Integrated Contamination Identification System [ICIS]

Design, concept, selected functionalities of the "dual use" system

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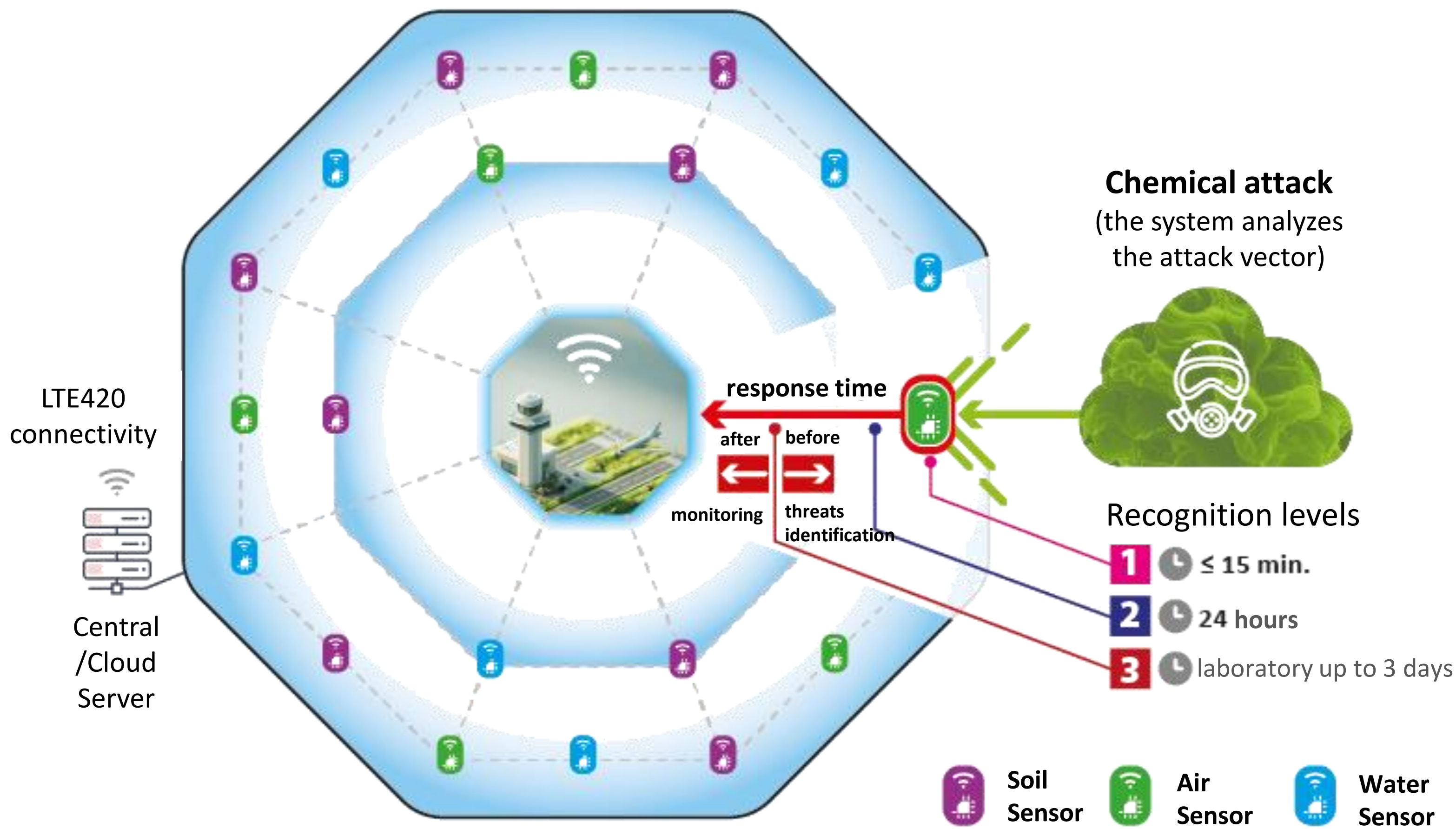
Agenda

- ✓ **Example events** — chemical attack, fire, traffic, hazardous waste
- ✓ **Target groups and events** — groups and events characteristics
- ✓ **Outline of the system structure** — system functionalities
- ✓ **Concept, idea** — recognition times, targets, preliminary contamination list, bioindicators, system build times

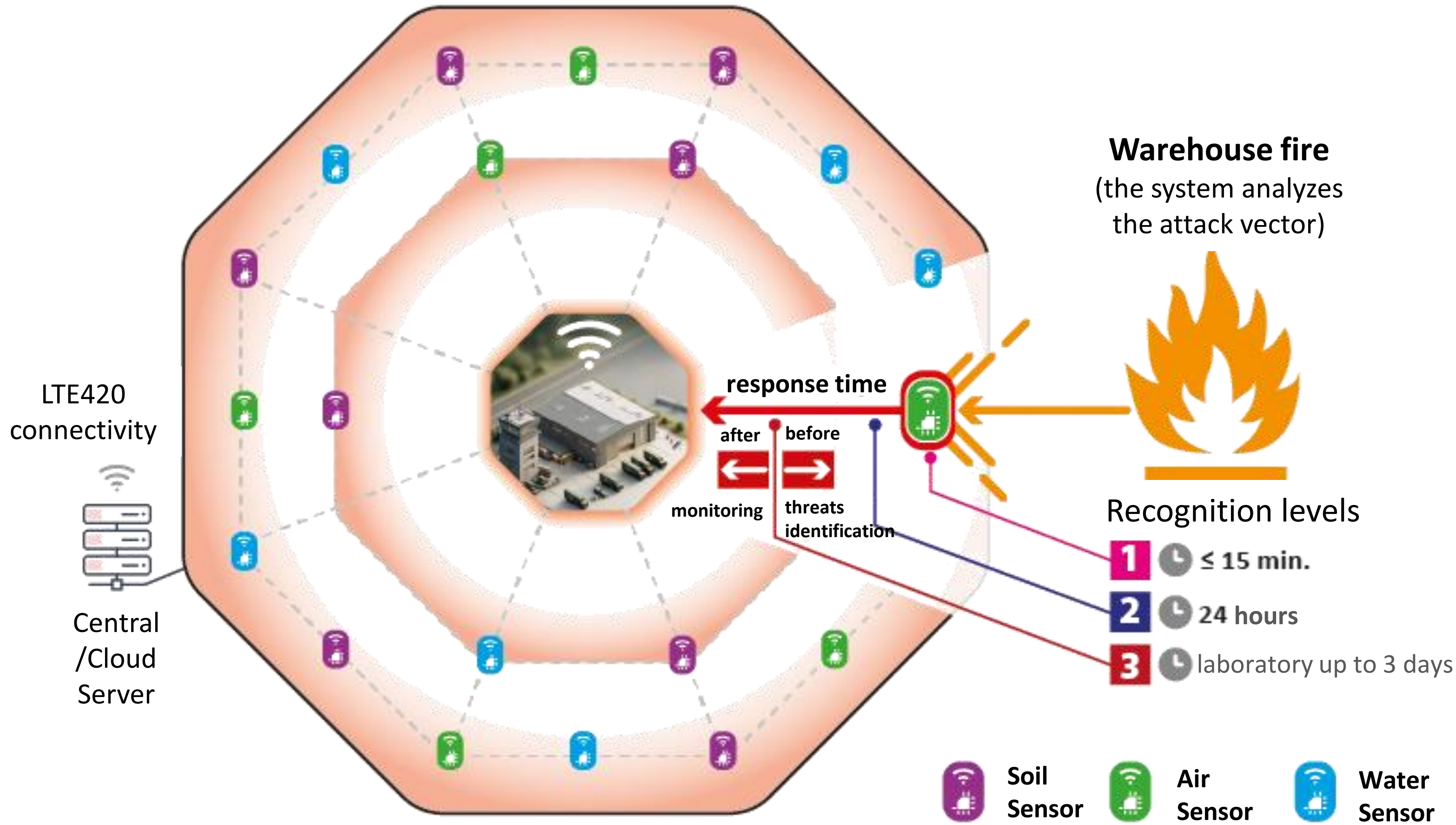
Appendices containing detailed descriptions of selected methodological issues

Incident: Chemical Attack/Toxic Emissions



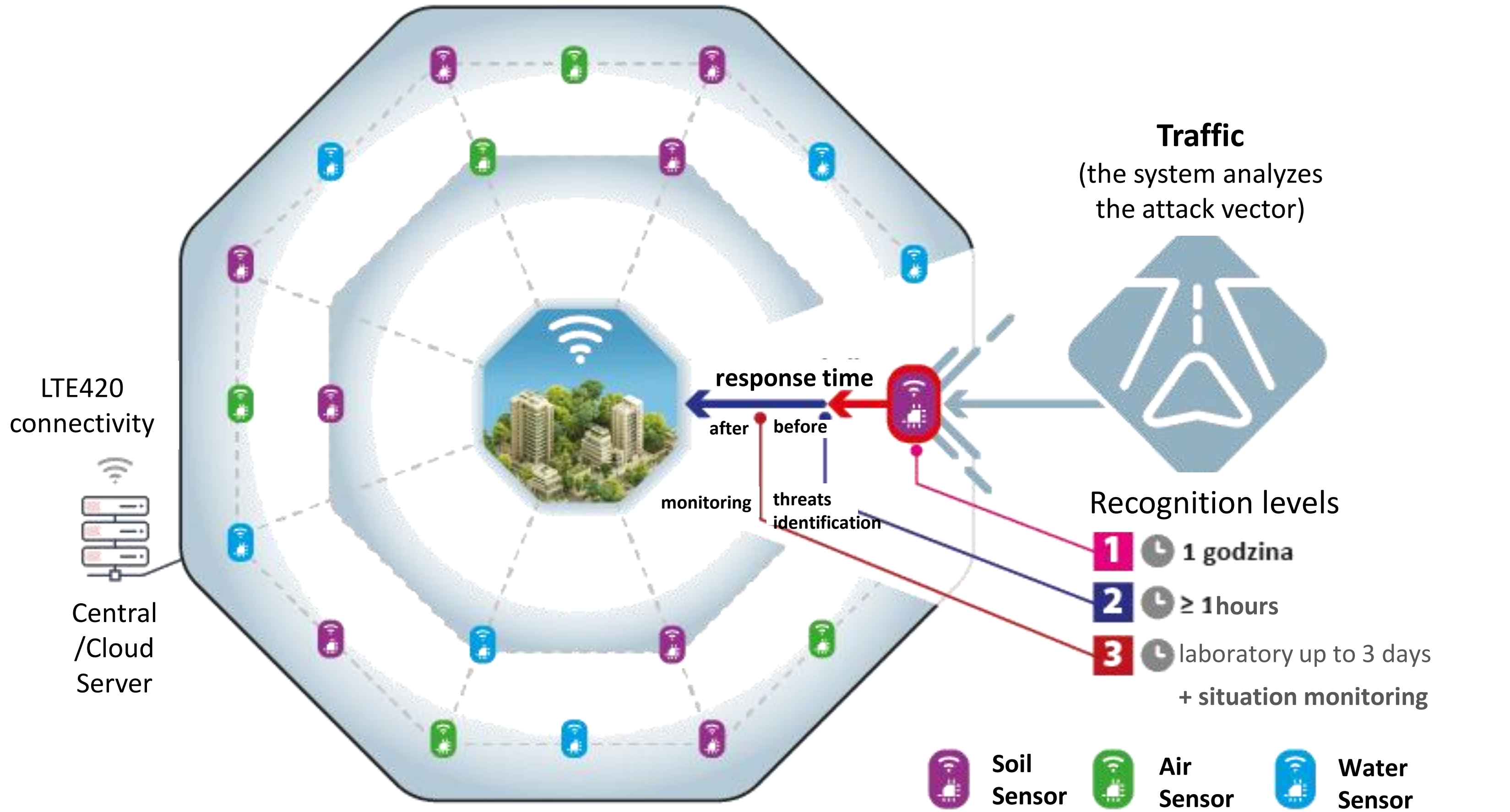
Types of sensors used: classic (low cost and reference), bioindicators, chromography-based

Incident: monitoring of fires before the occurrence and effects



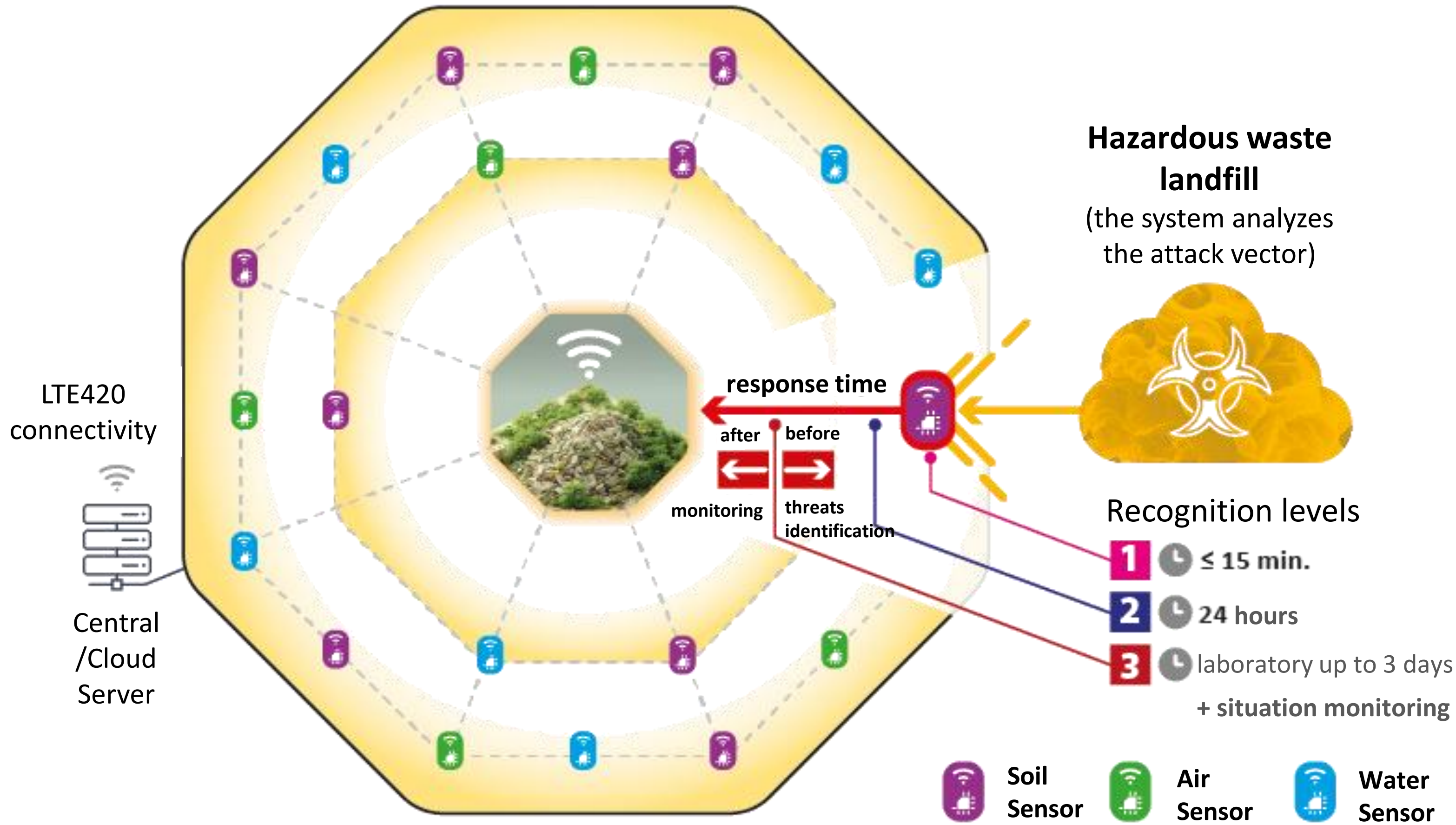
Types of sensors used: classic (low cost and reference), bioindicators, chromography-based

