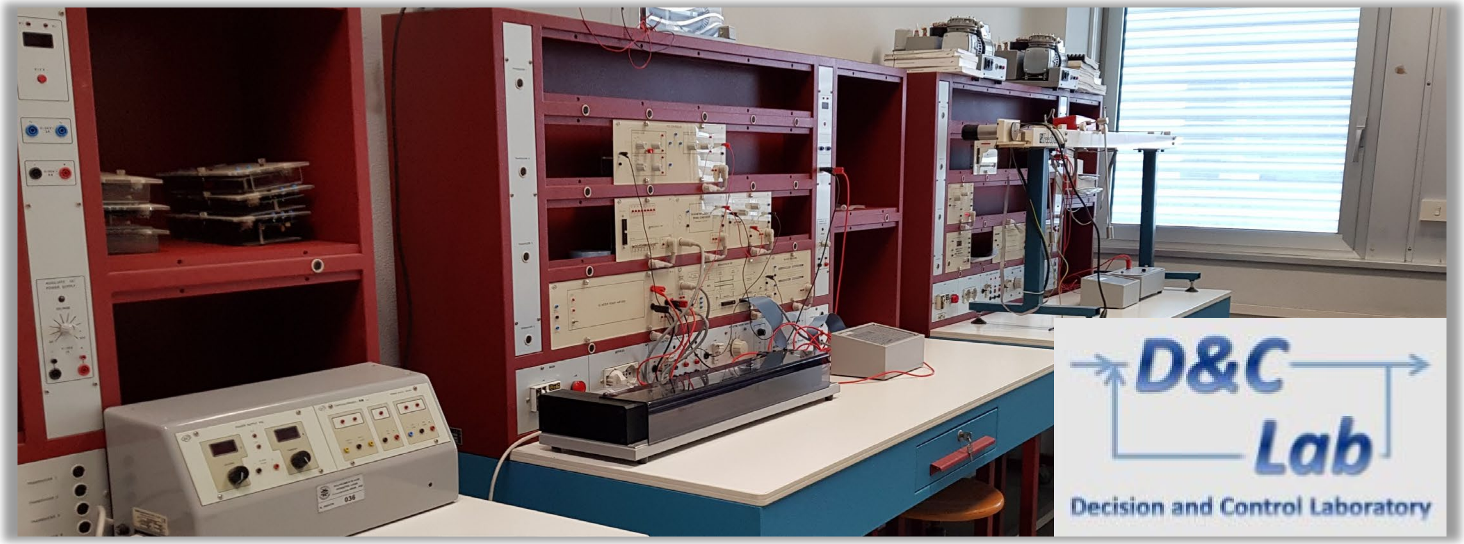


Research Activities

Decision & Control Laboratory
Politecnico di Bari

Website: http://dclab.poliba.it

LinkedIn: https://www.linkedin.com/company/dandclab

YouTube: https://www.youtube.com/channel/UCrroEhmYOtc2QAClCqIsOkw

People

Full Professor
Prof. Engr.
Mariagrazia DOTOLI
Scientific Coordinator

Assistant Professors

Dr. Engr.
Raffaele CARLI
Technical Responsible

Postdoctoral researcher

Dr. Engr.
Paolo SCARABAGGIO

PhD students

Engr. Bahman
ASKARI
XXXVI cycle

Engr. Lucilla
DAMMACCO
XXXVI cycle

Engr. Silvia
PROIA
XXXVI cycle

Engr. Giulia
TRESCA
XXXVI cycle

Engr. Augusto
BOZZA
XXXVII cycle

Engr. Nicola
MIGNONI
XXXVII cycle

Engr. Saba
ASKARI NOGHANI
XXXVIII cycle

Engr.
Alaa Ali HAMEED
XXXVIII cycle

Research assistants

Marino
CALEFATI

Luigi
MAZZOCCOLI

Silvia
STELLA

Farideh
SOHEYLI

Missions

Fostering the education of undergraduate/graduate students.

