From Theory to Practice: AI Applications in Multiple Sectors by the Institute Mihajlo Pupin

EuroCC4SEE Workshop in Belgrade, May 21st, 2025

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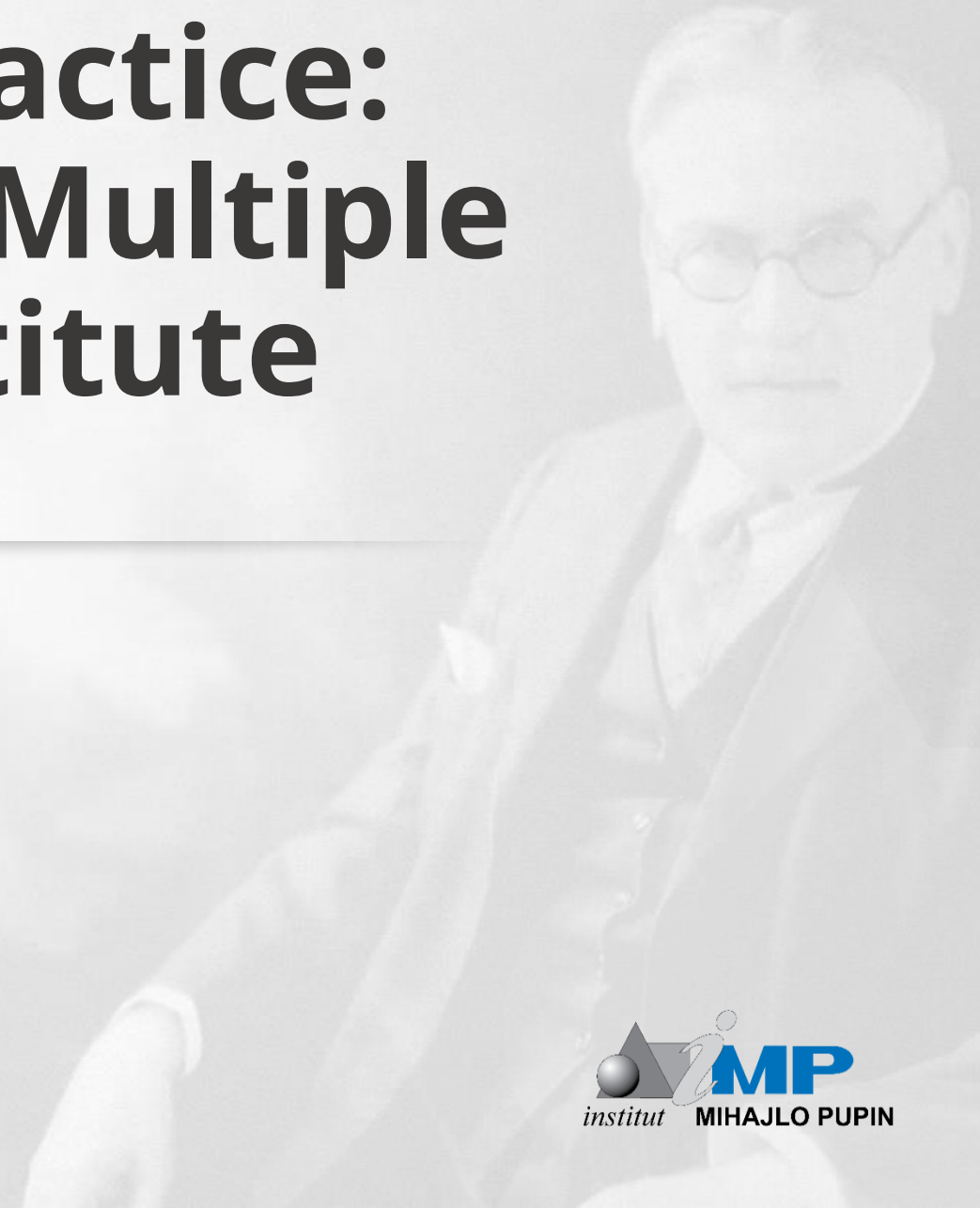

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Outline

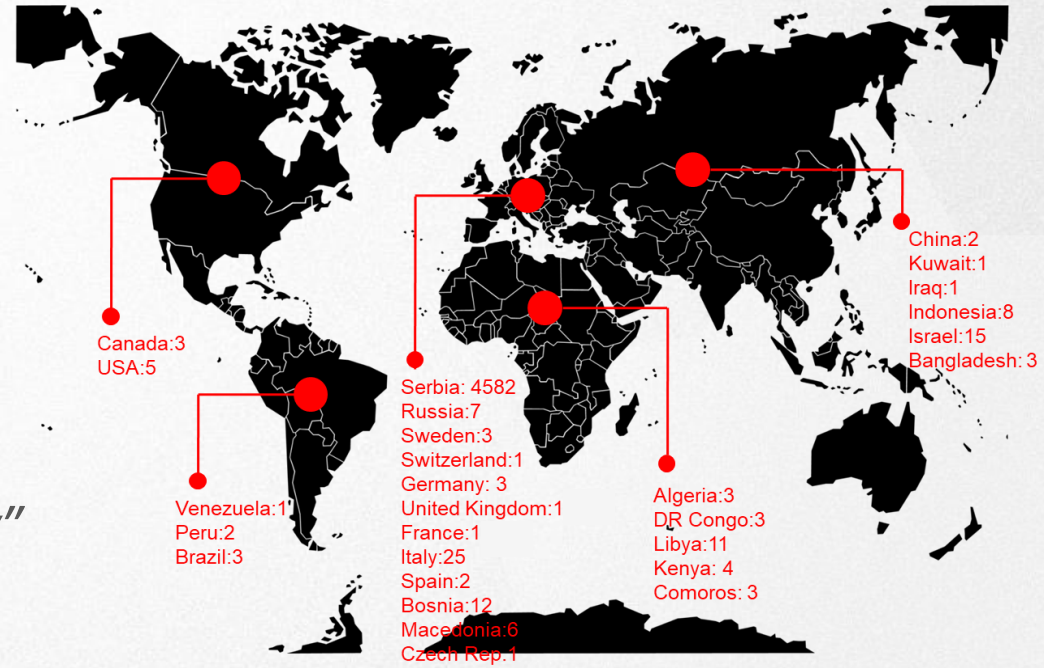
- The Institute Mihajlo Pupin: Research and Development Powerhouse
  - Our Solutions
  - Joining Forces with EU-Based R&D Partners
- Application of Artificial Intelligence in EU projects
  - Reinforcement Learning-Based Optimization of an HVAC System
  - Non-Intrusive Load Monitoring and Energy Disaggregation
  - Surrogate Data-Driven Optimization of a Manufacturing Process
  - Other Applications

INSTITUTE
MIHAJLO PUPIN

Research and Development Powerhouse

- One of the leading Serbian R&D institutions in **Applied information and communication technologies** (ICT)
- One of the biggest and oldest (1946) R&D institutes in the ICT area in the whole of Southeastern Europe
- **500+** employees, **350+** researchers & engineers
- Turnover **60M€.a**, **80%+** via Technology Transfer
- Affiliated to the University of Belgrade
- EU Commissionaire statement:

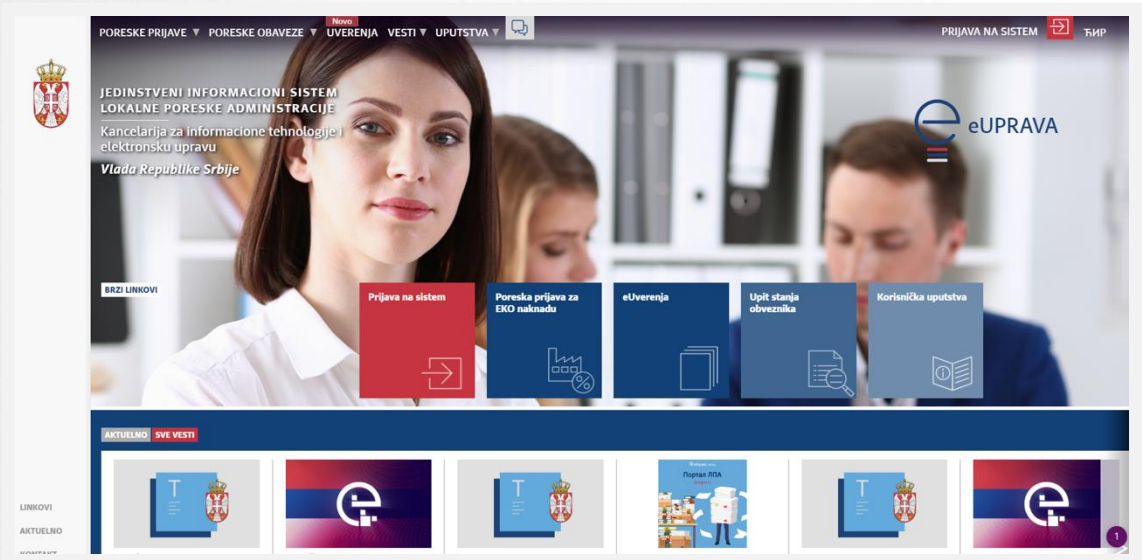
"Pupin as the best practice example for bridging academia and industry"



