Final Report 3.rd O.C. for TTE’s

SAKURA-APM

INNOVINNPROM

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Centre 4.0 KPI DIH

DIH PIAP

The BOWI project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 873155

Executive summary of TTE

The support of BOVI helped us achieve the following results :

1. Keep the team and continue working against the background of a significant economic downturn.
2. Significantly optimize the technology stack
3. Update the version and add new features to the system software.
4. Develop new version and upgrade SCADA and PLC software.
5. Obtain and analyze large arrays of grain elevator equipment operation data.
6. Select and test algorithms for the use of neural networks.
7. Conduct experiments on the use of artificial intelligence to optimize the efficiency of technological processes.

Many mentoring meetings from Centre 4.0 KPI DIH have been held. As a result, SMEs are fully satisfied with the received support which included assistance in setting up technical processes, technical and business consulting, etc. PIAP DIH helped a lot during TTE planning with technical and business advices.

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Deliverable D1 Requirements Specification

- The list of equipment and software application for TTE purposes has been created and discussed with TiR. The list includes hardware for data gathering and transfer, software IDEs and applications useful for TTE implementation.

Software specification

№	Component	Amount
1	CAD Route InnoVinnprom 2.0.17	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

Hardware specification

№	Component	Amount
1	Gateway Teltonika RUT955 / RUT956	3 + 1
2	Power Meter INNOVINNPROM PKZM-3Pf4Ch	17

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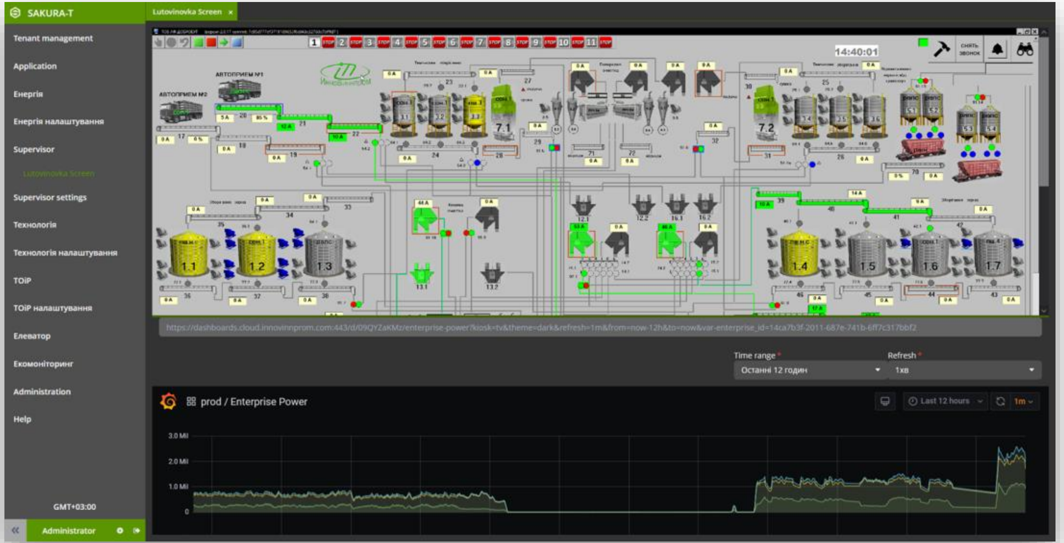
Deliverable D2.1 New Version of SCADA Software

- Add support for SCADA for export data for creating Digital Twin.
- Added support for the ID of each operation and each technological route.
- Implemented Ukrainian-language interface
- Development of a new version of the PLC firmware.



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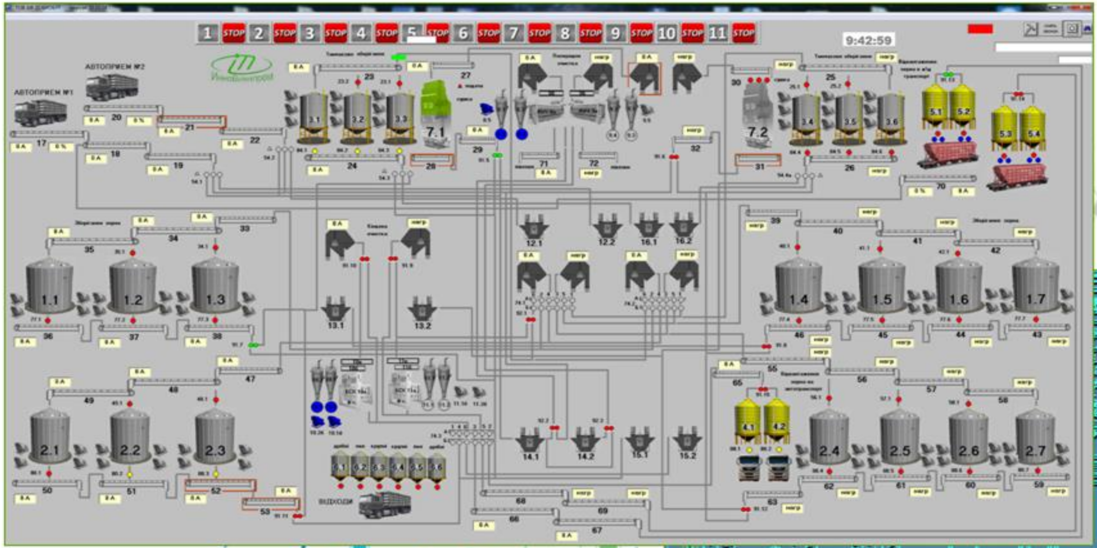
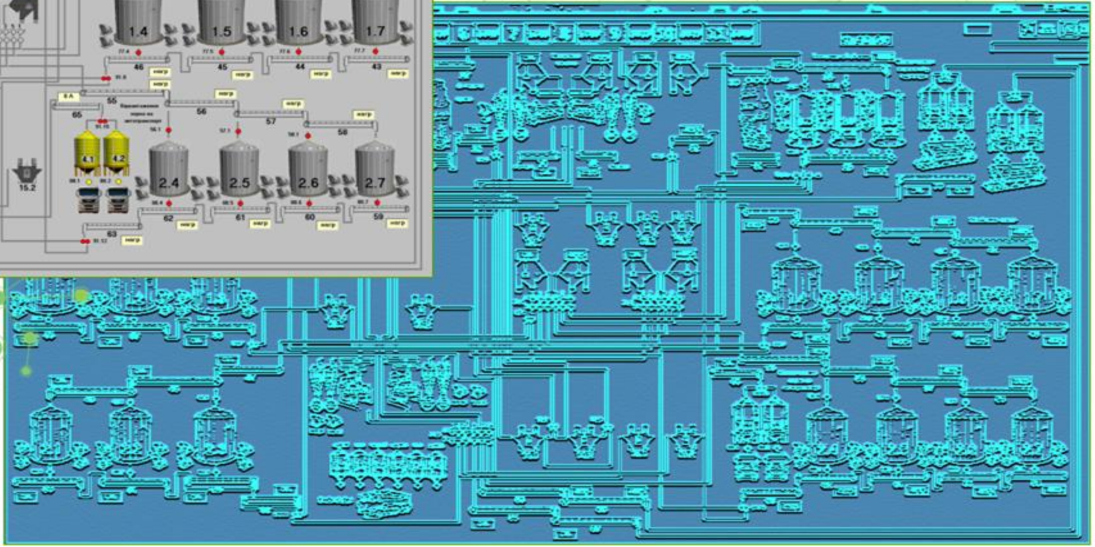
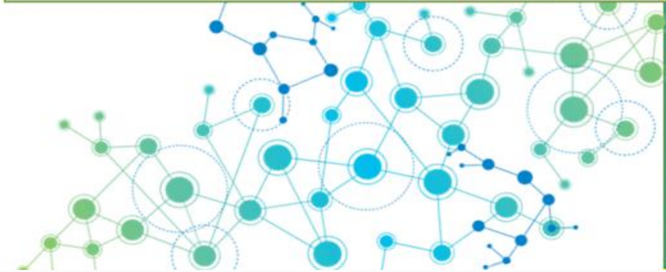
Deliverable D2.2 Digital Twin Production