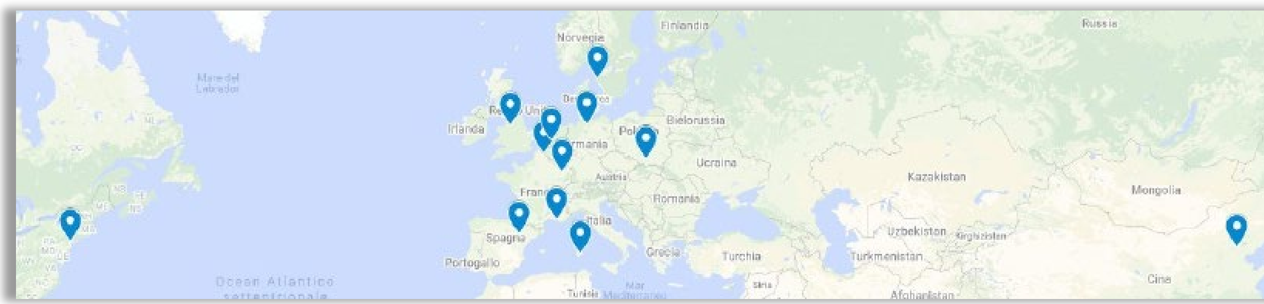
Supporting courses lab activities.

Performing theoretical/applied research in systems, control, optimization, and decision-making areas.

Collaborations

- International
  - AGH University of Science and Technology, Poland
  - Aix-Marseille Université AMU, France
  - Chalmers University, Sweden
  - Cracow University of Technology, Poland
  - Delft University of Technology, Netherlands
  - École Centrale de Lille, France
  - Hamburg Helmut Schmidt University, Germany
  - Manchester University, UK
  - New Jersey Institute of Technology of Newark, USA
  - Tsinghua University, China
  - Université de Nancy, France
  - University of Tokyo, Japan
  - University of Zaragoza, Spain
  - Polytechnic University of Catalonia, Spain
  - Polytechnic University of Bucharest, Romania

- National:
  - Cagliari University
  - University of Genoa



Consultancies

- Public companies:
  - AMTAB S.p.A.
  - Banque Centrale du Luxembourg
  - Ferrovie del Sud Est e Servizi Automobilisti S.r.l.
  - Municipality of Bari
  - Retegas Bari S.p.A.
- Private companies:
  - Cannillo S.r.l.
  - Centro Ricerche Fiat
  - COMAU S.p.A.
  - Divella S.p.A.
  - Dream Project S.p.A.
  - E-distribuzione
  - Elettric80 S.p.A.
  - Gigant Italia S.r.l.
  - GTS (General Transport Service) S.p.A.
  - IBM
  - Innolab S.r.l.
  - Le Gemme
  - Macnil Gruppo Zucchetti
  - Masmec S.p.A.
  - Mermec SpA
  - Nicola Veronico S.r.l.
  - OM Carrelli Elevatori S.p.A.
  - Planetek S.r.l.
  - Primadonna S.p.A.
  - SimNT S.r.l.
  - Sunalle-Il vecchio forno S.r.l.
  - Tangari S.r.l.
  - TERA S.r.l.
  - Veronico S.r.l.

Research Activities

Research Activities

- A1 Management and Control of Energy Systems
  - A1.1 Energy Scheduling
  - A1.2 Energy Resource Exchange / Sharing
  - A1.3 Optimal Power Grid Operation
  - A1.4 Power Grids Condition Monitoring
- A2 Management and Control of Large Scale Systems
  - A2.1 Smart Cities
  - A2.2 Smart Mobility
  - A2.3 Covid-19 Pandemic
  - A2.4 Social Networks
- A3 Modelling, Control, and Optimization for Industry 4.0 Applications
  - A3.1 Collaborative Robotics
  - A3.2 Smart Manufacturing Process Control
  - A3.3 Digital Twin
  - A3.4 Virtual Reality
- A4 Modelling, Control, and Optimization for Transport and Logistics
  - A4.1 Passengers Transport
  - A4.2 External Logistics
  - A4.3 Internal Logistics
- A5 Modelling, Control, and Optimization for Biomedical Application
  - A5.1 Medical Robotics