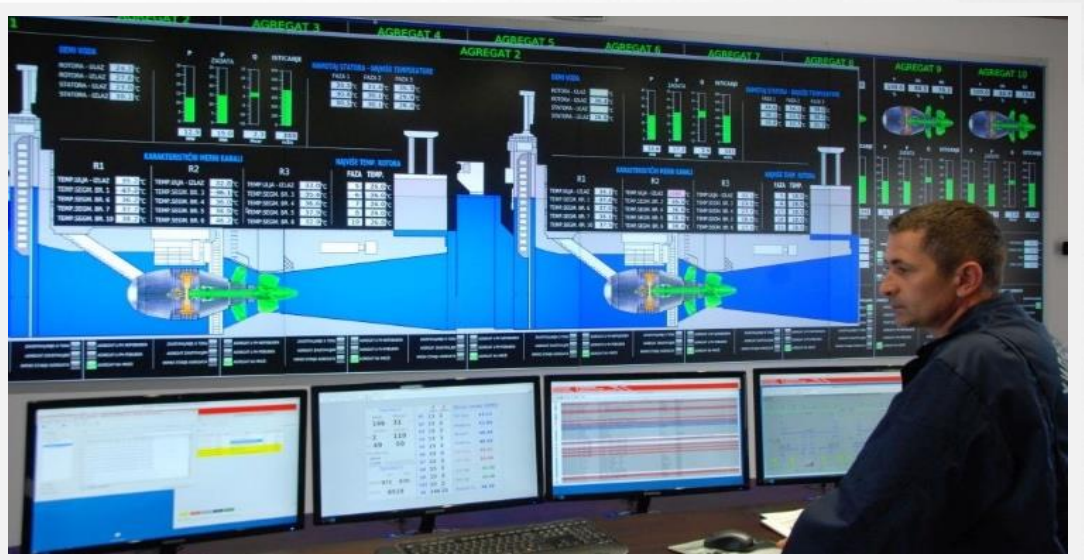
Our Solutions

MAIN PROGRAMS

- **Information Systems:** E-government solutions, Document Management Systems, Decision Support Systems, AI based systems
  - Local and central tax administration,
  - Serbian Business Registry and e-portal for reports ordering, payment and delivery (one stop shop)
  - ISs for Anti-Money Laundry Agency, Ministry of Agriculture, Ministry of Justice and Ministry of Interior



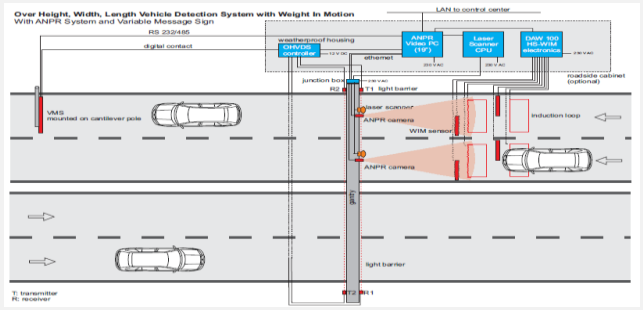
- **Process Control Systems:** Power Production, Transmission and Dispatching Control and Supervision Systems, Water Supply and Management Systems
  - 40 years in Process Control Systems
  - Supervisory Control and Data Acquisition Systems (SCADA) and Digital Control Systems (DCS)
  - Proprietary SCADA SW (VIEW®) and HW solutions (ATLAS®)



Our Solutions

MAIN PROGRAMS

- **Traffic Management Systems:** Urban Traffic Control, Tunnel Management, Highway Pay-Toll Systems, Parking and Access control system, Weight-in-motion detection
  - All pay-toll systems on Serbian motorways are products of R&D at IMP
  - Toll Collection systems in Serbia, Montenegro, Bosnia and Herzegovina and DR Kongo



Toll Plaza Belgrade (RS)

- **Railway Program:** Axle Counter, LED signals, HMI solutions
  - Universal Train-wheel Detector (UTD)
  - Train Axle Counter (BROS)
  - Universal LED module (LL-000)
  - Main, Shunting, Limit Track LED signals
  - Railway LED indicator signals
  - Railway safety HMI (MMI10)

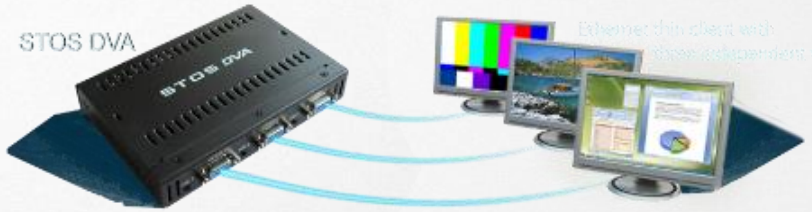
Our Solutions

MAIN PROGRAMS

- **Defense Program:** Simulation and Training Systems, Air War Gaming Systems, Radar signal processing systems, Electronic Surveillance Systems, Ballistic Analyzer

Virtual reality subsystem for flight simulators SL-G4 and SL-J22

- **Other Programs and Activities:** Robotics, Security, Embedded Systems, Surveillance, Alert & Warning Systems, etc.
  - Pico-ITX SBC based on TI's OMAP5430 SoC
  - TI DaVinci DM8168 Qseven Module
  - STOS DVA
  - LIVIAU S



Joining Forces with EU-Based R&D Partners

118 International Research Projects, over 500 partners

13 Horizon Europe (FULL-MAP, STUNNED, EUSOME, LEGOFIT, InterPED, HYCOOL-IT, STREAM IT, ECHO, FEDECOM, R2D2, IntelliLung, OMEGA-X, POLICY ANSWERS)

21 H2020 (NEON, AI-PROFICIENT, HESTIA, SINERGY, TRAPEZE, BorderUAS, PLATOON, TRINITY, IDEAS, REACT, LAMBDA, FeeelAgain, RESPOND, InBETWEEN, SlideWIKI, FLIRT, EEN INNO, FS4SMIH, EENSerbia, EENClientInnoJourney, EENInnoSJourney)

22 FP7 projects (REFLECT, AgroSENSE, META-NET, WBC-INCO-NET, HydroWEEE, ICT-WEB-PROMS, HELENA, EMILI, ENERGY WARDEN, PROCEED, LOD2, CASCADE, H-WEEE-DEMO, EPIC-HUB, SPARTACUS, GenderTIME, ResearchersNight, GeoKNOW, Danube INCO.NET, NoSQL-NET, Trafoon)

7 CIP/EIP (CESAR, EIIRC, GREEN, WEEEN, ICIP, IMAGEEN, Share PSI 2.0)

2 IPA Adrion (GoToTwin, CAROUSEL)

IPA Adriatic (PACCINO)

2 ERASMUS+ (BEST, RE-FEM)

4 SEE (Intervalue, FORSEE, WBINNO, TV-Web)

3 TEMPUS (CARE, HUTON, INCOMING)

8 COST Actions (IC1004, IC1304, CA16116, CA15104, NexusLinguarum, Distributed Knowledge Graphs, VOICES, INTERACT)

1 RSEDP2 (EMC)

2 UNDP (Smart Land, StreetAirPurifier)

3 FP6 projects (SARIB, PROMETEA, Web4WeB)

3 Interreg DANUBE (MOVECO, NewGenerationSkills, EDU-LAB)

2 EC Interreg/CADSES projects (I2E, STRIM)

6 IPA (EPS, Tax, Justice, Agro, POM, APML)

18 Bilateral projects (2 Switzerland, 3 France, 5 Germany, 1 Cyprus, 1 Greece, 1 Norway, 1 Portugal, 1 Slovenia, 3 China)

REINFORCEMENT LEARNING-BASED OPTIMIZATION OF AN HVAC SYSTEM

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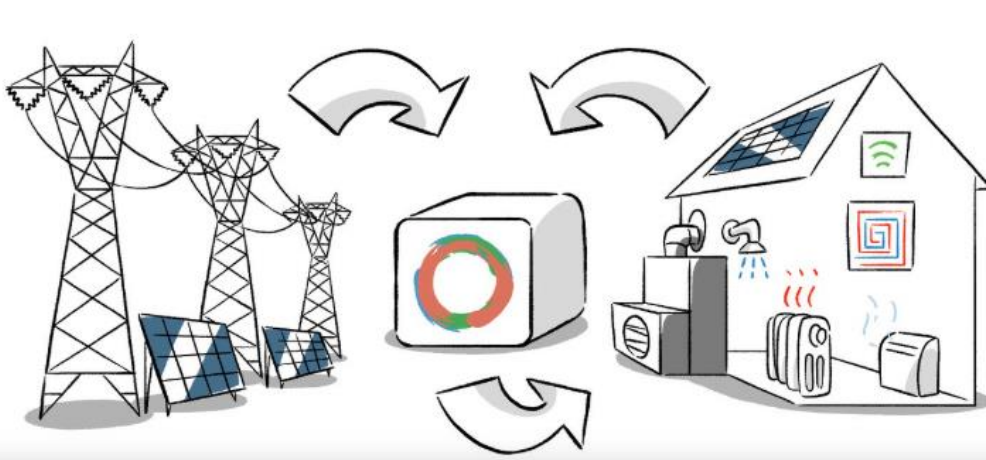
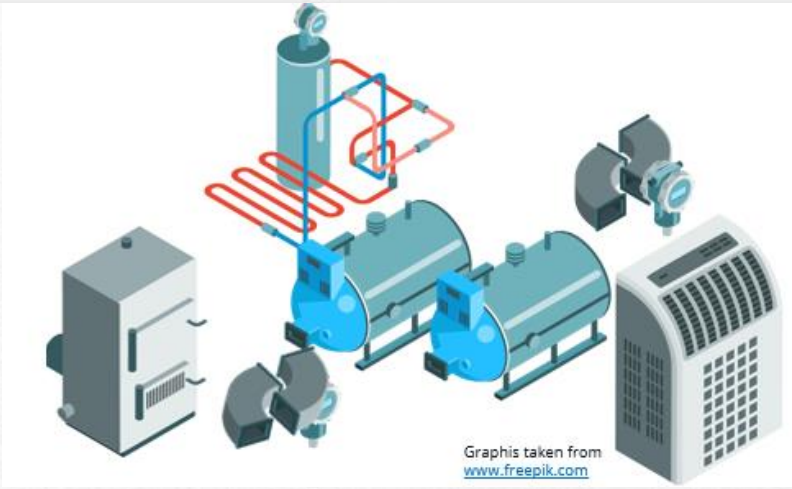
Reinforcement Learning-Based Optimization of an HVAC System