Incident: traffic monitoring



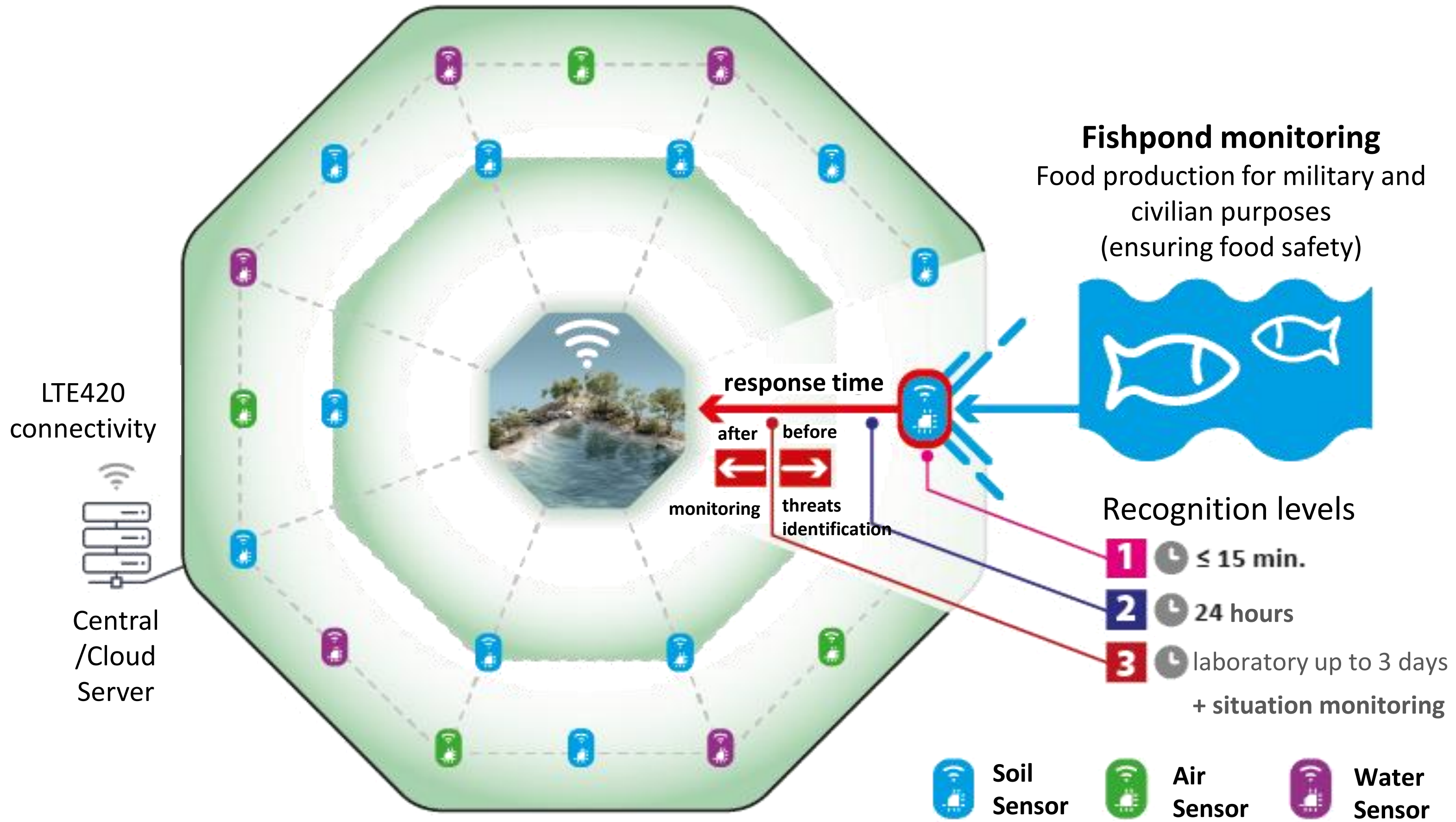
Types of sensors used: classic (low cost and reference), bioindicators, chromography-based

Incident: Hazardous Waste / Facilities Monitoring



Types of sensors used: classic (low cost and reference), bioindicators, chromography-based

Incident: Fishpond monitoring and food production Aquaculture



Types of sensors used: classic (low cost and reference), bioindicators, chromography-based

Introduction 1/2

Today's environmental threats to all three natural resources – from **air** pollution, **water** contamination to **soil** degradation – require modern and comprehensive **monitoring**, **forecasting**, **warning,** **reporting** and **prevention** tools based on foundamental and applied sciences.

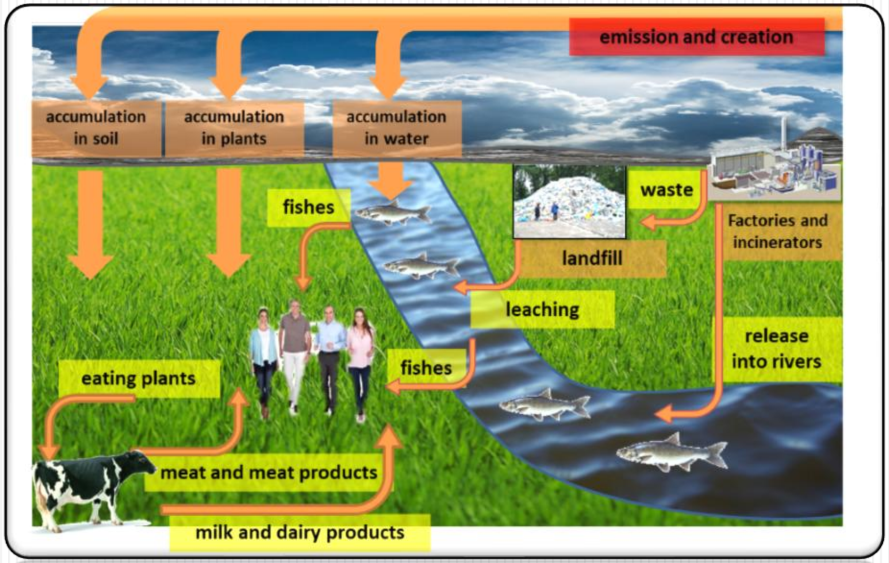
Current solutions in the country operate in a **distributed manner**: each focuses on **one type of threat**. This approach hinders a quick, reliable and precise assessment of the situation, and thus **limits the effectiveness** of protection and **remedial** measures.

The System **proposed** as part of the project is an **innovative**, **comprehensive solution** that collects and analyses data on air, water and soil in a single environment (**IT system**, **analytical system** and **new measuring devices**).

Introduction 2/2

A key element of the system is the possibility to **simultaneously** take into account the **interactions between these areas**, e.g. the migration of pollutants from the **air** through the **soil** to **groundwater** or the **secondary effects of emissions** into the atmosphere and the synergy of these effects.

Thanks to this, the system provides
complex picture of threats,
their causes and potential consequences.



Main goals of building the system 1/3

- It is possible **not to build** an integrated system (air, water, earth) and rely on many systems dedicated to individual phenomena (the current state in the country)...
- **The integrated system allows for holistic risk assessment and prediction, among others based on:**
  - **Interactions of factors** and their **effects**,
  - assessment of phenomena **before** and **after** the occurrence of events,
  - Migration of threats **throughout the natural environment**,
  - **Counteracting** selected threats.

Main goals of building the system 2/3

1. Identification of **contamination** and **events** (=phenomena) over time for a selected spatial location (domains: air, water, soil).
2. **Information** and **reporting**, including alert generation.
3. Stochastic modeling in both static and dynamic approaches allows for effective forecasting of phenomena, i.e., **forecasting the duration and level** of the phenomenon (**qualitative** and **quantitative**).
4. Research work on the **creation** and **adaptation** of **AI models** for heterogeneous measurement systems supporting early detection and warning of threats.
5. In-depth analyses of phenomena and their effects, enabling the development of **remediation** and **counteracted** programs.
6. **Resistance** to operational failures and **possible attacks**.
7. Scale of ISCI system operation: from **point** (up to 1 km), through **local** (up to approximately 100 km), and nationwide.

Main goals of building the system 3/3

7. Supporting the **sensor network** by **integrating satellite**, **drone**, **meteorological**, and other data, along with incorporating additional sources to clarify ambiguous situations, establish baselines, and confirm observations through independent channels, which **increases the stability** of generated warnings and resilience to missing data or individual sensor interference.
8. Creating a "**product**" that can be **deployed in a selected location** (for military and civilian applications).

ZSIS idea: alert levels = time and scope of analyses

Air
Water
Soil

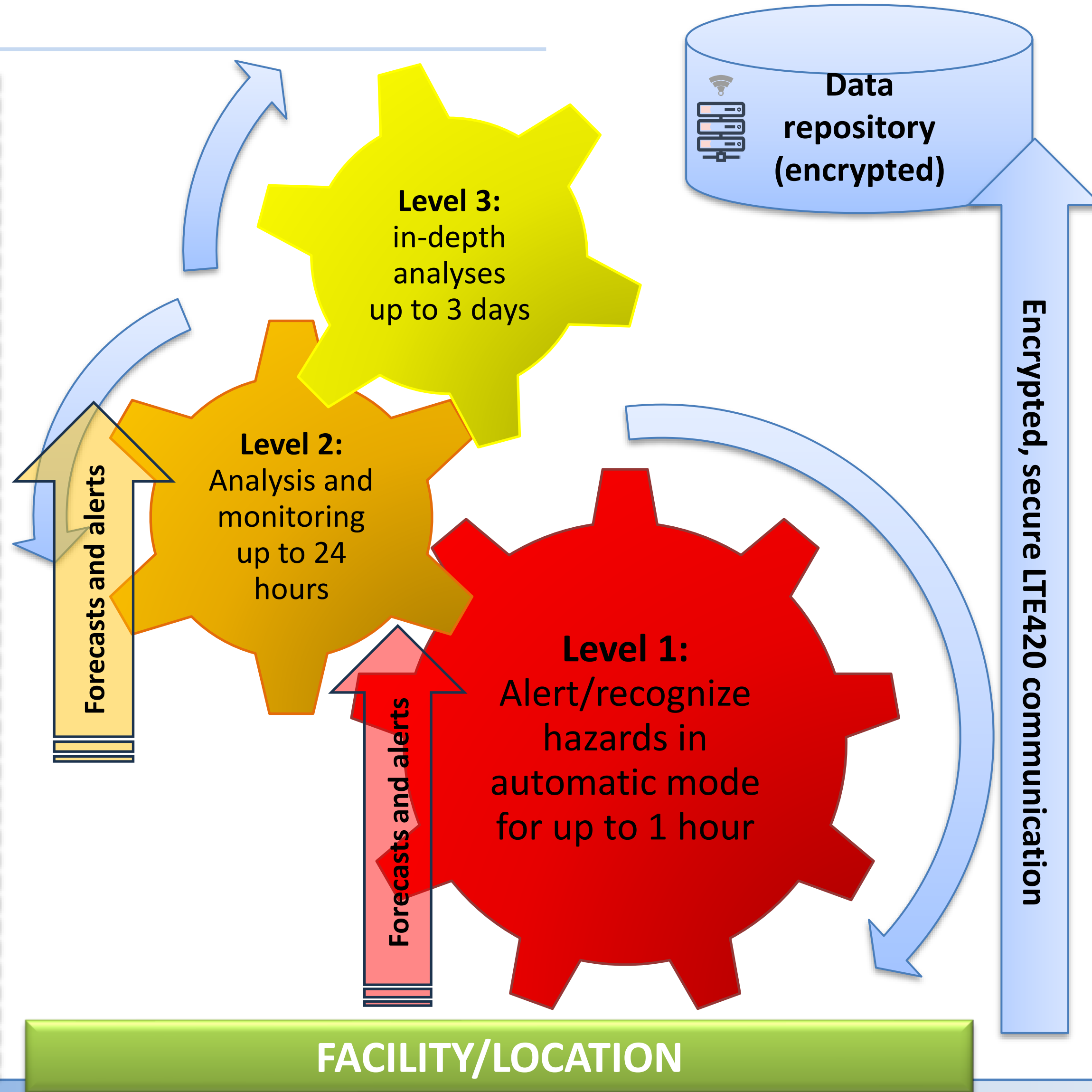
- Detailed laboratory analyses to:
  - confirm the threat,
  - verify the accuracy of the system alert,
- **Issue and generating internal and external alerts.**

Air
Water
Soil

- Own **accredited laboratory**
- Chromatography
- **RAMAN Spectrometry**
- To be developed: types of contamination, methodology

Air
Water - *option*
Soil - *option*

- Our own automatic meters - **bioindicators**, **chromatography**
- Automatic meters manufactured under license
- External automatic meters
- Results from GIS models and satellites (ICM or other sources; obtained)
- Data diagnostics, forecasts, internal and external alerts, online information



Integrated Contamination Identification System[ICIS] target groups

Military

- Military bases and training grounds
- Military facilities, e.g. **warehouses, airports**
- Military areas
- Other exposed...

Civil

- Municipalities, districts/JST
- Agglomerations
- Cities
- Seaports and airports
- Other

Probable selected example event locations (objects and areas):

- airports,
- military bases,
- industrial plants,
- infrastructure (bridges, tunnels, railways,
- dam reservoirs, water intakes, breeding ponds, water supply systems... etc.),
- towns and agglomerations.

The process of installing, building or implementing the system at the selected location

After reporting the need or necessity to run the system in the indicated location:

1. Area reconnaissance, including, m.in, the identification of
   a. **representativeness of the location of measuring stations**,
   b. **physicochemical and meteorological** conditions of the area,
   c. Specify **additional necessary** measurements.

   time: from approx. a few days to max. approx. 2 weeks

2. **Installation** of devices **and networking with models calibration**

   time: approx. a few days depending on the results of point 1 above

1. Starting the system
   time: from approx. a few hours to approx. a few days from the end of point 2 above

The process of installing, building or implementing the system at the selected location – system start-up time

The estimated time necessary to launch the system, starting from the **notification of the intention** to build to the **launch** of the monitoring system, ranges from 48 hours to max. approx. 3 weeks depending on the:

- **Natural resources** – air, water, earth measurements,
- **Measurement range** - selected substances and measuring devices,
- **Area and time – mathematical and stochastic models require historical data to work efficiently.**

*If it is necessary to **purchase dedicated** or **non-standard** measuring devices, the implementation time will be extended by the time necessary to complete the order (from 12 weeks to 6 months)..

*Starting the system is **not always** the same as stable operation in operating mode. Allows **always start monitoring** and **start the alerting process**.

Project **completion** time = **time for construction** and system startup

The project is planned for approximately **30 months** of design work (building the **information system – from 24** to 36 months depending on the scope of work and the type of application).

The time from the start of work to the launch of the monitoring system is estimated at about **15 to 18 months** of work, excluding the issue of delays in ordering components for the construction of new devices.

The problem of delays in ordering components in Polanda is expected to be resolved based on "advance" purchases in the supply chain and depends on final arrangements with the funding institution and beneficiaries.