A1 Management and Control of Energy Systems

A1.1 Energy Scheduling

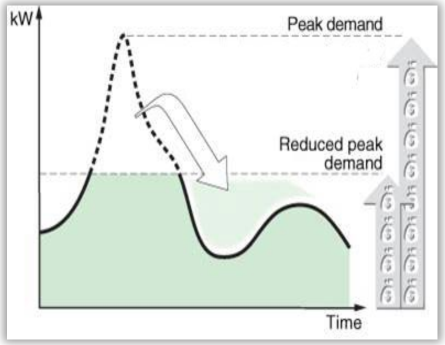
A1.2 Energy Resource Exchange / Sharing

A1.3 Optimal Power Grid Operation

A1.4 Power Grids Condition Monitoring

A1- Management and Control of Energy Systems

A1.1- Energy Scheduling (1/3)

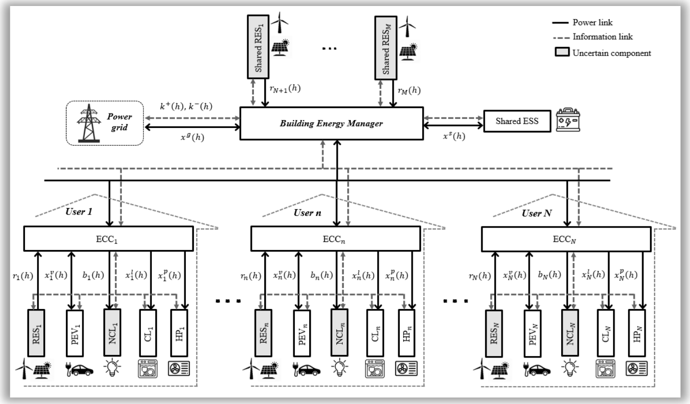


- Motivation
  - Energy efficiency and environmental sustainability...
  - ... requires efficient energy behaviors of all smart grid actors
    - important role of small end-users such as homes
    - need for development - at demand level - of energy optimization algorithms to obtain responsive and proficient behaviors of energy user
- Results
  - Survey on Control Approaches for Demand-Side Management in Smart Grids
    - Investigating the state-of-the-art on demand-side management (DSM) approaches in smart grids
  - Microgrid Control
    - Exploring centralized approaches for optimal energy management of microgrids, tackling the challenge of uncertainty in system parameters
  - Control of Networked Smart Energy Users
    - Exploring decentralized/distributed approaches for optimal energy management of networked energy systems

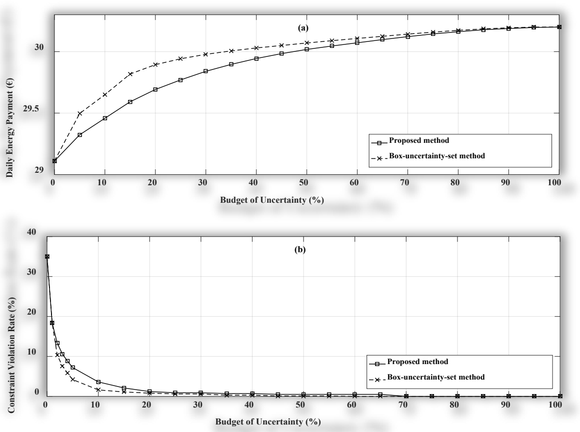
A1- Management and Control of Energy Systems

A1.1- Energy Scheduling (2/3)