Equipment control:

Total equipment	203 units
IoT control	65 units
Technological routes	11 units
Route options	2806 units





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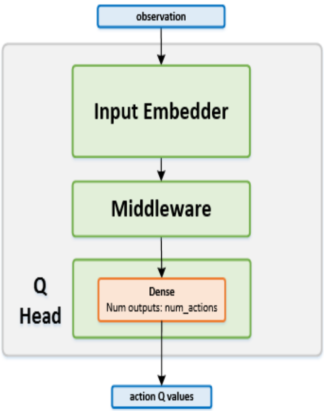
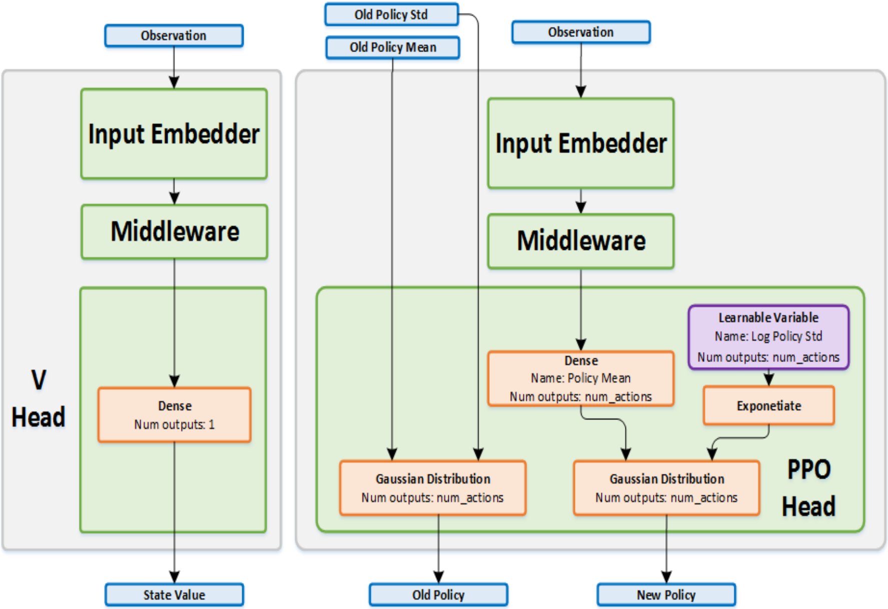
Deliverable D2.3 Analysis of analogues for the optimization of the TP using intelligent information technology

Block diagram DQN



Block diagram PPO



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

Parameter	DQN (Deep Q Network)	A2C (Advantage-Actor-Critic)	PPO (Proximal Policy Optimization)
Recurrent policies	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
MultiDiscrete (Action/Observation)	YES/NO	YES/YES	YES/YES
MultiBinary (Action/Observation)	YES/NO	YES/YES	YES/YES

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

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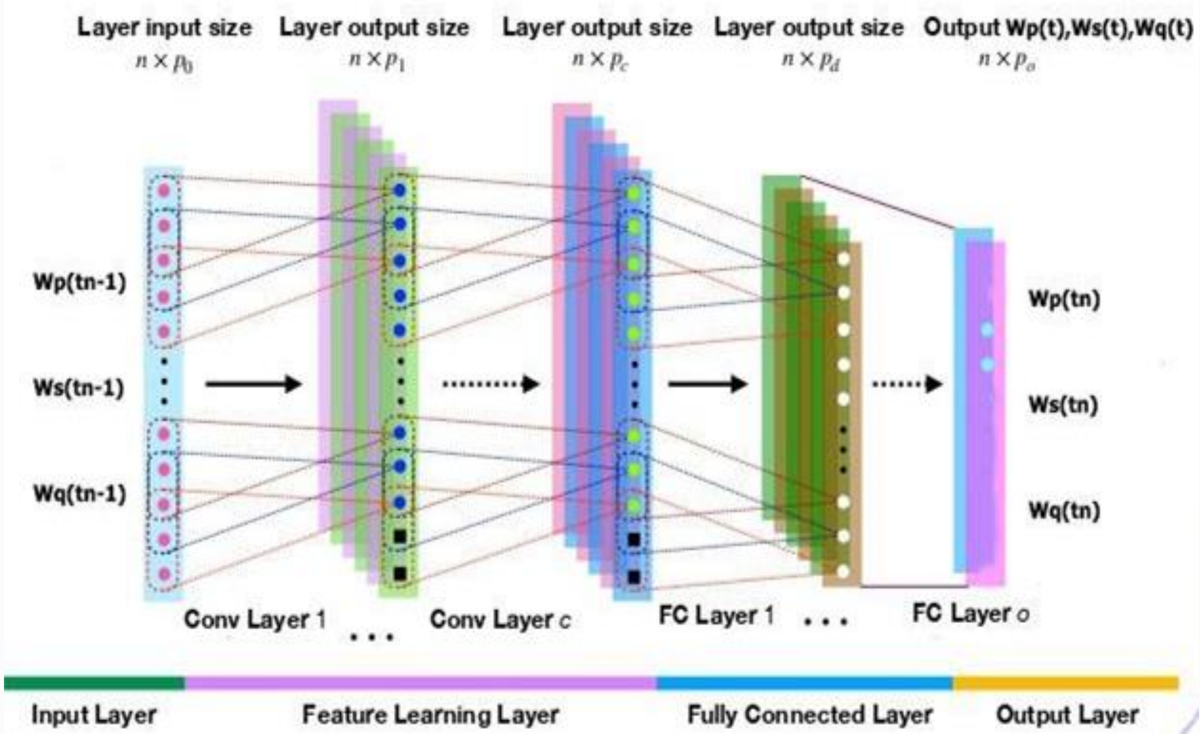
Deliverable D2.4 Architecture neural networks of typical nodes of grain elevator route devices: option 1