Identification levels and tools

- Level 1: up to 1 hour
  - Air measurement systems (continuous monitoring, grid data, others with an interval of <=1 hour)
  - Bioindicators (air, water, soil) – devices of our own design
  - Nano chromatographs – devices of our own design or created and manufactured in cooperation
- Level 2: up to 24 hours
  - Bioindicators, nano chromatographs, laboratory, semi-automatic and manual measurement systems, others
- Level 3: up to 3 days
  - Accredited laboratory

Informing and reporting, including alerts

- The IT and information system is designed to show the current state of selected phenomena (contamination and events)
  - Online
  - In graphic form
  - In the form of messages (e.g. about the level of threat)
  - In the form of alerts (individually to the indicated units)

Forecasts of duration, level of the phenomenon (qualitative and quantitative)

- Qualitative forecasts – information about increased risk and the fact of threat
  - Stochastic methods, e.g. a family of logistics models,
  - DLNM models and derivatives.
- Quantitative forecasts
  - Stochastic methods - forecasts of air pollutant concentrations (horizon up to 48 hours) taking into account interactions and time delays (models of OLS, MANOVA, GLM/GRM and other families.),
  - Neural networks, artificial intelligence models,
  - Point and/or spatial forecasts of the area, including ensamble forecasts.
- Hazard forecasts based on quantitative forecasts (e.g. risks to people with asthma at given times, e.g. health indices)

In-depth analyses of phenomena and their effects

- In-depth analyses are aimed at **precise identification** of phenomena (e.g. the exact level of contamination) in the time from 1 hour to 3 days

- They are performed by
  - **Accredited laboratory**,
  - Spectrometry and chromatography techniques, including the RAMAN spectroscope.

- **Effects** are assessed on the basis of **projections, scenarios and/or experts.**

Resistance to operational failures and attacks

- The system in internal communication is based on the **LTE 420** system proven in natural disasters by the partner, DGT/Polkomtel
- Encrypted

Post-incident actions, remediation programs

- **Monitoring** the scene of the incident and identifying the time when the threat or hazard ceases (e.g. radiation, contamination, pollution, etc.),
- **Population recovery programs** developed with military doctors,
- **Radioactivity** protection.

Contamination List

- **The list of contaminations** must be prepared and **can be expanded** (in cooperation with the Military Medical Institute, Ministry of National Defence, State Fire Service and other institutions) – it is **the basis** for building an integrated system

- **The list of events** is based on the **list of contaminations**

- Based on the lists, methodologies and methods for detailed identification of contamination (e.g. time of recognition, selected stochastic models)

Final product

The end result is a **product:**

- Sold as a system to be deployed (devices + app + communication)
  - ✓ *Before implementation, an initial analysis at the location (e.g. station location) carried out by experts is necessary*

- End Product as a **Service** with Support Programs

- The final product as a **closed/dedicated system** for the Ministry of National Defence or another institution

Works in the area of construction of new devices based on bioindicators

The **complexity of matrices**, individual components of the environment, their multiphase increases in a series: **air** > **water** > **soil**. Along with this complexity, the number and variety of interactions that pollution introduced with civilization activities is subject to.

It is estimated that there are more than **100,000 toxic compounds** in the environment.
Chemical analytics with the use of highly specialized analytical equipment with high resolution and identification potential undertakes the development of procedures for quantitative assessment of the level of pollution with specific compounds of individual environmental components.

Knowledge of concentrations, even hundreds of toxic compounds, in a given matrix, unfortunately does **not translate** into an assessment/information about the harmful impact/impact on living organisms, including humans.

The effect of **mixtures of compounds** is of the nature of **addition**, **synergism** or **antagonism**. The effect of the impact (cytotoxicity, genotoxicity, mutagenicity or endocrine) is also important. Very important information is also the **persistence of the toxin** in the environment or its ability to **bioaccumulate**.

An important parameter in the impact assessment is **bioavailability**, as well as the assessment of the impact in the short time (**acute toxicity**) and in the long term (**chronic toxicity**).

Works in the area of construction of new devices based on bioindicators

It is also important that compounds undergo **transformations**, and the **products of transformation** may turn out to be **more toxic than the primary**/starting substance. Therefore, biotests using different **bioindicators** (standard organisms or fragments thereof) to assess the comprehensive/overall impact of pollutants in a specific matrix are becoming increasingly important in assessing the quality of the environment.

The **bioassay market** is constantly evolving, a wide range of tests is available for the **aqueous matrix**, the area of bioassays for the **solid phase** is relatively sufficient, while there are practically **no bioassays for the gas phase** (air).

The project proposes to **develop a bioassay for the gas phase**. This test will be based on the **body of the mussel** as a bioindicator.

ECD sensor: Based on commercially available ECD (Electron Capture Detector, or mECD) detectors, development of a sensor concept for measuring the presence of F- and Cl-organic compounds in pure water samples.

Preliminary list of contamination (external source in polish lang.)

	lp.	skażenie/pomiar	zaniecz. /grupa skażeń	obszar1	obszar2	rodzaj pomiaru	typ urz. pomiarowego	czas pomiaru1	czas pomiaru2	poziom systemu	oddziaływanie	stopień zagrożenia [1 - najbardziej niebezp. do 10 - niebezpieczne]	konieczność pomiarów (1 - konieczne do 10 - przydatne); 0 - czy mierzyć?	Doszczegółowienie opisowe	1. Inne, ważne	2. Inne, ważne
monitoring	1	NO2, Nox, NO	z	powietrze		automatyczny	1	1h		1	górne drogi oddechowe, układ krwionośny, płuca	5, [5]	1	*stężenia związane głównie z ruchem ulicznym*	pomiar możliwy w urządzeniu z interwałem 1 sek.; urz. Pomiarowe ref. low costy	prognzowanie możliwe modelami stat i SNN; modele GRM, GLM, DLNM do raportów
	2	PM10	z	powietrze		automatyczny	1	1h		1	górne drogi oddechowe, układ krwionośny, płuca	5, [5]	1	*stężenia związane z emisjami*	pomiar możliwy w urządzeniu z interwałem 1 sek.; urz. Pomiarowe ref. low costy	prognzowanie możliwe modelami stat i SNN; modele GRM, GLM, DLNM do raportów
	3	PM25	z	powietrze		automatyczny	1	1h		1	górne drogi oddechowe, układ krwionośny, płuca	5, [8]	1	*stężenia związane z emisjami*	pomiar możliwy w urządzeniu z interwałem 1 sek.; urz. Pomiarowe ref. low costy	prognzowanie możliwe modelami stat i SNN; modele GRM, GLM, DLNM do raportów
	4	O3	z	powietrze		automatyczny	1	1h		1	górne drogi oddechowe	2, [8], 6(NO2, O)	3	*silnie toksyczne; trzeba iwazględniać przemiany fotochemiczne w cyklu dobowym; Interakcje z NO2*	pomiar możliwy w urządzeniu z interwałem 1 sek.; urz. Pomiarowe ref. low costy	prognzowanie możliwe modelami stat i SNN; modele GRM, GLM, DLNM do raportów
	5	SO2	z	powietrze		automatyczny	1	1h		1	ogólny stan	5, [8]	7			
	6	temp	z	meteo		automatyczny	1	1h		1	czynnik wejściowy dla modelowania		1			
	7	pr.m kier wiatru	z	meteo		automatyczny	1	1h		1	czynnik wejściowy dla modelowania		1			
	8	gwm	z	meteo		automatyczny	6	1h		1	czynnik wejściowy dla modelowania		1	*[gwm] głębokość warstwy mieszania; zaleganie warstwy inwersyjnej w m npm*	moźiwość pozyskania z modeli bilansowych (ICM)	
	9	PM1	z	powietrze		automatyczny	1 lub 2	1h		1	górne drogi oddechowe, układ krwionośny, płuca, mózg	5, [2]	2	*stężenia związane z emisjami i ew. branią biologiczną*	pomiar możliwy w urządzeniu z interwałem 1 sek.; urz. Pomiarowe ref. low costy	prognzowanie możliwe modelami stat i SNN; modele GRM, GLM, DLNM do raportów
	10	CO2, CO	z	powietrze		automatyczny	2	1h		1			2			
	11	wilg	z	meteo		automatyczny	1	1h		1	czynnik wejściowy dla modelowania		1			
	12	ciśn	z	meteo		automatyczny	1	1h		1	czynnik wejściowy dla modelowania		2			
	13	ruch uliczny, n poj., v poj.	z	egzogeniczne		automatyczny	6	1h		1	czynnik wejściowy dla modelowania		2			
	14															
	15															
	16															
	17															
	18															
	19															
skażenia	20	radiacja	A	powietrze	gleba			**1h ?**		1	*opis poniżej*	1	0			
	21	rycyna	B	powietrze				**1h ?**		1, 3	*opis poniżej*	1	0			
	22	filowirusy	C	powietrze				**1h ?**		1, 3	*opis poniżej*	1	0			
	23	prątek gruźlicy	C	powietrze				**1h ?**		1, 3	*opis poniżej*	1	0			
	24	cyjanowodór	C1	powietrze				**1h ?**		1	*opis poniżej*	1	0			
	25	iperyt	C2	powietrze				**1h ?**		1	*opis poniżej*	1	0			
	26	chlor	C3	powietrze	woda			**1h ?**		1	*opis poniżej*	1	0			
	27	fosgen	C3	powietrze				**1h ?**		1	*opis poniżej*	1	0			
	28	tabun	C4	powietrze				**1h ?**		1	*opis poniżej*	1	0			
	29	sarin	C4	powietrze				**1h ?**		1	*opis poniżej*	1	0			
	30	cyklosarin	C4	powietrze				**1h ?**		1	*opis poniżej*	1	0			
	31	soman	C4	powietrze				**1h ?**		1	*opis poniżej*	1	0			
	32	VX	C4	powietrze				**1h ?**		1	*opis poniżej*	1	0			
	33	LSD	C5	powietrze		*czy mierzyć?*		**1h ?**		1	*opis poniżej*	1	0			
	34	gaz łzawiący (lakrymatory)	C6	powietrze				**1h ?**		1	*opis poniżej*	1	0			
	35	agent orange (defolianty)	C6	powietrze				**1h ?**		1	*opis poniżej*	1	0			
	36	pomiar toksyczności wobec bakterii V. fischeri po 30 min, może być zautomatyzowany, oraz pomiar wobec małżoraczka po 72 godz (lub krócej).	C7	powietrze				<1h oraz po 72 godz.		2	opis poniżej					
	37	wody (automatyczna pomiaru toksyczności wobec bakterii V. fischeri po 30 min, metoda jest dostępna komercyjnie, była stosowana przy zabezpieczaniu olimpiady w Berlinie - bezpieczeństwo wody pitnej dla sportowców). Bardzo wrażliwe są też Thamnocephalusy i Daphnie.	C7	woda				<1h		2	opis poniżej					
	38	gleby (toksyczność wobec małżoraczka po 72 godz, można analizować ekstrakty wodne z zastosowaniem V. fischeri po 30 min. a także wykorzystać testy z zastosowaniem roślin)	C7	gleba				<1h oraz po 72 godz.		2	opis poniżej					
	39															
	40															

Research
and **project**
offer

Dziękuję za uwagę…

Thank you for your attention…

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Additional resources related to selected topics partner and own descriptions

1. **Radiation** protection (Mineral and Energy Economy Research Institute of the Polish Academy of Sciences) *prof. Magdalenia Wdowin*
2. **Statistical methods of diagnostics** of measurement and interpolation of missing data (Institute of Environmental Engineering of the Polish Academy of Sciences-IPIŚPAN) *prof. Piotr Oskar Czechowski*
3. Examples of **statistical models** of **forecasting** and identification of pollutants implemented in Poland (IPIŚ PAN, PW) *prof. Piotr Oskar Czechowski, prof. Artur Badyda*
4. Examples of selected, **prototype analytical systems** implemented in Poland (Warsaw University of Technology-PW, Gdynia Maritime University-UMG) *prof. Mariusz Rogulski, prof. Piotr Oskar Czechowski, prof. Artur Badyda*
5. Works in the area of **construction of new devices based on bioindicators** (Department of Environmental Toxicology) *prof. Lidia Wolska*
6. Works in the field of **Artificial Intelligence** and **Neural Networks** (Institute of Theoretical and Applied Informatics Polish Academy of Sciences) *prof. Krzysztof Grochla*
7. Critical network**LTE420** (DGT) *dyr. Piotr Bułło*
8. Works and solutions in the area of **equivalence** of **measurement methods** and m**easurement results** in proprietary measuring devices (UMG, PW, IPIŚPAN) *dr. Tomasz Owczarek, prof. Mariusz Rogulski, prof. Piotr Oskar Czechowski*

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1. **Radiation** protection
(Mineral and Energy Economy Research Institute of the Polish Academy of Sciences) *prof. Magdalenia Wdowin*

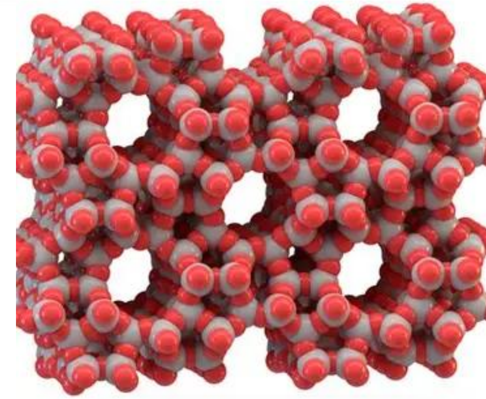
IGSMiE PAN

Instytut Gospodarki Surowcami Mineralnymi i Energią PAN

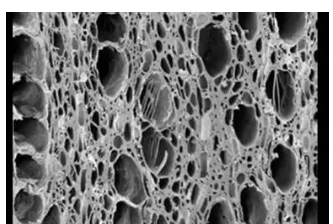
Autorzy: **Wdowin Magdalena – Dyrektor Instytutu**

Afiliacja: IGSMiE PAN

Synthetic and natural zeolites and activated carbons



Coals Activated



Zeolites from waste

Innovative BlackGlass Composite

Experimental work to date has shown the possibilities of using the fully applicable construction material lying on the heaps.
Material developed by Geminus Sp. z o.o. and developed in cooperation with IGSMiE PAN.
The attempts made to characterize the material led to its future implementation application:

- *radiation absorption,*
- *absorption of sound waves,*
- *forming shapes that can be used in construction and architecture (bunker lining),*
- *high-temperature purification and catalysis systems,*
- *Electrodes.*

The material has the ability to be easily formed into any shape because it is pre-synthesized in the liquid phase.

Geminus Sp. z o.o.

Instytut Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk

Ongoing project related to

M-era.Net

NCBR
Narodowe Centrum Badań i Rozwoju

Title: Circular economy through sustainable technology for the recovery of critical raw materials (REE) from selected waste materials

Instytut Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk

Geminus Sp. z o.o.

UMCS
MARIA CURIE-SKLODOWSKA UNIVERSITY IN LUBLIN

VSB TECHNICAL UNIVERSITY OF OSTRAVA

TENMAK
TURKISH ENERGY, NUCLEAR AND MINERAL RESEARCH AGENCY

The project will allow to develop technologies for the recovery of rare earth elements necessary for the production of military equipment

2. **Statistical methods of diagnostics** of measurement and interpolation of missing data (Institute of Environmental Engineering Polish Academy of Sciences) *prof. Piotr Oskar Czechowski*

High quality measurement data

Ensuring a **reliable and objective** assessment of the quality of measurements of concentrations of pollutants and contamination allows, for:

- precise **diagnosis** both in the operative mode and in terms of time and cross-section,
- **warning and counteracting** contamination and its consequences,
- **avoid problems** related to the **propagation** of errors in forecasts.
- **counteracting** the effects of pollution requires reliable and reliable monitoring of the state of the atmosphere, i.e. direct measurements of contamination.

lack of solutions – measurement data diagnostics

- The analytical methods used so far (Dixon, Rosner, Welsh statistical tests, and methods based on the three-sigma rule) are insufficient for two reasons:
    - unsuitability for **processing large data sets**,
    - they do not allow for the identification of the **causes of errors**.

- The essence of the applied data quality assessment methods is the identification of errors in data based on the deviation of the measurement value from an assumed standard, e.g., the form of the distribution.

lack of solutions cont.

- The methods used for error detection in data **do not take** into account:
  - the human factor,
  - the specifics of device operation,
  - device imperfections,
  - environmental influences,
  - **the causes of errors**.