Work conducted within Horizon ECHO project: **E**fficient **C**ompact Modular T**H**ermal Energy St**O**rage System (2023-2026)

- Project aimed at developing **novel modular, compact, high performances and Plug&Play thermal energy storage (TES)** solutions for heating, cooling and domestic hot water (DHW) production
- TES systems enable electricity load shifting, supporting flexible energy systems
- ECHO TES based on thermo-chemical and phase changing materials
- Overall Heating Ventilation Air-Conditioning (HVAC) system consists of TES, heat pump, various tanks, pumps, valves and fan coils
- Its operation is quite complex - a suitable control algorithm required

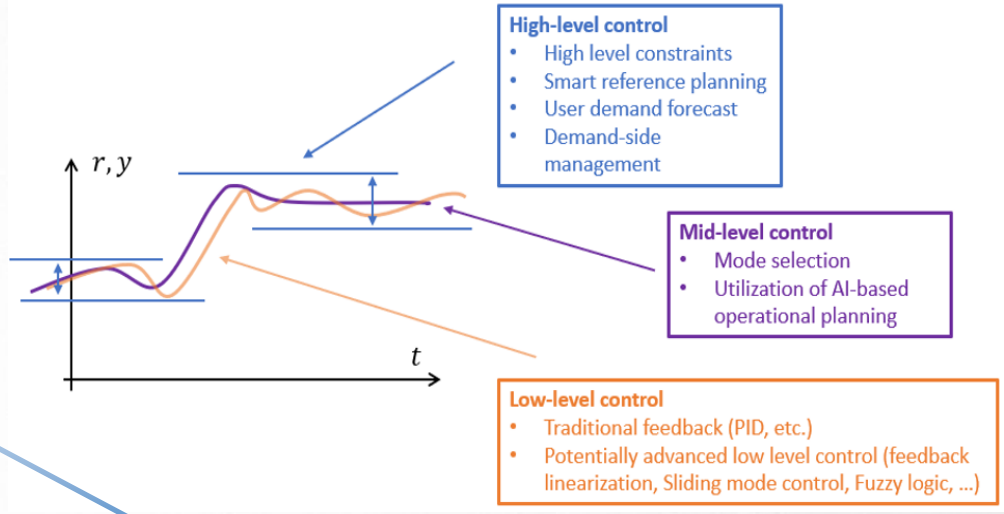




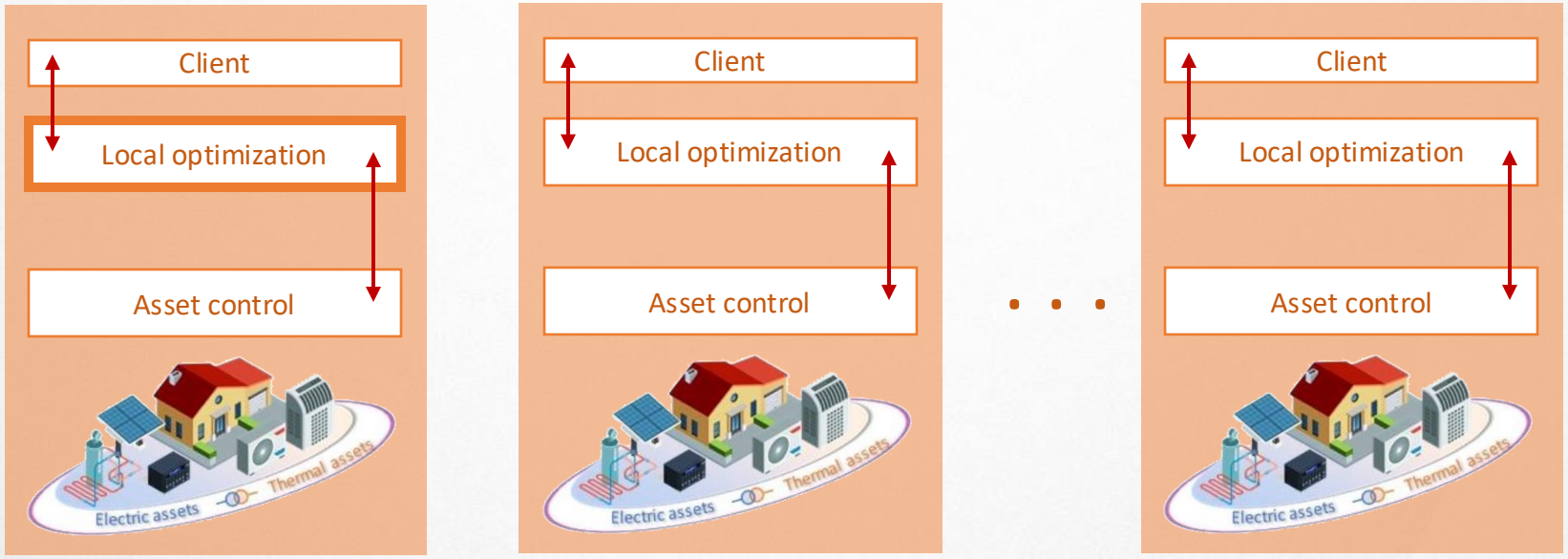
Reinforcement Learning-Based Optimization of an HVAC System

- **Reinforcement learning (RL) a backbone of local optimization**, aka mid-level/prosumer level control