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 **convolutional neural network** (CNN) with a complex architecture CNN model

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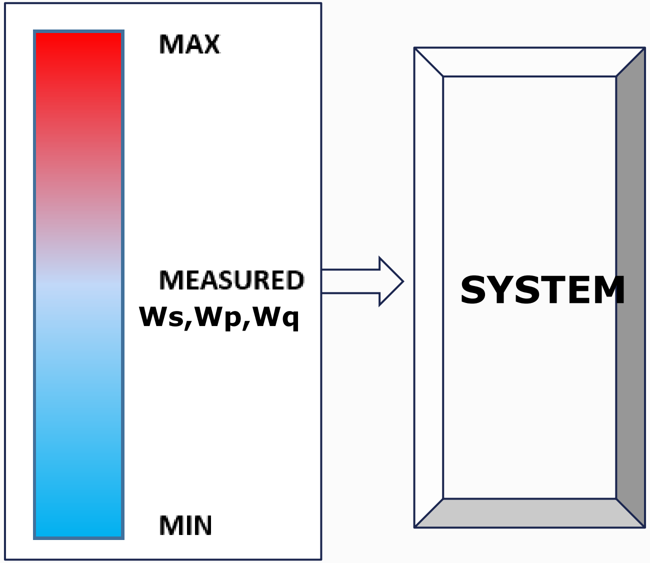
Deliverable D2.5 Planning of experiments necessary for training of neural network models of nodal devices and system as a whole



At the experimental stage, 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.

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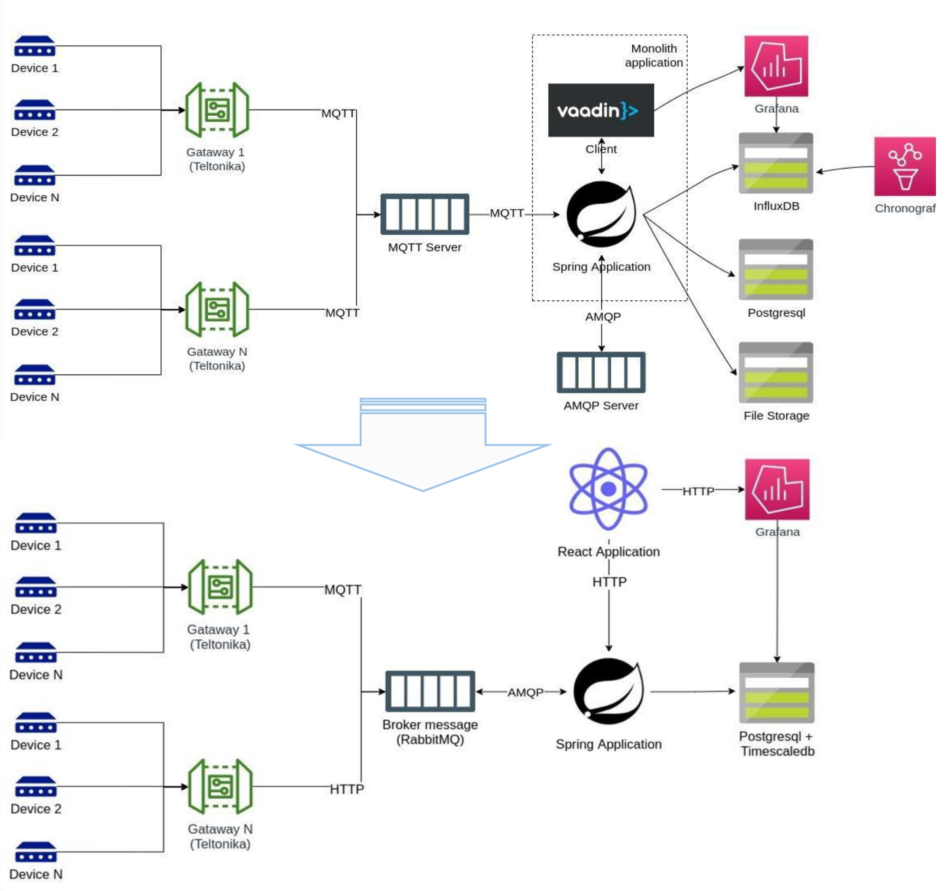
Deliverable D2.6 Optimize the Technology Stack

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



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Deliverable D2.7 New Version of System Software

1. Added support of application localization. Added English locale.
2. Added dark theme to web interface of the system.
3. The structure of the menu and interface windows has been changed.

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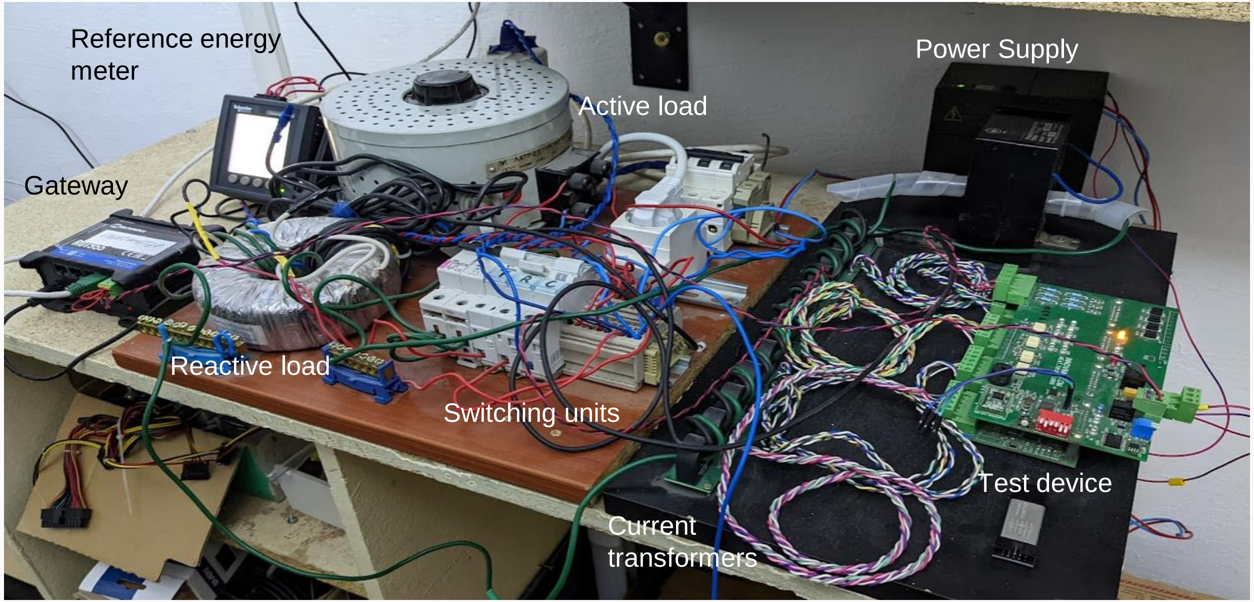
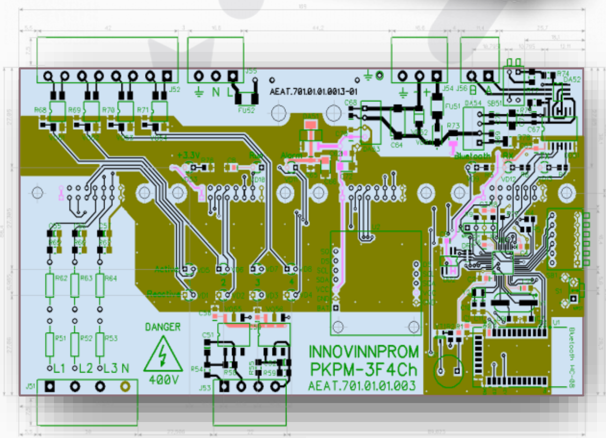
Deliverable D2.8 Modernized Energy Meters

A new version of the V3.0 device has been developed, and design documentation for production has been prepared.