Partial objectives of the work

Proposing a **coherent** and **flexible methodology** tailored to the specifics of an air quality monitoring network, supporting the identification of **potential errors** in measurement results.

Designing and building an information system that provides:

- **verification** of the correctness of the methodology,
- **optimization** of computation time,
- **scalability** taking into account new causes of errors recognized in the future as well as **future new methods** of their identification.

For what purpose?

The developed methods for error identification in measurements and the information system will contribute to more effective achievement of the system's goals by:

- **increasing the precision** of error identification,
- **reducing the time** required to perform data quality assessment on an annual basis and operational work compared to the evaluation carried out by the system operator,
- enabling reliable estimation of a **greater number of stochastic models** = improving the **quality of forecasts** and the **ability to identify a larger number** of exogenous **factors**.

THE ESSENCE OF THE SOLUTION (1)

Recognizing a measurement result that deviates from the reference level **as erroneous** is **insufficient**.

A **detailed analysis** of the **causes of identification** is necessary in order to make a decision to **eliminate** the erroneous measurement or to **retain** the atypical but correct measurement.

The question arises:
How to distinguish erroneous measurement results from observations caused by natural factors, such as sudden meteorological changes or incidental street traffic?

THE ESSENCE OF THE SOLUTION (2)

The **analysis of the impact** of **removing a measurement**/group of erroneous measurements on the others, in various aspects of the phenomenon, **allows for the identification** of the **causes** of a potential error and the **decision** to eliminate it.

The developed methodology currently includes a selected **set of measures** and **six stages** covering four key aspects of the phenomenon.

THE ESSENCE OF SOLUTION (3)

The **fundamental mechanism** in the error identification process is the assessment of the **impact of removing erroneous** measurements on the remaining ones.

Selected measures based on **causal relationships** (regression) determined by models aim to **indicate the causes of error** identification in the relationship (exogenous, endogenous, or combined factors).

The stages of the diagnostic process **encompass the sources of error** occurrence, which have been previously classified.

THE ESSENCE OF SOLUTION (4)

The **dependent variable** - subject to quality assessment - is a selected sequence of measurement results in a strong measurement scale.

On the side of **independent** variables, there are:

- **exogenous** variables (e.g., **meteorological** measurements, **emissions**, **metacharacters**),
- previously identified **properties of the variable** under analysis (**distribution** shape, **periodic** changes, and others).

ESSENCE OF SOLUTION (5): selected measures

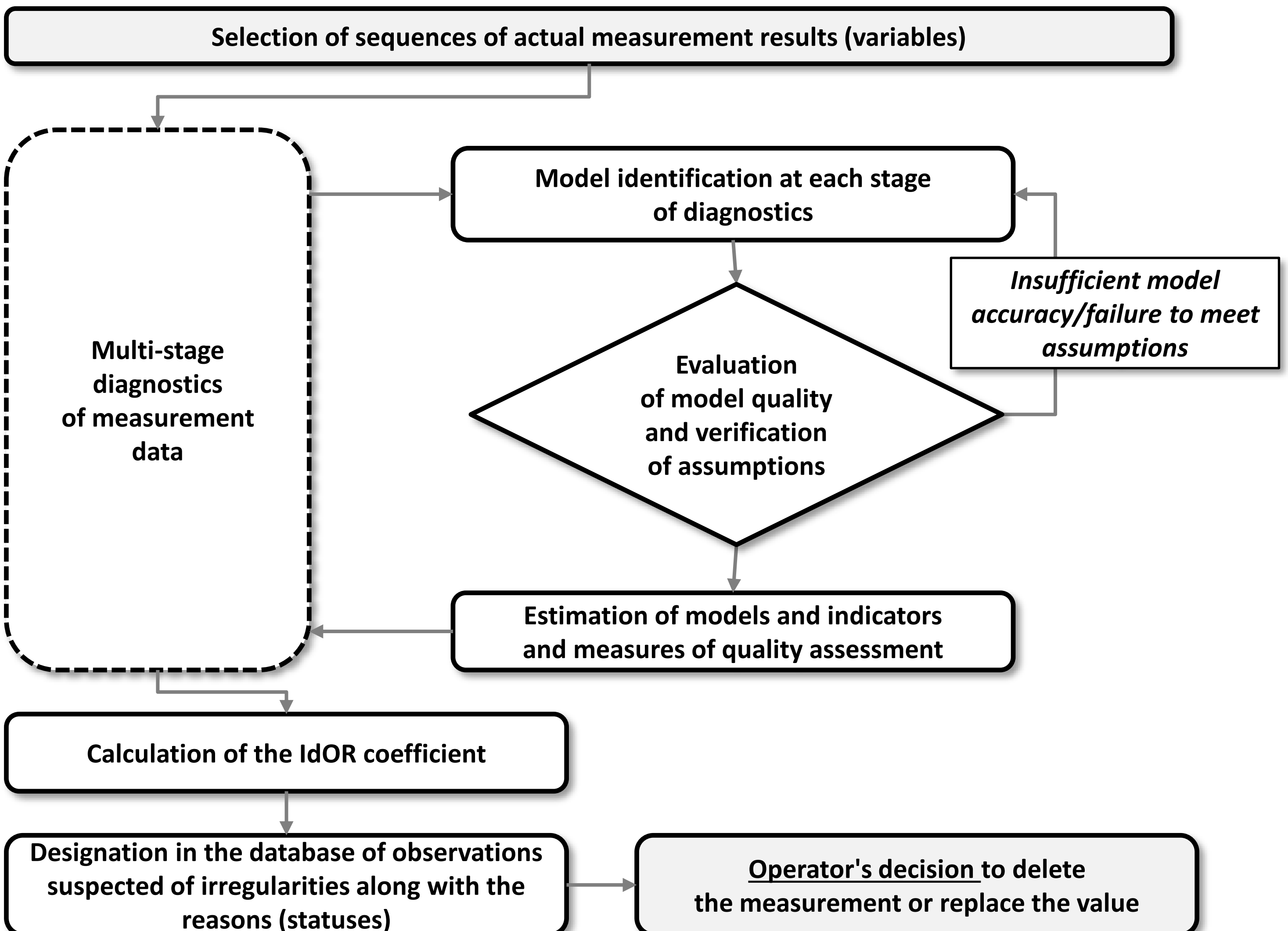
DFITS	***h_i***	*distances:* ***Cook, Mahalanobis, F_i***
Most often an incorrect measurement	**Requiring further analysis**	**Most often natural**
OUTLIERS	*INFLUENTIAL OBSERVATIONS*	*DISTANT OBSERVATIONS*
1. High residual value. 2. Little impact on the directional coefficient of regression (after elimination); possibility of changing the direction of the line. 3. Change in the intercept (after elimination). 4. Significant improvement in fit and strength of correlation (after elimination).	*1. Strong influence on the magnitude of regression parameters - significant impact on the position of the line. 2. Significant reduction of the random error component (after elimination).*	*1. After elimination from the set, the parameters and core fitting do not undergo significant changes.*

THE ESSENCE OF SOLUTION (6): stages of the process

Stage		Stages of analysis; fields of analysis	Reference level / assumptions of applicability	Order of magnitude $\hat{y}_i$ (y_i variable subjected to quality assessment)
1	One-dimensional	Stage of raw data evaluation; *t, f*	Intermediate level / no assumptions	$\hat{y}_i = \overline{y}$
2		Stage of evaluation of measurement result distributions; *f*	Identified distribution function of the variable; linearized cumulative distribution function / no assumptions; distribution identified in the system	$\hat{y}_i = a + bx_i$ where: x_i – empirical quantiles, $\hat{y}_i$ - theoretical quantles of the identified distribution.
3		Waveform and spectrum assessment stage; *f, t*	Nonlinear model taking into account periodicity / assumptions of stochastic processes taken into account at the stage of numerical implementation	$\hat{y}_i = x_t = f(t) + \sum_{i=1}^{\frac{n}{2}} \left[\alpha_i \sin\left(\frac{2\pi}{n} it\right) + \beta_i \cos\left(\frac{2\pi}{n} it\right)\right]$ where: α_i, β_i - parameters .
4		Stage of statistical evaluation of distribution of measurement results; *f*	Normal distribution/normal distribution of variable; manual check required	Not present $\hat{y}_i$ and resistant measures; the analysis is performed based on iterative Rosner and Grubbs tests.
5	Multidimensional	Stage of multivariate evaluation in pairs; *t, f, s*	Relationship between two variables / assumptions as in the OLS model; checked by the system	$\hat{y}_i = a_p + b_p x_{pi}$ for each pair p of the selected variables, where: $p = 1 \ldots k$ where k denotes the number of independent variables, $a -$ const., $b -$ model parameters, $\hat{y}_i$ – theoretical values for the selected dependent variable.
6		Stage of assessing the multidimensional impact of exogenous factors; *t, f, s*	The relationship defining the combined effect of several independent variables on the measurement results of concentration / assumptions as in the OLS model	$\hat{y}_i = a + b_1 x_{1i} + b_2 x_{2i} + \cdots + b_k x_{1k}$ where: *k* denotes the number of independent variables, $a -$ constant term, $b -$ model parameters, $\hat{y}_i$ – theoretical values for the selected dependent variable.

domains: t-time; f-frequency; s-space

ESSENCE OF THE SOLUTION (7): synthetic algorithm of the data diagnostic process



domains: t-time; f-frequency; s-space

Examples of statistical models for forecasting and identification of pollution implemented in Poland

Forecasting model (*Generalized Regression Model*) an example from AirVarsovia and AirRawicz systems

$$\boldsymbol{c_{t+1}}^{\boldsymbol{W}} = \boldsymbol{g}(p_t{}^W c_t{}^W + p_{t-1}{}^W c_{t-1}{}^W + \cdots + p_{t-r}{}^W c_{t-r}{}^W + p_t^{kW} kW_t{}^W + \cdots + p_{t-m}^{kW} kW_{t-m}{}^W + p_t^{vW} vW_t{}^W + \cdots + p_{t-m}^{vW} vW_{t-m}{}^W + p_t^{teW} teW_t{}^W + \cdots + p_{t-m}^{teW} teW_{t-m}{}^W + p_t^{ciW} ciW_t{}^W + \cdots + p_{t-m}^{ciW} ciW_{t-m}{}^W + p_t^{wiW} wiW_t{}^W + \cdots + p_{t-m}^{wiW} wiW_{t-m}{}^W + p_t^{prpW} prpW_t{}^W + \cdots + p_{t-m}^{prpW} prpW_{t-m}{}^W + p_t^{prmW} prmW_t{}^W + \cdots + p_{t-m}^{prmW} prmW_{t-m}{}^W + p_t^{opW} opW_t{}^W + \cdots + p_{t-m}^{opW} opW_{t-m}{}^W + p_t{}^W WDay(i)_t{}^W + \cdots + p_{t-m}{}^W WDay(i)_{t-m}{}^W + p_t{}^W HH(ii)_t{}^W + \cdots + p_{t-m}{}^W HH(ii)_{t-m}{}^W)^W + e_t{}^W + e_{t-1}{}^W + \cdots + e_{t-r}{}^W$$

where:

$c_{t+1}{}^W$ - forecast concentration of the air quality index at the station W in time t+1 for t=1 to 505 hours counting backwards from the moment (date and time) of modeling and forecasting for the future(t+1, t+2,….,t+48)

$c_t{}^W, c_{t-1}{}^W, \dots, c_{t-r}{}^W$ - the measured **concentration** of the air quality index at the station W at time t, t-1,…, t-r, where r is the length of the historical series determined at the identification stage (r=505);

$p_t{}^W, p_{t-1}{}^W, \dots, p_{t-r}{}^W$ - estimated parameters of air quality index concentrations at the W station over time*t, t-1,…, t-r,;*

$WDay(i)_t{}^W, \dots, WDay(i)_{t-r}{}^W$ – variables identifying the **weekly cycle** after and from 1 to 7 at station W at time t where r is the length of the historical series determined at the identification stage; each day of the week (from 1 to 7) is represented by a 0-1 independent variable;

The model – en example from AirVarsovia and AirRawicz forecasting systems

$HH(ii)_t{}^W, \dots, HH(ii)_{t-r}{}^W$ - variables identifying the **daily cycle of changes** (**traffic and photochemical transformations**) after ii from 0:00 to 23:00 at the station W at time t where in turn r is the length of the historical series determined at the identification stage;

k – wind direction, *v-wind speed*, *te-temperature*, *ci*-pressure, *prp*-vertical speed, *prm*-radiation, *op*-precipitation, *wi*-humidity;

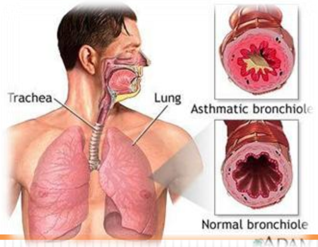
$e_t{}^W$ – the rest of the models at the stationW;

$g()^W$ – model binding function selected depending on the distribution of the random component (normal, gamma, Poisson).

Model is based on hourly data **takes into account** key factors affecting the imissions (PM_{10},$PM_{2,5}$, NO_2, O_3): **imissions**, **cycles** of changes (hourly, daily, weekly), **traffic**, **photochemical transformations**, **meteorological** and others.

One of the most important model property is to detect **nonlinear interdependencies**

Sample conclusions (3) – from GLM models



With an increase in the level of **nitrogen dioxide** in Krakow **by 10 mg/ m³**, the risk of asthma **exacerbation increases by 9%,** assuming that other variables remain unchanged.

With the increase in the level of **PM10** in Krakow **by 10 mg/ m³**, the risk of asthma exacerbation **increases by 4%,** assuming that other variables remain unchanged.

With an increase in the level of nitrogen dioxide in the Tri-City **by 10 mg/ m³**, the risk of asthma exacerbation **increases by 10%,** assuming that other variables remain unchanged.
With an increase in the level of **PM 2.5** in the Tri-City **by 10 mg/ m³**, the risk of exacerbation of asthma **increases by 3%**, assuming that other variables remain unchanged.

(*right table*) Characteristics of final models (with and without interactions) describing effects of air pollutants and weather conditions on number of all-cause deaths (2020-2018)

Data for air pollutant levels and weather conditions were taken to the models for each location separately. Numbers represent number of times the variable was present in the final models. Statistically significant interactions and single variables included in the final models are shown and ordered by decreasing effect strength.