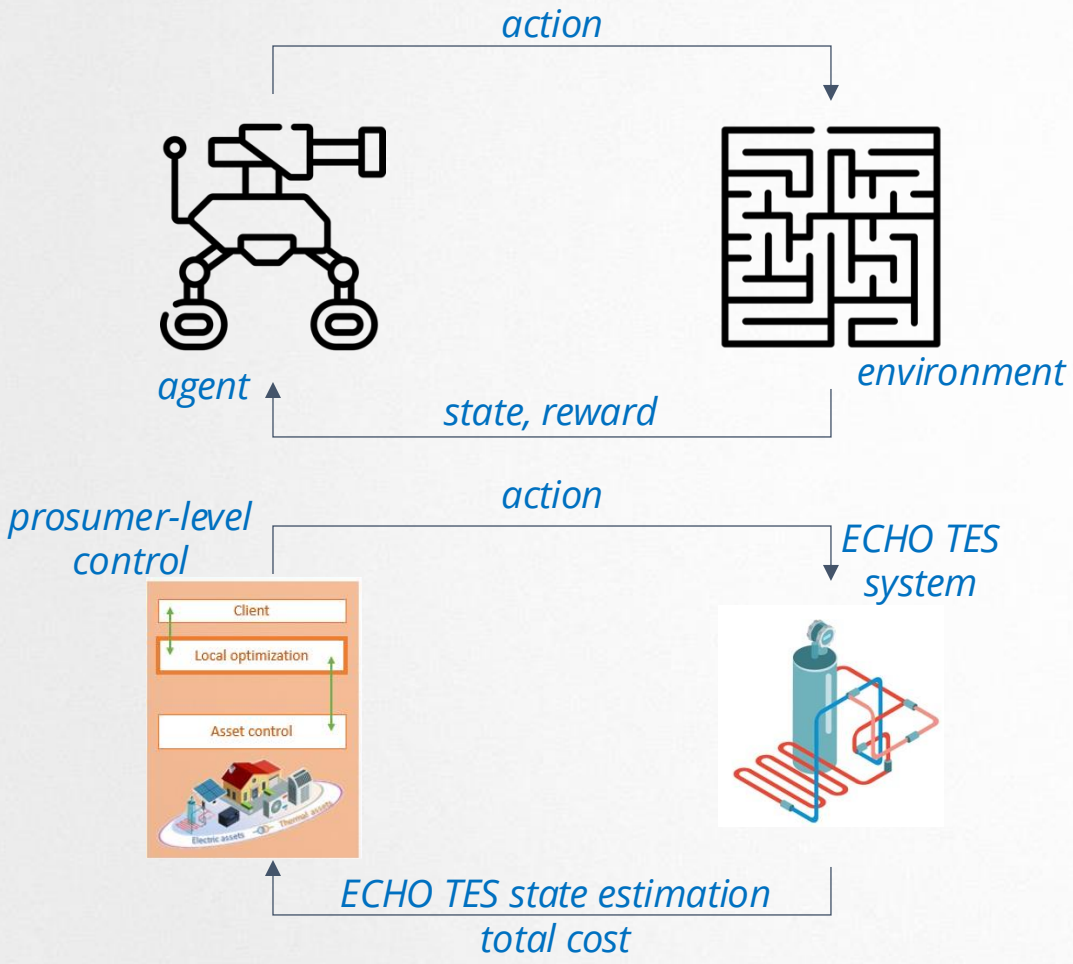
electrical community optimization



Graphis taken from www.freepik.com



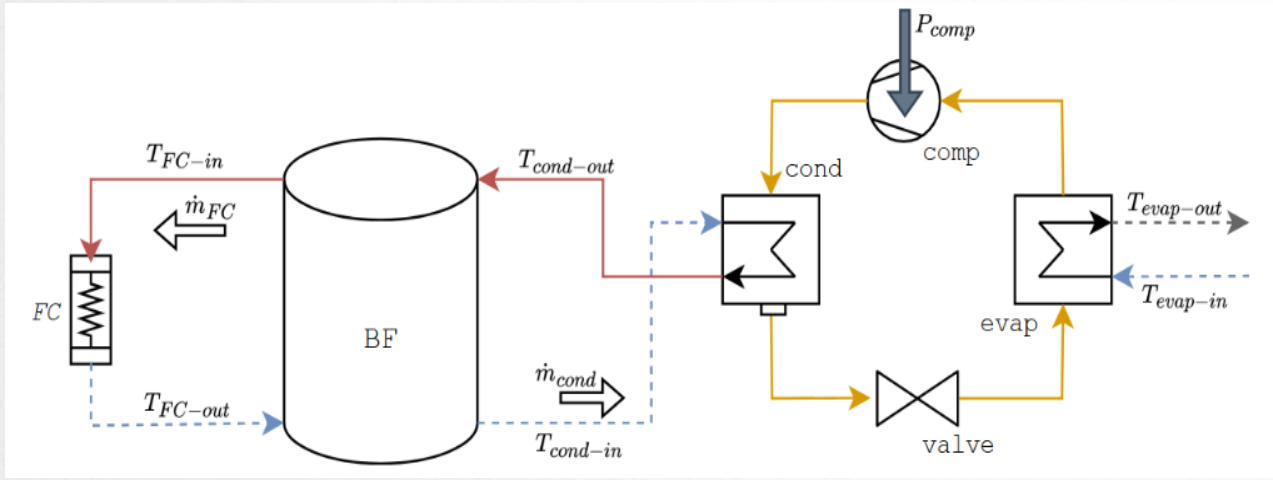
Reinforcement Learning-Based Optimization of an HVAC System

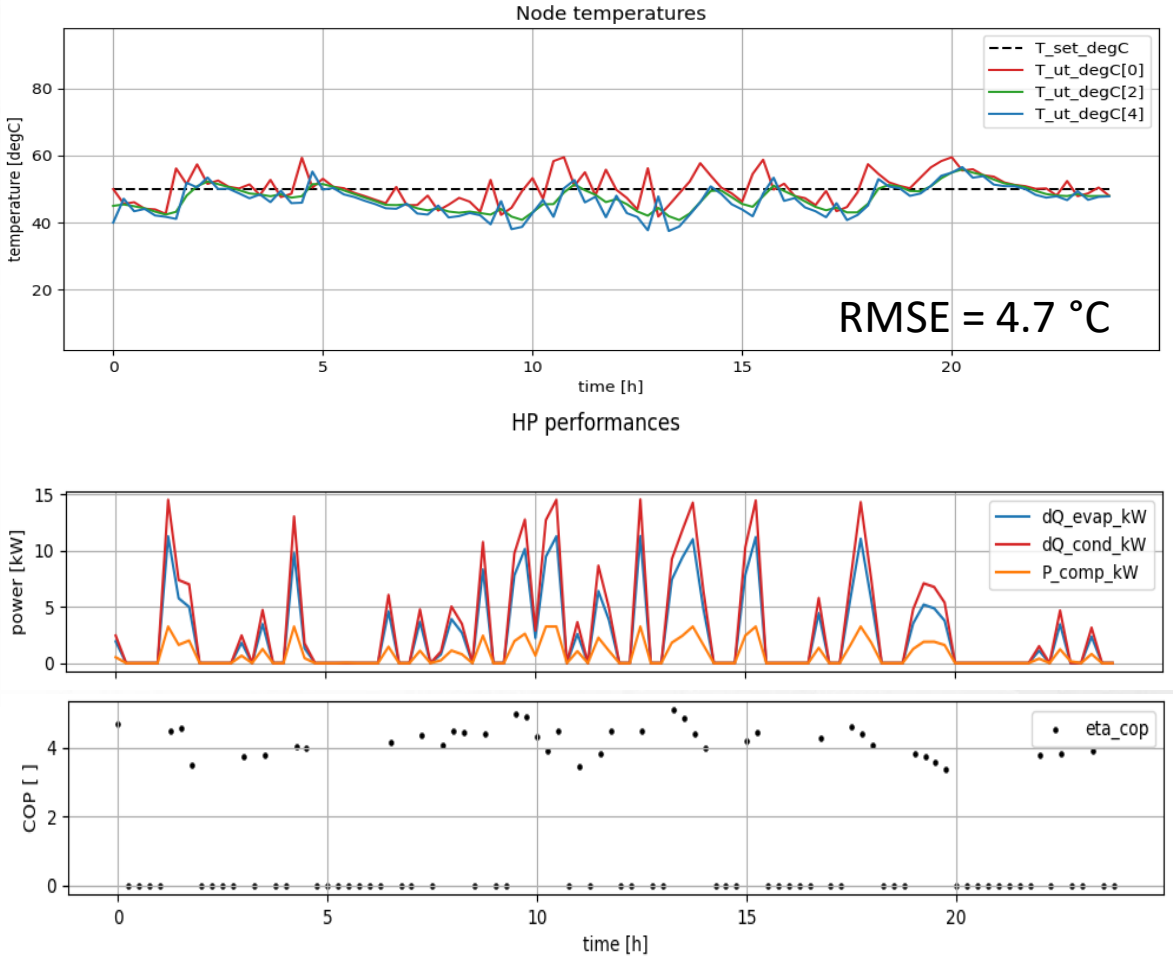


- Mid-level control objective - to **find the optimal asset schedule or optimal system state** (e.g. TES charge/discharge/idle) to achieve some predefined goal (e.g. reduce costs):
  - agent is a mid-level control algorithm
  - environment is the ECHO TES system
- **Minimization of the total cost of energy** for 24-hour period with 15-minute time resolution
- Model of environment (ECHO TES system) necessary to train the RL – white-box modelling approach
- Various system measurements and forecasts were used:
  - Estimated thermal and electrical demand
  - Forecasted available RES (e.g. PV)
  - Current SoC of ECHO TES
  - Pricing scheme

Reinforcement Learning-Based Optimization of an HVAC System

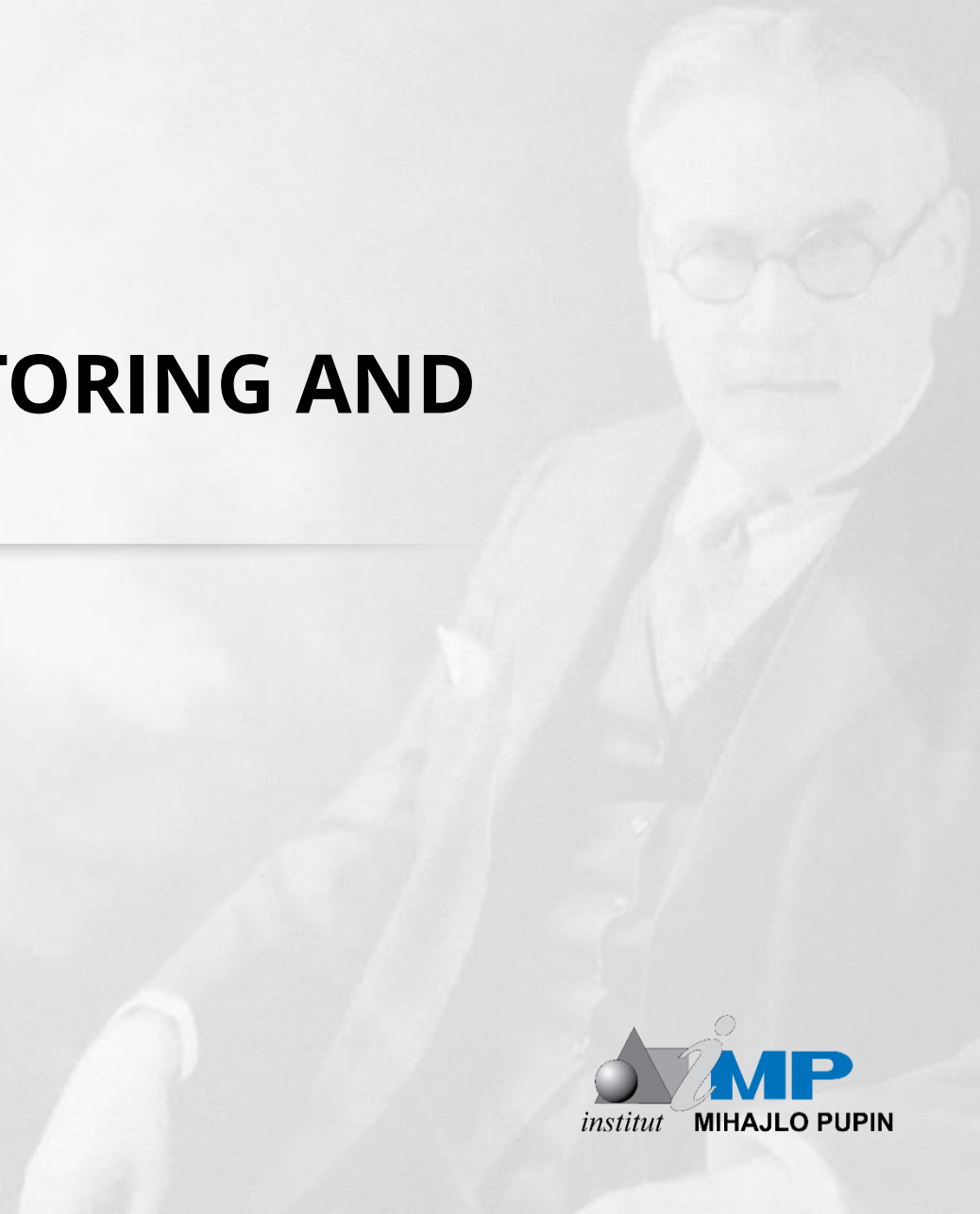
- **Deep Deterministic Policy Gradient** (DDPG) as an adaptation of deep Q-network approach (DQN) for continuous space
  - Presence of not only critic network, but also actor network for modeling actor policy
- Temperature T_{FC-in} setpoint tracking through compressor power P_{comp} for ensuring a stable supply for users' heating
  - Maximizing reward, minimizing RMSE between T_{FC-in} and T_{set}