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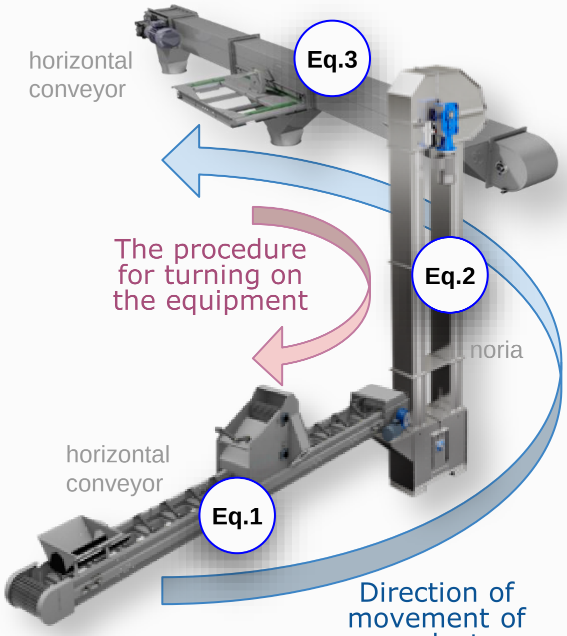
Deliverable D3.1 Data sources for the AI module



Technological route

Route operating time

Technological delay

Technological delay

Eq.1 → Eq.2 → Eq.3 →

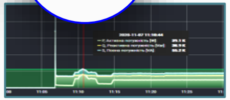
The procedure for turning on the equipment

Direction of movement of products

Eq.1

Power-on time
Three-phase voltage
Three-phase current
Power factor (cos φ)
Active, reactive, full power
Active, reactive, full energy
Time out
Product
Bearing temperature
Status of the sensors
Term of work
Term of maintenance
Season
Time of day
Work shift

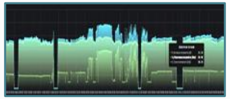
Eq.2



Power-on time
Three-phase voltage
Three-phase current
Power factor (cos φ)
Active, reactive, full power
Active, reactive, full energy
Time out
Product
Bearing temperature
Status of the sensors
Term of work
Term of maintenance
Season
Time of day
Work shift

Eq.3

Power-on time
Three-phase voltage
Three-phase current
Power factor (cos φ)
Active, reactive, full power
Active, reactive, full energy
Time out
Product
Bearing temperature
Status of the sensors
Term of work
Term of maintenance
Season
Time of day
Work shift



Route operating time
Power-on time
Active, reactive, full energy
Time out
Product
Season
Time of day
Work shift

The equipment involved in the route is turned on starting from the last device, turned off starting from the first device

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Deliverable D3.2 Generated data for the AI module

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	$\cos\varphi = \frac{1}{n}\Sigma x_n$							

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

Deliverable D3.3 Data preparation for the AI module

Table 2

route_history.csv

Information about
Route

Time of operation of the route **T route**

The total energy of the route as the sum of the energies of the equipment involved in the route:

Ws route = Σ Ws equipment

Arithmetic average value of the load of the equipment involved in the route:

$$\cos\varphi \text{ route} = \frac{1}{n}\Sigma \cos\varphi \text{ equipment}_n$$

Table 4

equipment_in_route_history.csv

Information about
Equipment en route

The total energy consumed by a unit of equipment during the operation of the route:

Ws equipment = Ws stop – Ws start

or the integral of the instantaneous power values during the operation of the route **∫ Ps**

Arithmetic average value of the load of a unit of equipment in the route as an arithmetic average of instantaneous values during the operation of the route

$$\cos\varphi \text{ equipment} = \frac{1}{n}\Sigma \cos\varphi_n$$

Table 1

energy_20xx_xx.zip

Information about
Equipment parameters

Real-time parameters of the equipment unit:

Incremental energy value of the **Ws**

Instantaneous power value of the **Ps**

MInstantaneous value of the **cos φ**

The rest of the equipment data

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

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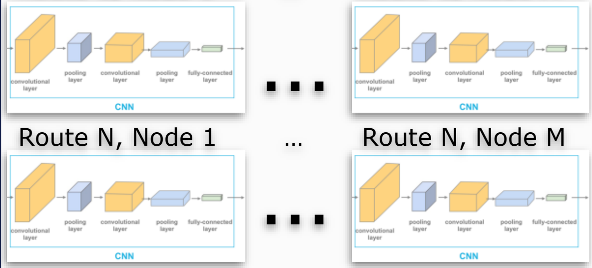
Deliverable D3.4 Choice of information technology for optimization of production at the grain elevator

DATA

Routes with CNN model for each node

Route 1, Node 1 ... Route 1, Node M

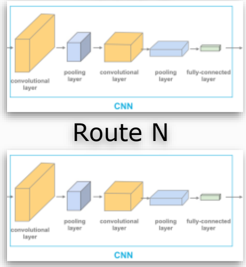
Route N, Node 1 ... Route N, Node M



Routes with CNN model for each route

Route 1

Route N



Option 1. IT for optimization of routes with RL

Option 2. Calculation output of all models

Option 3. Calculation output of all models

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

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

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 3.