- Microgrid Control
  - Aim:
    - provide a smart energy scheduling for a public (or private) microgrid (both electrical and thermal carriers) under uncertain data (generation, consumption, pricing).
  - Methodologies:
    - Cardinality-constrained robust optimization
    - Receding horizon
  - Advantages:
    - full exploitation of the potential of load flexibility, local energy generation and storage to reduce the individual user energy consumption cost and PAR (Peak to Average Ratio)



Scheme of microgrid energy flows and connections

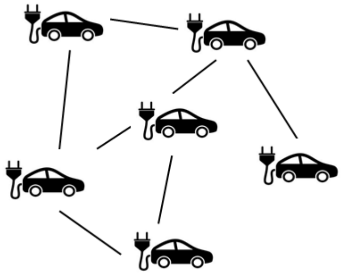


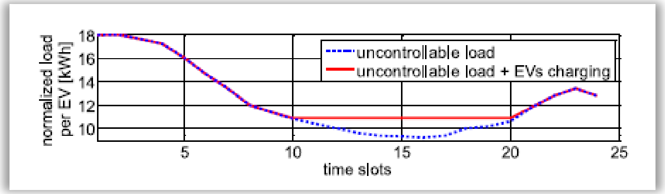
Hosseini, S. M.; Carli, R.; Dotoli, M., “Robust Optimal Energy Management of a Residential Microgrid under Uncertainties on Demand and Renewable Power Generation,” IEEE Transactions on Automation Science and Engineering (TASE), vol. 18, no. 2, pp. 618-637, 2021.

Carli, R.; Cavone, G.; Pippia, T.; De Schutter, B.; Dotoli, M., “Robust Optimal Control for Demand Side Management of Multi-Carrier Microgrids”, in IEEE Transactions on Automation Science and Engineering (TASE), 2022. in press.

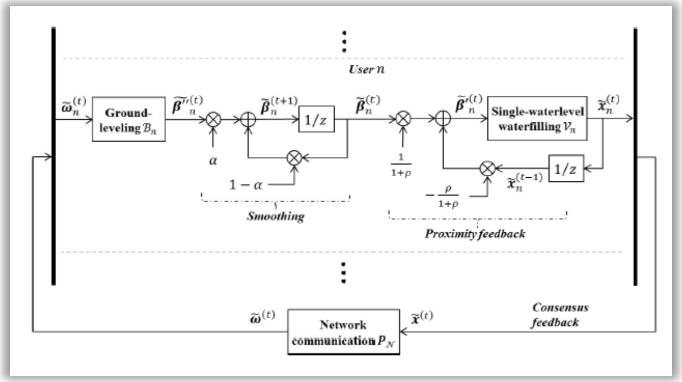
A1.1- Energy Scheduling (3/3)

- Control of Networked Smart Energy Users
  - Aim:
    - Optimally scheduling the energy activities of a large-scale fleet of electric Vehicles (EVs) and/or a district of smart homes
  - Methodology:
    - iterative distributed / decentralized algorithm based on duality, proximity, and consensus theory (e.g., distributed proximal-Jacobian ADMM)
  - Advantages:
    - ensuring a cost-optimal profile of the aggregated energy demand, complying with the energy users individual needs;
    - satisfying the resource constraints depending both on power grid components capacity and load locations in the distribution network;
    - using a minimal information structure, without relying on a central decision maker.





