 | 599,58 | 205,88 | 41,58 | 108,34 | 1 794,40 | 2 209,20 | 1 647,98 | 0,42 | 0,33 | 0,36 | 3 |
| 5 | 49,72 | 191,78 | 548,60 | 144,94 | 467,40 | 1 109,19 | 156,41 | 508,88 | 1 199,03 | 0,32 | 0,38 | 0,46 | 4 |
| 6 | 195,29 | 168,03 | 35,80 | 213,04 | 235,14 | 36,85 | 290,29 | 289,68 | 47,57 | 0,67 | 0,58 | 0,75 | 5 |
| 7 | 307,84 | 604,50 | 512,04 | 941,12 | 1 456,87 | 1 073,66 | 995,59 | 1 584,54 | 1 153,27 | 0,31 | 0,38 | 0,44 | 6 |
| 8 | 0,50 | 6 945,43 | 6 709,04 | 2,59 | 12 150,21 | 10 674,17 | 4,15 | 14 180,27 | 12 089,93 | 0,12 | 0,49 | 0,55 | 7 |
| 9 | - | 309,18 | 406,55 | - | 399,05 | 395,08 | 1,40 | 507,22 | 519,39 | - | 0,61 | 0,78 | 8 |
| 10 | 735,97 | 1 363,09 | 1 779,24 | 1 899,85 | 3 077,65 | 3 417,63 | 2 052,37 | 3 399,53 | 3 749,24 | 0,36 | 0,40 | 0,47 | 9 |
| 11 | 2 834,72 | 6 786,32 | 5 318,18 | 7 128,47 | 12 014,16 | 8 567,29 | 7 782,52 | 14 024,41 | 9 738,61 | 0,36 | 0,48 | 0,55 | 10 |
| 12 | 433,36 | 1 947,92 | 954,95 | 517,85 | 2 405,19 | 1 222,68 | 688,73 | 3 145,36 | 1 471,38 | 0,63 | 0,62 | 0,65 | 11 |
| 13 | 6,59 | 28,51 | 71,85 | 27,33 | 109,08 | 244,87 | 28,16 | 112,52 | 251,34 | | | 0,29 | |
| 14 | 315,64 | 187,19 | 23,17 | 728,79 | 269,43 | 38,85 | 786,77 | 331,51 | 43,31 | 0,40 | 0,56 | 0,53 | 13 |
| 15 | 1 337,04 | 1 849,53 | 572,41 | 1 876,13 | 1 952,92 | 633,48 | 2 328,84 | 2 736,08 | 869,07 | 0,57 | 0,68 | 0,66 | 14 |
| 16 | 569,63 | 1 272,28 | 609,24 | 1 346,03 | 1 778,33 | 921,61 | 1 447,14 | 2 205,06 | 1 045,70 | 0,39 | 0,58 | 0,58 | 15 |
| 17 | 4,12 | 848,61 | 718,53 | 11,74 | 1 537,90 | 1 249,42 | 12,73 | 1 775,91 | 1 392,86 | 0,32 | 0,48 | 0,52 | 16 |
| 18 | 6 906,49 | 9 096,82 | 7 662,77 | 13 973,36 | 19 197,77 | 15 525,50 | 15 674,66 | 21 416,49 | 16 876,21 | 0,44 | 0,42 | 0,45 | 17 |
| 19 | 181,85 | 2 151,74 | 2 185,26 | 200,59 | 1 626,10 | 1 433,69 | 269,97 | 2 685,22 | 2 281,82 | 0,67 | 0,80 | 0,96 | 18 |
| 20 | 0,62 | 0,51 | 207,61 | 1,42 | 1,61 | 366,42 | 4,94 | 4,31 | 404,89 | 0,13 | 0,12 | 0,51 | 19 |
| 21 | 1,68 | 163,61 | 299,46 | 3,47 | 179,71 | 347,16 | 5,08 | 249,69 | 466,34 | 0,33 | 0,66 | 0,64 | 20 |
| 22 | 696,46 | 717,74 | 730,03 | 977,58 | 831,02 | 827,97 | 1 205,60 | 1 111,95 | 1 033,27 | 0,58 | 0,65 | 0,71 | 21 |
| 23 | 554,60 | 779,67 | 57,92 | 1 031,46 | 1 324,38 | 78,75 | 1 168,91 | 1 542,91 | 92,46 | 0,47 | 0,51 | 0,63 | 22 |
| 24 | 1 031,28 | 8 354,21 | 8 425,49 | 3 096,73 | 15 588,28 | 15 370,70 | 3 293,34 | 17 956,66 | 17 067,50 | 0,31 | 0,47 | 0,49 | 23 |
| 25 | - | - | - | - | - | - | 1,11 | 0,87 | 0,72 | - | - | - | |
| 26 | - | 2,02 | 33,80 | - | 9,44 | 151,66 | 0,12 | 9,62 | 152,16 | - | 0,21 | 0,22 | |
| 27 | 659,34 | 1 126,90 | 823,09 | 1 138,52 | 1 628,82 | 963,09 | 1 329,10 | 1 998,56 | 1 188,40 | 0,50 | 0,56 | 0,69 | 24 |
| 28 | 1,44 | 0,09 | 0,33 | 1,69 | 1,10 | 0,24 | 133,71 | 119,09 | 49,13 | 0,01 | - | 0,01 | |
| 29 | - | - | - | - | - | - | 1,08 | 0,84 | 0,45 | - | - | - | |
| 30 | 750,08 | 1 184,88 | 1 087,73 | 1 209,92 | 1 444,55 | 1 480,15 | 1 431,96 | 1 888,55 | 1 744,51 | 0,52 | 0,63 | 0,62 | 25 |
| 31 | 399,62 | 780,89 | 94,83 | 625,64 | 1 239,83 | 167,61 | 749,85 | 1 474,69 | 184,39 | 0,53 | 0,53 | 0,51 | 26 |
| 32 | 667,97 | 662,40 | 507,64 | 329,29 | 87,59 | 7,12 | 1 216,42 | 1 769,33 | 1 281,39 | 0,55 | 0,37 | 0,40 | 27 |
| 33 | 1 562,44 | 832,02 | 1 018,25 | 2 400,36 | 1 205,86 | 1 604,72 | 2 883,03 | 1 494,99 | 1 832,36 | 0,54 | 0,56 | 0,56 | 28 |
| 34 | 15,83 | 141,95 | 121,87 | 31,64 | 158,64 | 274,89 | 592,51 | 3 747,08 | 3 490,65 | 0,03 | - 0,04 | 0,03 | |
| 35 | 261,87 | 344,79 | 159,93 | 551,10 | 599,50 | 438,40 | 611,17 | 692,10 | 452,29 | 0,43 | 0,50 | 0,35 | 29 |
| 36 | 2 154,12 | 2 521,54 | 796,93 | 149,48 | 578,96 | 154,95 | 2 202,30 | 2 647,08 | 832,58 | 0,98 | 0,95 | 0,96 | 30 |
| 37 | 446,54 | 1 869,59 | 967,98 | 551,22 | 2 550,80 | 1 272,97 | 724,70 | 3 208,12 | 1 516,97 | 0,62 | 0,58 | 0,64 | 31 |
| 38 | 795,07 | 1 193,78 | 760,61 | 925,52 | 1 168,55 | 748,69 | 1 236,42 | 1 703,74 | 994,97 | 0,64 | 0,70 | 0,76 | 32 |
| 39 | 1 542,43 | 2 182,66 | 1 159,77 | 1 523,58 | 1 905,88 | 1 228,36 | 2 199,62 | 2 970,61 | 1 738,92 | 0,70 | 0,73 | 0,67 | 33 |
| 40 | 17,71 | 196,88 | 688,49 | 30,85 | 227,64 | 702,90 | 36,31 | 307,74 | 906,33 | 0,49 | 0,64 | 0,76 | 34 |