***R2 (inter.)**, adjusted coefficient of determination for models with interactions;*
***R2 (univ.)**, adjusted coefficient of determination for models without interactions; **df**, degrees of freedom of the final model;*
***PM10**, particulate matter of size 10 µm or less;*
***PM2.5**, particulate matter of size 2.5 µm or less; pressure, atmospheric pressure; wind, wind speed; temperature, air temperature; humidity, air humidity*

	Warsaw	Cracow	Tricity
R^2 (inter.)	24.0%	9.9%	12.7%
R^2 (univ.)	*19.7%*	*9.4%*	*11.2%*
df	*2 800*	*2 860*	*2 888*
Year	3	2	3
Season	4	1	1
NO_2	2	2	0
O_3	2	2	1
PM_{10}	2	1	2
$PM_{2.5}$	2	1	0
Pressure	2	2	2
Wind	2	1	1
Temperature	4	1	2
Humidity	1	2	0
Precipitation	1	0	1
Interactions:	O_3*temperature Pressure*temperature $PM_{2.5}$*wind Season*O_3 Year*PM_{10} NO_2*humidity PM_{10}*precipitation PM_{10}*temperature Season Season*NO_2 Season*pressure Year*temperature Year*wind	Season*humidity Pressure $PM_{2.5}$*wind NO_2*O_3 Pressure*temperature Year*PM_{10} NO_2*humidity Year*O_3	O_3*PM_{10} Season Pressure*temperature Year*pressure Year*temperature PM_{10}*precipitation Year*wind
Single factors:	*Season* *O_3* *PM_{10}* *Year* *Temperature* *Pressure*	*Year* *Season* *NO_2* *Pressure* *Wind* *Temperature* *$PM_{2.5}$* *O_3*	*Season* *O_3* *Year* *Temperature* *Humidity* *NO_2* *PM_{10}*

(*right table*) Characteristics of final models (with and without interactions) describing effects of air pollutants and weather conditions on number of pneumonia-related hospitalizations (2020-2018)

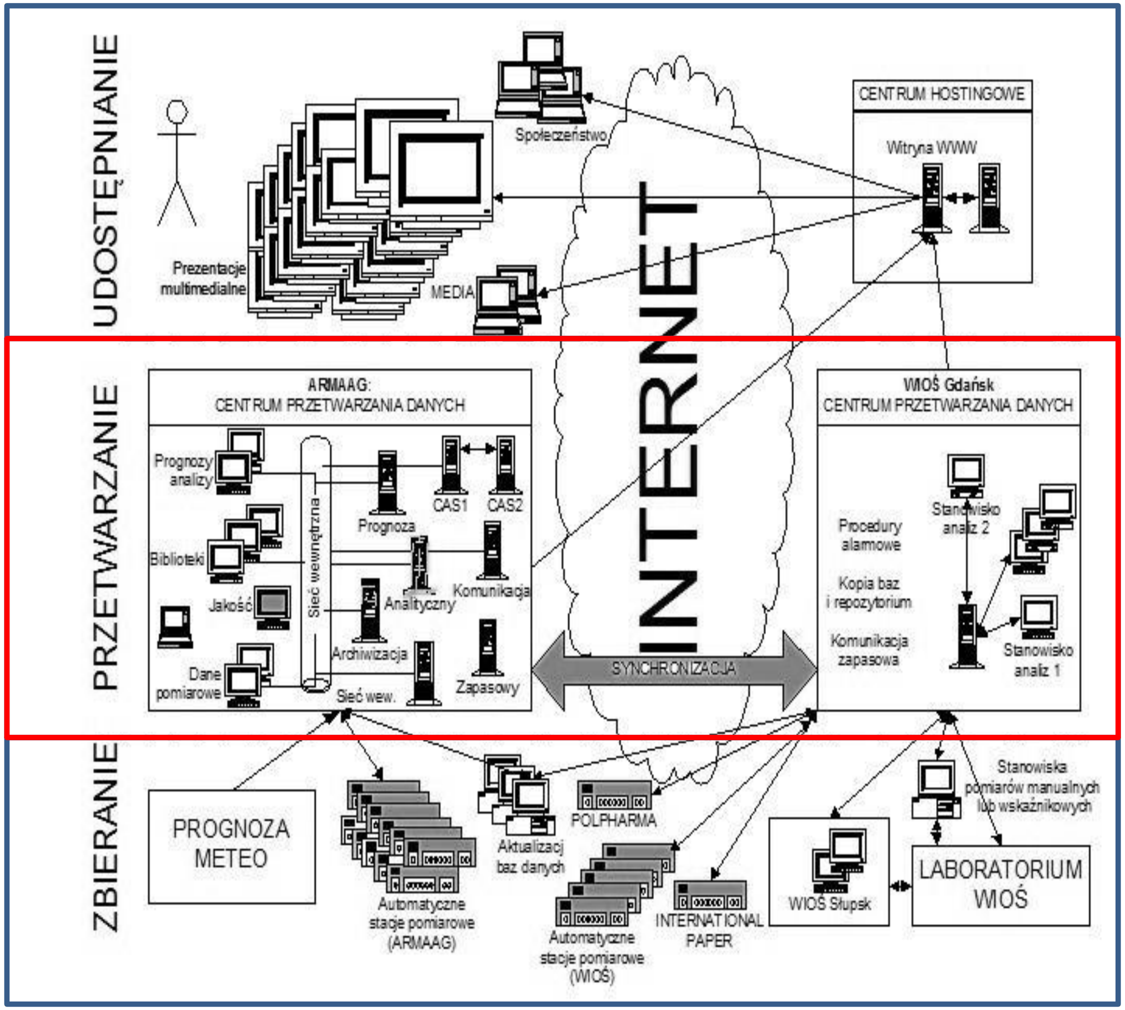
Data for air pollutant levels and weather conditions were taken to the models for each location separately. Numbers represent number of times the variable was present in the final models. Statistically significant interactions and single variables included in the final models are shown and ordered by decreasing effect strength.

***R2 (inter.)**, adjusted coefficient of determination for models with interactions;*
***R2 (univ.)**, adjusted coefficient of determination for models without interactions; **df**, degrees of freedom of the final model;*
***PM10**, particulate matter of size 10 µm or less;*
***PM2.5**, particulate matter of size 2.5 µm or less;*
pressure, atmospheric pressure; wind, wind speed; temperature, air temperature; humidity, air humidity

	Warsaw	**Cracow**	**Tricity**
R^2**(inter.)**	45.8%	29.8%	17.4%
R^2 ***(univ.)***	*40.8%*	*26.1%*	*16.7%*
df	2 800	2 860	2 888
Year	5	5	1
Season	3	4	1
NO_2	3	2	3
O_3	1	1	2
PM_{10}	1	3	1
$PM_{2.5}$	1	1	0
Pressure	4	0	2
Wind	2	3	3
Temperature	4	5	3
Humidity	1	3	1
Precipitation	0	0	0
Interactions:	Season*humidity	Temperature*humidity	Pressure*temperature
	NO_2*pressure	NO_2*humidity	Season*O_3
	NO_2*wind	Season	NO_2*O_3
	Season*PM_{10}	PM_{10}*temperature	Wind*temperature
	NO_2*temperature	Season*PM_{10}	Pressure
	Pressure	Season*humidity	PM_{10}*wind
	Pressure*temperature	Season*temperature	NO_2*wind
	$PM_{2.5}$*temperature	Wind*temperature	NO_2*humidity
	Year*O_3	Year*O_3	Year*temperature
	Season*temperature	Year*temperature	
	Year*temperature	Year*PM_{10}	
	Year*wind	NO_2*wind	
	Year	Year*$PM_{2.5}$	
	Year*pressure	Year*wind	
Single factors:	*Temperature*	NO_2	NO_2
	NO_2	*Temperature*	*Temperature*
	Season	*Season*	*Season*
	Wind	*Wind*	PM_{10}
	Pressure	*Pressure*	O_3
	Year	*Year*	*Wind*
			Pressure
			Year

Examples of selected, prototype analytical systems implemented in Poland

Operating air contamination warning system (Tricity system)

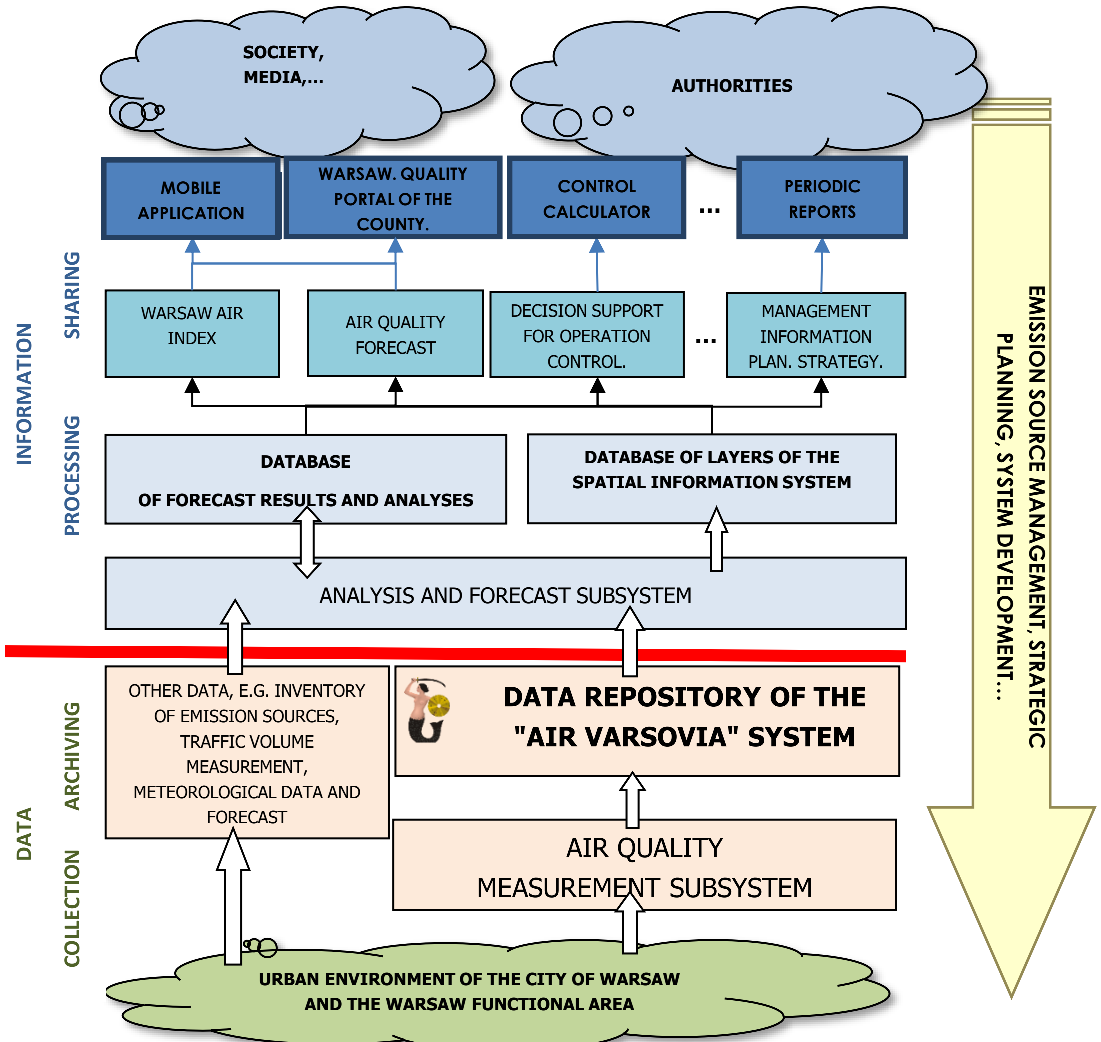


<u>Layer 3: Measurement results are also used for modeling and forecasting</u>

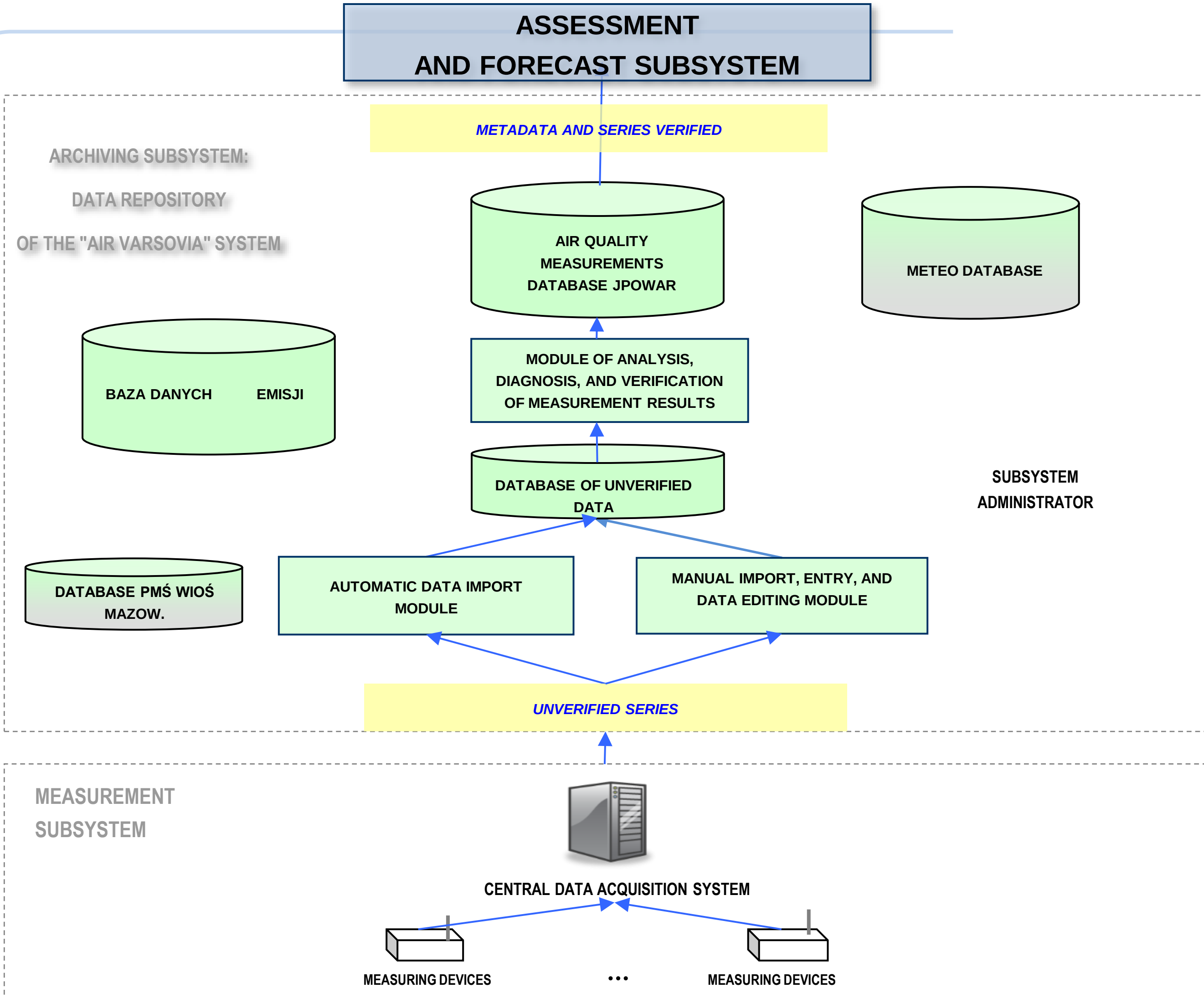
<u>Layer 2: Evaluation of the quality of measurement data using analytical methods</u>

<u>Layer 1: The quality of data is ensured by reference measuring devices and the competencies of the personnel.</u>

Operating air contamination warning system (Warsaw system)