It was option 3 that ensured the optimal duration of calculations, which is important for the operator

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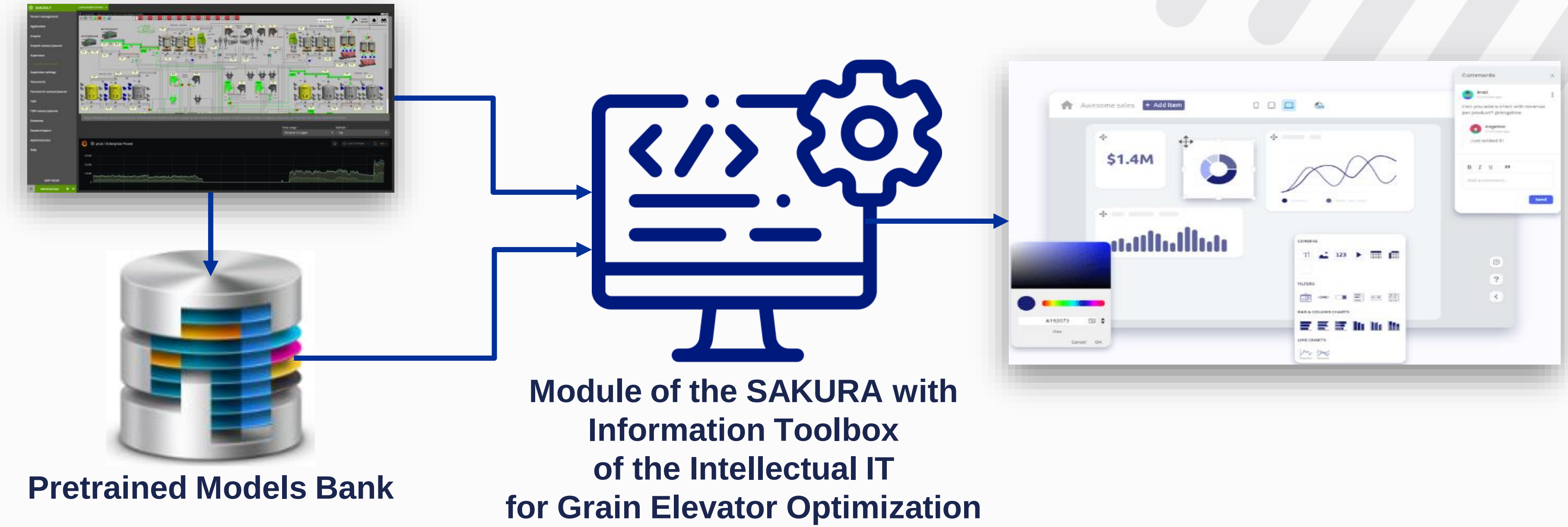
Deliverable D3.6 Construction of intelligent simulator for simulation and visualization of the grain elevator technological cycle and optimization of its routes and equipment parameters



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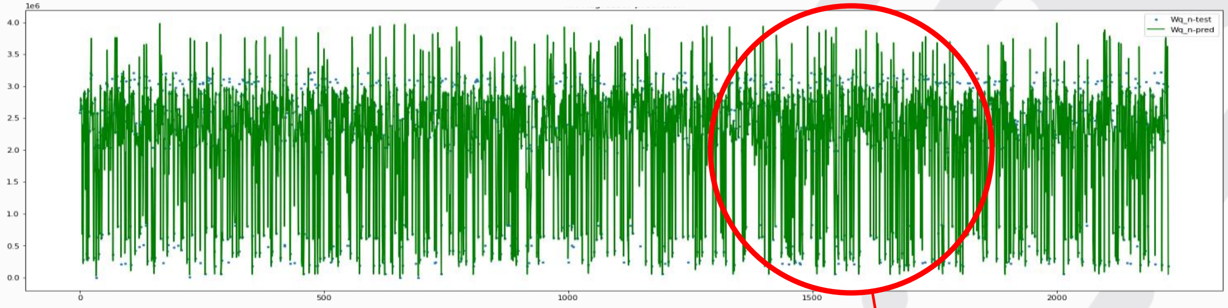
Deliverable D3.5 Creating trained neural network model for grain elevator route based on real data

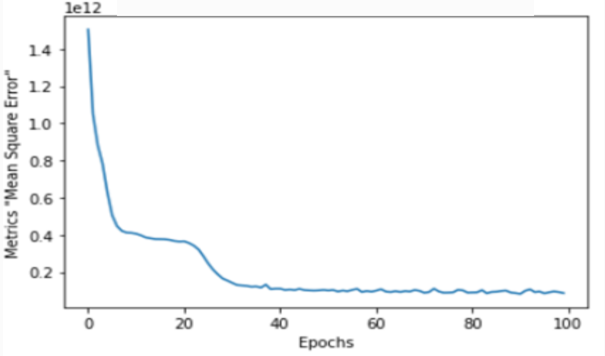
ML of NN model:

```
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
```

NN Regressor predicting:

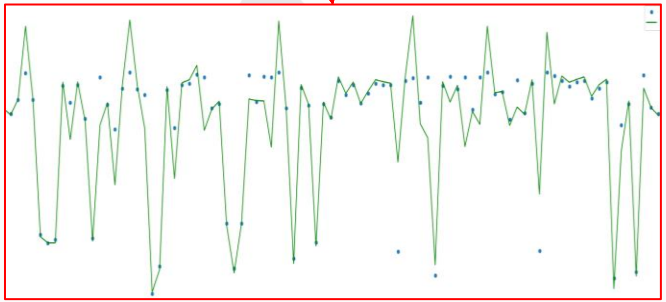


Metrics of NN model:



Probability 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
```



60 % Training	20 % Validation	20 % Testing

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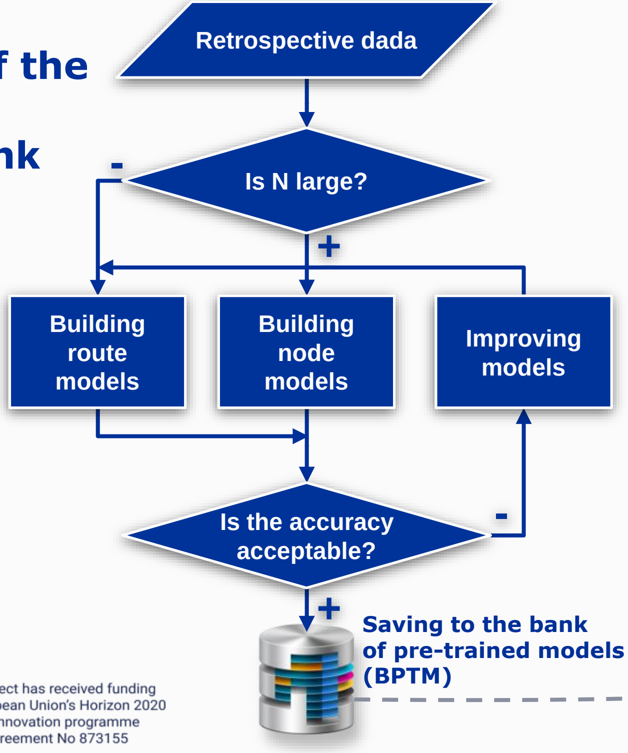
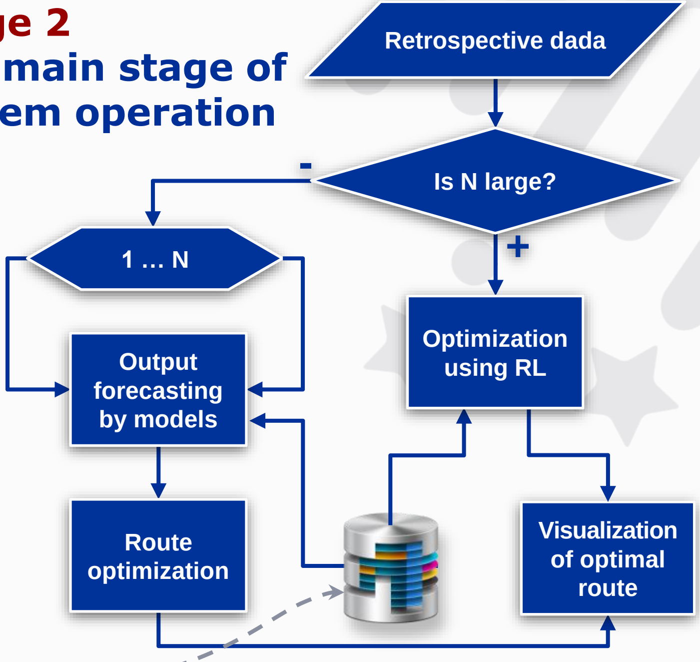
Deliverable D3.7 Construction of algorithms for optimizing grain elevator routes based on new data using machine learning technologies with reinforcement

Stage 1
Creation of the Pretrained Models Bank



Stage 2
The main stage of system operation



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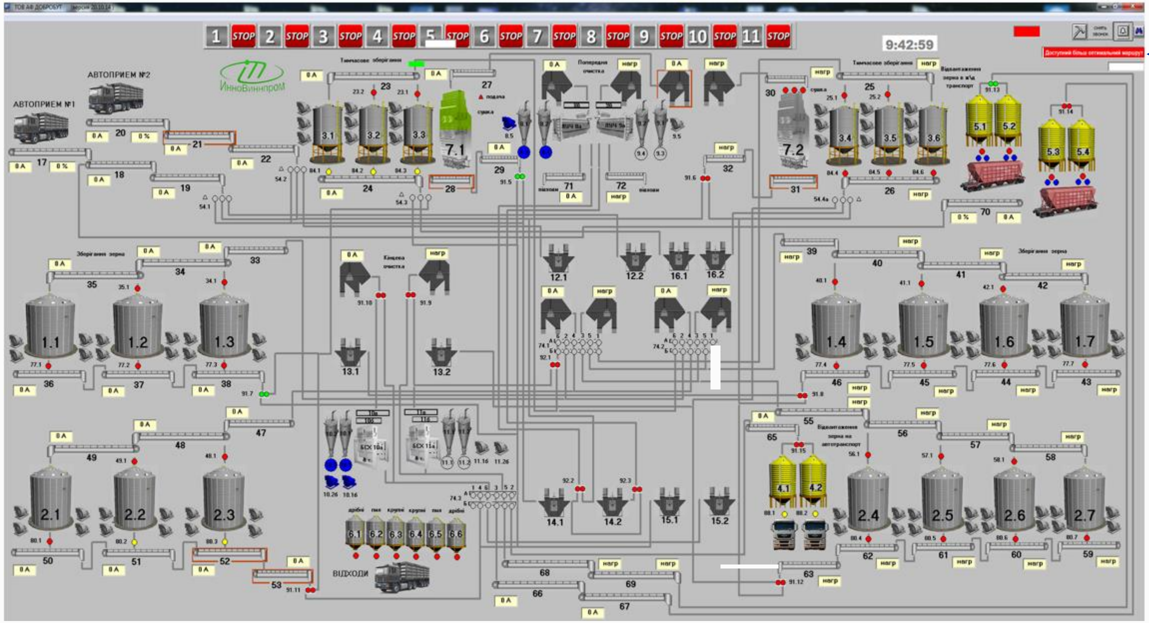
Deliverable D3.8 Selection of the optimal routes using intelligent simulator



НЕОПТИМАЛЬНИЙ МАРШРУТ

The menu for selecting routes and options, configuring the search for optimal routes

For the convenience of the personnel, we have left the SCADA interface familiar to elevator operators unchanged. Only in the upper right corner was added a menu for choosing the optimal route (route option).

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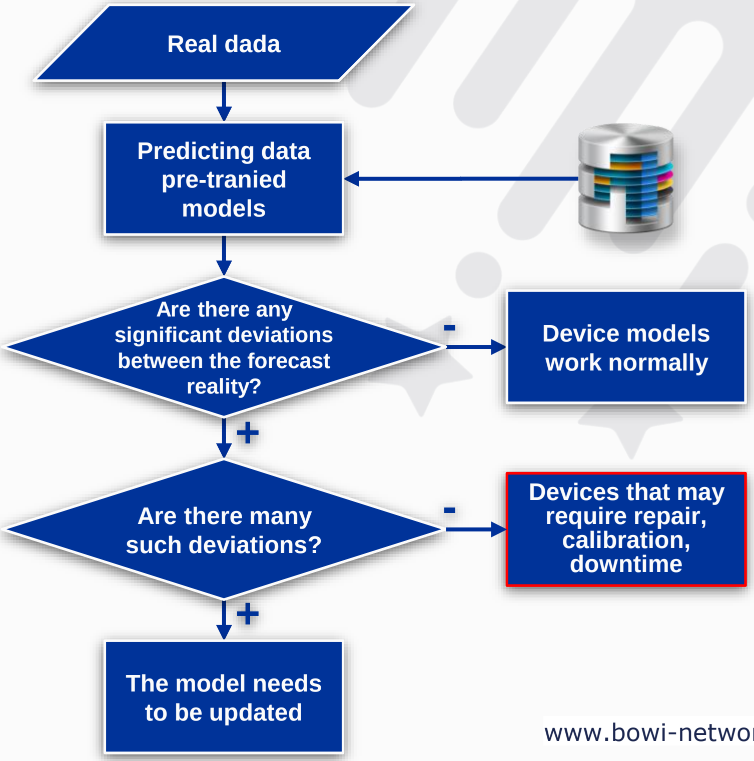
Deliverable D3.9 Implementation of algorithms for automatic detection of devices that may require repair, calibration, downtime, etc.

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**



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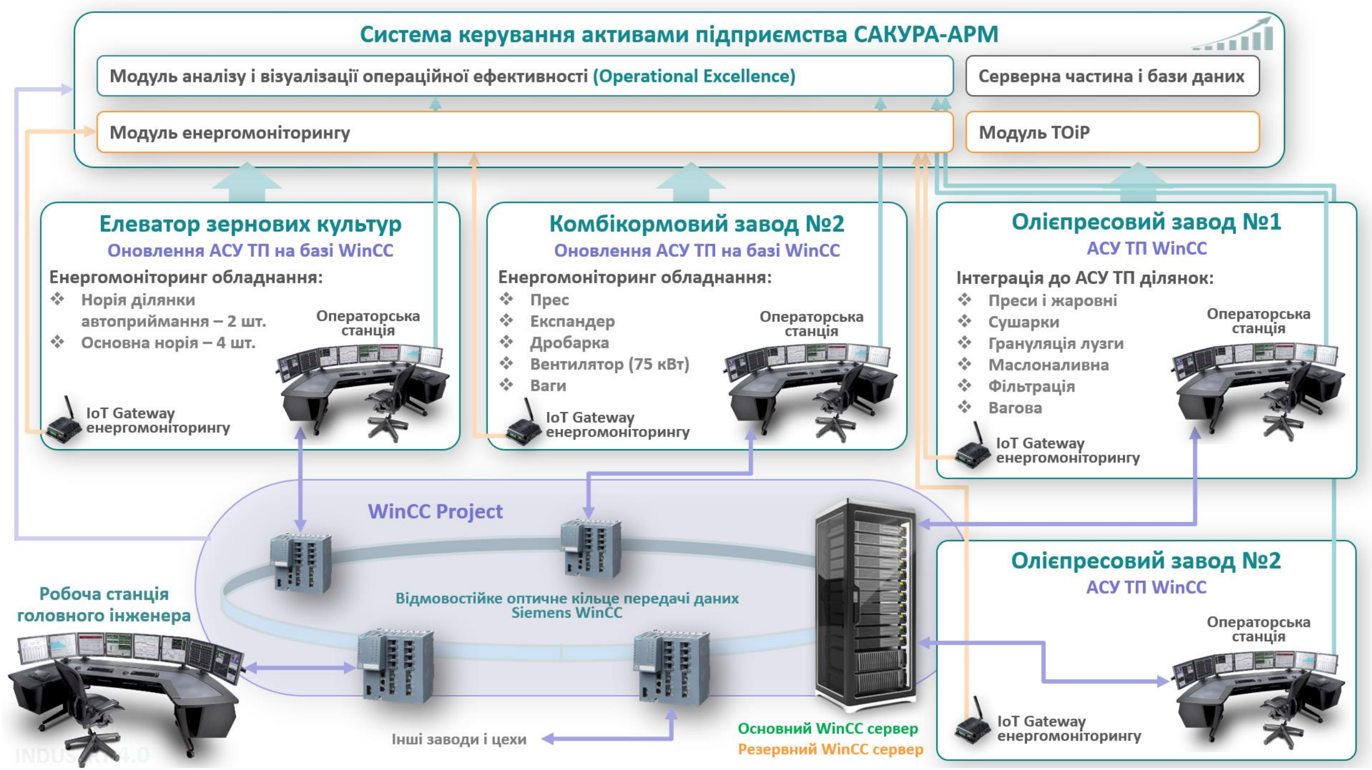
Deliverable D5.1 Implementation Plan

In the course of the project, an Implementation Plan for the implementation of the SAKURA-APM system at the complex of enterprises of the agro-industrial holding was developed.



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Features of KPI calculation

During the operation and development of SAKURA-APM, we received more than 100GB 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 for long-term research, which is a consequence of the need to move large volumes of grain.
- The impossibility of interrupting 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.

Therefore, to assess the achieved KPIs, we compared the data obtained for the period October 2021 - January 2022 with the data obtained for the period October 2022 - January 2023. In this way, we received two huge tables with data that allowed us to conduct some analysis of the results of the work. We calculated data on the weight of the product based on the calculation of the load factor of each unit of equipment in accordance with the conducted experiments on measuring the dependence of the load factor of the equipment on the real weight of the product.

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KPI 1. Increasing the number of system functions

Target value of KPI: **Increasing the number of SAKURA-APM system functions from 4 to 7**

Reached value of KPI: **7**

function 1:
Energy monitoring

function 2:
Energy efficiency

function 3:
Maintenance and repair

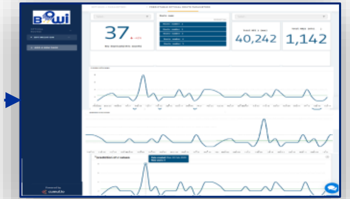
function 4:
Product control

function 5:
AI Routing

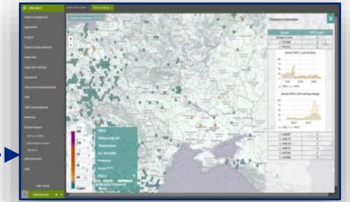
function 6:
Prediction of energy consumption

function 7:
Environmental monitoring

The dashboard allows you to display – The optimal action diagram (parameter J). Using scrolling, you can select the required number of nodes on the route. On the graph you can view the information on the relevant node.