| Maximum efficiency | 0,65 | % |
|---|---|---|
| Achieved efficiency 1 | 0,45 | 30,8 |
| Achieved efficiency 2 | 0,54 | 16,9 |
| Achieved efficiency 3 | 0,59 | 9,2 |

Equipments | 01_10_2020_31_01_2021 | 01_10_2021_31_01_2022 | 01_10_2022_31_01_2023_ | Routes | route_total_01_10_2020_31_01_20 | route_total_01_10_2021_31_01_20 | route_total_01_10_2022_31_01_20 | routes_sum

A comparison of the results of the operation of the grain elevator **before the application of IoT technologies** and after (period October 2020 - January 2021 and October 2021 - January 2022) showed a **9% increase** in the energy efficiency of the elevator. The total floor factor increased **from 0.45 to 0.54** due to informing the personnel and management of the elevator and applying administrative measures to influence the work, improving operational decisions of the personnel.

A comparison of the results of the elevator operation before and after the **application of AI and ML technologies** (the period October 2021 - January 2022 and October 2022 - January 2023) showed a **5% increase** in the energy efficiency of the elevator. The total floor factor increased **from 0.54 to 0.59.**

**In this way, we achieved typical values of energy efficiency improvement, which are confirmed by the world experience of using IT technologies.**
**As a rule, these values are within 10 … 15%. We reached a value of 14%.**

However, as shown by the work of the conveyor equipped with a vector frequency converter (item #36 in the table), replacing engines with modern economic engines and equipping the equipment with vector frequency converters can give a much greater effect. Thus, the power factor of conveyor #36 was 0.95 … 0.98.

Thus, the modernization and retrofitting of the grain elevator with **vector frequency converters** can increase the overall energy efficiency of the enterprise by **15 … 20%**.

## Work results: Reducing the percentage of inefficient use of grain elevator equipment

| Period | Active energy Wp, [kWh] | Reactive energy Wq, [kVARh] | Total energy Ws, [kVAh] | Power factor cos φ | Inefficiency % |
|---|---|---|---|---|---|
| October 2020 - January 2021 | 54 554,13 | 119 744,93 | 137 975,99 | 0,45 | 30,8 |
| October 2021 - January 2022 | 107 403,55 | 177 044,77 | 218 273,11 | 0,54 | 16,9 |
| October 2022 - January 2023 | 93 260,02 | 146 739,53 | 174 222,06 | 0,59 | 9,2 |

Since we did not have the opportunity to operate with the real weight of products, we operated with the equipment load parameter, which, according to the results of practical experiments, depends linearly on the number of moved products.