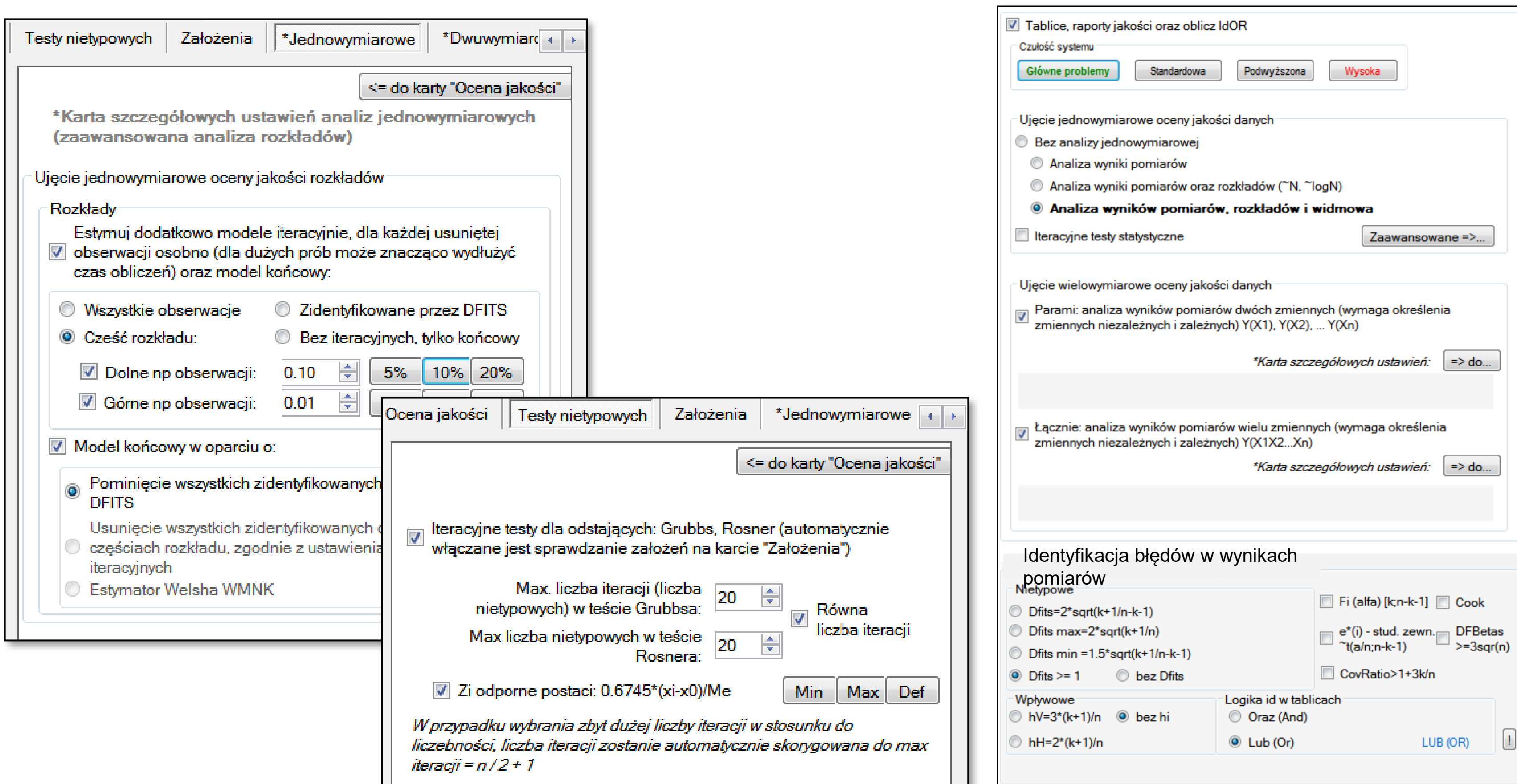


Operating air pollution forecasting system (system of Warsaw and Rawicz)

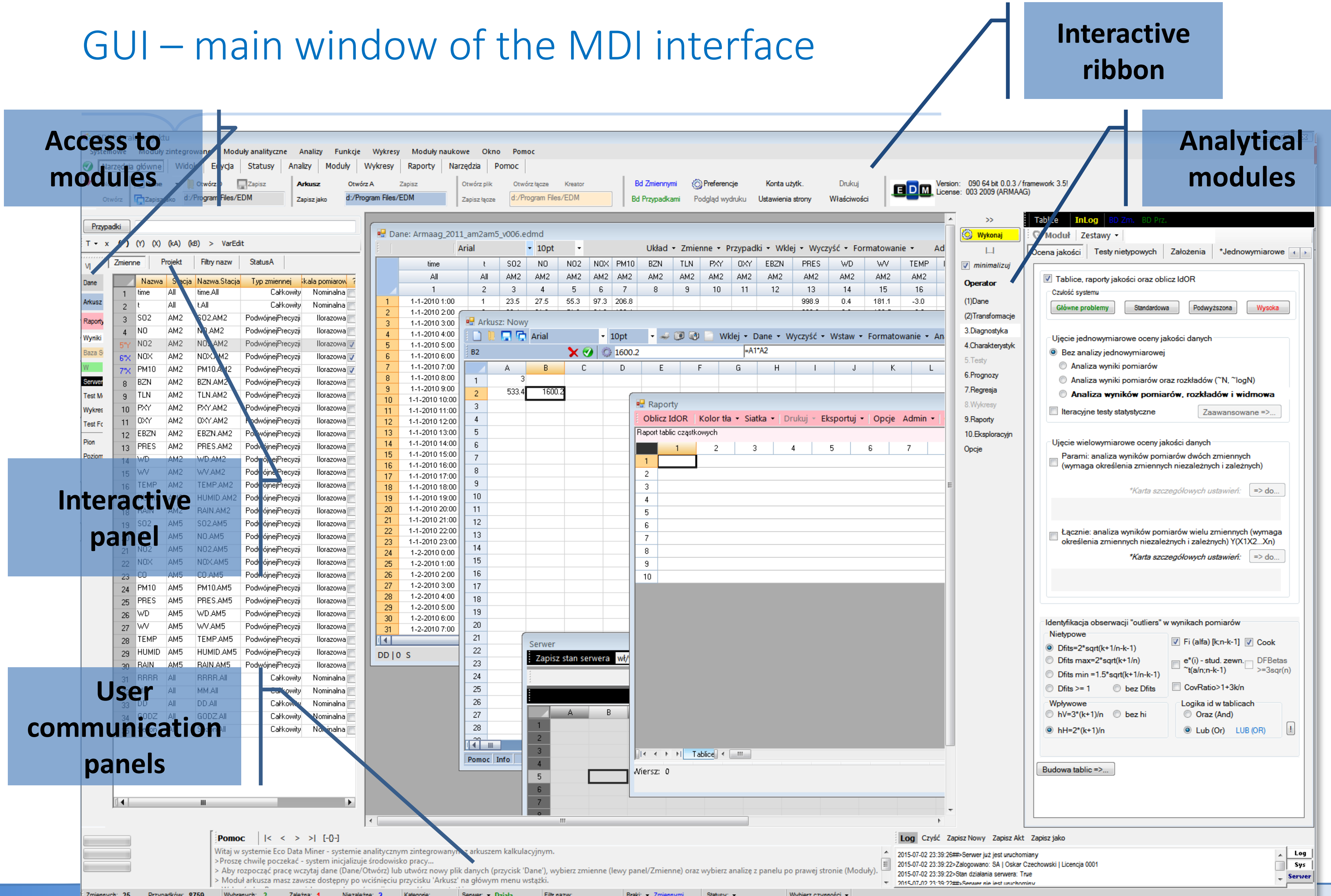


System in operation... only in polish language

windows of the operating system show the primary goal: simplicity of use for the operator with simultaneous extensive possibilities of shaping the details of analyses and stochastic models

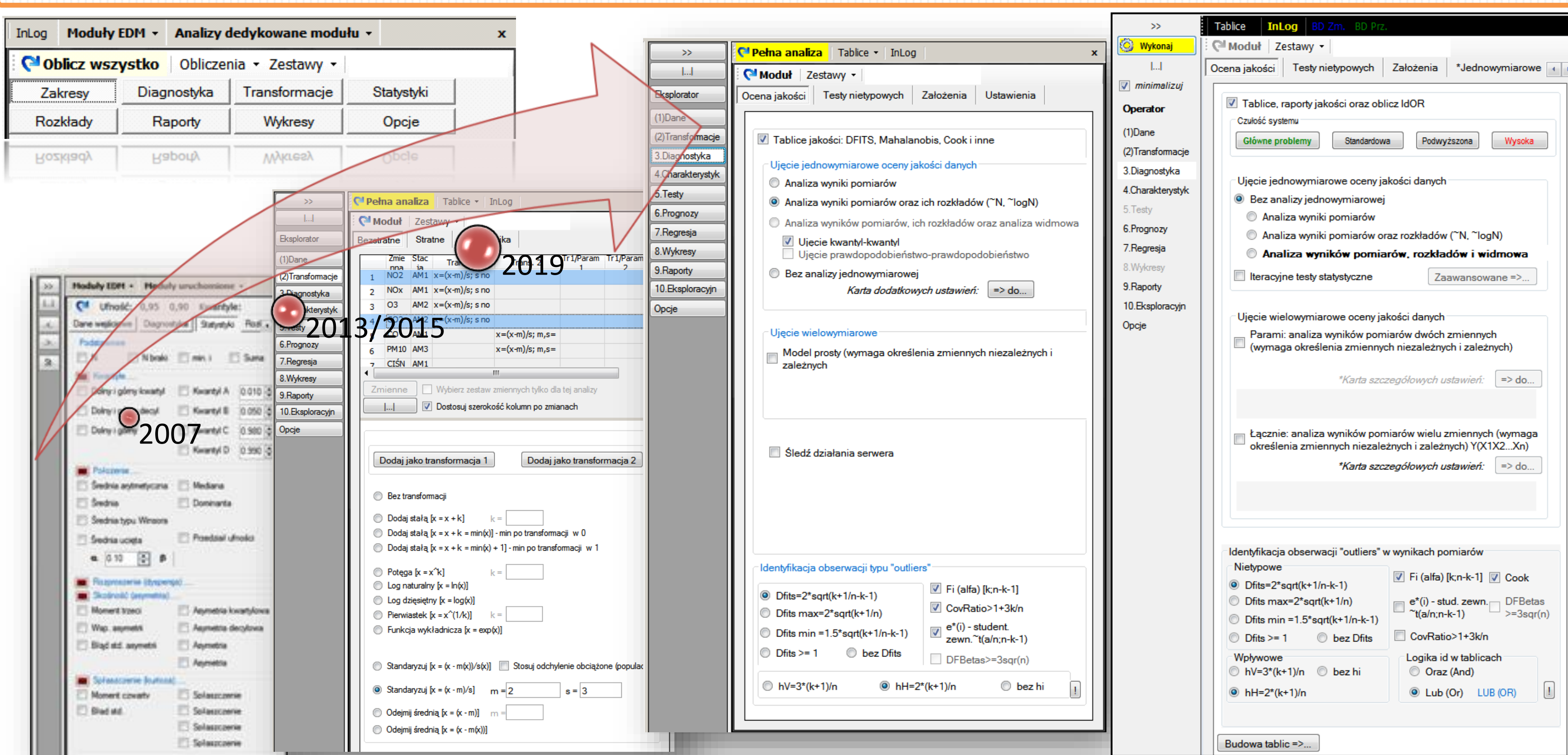


GUI – main window of the MDI interface



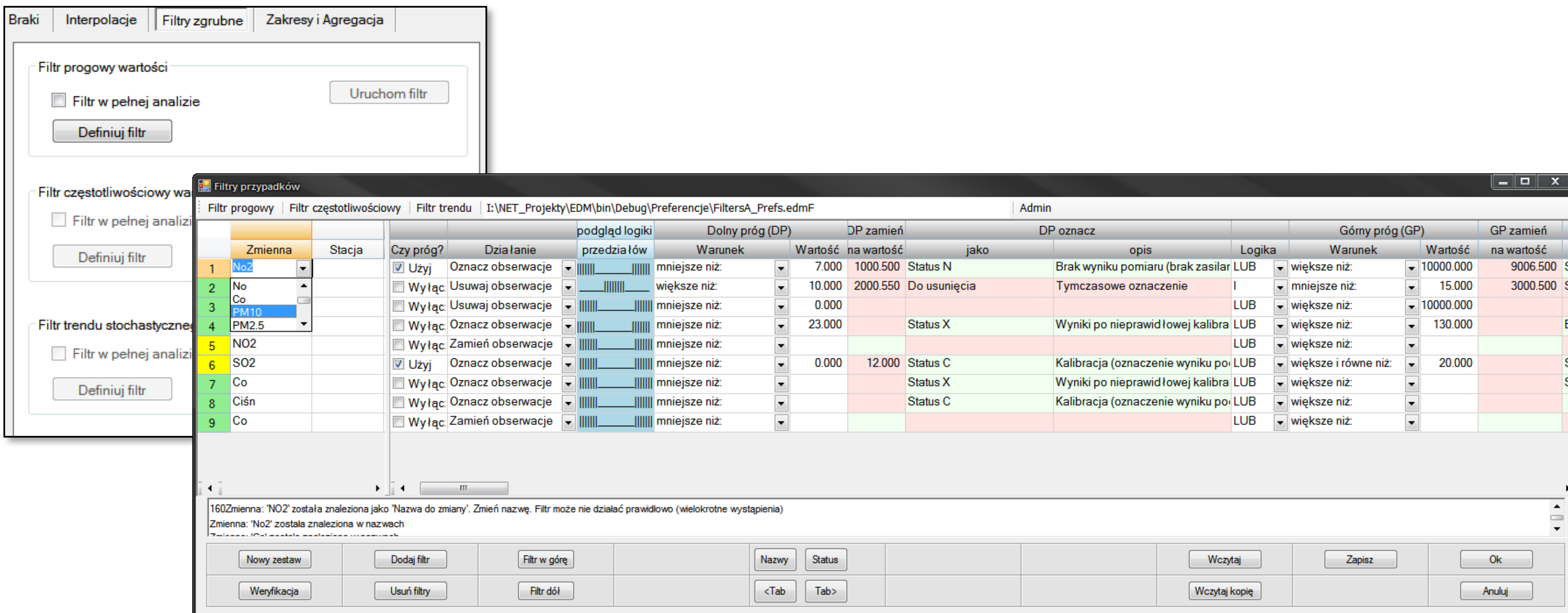
GUI - evolution

The GUI was designed in 2006 and **still allows** for flexible and convenient task execution. For operators without a mathematical background, operating the system is as simple as pressing a single yellow button, after selecting the variables for analysis and modeling.



GUI – data filters

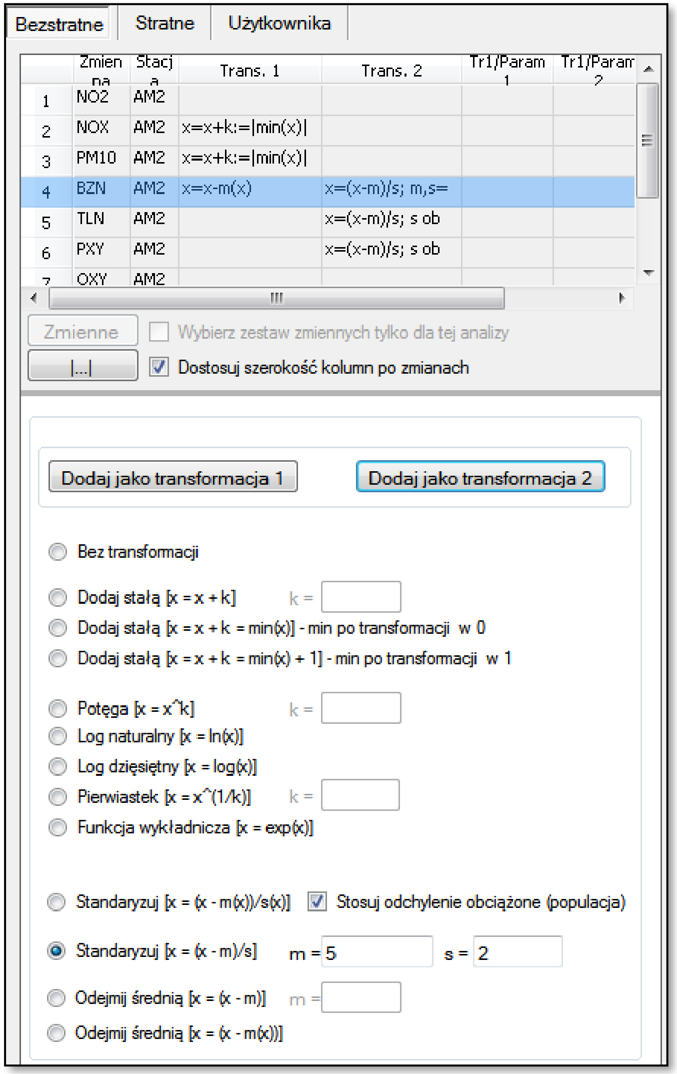
The **filter mechanism** aims to effectively eliminate **gross measurement errors**: among others, based on threshold values, the three-sigma rules family, and basic properties of statistic distributions. It is designed to perform **all specified filters** in repository in a **single pass**, along with clear information about their operation.