Jelić, D., Jelić, M., Stanković, K., Batić, M. Reinforcement Learning-Based Smart Temperature Control for Buffer Tanks in HVAC Systems. Presented on ICIST 2025; to be published in the corresponding Springer proceedings soon.

NON-INTRUSIVE LOAD MONITORING AND DISAGGREATION



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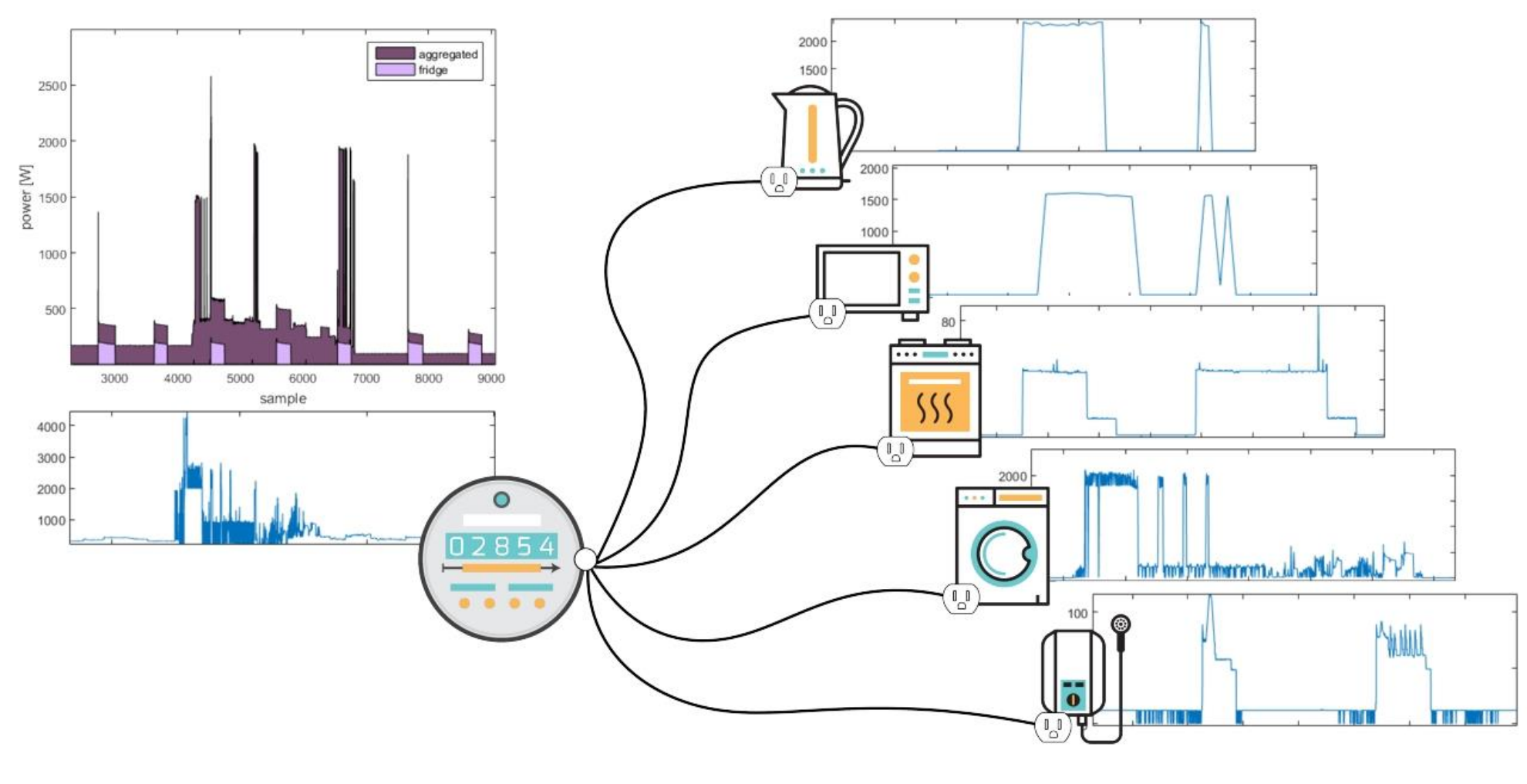
Non-Intrusive Load Monitoring and Disaggregation

Work conducted within H2020 HESTIA: **H**olistic d**E**mand response **S**ervices for European residen**TIA**l communities (2020-2024)

- Project aimed at developing a cost-effective solution for the next-generation demand-side response services.
- **Power consumption disaggregation** on the **appliance level**
- The goal was to develop automated model that can learn which appliances are ON over a period of time
- **Non-Intrusive Load Monitoring (NILM)**
- Generalization issue in model training required special attention

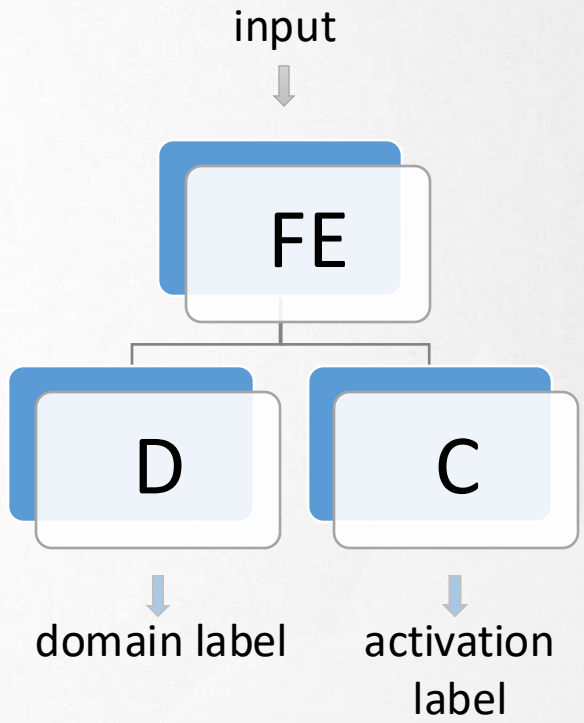
Non-Intrusive Load Monitoring and Disaggregation



- *Pujić D, Tomašević N, Batić M. A Semi-Supervised Approach for Improving Generalization in Non-Intrusive Load Monitoring. Sensors. 2023; 23(3):1444. https://doi.org/10.3390/s23031444*