Valley filling in EVs charging control problem



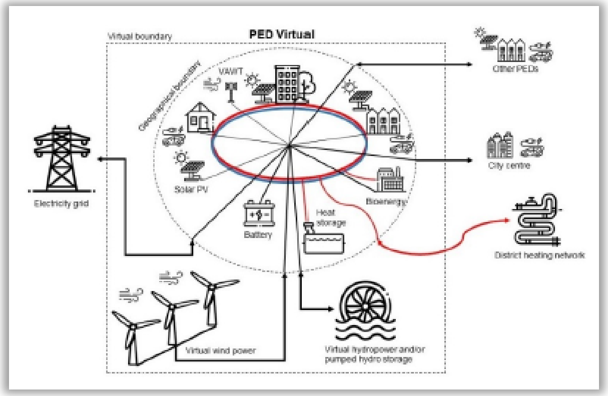
Distributed waterfilling control strategy

- Carli, R. and Dotoli, M., “Distributed Alternating Direction Method of Multipliers for Linearly-constrained Optimization over a Network,” IEEE Control Systems Letters. vol. 4, no. 1, pp. 247-252, 2020.
- Carli, R. and Dotoli, M., “A Distributed Control Algorithm for Waterfilling of Networked Control Systems via Consensus,” IEEE Control Systems Letters, vol. 1, no. 2, pp. 334-339, Oct. 2017.
- Hosseini, S. M.; Carli, R.; Cavone, G.; Dotoli, M., “Distributed Control of Electric Vehicle Fleets Considering Grid Congestion and Battery Degradation,” Internet Technology Letters, 2020, 3:e161.

A1- Management and Control of Energy Systems

A1.2- Energy Resource Exchange / Sharing (1/3)

- Motivation
  - growing shift from traditional schemes to aggregative complex entities…
  - … requires a radical change towards a more interactive structure
    - Energy systems need to be arranged in intelligent networks, capable of receiving two-way energy flows, making producers and consumers interact

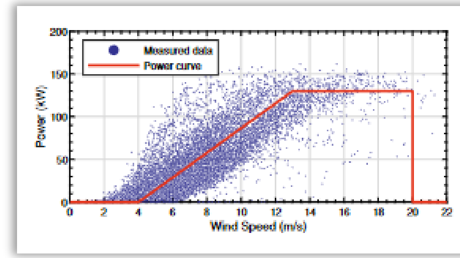


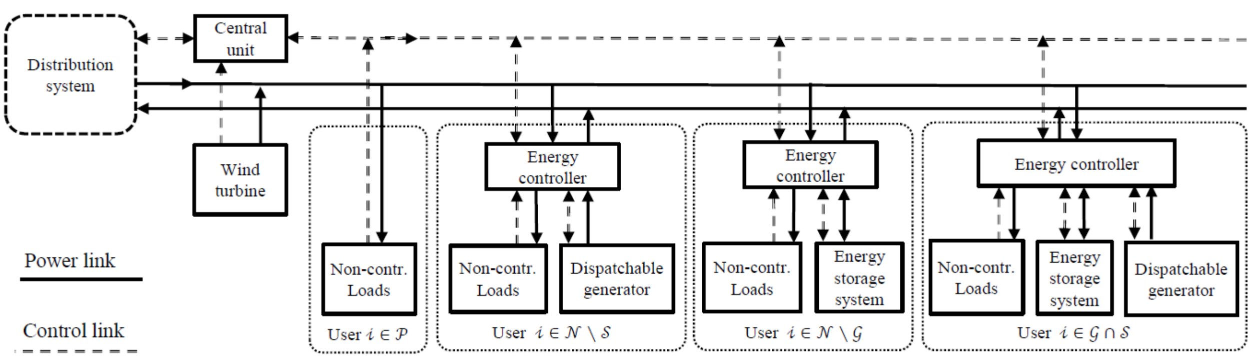
Scheme of Positive Energy District / Community

- Results
  - defining new control architectures and frameworks for intelligent energy networks, as enabling tools to transform the grid from a rigid system to a flexible and sustainable asset.
  - developing control mechanisms integrating optimization and game theory, aimed at making energy systems capable of:
    - conveniently trading local energy exchanges, optimally sharing common energy resources, leveraging on loads flexibility, pursuing instantaneous self-consumption, while reducing overall costs and improving sustainability

A1.2- Energy Resource Exchange / Sharing (2/3)