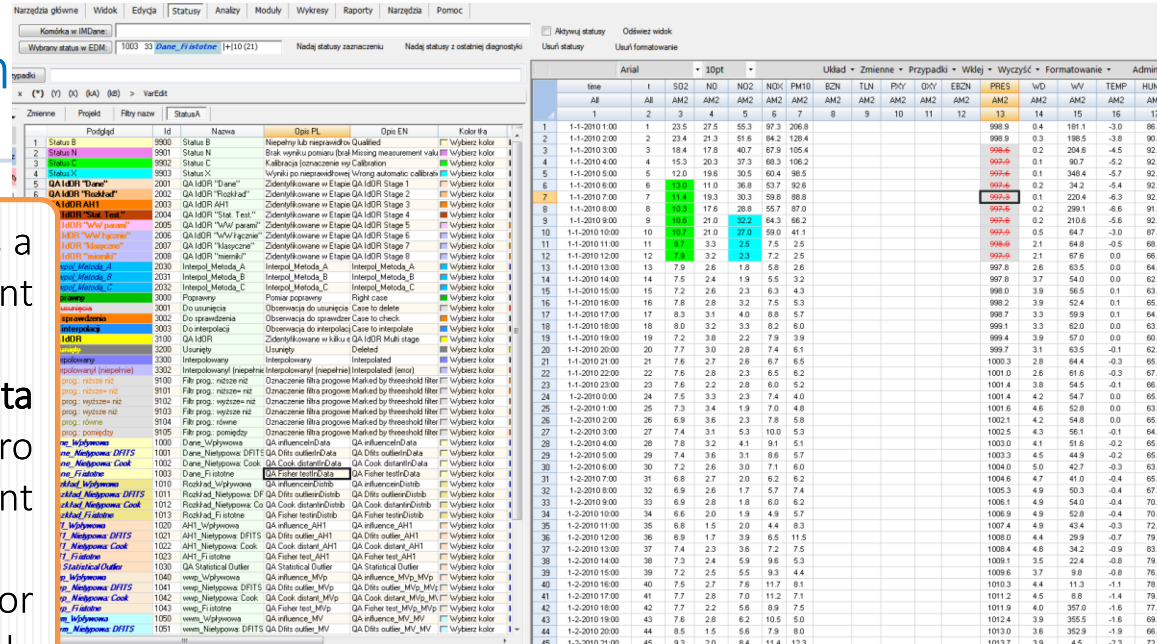
GUI – data transformations

The mechanism of variable transformation – **lossless** and **lossy** – before starting modeling and analysis involves a type of batch programming in order to, among other:
stabilize variables over time,
standardize and comparably distribute distributions,
ensure stationarity and other basic assumptions of stochastic forecasting models.

Like all other built-in mechanisms, it is designed with **efficiency**, e.g., performing all transformations in a single step in a single stage.



GUI – status mechanism



The **status mechanism** for each variable is a tool built directly into the measurement data repository. Its main tasks include:

- notifying the operator of selected **data anomalies** (e.g., loss of the zero reference level, so-called measurement drift),
- **exceeding threshold values**, for example, as a result of previously performed transformations,
- automatic **internal communication** between analytical objects (data diagnostic results -> transformations -> modeling results -> forecasts -> reports) allowing the system to take automatic actions without operator intervention,
- generating basic reports,
- and issuing basic alerts.

The tool is designed to enable:

- **flexible future expansion** – an independent database of statuses defined by the operator,
- operation **without affecting the effectiveness** of the analytical and mathematical modeling modules.

Work in the area of building new devices based on bioindicators (ZTŚ)

Work in the area of developing new devices based on bioindicators

The complexity of matrices, individual environmental components, and their multiphase nature increases in the following order: **air > water > soil**. Along with this complexity, the number and diversity of interactions to which pollutants introduced by human activity are subjected also increase.

It is estimated that over 100,000 compounds with **toxic** effects are present in the environment.
Chemical analytics using highly specialized analytical equipment with high resolution and identification potential undertakes the development of procedures for quantitative assessment of the pollution level of specific compounds in individual environmental components.

Knowledge of the concentrations of even hundreds of toxic compounds in a given matrix, unfortunately, does not translate into an assessment/information about harmful effects or impacts on living organisms, including humans.

The interaction of **mixtures of compounds** can be **additive**, **synergistic**, or **antagonistic**. Also important is the effect of the interaction (cytotoxicity, genotoxicity, mutagenicity, or endocrinicity). Very important information also includes the toxin's persistence in the environment and its ability to bioaccumulate.

A crucial parameter in impact assessment is bioavailability, as well as the evaluation of effects in the short term (**acute toxicity**) and over a longer period (**chronic toxicity**).

Work in the area of building new devices based on bioindicators

It also matters that compounds undergo **transformations**, and the **products of these transformations** may prove to be more toxic than the original/initial substance.

Therefore, in environmental quality assessment, **bioassays** using various **bioindicators** (standard organisms or their parts) to evaluate the comprehensive/overall impact of pollutants in a given matrix are becoming increasingly important.

The **bioassay market** is continuously developing; a wide range of tests is available for the **water matrix**, the area of bioassays for the **solid phase** is relatively sufficient, while bioassays for the **gas phase** (air) practically do not exist.

The project proposes the development of a **bioassay for the gas phase**. This test will be based on the **ostracod organism** as a **bioindicator**.

Work in the field of building new devices based on bioindicators

The next research steps aimed at developing a biotest are:

- Selection of the sorbent and indication of its scope of application. Based on breakthrough volume measurements for a maximum of three selected sorbents against compounds with weak sorption and their impact on a chosen test organism, the most advantageous sorbent will be selected..

- Development of an analytical procedure for the selected sorbent:

procedure for sample collection (airflow rate, volume, sorbent mass) and validation of this stage, optimization of the form and contact time of the sample with the bioindicator, selection of a control sample, specification of boundary conditions for test acceptability, development of a protocol for the conducted test including the method of toxicity calculation, selection of appropriate equipment and instruments to perform the test

1. Validation of the entire procedure based on previously selected compounds,
2. Evaluation of the possibility of automating the procedure for sampling and assessing air sample toxicity.

The result of the above actions will be a procedure for toxicity assessment based on bioindication for gas samples (including air).).

Work in the area of building new devices based on bioindicators

ECD sensor

Based on commercially available ECD (Electron Capture Detector, or mECD) detectors, development of a sensor concept for measuring the presence of F- and Cl-organic compounds in clean water samples.

F- and Cl-organic compounds, especially PFAS, constitute a group of substances that are very persistent in the environment, accumulate in the body, and are exceptionally resistant to metabolic transformations and degradation processes..

These compounds are classified as endocrinely active substances, which are currently the focus of attention for many institutions (including WHO) because exposure to PFAS can lead to serious health problems..

Potential health effects include kidney and liver damage, cancers, fertility disorders, and immune system dysfunction..

Work in the area of Artificial Intelligence and neural networks (IITiS PAN)

Work in the area of AI and ANN 1/2

Work in the area of **creating and adapting AI models** for heterogeneous measurement systems supporting early detection and warning of threats.

Develop and adapt models for **classification**, **pattern recognition**, **anomaly detection**, **automatic calibration**, and **detection of sensor faults and degradation**. Rely on extensive experience in classical signal processing and deep learning (CNN, transformer) to move from measurements to reliable decisions and alarms.

Support the sensor network by **integrating satellite**, **drone**, **meteorological**, and other data.

Consider additional sources to **refine ambiguous situations**, **establish baseline levels**, and confirm observations through independent channels, which **increases the stability of generated warnings** and resilience to **missing data** or **interference from individual sensors**.

Work in the area of AI and ANN 1/2

Provide **explainability** and **transparency** of models, including methods for **interpreting black box classifiers**. Combine this with natural language processing solutions based on LLMs, enabling the system to present, in addition to an alert, an understandable analysis pathway for verification by the operator.

Create models of phenomena and observe the alignment of the currently developing situation with the simulation. Use this for **prediction**, **risk assessment**, **scenario comparison**, and **evaluation of the effects of intervention actions**.

Critical network LTE420

Critical network LTE420 (Polkomtel), communication devices (DGT)1/4

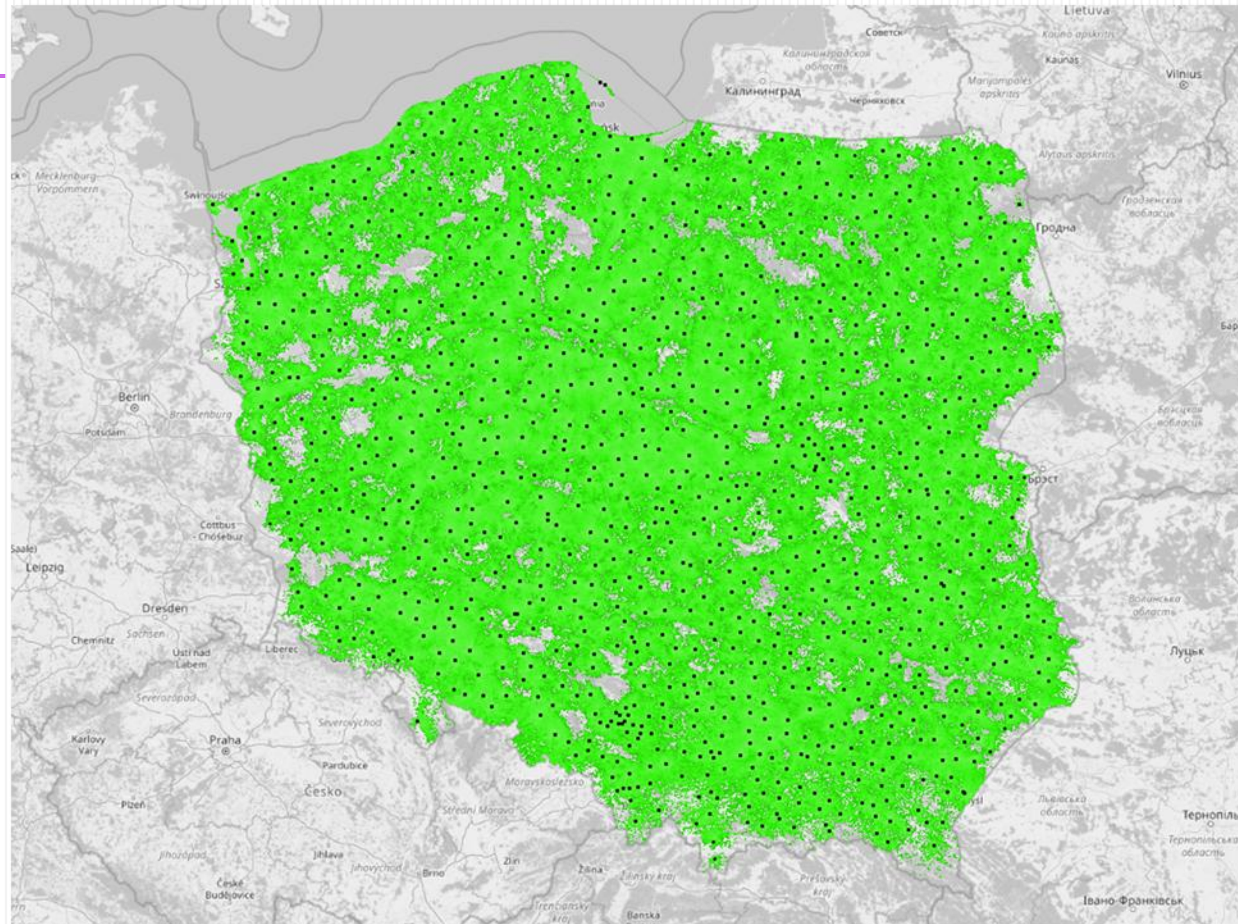
LTE420

A broadband network for special purposes implemented by Polkomtel

Nationwide coverage, 1011 base stations

Coverage 95% - 2024r

Ready to use!

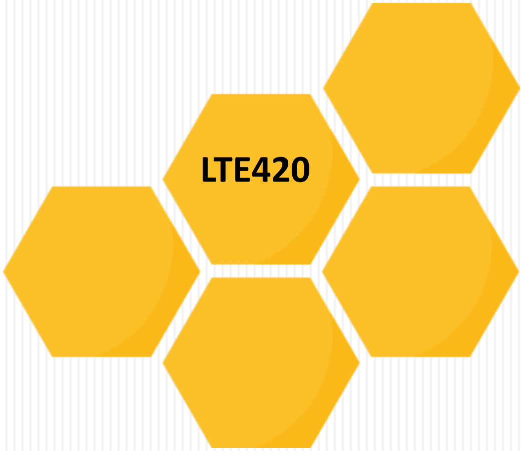


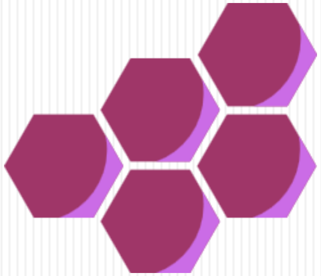
Critical network LTE420 2/4

Radio cell range - advantage of LTE 420

DGT
www.dgt.pl

Range up to 24 km from the base station

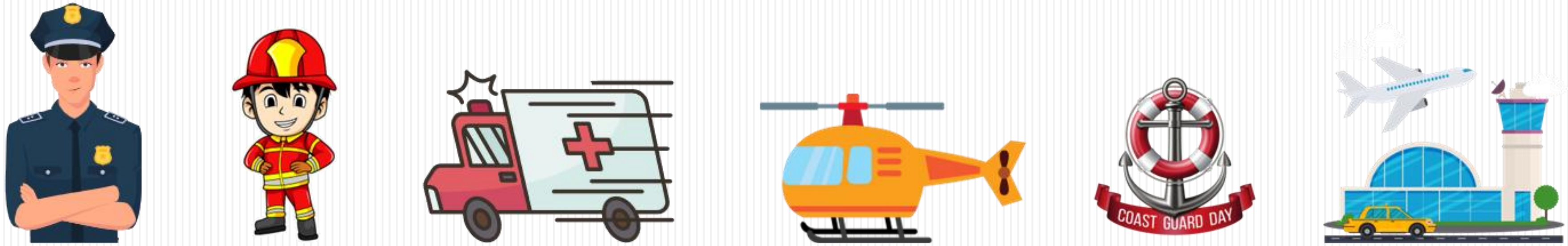




Range **2.8** times greater than **900 MHz**

Range **13.6** times greater than **1800 MHz**

A network built for users' needs



Critical network LTE420 3/4

Critical network LTE420

DGT
www.dgt.pl

Cybersecure

Available only for users with a dedicated Polkomtel SIM card, not offered on the individual user market.

Multirange

Access to the 420 MHz band and PLUS commercial bands on one SIM card with the option to choose the "420 only" mode.

Interoperable

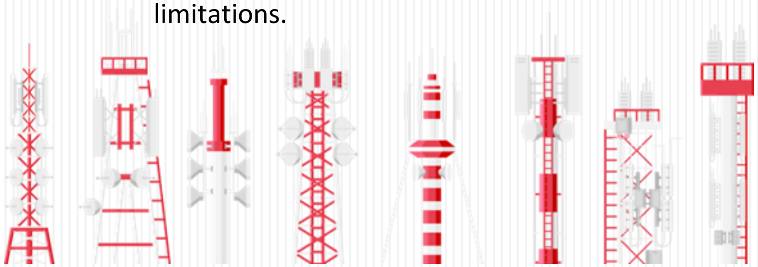
Integration with analog radio systems, DMR, Tetra through the DGT MCX system

Maintenance-free

Without involving technical services – the entire solution is implemented and maintained by the service provider with an SLA at the agreed level.

Resistant

for cellular network overloads, the possibility of "illuminating" areas with insufficient coverage, possible power backup.
Dedicated to critical communication according to the UKE reservation decision, not subject to commercial network limitations.