Non-Intrusive Load Monitoring and Disaggregation

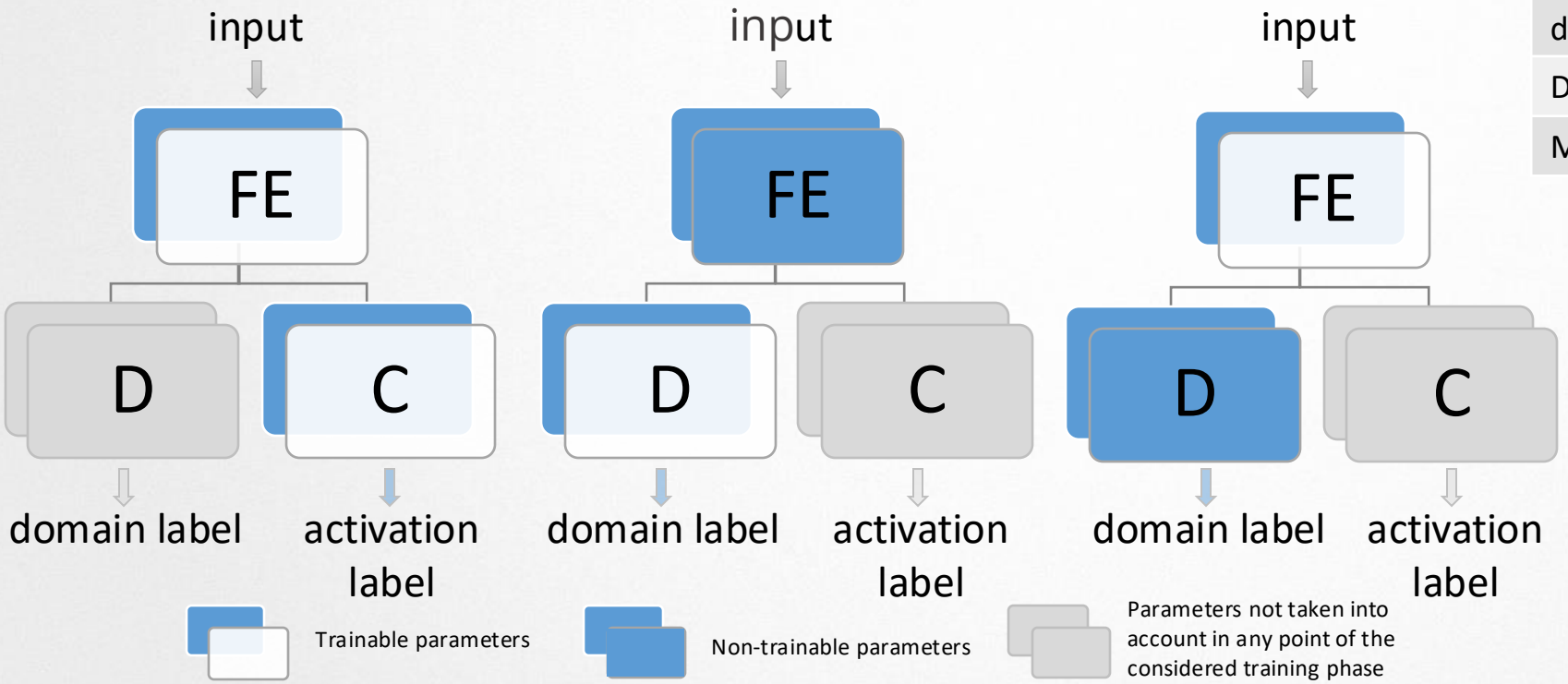
- Pilot houses usually unequipped with appliance individual consumption measuring sensors
  - Labels (individual consumption) are available only in public data sets
- Training on one data set and testing on the other can significantly decrease the performance of the model
- **Domain adversarial neural network (DANN)** approach
  - designed to train the model so that it extracts the features that are relevant for the problem, not for the domain
  - specific architecture and training process:
    - **feature extractor (FE)** for obtaining relevant features from aggregated consumption
    - **classifier (C)** for classification whether appliance is on or off depending on the extracted features
    - **discriminator (D)** to classify the domain of the input data (training or testing)



Non-Intrusive Load Monitoring and Disaggregation

- NILM intended for high consuming appliances
- Methodology applied on four different appliances from REDD and UK-DALE data set

	REDD	REDD + UK-DALE	
	Seq2point	Seq2point	DANN
Refrigerator	85%	59%	**62%**
Tumble dryer	85%	80%	**82%**
Dishwasher	88%	78%	**79%**
Microwave	82%	**89%**	84%



SURROGATE DATA-DRIVEN OPTIMIZATION OF A MANUFACTURING PROCESS

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Surrogate Data-Driven Optimization of a Manufacturing Process

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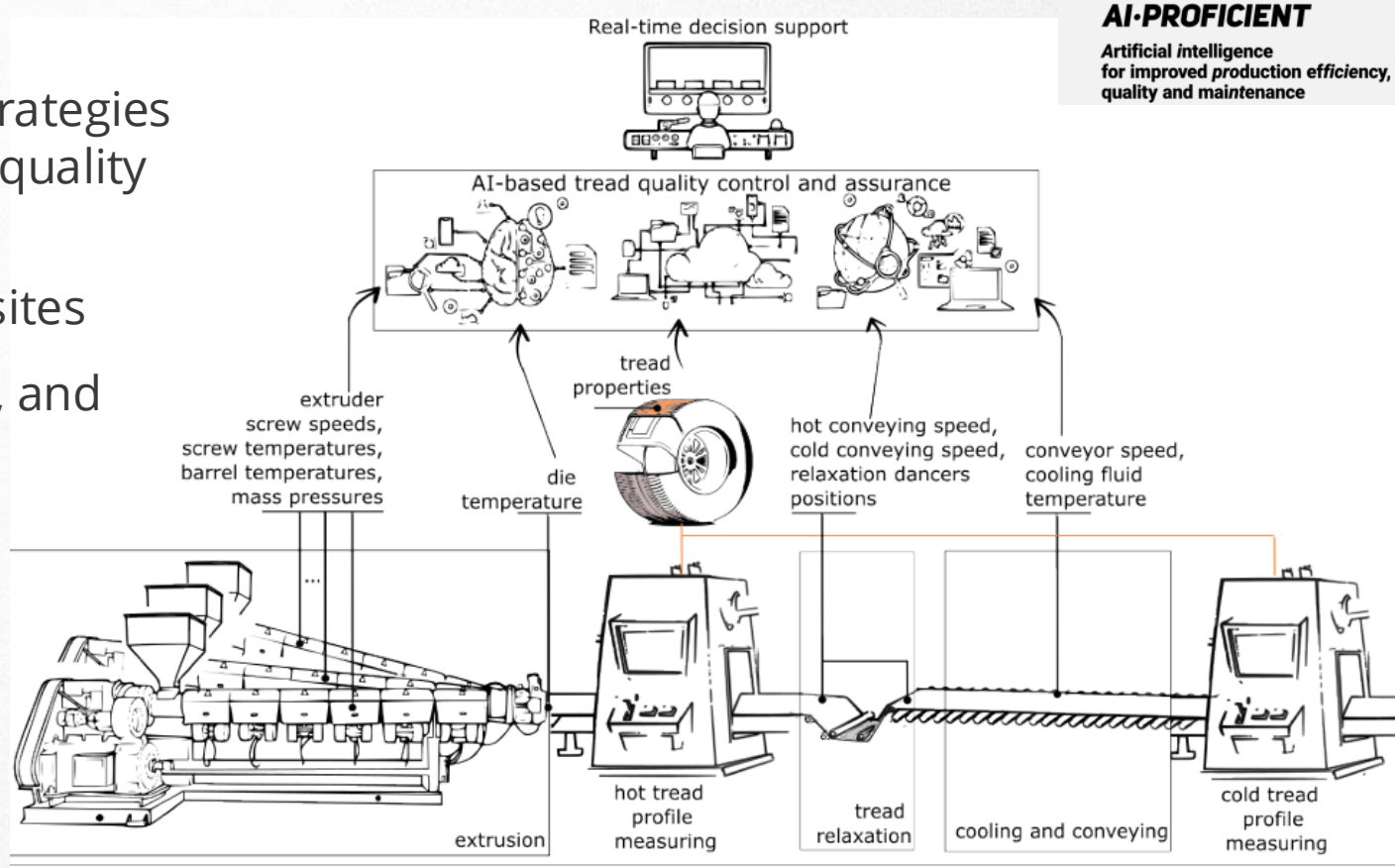
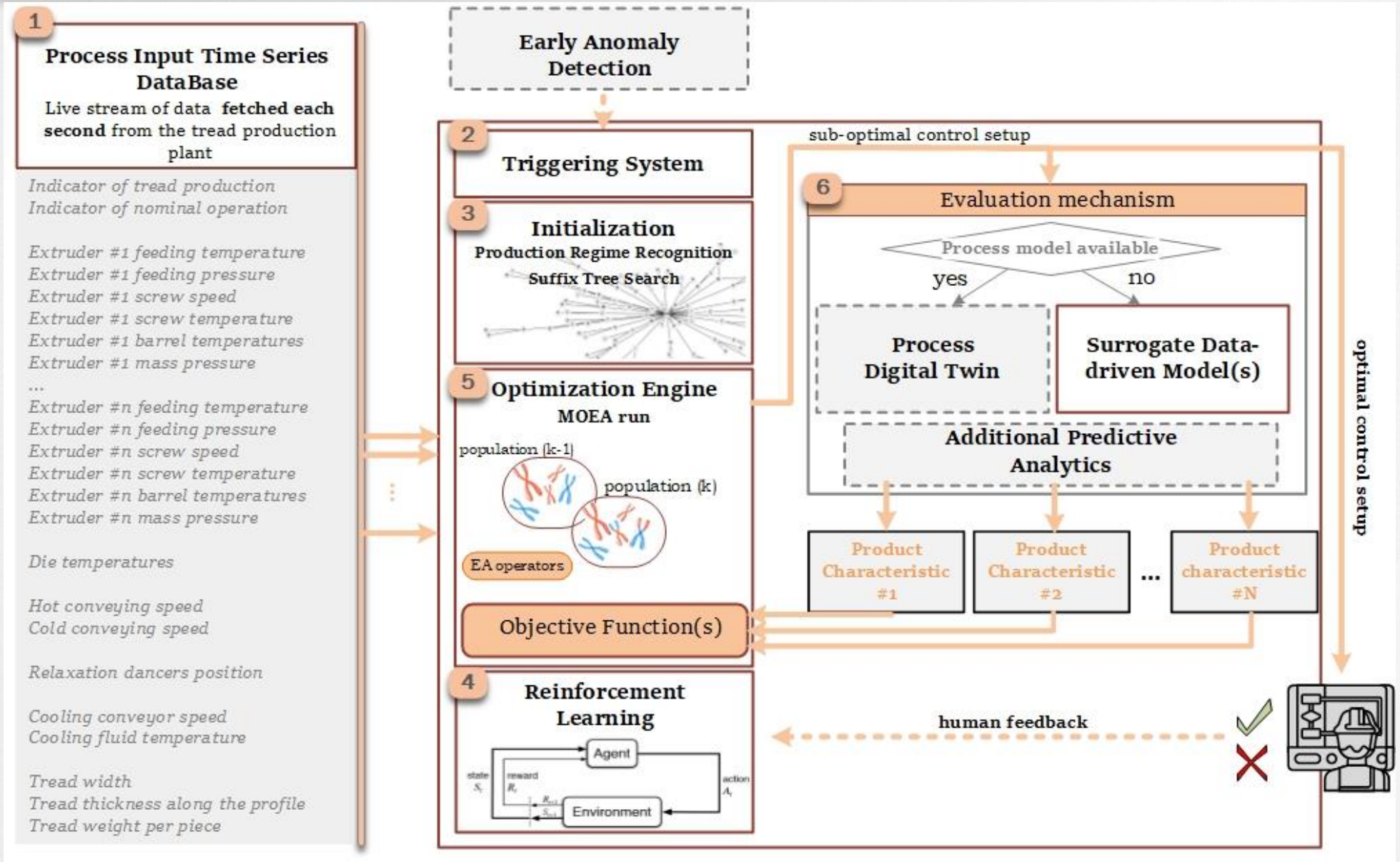
AI·PROFICIENT
Artificial intelligence for improved production efficiency, quality and maintenance