Due to the fact that the energy consumed by the elevator cannot be an indicator for evaluating energy efficiency, the Power factor (averaged cos φ) was chosen as the main parameter.

A number of practical experiments were conducted on weighing at key points of the elevator the amount of grain products moved during the reference period of time. At the same time, the reference average value of the Power factor at the maximum permissible load and throughput of the equipment was **0.65**. We used this value as 100% efficiency.

**The Inefficiency value of 16.9% was achieved as a result of the application of IoT technologies thanks to the administrative influence and optimization of SCADA, the value of 9.2 thanks to the application of AI**.

The increased efficiency of choosing the optimal routes, based on more accurate forecasting of their energy consumption, made it possible to ensure a reduction in energy consumption.

Our hypothesis was confirmed that the technological route with the least amount of equipment is not necessarily the most energy-efficient, since the throughput capacity of the equipment and the type of grain moved are not taken into account.

## Work results: Reducing of energy consumption of technological equipment of grain elevator


TTE showed that during the design and construction of the elevator, the designers made a mistake by choosing motors of excessive power for the equipment. During TTE, we did not manage to achieve significant results through the use of information and operational technologies, a maximum of **1...2%**. The reactive power component remained practically constant, as it significantly exceeds the active energy component.

However, we managed to find a way to solve the problem - this is the installation of vector frequency converters. Another effective, but expensive way is to replace the engines with more modern engines of lower power.

We installed vector frequency converters and performed a number of experiments that showed that at any load of the test unit of equipment (transporter No. 36) the Power factor was within 0.95...0.98. That is, **it was possible to reduce energy consumption to 2...5%.**

The application of IT did not give a significant result in terms of reducing the energy consumption of the equipment (reduction of losses by 1...2%), because the error in the design of the elevator and the choice of electric motors led to a significant percentage of the reactive power component, which significantly exceeds the consumption of active power, which cannot be optimized thanks to the use of IT and OT technologies.

IT is effective in the direction of increasing the efficiency of the use of equipment when it is used for maintenance and repair planning, analysis and forecasting of the condition of the equipment. This aspect was not part of the grant tasks.

However, we managed to find and test a solution to the problem of excessive inefficient equipment consumption - this is the installation of vector frequency converters and the replacement of excessively powerful motors with optimal ones. However, the **installation of PCV on one of the elevator equipment units made it possible to achieve an efficiency of 0.95...0.98%, and accordingly reduce losses to 2...5%.**

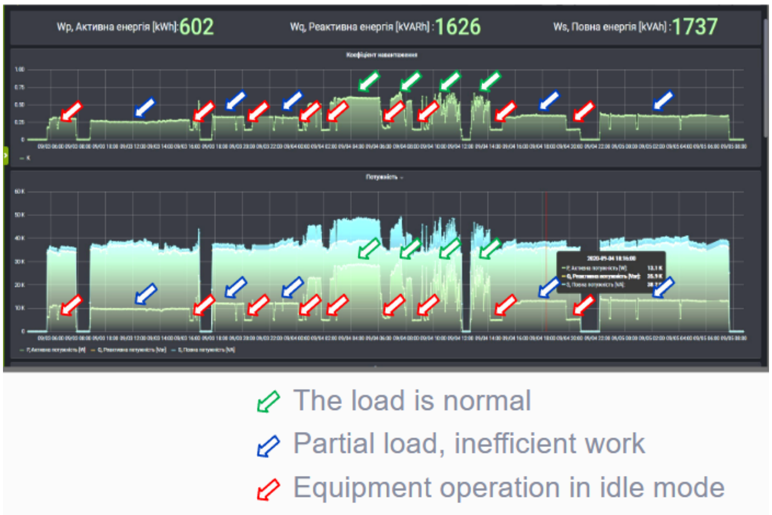
These recommendations are voiced to the owners and managers of the elevator, but they require significant capital investments (investments).

The problem of saving on the installation of PVC during the design and construction of elevators is typical for elevators in Ukraine. In our opinion, the EU should consider the problem of reducing the energy consumption of Ukraine's elevators, as the grain storehouse of the EU and the world, and consider the issue of investing in optimizing energy consumption, which can affect the cost of agricultural products as a whole.

## Work results: Reducing of technological delays and downtime of grain elevator equipment

Reducing of technological delays and downtime of grain elevator equipment was achieved in the following ways:

- According to the results of the analysis of the operation of the equipment (time of acceleration of the engines, time of supplying the product to the next unit of equipment, etc.), we at SKADA reduced the time of switching on and off the routes .
- Real-time monitoring of the load (product availability on transport equipment) made it possible to automatically detect cases of equipment operating in idle mode and equipment problems that could cause an unplanned stop on the route.




The result was achieved by detecting the calculation of the operation of the equipment with a low load or completely without load and making the appropriate settings in the SCADA software.