The dashboard allows for the selected route and node to plot the predicted values of parameters Ws, Wp, Wq and J as a function of time, information is available for each type of node concerned:
$J = ksWs + kpWp + kq(Wqmax - Wq)$



Visualization of data received from environmental monitoring stations in the form of scalable icons.
Visualization of data obtained from public environmental monitoring networks.
Analytical processing of data, formation of reporting forms for the selected period

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KPI 2. Reducing the percentage of inefficient use of grain elevator equipment

Target value of KPI: **from 17% to 10%**

Reached value of KPI: **10%**

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

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 technologies.

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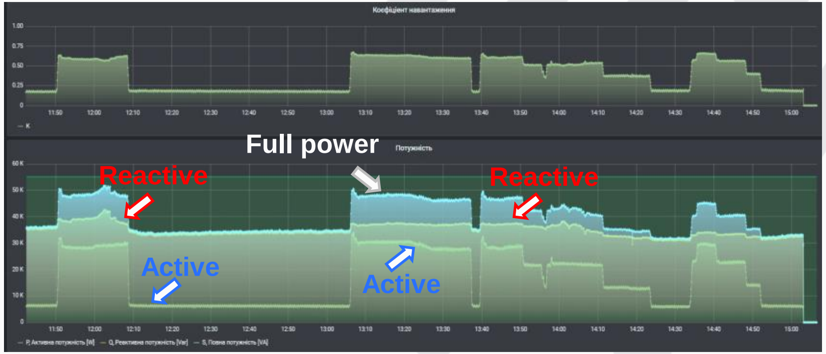
Generalized statistical data file:
D4.1.1 Operation statistics.xlsx

KPI 3. Reducing of energy consumption of technological equipment of grain elevator

Target value of KPI: **from 17% to 10%**

Reached value of KPI: **10%**

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%.**

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Generalized statistical data file:
D4.1.1 Operation statistics.xlsx

KPI 4. Reducing of technological delays and downtime of grain elevator equipment

Target value of KPI: **from 5% to 3%**

Reached value of KPI: **3%**

The planned KPI level was achieved in the following ways:

1. 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.
2. 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 load is normal

Partial load, inefficient work

Equipment operation in idle mode

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KPI 5. Negotiations with potential customers

Target value of KPI: **Negotiations regarding the introduction of SAKURA-APM with two potential clients**

Reached value of KPI: **4**

1. Negotiations are underway regarding the implementation of SAKURA-APM at **5 enterprises** of the **MHP agricultural holding**, an **Implementation Plan** has been developed, a number of **contracts have been concluded**, during which INNOVINNPROM performs work on the preliminary modernization of SCADA systems.
2. Negotiations are underway regarding the implementation of S-APM at the **7 grain elevators** of the **ASTARTA-Kyiv agricultural holding**, commercial proposals have been submitted, and a **test version of the system** has been deployed at one of the enterprises.
3. Negotiations are underway regarding the implementation of S-APM at the **7 grain elevators** of the **ZahidBug agricultural holding**, commercial offers were provided.
4. Negotiations are underway regarding the implementation of S-APM at the **3 grain elevators** of the **Agroprosperis agricultural holding**, commercial offers were provided.

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KPI 6. Participation in public events (conferences, forums, fairs, exhibitions, etc.)

Target value of KPI: **Participation in two events** Reached value of KPI: **>10**

1. Monthly public meetings with heads of enterprises within the **Vinnytsia Cluster of Instrumentation and Automation**
2. Speech with a presentation of SAKURA-APM for enterprise managers at the site of **MHP agricultural holding**
3. Participation in the Scientific & Technical Conference at the **Vinnytsia National Technical University**