- Aim and motivation:
  - renewable energy sources (RESs) are difficult to integrate in power system due to their stochastic time-varying nature
  - reduce the gap between the RESs generation and the energy demand by linking the energy price to the RESs in grids with:
    - group of prosumers/consumers
    - storage energy systems
    - dispatchable generators
    - controllable electric/thermal loads
- Methodologies:
  - centralized/decentralized optimization and game theory
  - stochastic predictive control approaches





A1- Management and Control of Energy Systems

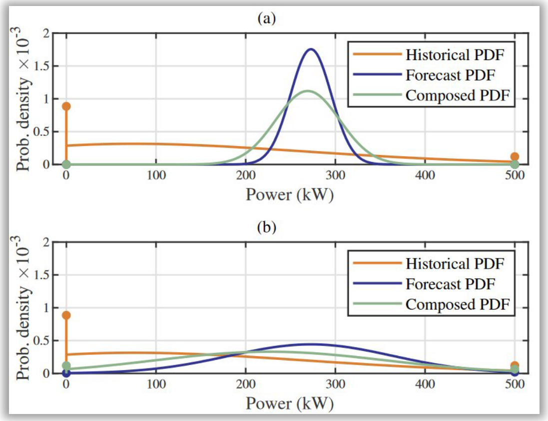
A1.2- Energy Resource Exchange / Sharing (2/3)

$$\begin{array}{ll} \underset{u(t)}{\text{minimize}} & \tilde{f}(u(t), \tilde{w}(t)) \\ \text{subject to} & \text{Model constraints} \end{array}$$

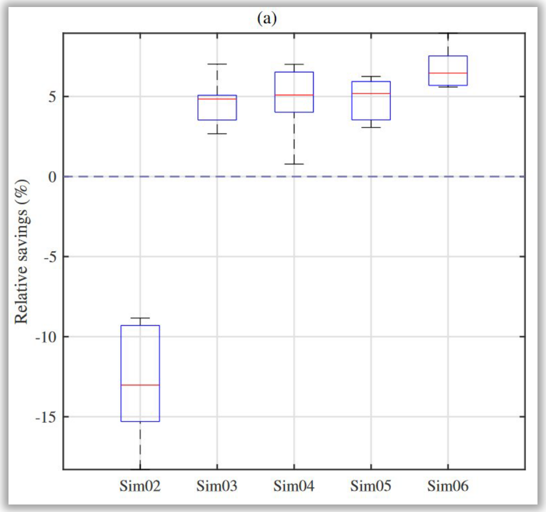
$$f(u(t), w(t)) = \mathbb{E}[f(u(t), w(t))]$$

$$\hat{f}(u(t), \hat{w}(t)) = \frac{1}{N} \sum_{n=1}^{N} f_n(u(t), w_n(t))$$

$$f_W(v) = \begin{cases} \frac{k_W}{\lambda_W} \left(\frac{v}{\lambda_W}\right)^{k_W - 1} \exp\left(-\left(\frac{v}{\lambda_W}\right)\right)^{k_W} \\ 0 \end{cases}$$



- **Contribution:**
  - coordinate multiple autonomous entities with the goal of reducing the gap between the variable stochastic distributed generation and adjustable load demand
  - nearby users optimally share renewable energy sources / storage systems to jointly take advantage of the collective locally harvested/stored energy

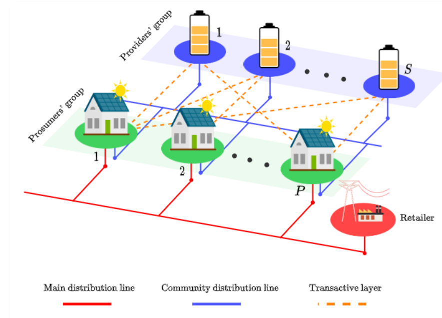


- **Future research directions:**
  - Limited power flow models
  - Data-driven optimal asset utilization in networked energy systems