Work conducted within H2020 AI-PROFICIENT: **A**rtificial **I**ntelligence for improved **PRO**duction ef*FICIE*ncy, quality and mai**NT**enance (2020-2023)

- Project aimed at developing proactive control strategies to improve manufacturing processes efficiency, quality and maintenance.
- **Tire tread production plant** – one of the pilot sites
- Key product characteristics like thickness, width, and weight are continuously monitored
- Their control within tight quality limits required
- Hundred of different treads yearly produced
- A wide range of process conditions and product specifications
- **AI-based Quality analysis and assurance tool**

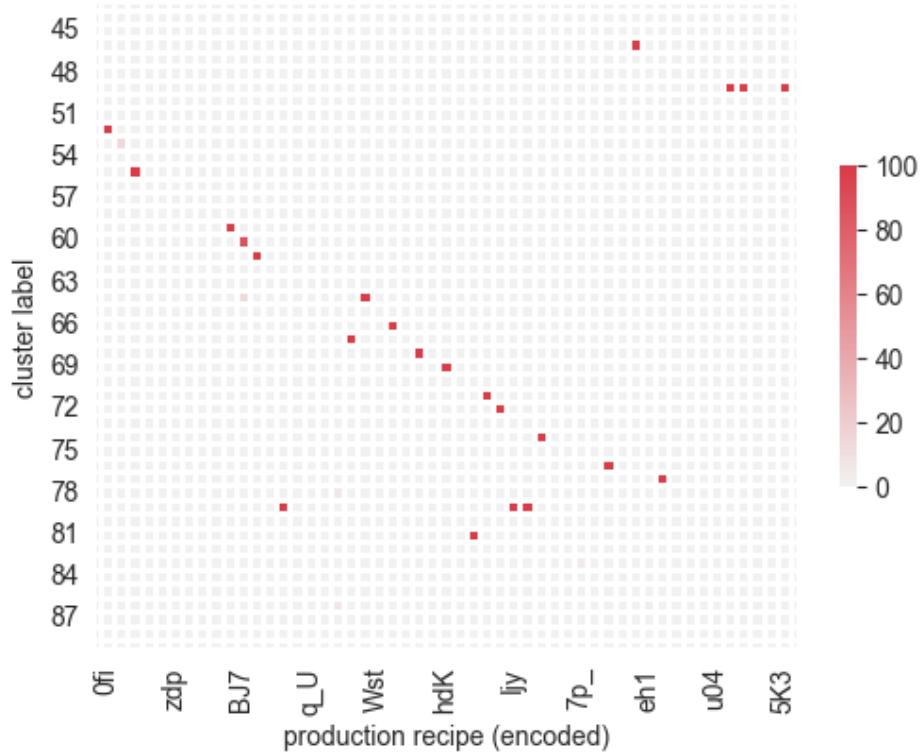


Surrogate Data-Driven Optimization of a Manufacturing Process

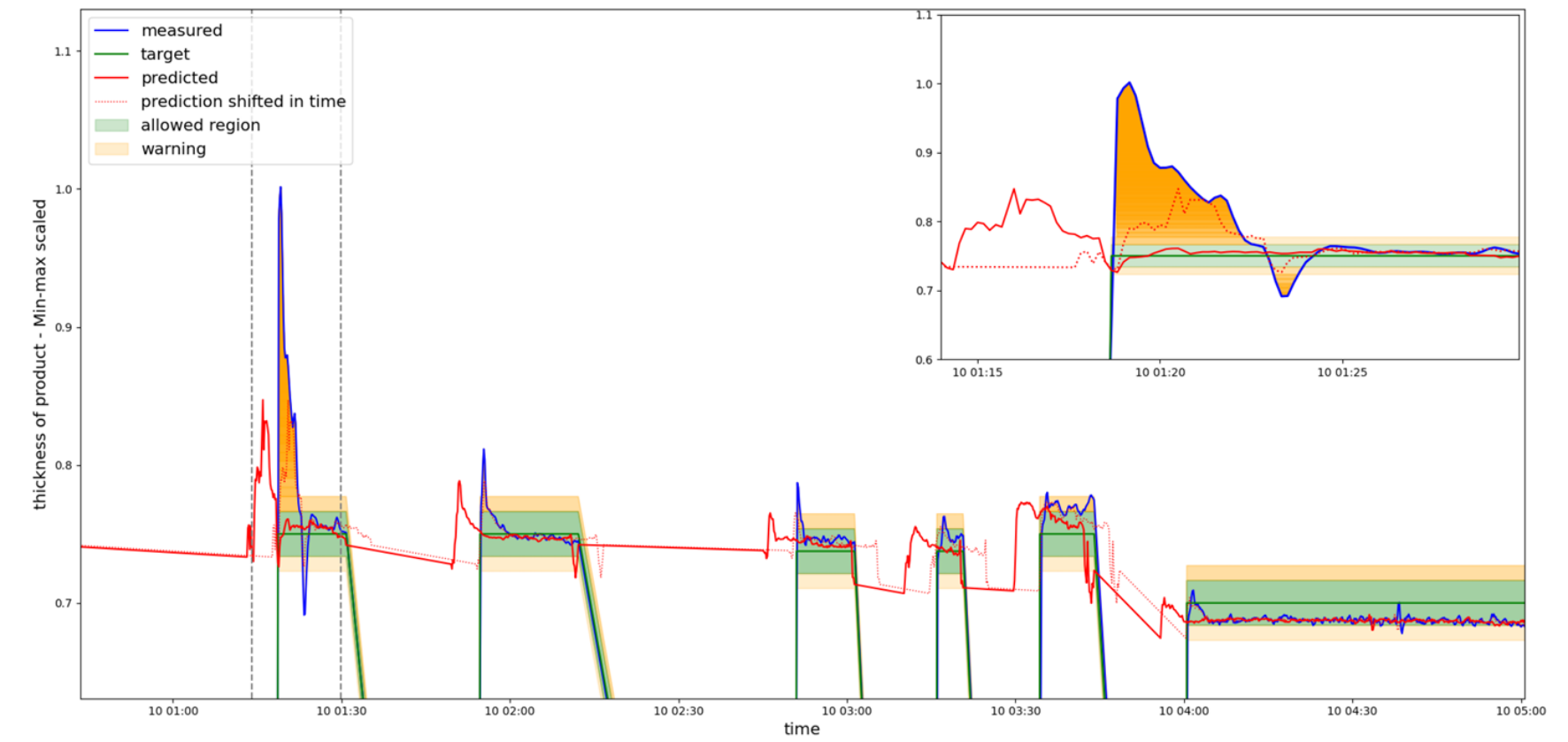


Surrogate Data-Driven Optimization of a Manufacturing Process

- Multi-objective evolutionary optimization based on decomposition (MOEA/D)
- Surrogate data-driven models (machine learining)
  - simulate how various process parameter combinations impact product quality.
- Production regime recognition prevents excessively long execution
  - optimization constrained to the local environment of a current working point
  - Density-Based Spatial Clustering of Applications with Noise (DBSCAN)
  - Process modelling with suffix trees
  - Recipe-agnostic clustering (modified purity metric achieved **93.42%**)
- Optimization initialization based on Suffix tree search
  - Execution time reduction of up to **76.9%**