   System Analysis and Information Technologies Department. Topic: Development of information technologies to optimize grain elevator operation using neural network models and reinforcement learning methods.
4. Presentation of the company's capabilities, including PaaS SAKURA-IIOT in **Vinnytsia City Hall**

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KPI 7. Publications in media and social networks

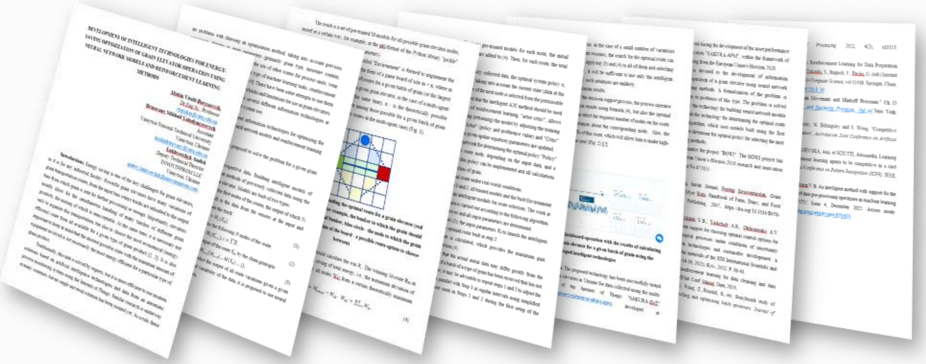
Target value of KPI: **Creation of three publications**

Reached value of KPI: **3**

Publication on the **Company website**:
https://innovinnprom.com/galuzevi-rishennya/sakura-apm

Publication in the **LinkedIn network**:
https://www.linkedin.com/feed/update/urn:li:activity:6915988724539346944/

Publication jointly with **Vinnytsia National Technical University**
D5.2_Theses_Munich_BOWI.docx
V International Scientific and Practical Conference Scientific Progress: Innovations, Achievements and Prospects, No 29



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Support from BOWI project

Many mentoring meetings from Centre 4.0 KPI DIH have been held – 9 meetings on a regular basis according to the schedule agreed in the TAR – second and fourth Tuesday of each month. Also, it should be noted support from PIAP DIH which included Technical and business consulting, TAR improvements, etc. According to the results of the meetings, SMEs received the following support from BOWI and benefit from that:

- Assistance in setting up technical processes;
- Technical and business consulting;
- Monitoring the implementation of the project plan;
- Coordination of assistance to customers and project executors;
- Coordination and assistance in the preparation of the report and presentations on the project;
- Organizing communications with other project participants;
- Consultations on the formation and improvement of KPI.

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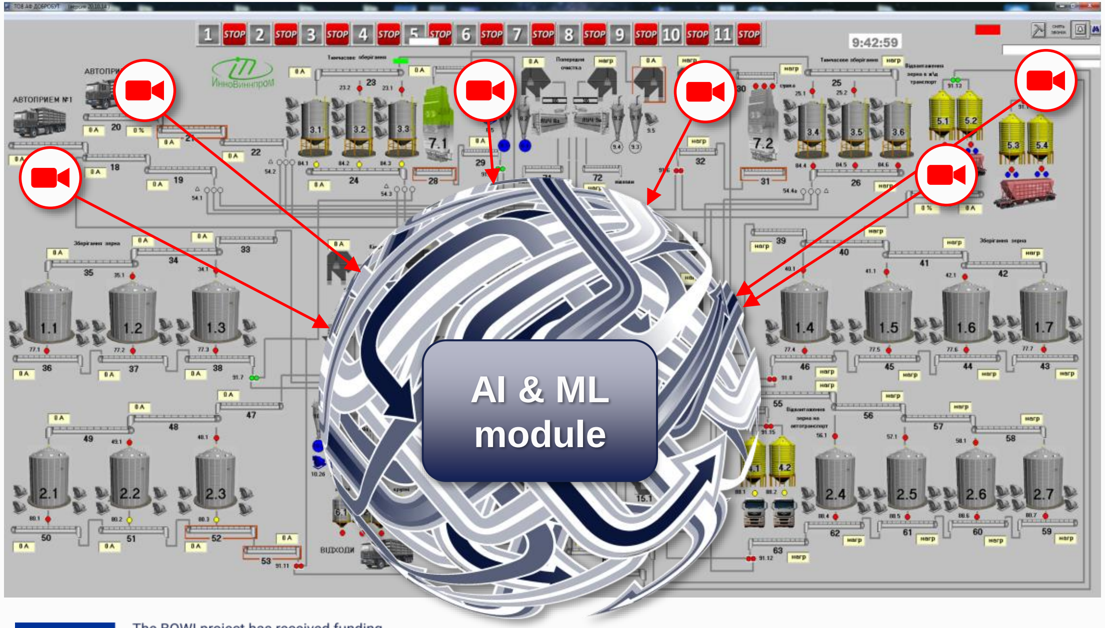
Support from DIH PIAP

During TTE, we faced the problem of choosing and training AI and ML models for different grain crops. After carrying out an expert assessment of the problem, DIH PIAP offered us to install additional IoT sensors in the most important places of the technological process, namely intelligent video cameras to recognize the types of grain crops that are received or shipped from the grain elevator.



Support from DIH PIAP:

- Networking, project management consulting.
- Selection of equipment, design of auxiliary elements and embedded software.
- Choosing an intelligent camera, designing interfaces, creating a framework for the necessary software.
- Preparation of the description of system in the form usable in future applications for funds, e.g. state-of-art with innovation aspects mentioned.

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Links and info

- INNOVINNPROM LTD
  Shevchenka 5a street, Vinnytsia, Ukraine
- Link to company web site:
  https://innovinnprom.com
- Link to TTE web site:
  https://innovinnprom.com/galuzevi-rishennya/sakura-apm
- Link to project:
  https://cloud.innovinnprom.com
- Link to ECO web site:
  https://www.eco.sakura.ms/?lang=en
- Detailed version of presentation
  https://docs.google.com/presentation/d/1Dk07izCzSphVNH4HDoegGIxWfJVM3ctB/edit

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This project was funded from BOWI Horizon 2020 project

SAKURA-APM