Critical LTE420 network data transmission device (DGT) 4/4

DGT
www.dgt.pl

LTE cat.4 B87 (z B3 i B8)

- 4 x Fast Ethernet (mode routed i bridge)
- 2 x RS485 with optocoupling and remote access (UDP i TCP)
- 4 digital-analog input ports
- 2 digital-analog output ports
- 2 x SIM
- IPSEC z IKEv2
- Route-based VPN
- VFR (Virtual Routing and Forwarding)
- NAT
- DNP3.0
- LwM2M

Works and solutions in the area of equivalence of measurement methods and measurement results in proprietary measuring devices

Works and solutions in the area of **equivalence** of measurement methods and measurement results in proprietary devices part 1 of 12

- The system **plans the construction** of **new**, **proprietary measurement devices** for hazard identification at the first two recognition time levels of the ICIS system – up to 1 hour and up to 3 days, based on, among others:

- Bioindicators
- Chromatography
- Classical measurement sensors

Non-referential devices are **significantly cheaper** to produce and operate, which allows for monitoring a large area with many devices, but the measurement results may differ from the referential measurement. One method to **ensure high-quality measurement results** (air, water, soil), alongside **satellite measurements** and a wide spectrum of **data diagnostic** methods, is a developed and evolving **methodology of measurement** result **equivalence** based on **stochastic and mathematical** models and methods. Previous solutions – **pilot** projects – mainly come from the area of **air pollution** measurements.

Works and solutions in the area of **equivalence** of measurement methods and measurement results in proprietary devices part 2 of 12

Measurements of pollutant concentrations are carried out using methods specified in legal regulations that are appropriate for a given pollutant. These are called **reference methods**. Measurements obtained using these methods are considered correct and appropriate.

In most cases, the use of reference methods is **costly** and may **not provide adequate spatial** and **temporal resolution** of measurements. Therefore, in many applications, **alternative methods for measuring** pollutant concentrations are used, mostly electronic methods.

An example is the study of PM_{10} particulate matter concentrations in the air. The reference method is the gravimetric method, which involves passing atmospheric air through very fine filters and then analyzing the residue left on these filters.

However, this method is inconvenient because such analysis is performed in dedicated laboratories. This means that measurements are conducted with an accuracy of up to **one day**, and the need to replace filters and transport them to the laboratory increases the operating costs and **causes delays** in the analyses performed.

Works and solutions in the area of **equivalence** of measurement methods and measurement results in proprietary devices part 3 of 12

An alternative to the gravimetric method are, for example, low-cost electronic devices using:

- optical methods based on laser light reflection from pollutant particles,
- tapered element oscillating microbalance (TEOM),
- methods based on the absorption of beta radiation.

Using alternative measurement methods will always lead to results **different from the reference** ones. In this case, the problem is obtaining results comparable to the reference results.

It is important to be sure that the application of the alternative method appropriately approximates the actual concentration values of this pollutant.

Works and solutions in the area of **equivalence** of measurement methods and measurement results in proprietary devices part 4 of 12

For professional applications, it is necessary to demonstrate the equivalence of an alternative measurement method with the reference method.

A measurement method is equivalent to the reference if the probability of obtaining measurements significantly different from the reference is extremely low.

From a mathematical standpoint, this problem is not particularly complicated and is precisely described in legal documents.

For example, in the EU, the methodology for testing the equivalence of methods in air protection is described in the Guidance to Demonstration of Equivalence of ambient air monitoring methods.

Work and solutions in the area of **equivalence** of measurement methods and measurement results in proprietary devices part 5 of 12

*The most important element of equivalence testing of methods is **ensuring** an **adequate amount of measurement data** of **appropriate quality**.*

*It **is necessary** to provide measurement data **from the reference** device as well as **measurements from devices** using the **tested method**. It is assumed that there will be at least two test devices to also verify measurement repeatability.*

*These devices are initially tested under laboratory conditions to check their **functioning** and **calibration**. Then, measurements are taken under field conditions meant to reflect the actual working conditions of the devices.*

*Due to the **lack of homogeneity** of air pollution and its significant **spatial variability**, all devices must be located in close proximity to test "the same air."*

*It is also necessary to conduct measurements under **different weather conditions**, at **various times of the year**, and with **varied environmental parameters** (temperature, air humidity, wind strength). Then, similar studies are **conducted** at **other locations** to eliminate the specific influence of the environment.*

*However, each time the devices must be in the **immediate vicinity of the reference device**.*

Works and solutions in the area of **equivalence** of measurement methods and measurement results in proprietary devices part 6 of 12

*The **obtained results** are then subjected to **statistical analysis**. Therefore, it is necessary to obtain an appropriate number of measurements from each location and each season.*

*The **differences** between the **reference** and **test** measurements are supposed to be **random** (not deterministic) and **small**. This causes the equivalence study process to be **time-consuming** and unfortunately **quite costly**.*

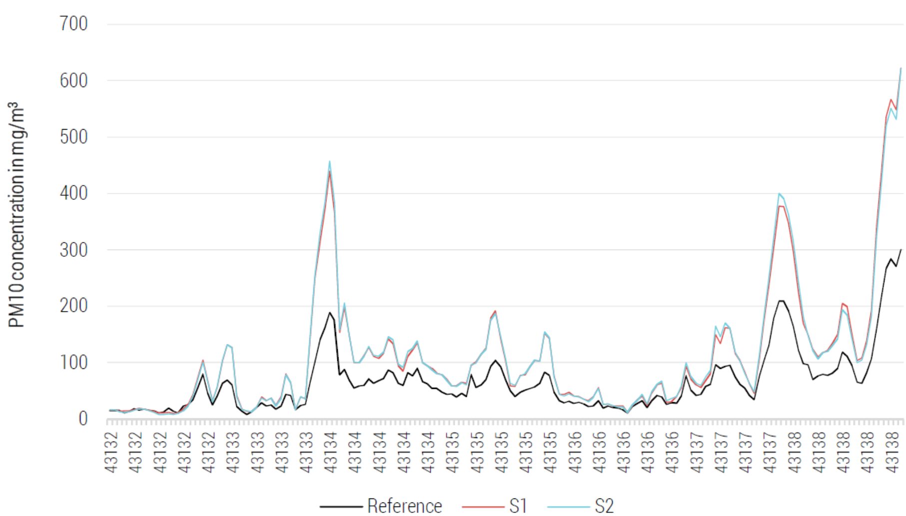
*A separate issue is the change in the **density of measurements** compared to the reference method. **Increasing** the **measurement frequency** may cause the occurrence of specific errors, the identification of which is very difficult or even impossible due to the lack of reference measurements.*

Equivalence – selected preliminary test results of PM_{10} sensors
part 7 of 12

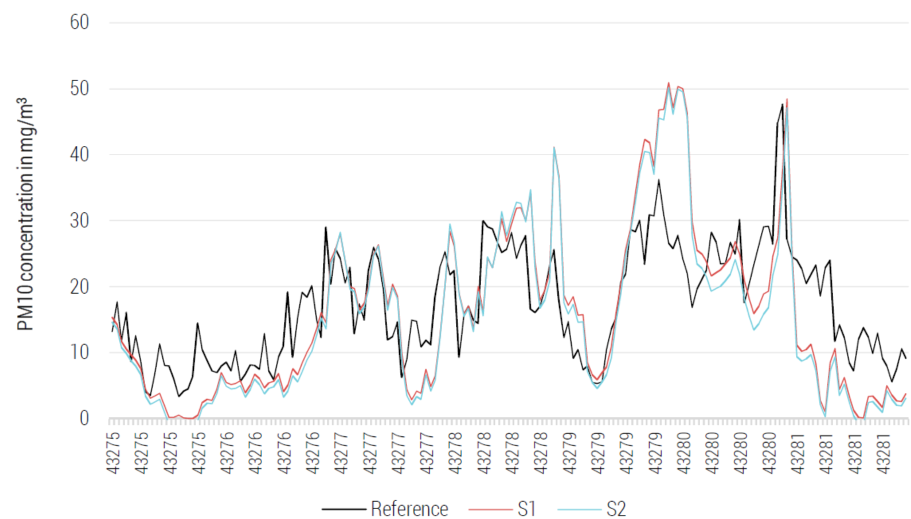
*Is it possible to **create a mathematical function** to correct concentration measurements from a low-cost PM_{10} sensor so that the values **match reference measurements**?*

Equivalence – selected preliminary test results of PM_{10} sensors
part 8 of 12

To create comparison sets and **conduct equivalence**, multi-month comparative data with a 1-hour interval (low-cost sensors and measurement results from the reference station) collected in **various climatic conditions** were used.



PM_{10} concentrations for the reference device and the tested devices (S1 and S2) in a selected week of the cold period



PM_{10} concentrations for the reference device and the tested devices (S1 and S2) in a selected week of the warm period

Equivalence – selected preliminary test results of PM_{10} sensors
part 9 of 12

* Repeatability testing - uncertainty between probes

$$u_{BS}^2 = \frac{\sum_{i=1}^{N} \left(y_{i,1} - y_{i,2}\right)^2}{2n}$$

* Testing extended uncertainty

$$W_{CM} = 2 * \sqrt{\frac{\frac{RSS}{n-2} - u^2(x_i) + [a + (b-1) * x_i]^2}{LV}}$$

Equivalence – selected preliminary test results of PM_{10} sensors
part 10 of 12

Corrective functions with satisfactory properties were obtained only for the **linear regression model** and forms using a **quadratic polynomial** (second degree).

Table 1. Multiple linear regression models for PM_{10} concentrations and the results of model cross-validation

Model description	Estimated form	RMSE for training set	Adjusted	*F* test statistics	RMSE for testing set
LM**	y_W=14.93+0.51*y_T	12.671	0.876	15294.975*	13.412
LM-TVH**	y_W=46.37+0.51*y_T-0.25*T -3.29*V+ -0.31*H	11.552	0.897	4711.376*	12.403
LM-TV	insignificant structural parameters	-	-	-	-
LM-TH	y_W=37.58+0.52*y_T-0.21*T -0.26*H	11.682	0.895	6125.838*	12.570
LM-VH	y_W=37.14+0.53*y_T-2.41*V-0.26*H	11.759	0.893	6037.044*	12.833
LM-T	insignificantstructuralparameters	-	-	-	-
LM-V	y_W=13.86+0.53*y_T+1.86*V	12.618	0.877	7720.975*	13.414
LM-H	y_W=31.81+0.52*y_T-0.22*H	11.830	0.892	8934.002*	12.841

* indicates statistically significant results with ***a***=0,05
** indicates the models selected for further analysis
y_w – reference concentration of PM_{10}, y_T – tested sensor concentration of PM_{10}, T – temperature, V – wind speed,
H – relative humidity

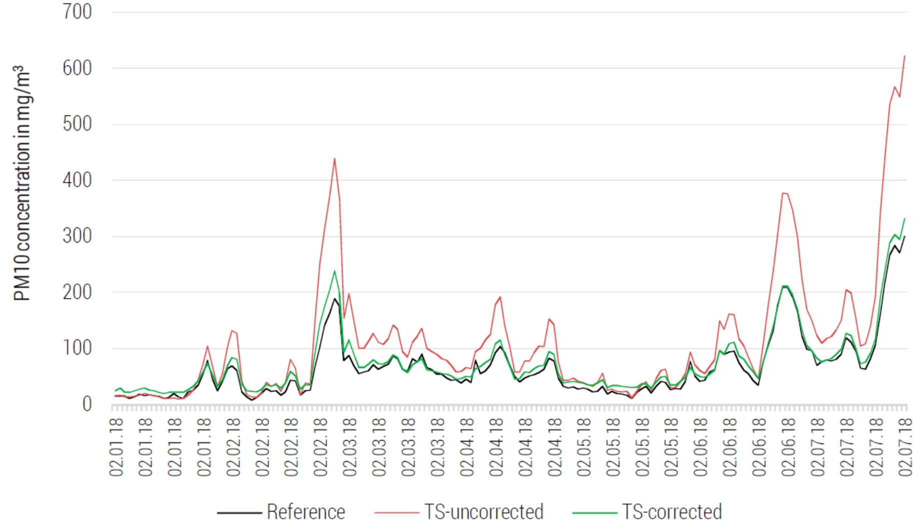
Equivalence – selected preliminary test results of PM_{10} sensors
part 11 of 12

Table 2. Multiple regression models for PM_{10} concentrations for the quadratic polynomial and the results of cross-validation of the model

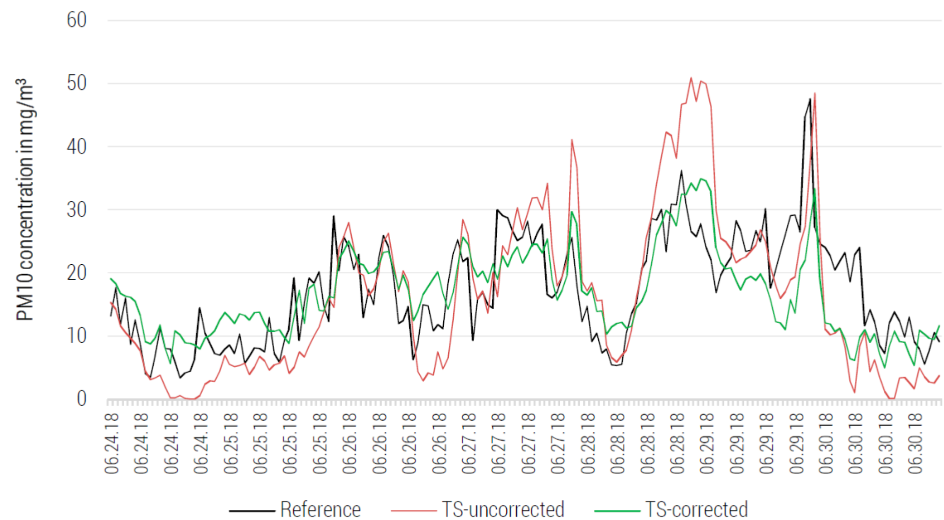
Model description	Estimated form	RMSE for training set	Adjusted	*F* test statistics	RMSE for testing set
QP**	y_w=13.62+0.57*y_T-0.0002*y_T^2	12.572	0.878	7784.455*	14.059
QP-TVH**	y_w=42.40+0.56*y_T-0.0001*y_T^2-0,19*T+ -2.55*V-0.3*H	11.477	0.898	3818.908*	13.037
QP-TV	y_w=8.79+0.61*y_T-0.0002*y_T^2+0.08*T +2.73*V	12.454	0.880	3977.971*	14.730
QP-TH	y_w=34.99+0.58*y_T-0.0002*y_T^2-0.14*T + -0.26*H	11.555	0.897	4708.580*	13.533
QP-VH	y_w=34.77+0.60*y_T-0.0002*y_T^2-1.64*V + -0.26*H	11.579	0.896	4686.681*	110.101
QP-T	y_w=12.45+0.58*y_T-0.0002*y_T^2+0.07*T	12.563	0.878	5199.090*	14.303
QP_V	y_w=10.36+0.59*y_T-0.0002*y_T^2+2.63*V	12.471	0.880	5287.417*	14.384
QP-H	y_w=30.95+0.61*y_T-0.0002*y_T^2-0.24*H	11.610	0.896	6211.692*	14.137

* indicates statistically significant results with ***a***=0.05
** indicates the models selected for further analysis
y_w – reference concentration of PM_{10}, y_T – tested sensor concentration of PM_{10}, T – temperature, V – wind speed, H – relative humidity

*Equivalence – selected preliminary **research final results** of PM_{10} sensors part 12 of 12*



PM_{10} concentrations for the reference device and the tested sensor uncorrected data and after applying the LF-TVH correction function in the selected week of the cold period



PM_{10} concentrations for the reference device and the tested sensor uncorrected data and after applying the LF-TVH correction function in the selected week of the warm period

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Dziękuję za uwagę…

Thank you for your attention…

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