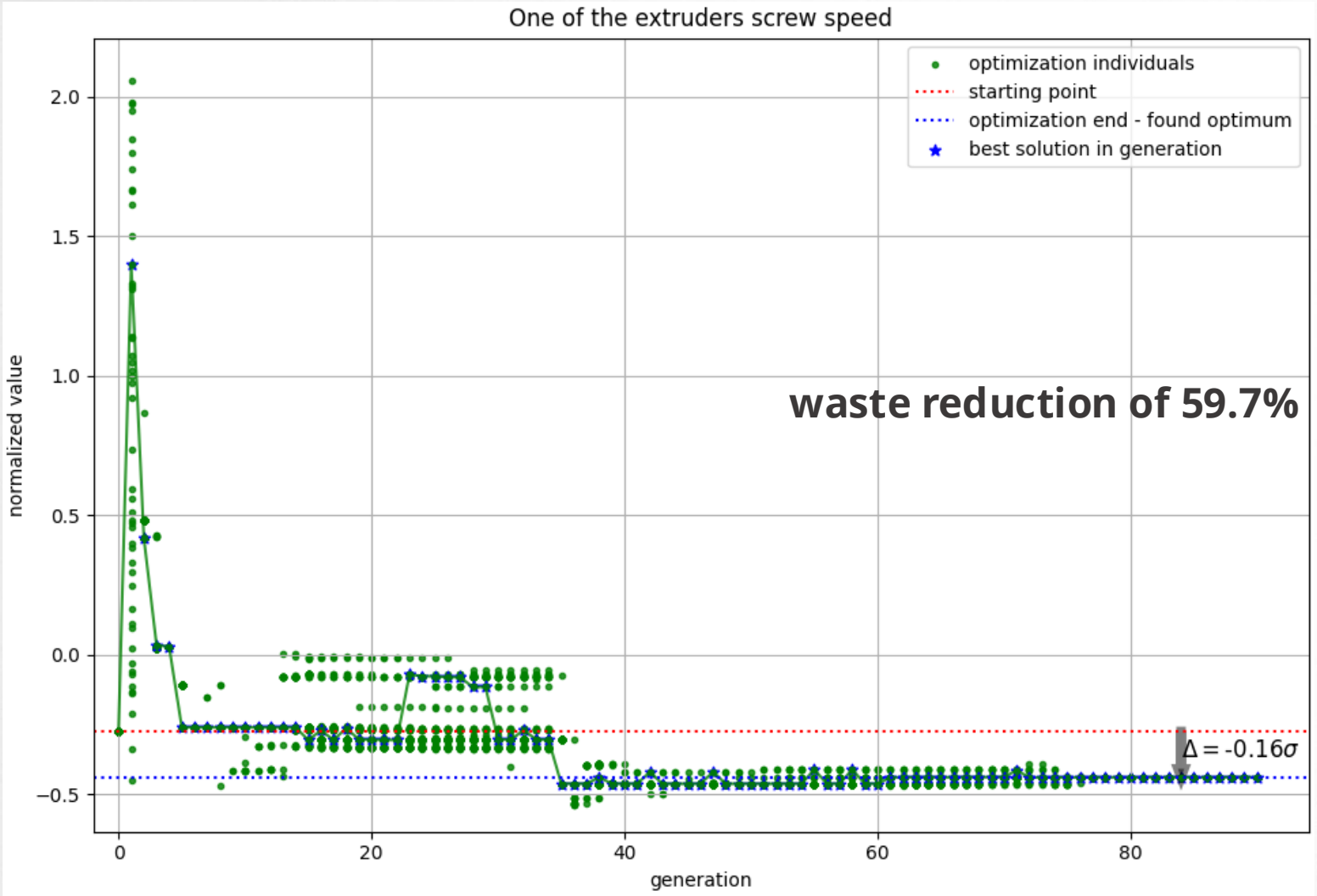


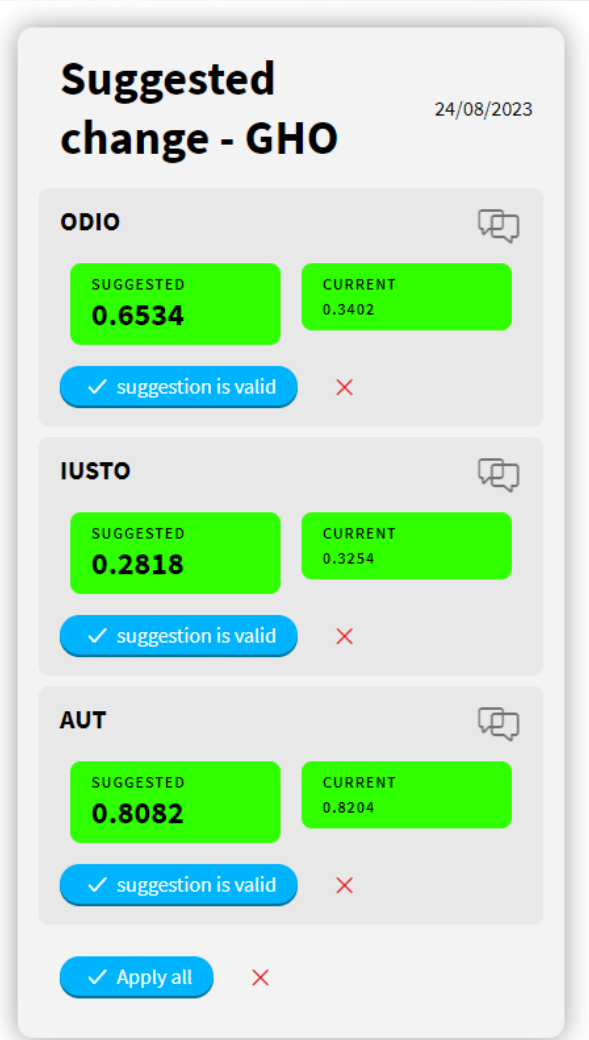
Surrogate Data-Driven Optimization of a Manufacturing Process



- *K. Stanković, D. Jelić, N. Tomašević, and A. Krstić, 'Manufacturing process optimization for real-time quality control in multi-regime conditions: Tire tread production use case', Journal of Manufacturing Systems, vol. 76, pp. 293–313, 2024, doi: https://doi.org/10.1016/j.jmsy.2024.07.015.*

Surrogate Data-Driven Optimization of a Manufacturing Process





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OTHER APPLICATIONS

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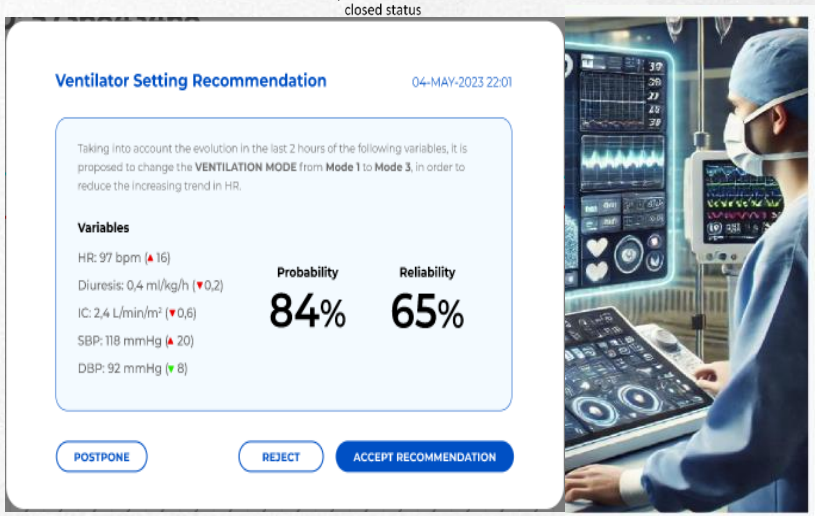
Other Applications

- **Forecasters of different purposes** - PV production, wind turbine production, national electrical load, residential/commercial facilities electrical load
- **Consumer energy efficiency benchmarking** service
- Decision support system for **mechanical ventilation in intensive care units**
- **Results recognized by EU Innovation Radar**
- **Innovative solutions**, https://project-sinergy.org/Innovative-solutions
- **Publications**:
  - *D. Pujić and N. Tomašević, "Hybrid ensemble neural network approach for photovoltaic production forecast," 2021 29th Telecommunications Forum (TELFOR), Belgrade, Serbia, 2021, pp. 1-4, doi: 10.1109/TELFOR52709.2021.9653369.*
  - *Esnaola-Gonzalez I, Jelić M, Pujić D, Diez FJ, Tomašević N. An AI-Powered System for Residential Demand Response. Electronics. 2021; 10(6):693. https://doi.org/10.3390/electronics10060693*
  - *F. Safaei et al., 'X-Vent: ICU Ventilation with Explainable Model-Based Reinforcement Learning', in ECAI 2024, IOS Press, 2024, pp. 4719–4726. doi: 10.3233/FAIA241069.*



THANK YOU FOR YOUR ATTENTION!

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