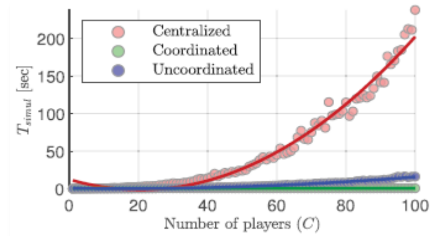
- P. Scarabaggio, S. Grammatico, R. Carli, and M. Dotoli, "Distributed Demand Side Management With Stochastic Wind Power Forecasting", *IEEE Transactions on Control Systems Technology*, vol. 30, no. 1, pp. 97–112, 2022
- Carli, R.; Dotoli, M.; Jantzen, J.; Kristensen, M.; Othman, S. B., "Energy Scheduling of a Smart District Microgrid with Shared Photovoltaic Panels and Storage: the case of the Ballen marina in Samsø", Energy – The International Journal, 198, 117188, 2020.

A1 - Management and Control of Energy Systems

A1.2- Energy Resource Exchange / Sharing (3/3)



- Aim and motivation:
  - optimal energy flow schedule of a group of prosumers, characterized by their own demand and renewable generation, and a group of energy storage service providers, able to store the prosumers' energy surplus and, subsequently, release it upon a fee
- Methodologies:
  - game-theoretical transactive control frameworks
- Advantages:
  - powerful economy driven control mechanisms for effectively coordinating and trading energy flows among the actors
- Future research directions:
  - absence of modelling errors and nonidealities (e.g., latency, faults)



$$v_{\mathcal{C},n}^{(\tau+1)} = \underset{v_{\mathcal{C},n}\in\mathcal{K}_{\mathcal{C},n}}{\arg\min}\ J_{\mathcal{C},n}(v_{\mathcal{C},n}) + \gamma_{\mathcal{C},n}^{(\tau)} + \theta_{\mathcal{C},n}^{(\tau)}$$

$$J_{\mathcal{P},i}(v_{\mathcal{P},i}) = \sum_{t\in\mathcal{T}}\Bigg[\underbrace{C_t p_{it}^{\uparrow} - R_t p_{it}^{\downarrow} + L_t \sum_{h\in\mathcal{N}_i} s_{iht}}_{\text{Energy cost, revenues and storage fee}} + \underbrace{\frac{1}{2}\xi_i\Big(p_{it}^{\uparrow^2} + p_{it}^{\downarrow^2} + \sum_{h\in\mathcal{N}_i}\big(d_{iht}^{\uparrow^2} + d_{iht}^{\downarrow^2}\big)\Big)}_{\text{Energy transmission costs}}\Bigg]$$

$$\theta_{\mathcal{P},i}^{(\tau)} = \frac{\rho}{2}\left(\left\|d_i^{\downarrow} - d_i^{\downarrow(\tau-1)}\right\|^2 + \left\|d_i^{\uparrow} - d_i^{\uparrow(\tau-1)}\right\|^2\right)$$

$$\theta_{\mathcal{S},j}^{(\tau)} = \frac{\rho}{2}\left(\left\|q_j^{\downarrow} - q_j^{\downarrow(\tau-1)}\right\|^2 + \left\|q_j^{\uparrow} - q_j^{\uparrow(\tau-1)}\right\|^2\right)$$

$$\gamma_{\mathcal{P},i}^{(\tau)} = \sum_{t\in\mathcal{T}}\sum_{h\in\mathcal{N}_i}\left[\lambda_{iht}^{(\tau)}(d_{iht}^{\uparrow} - q_{iht}^{\downarrow}) + \mu_{iht}^{(\tau)}(d_{iht}^{\downarrow} - q_{iht}^{\uparrow})\right]$$

$$\gamma_{\mathcal{S},j}^{(\tau)} = \sum_{t\in\mathcal{T}}\sum_{k\in\mathcal{M}_j}\left[\lambda_{kjt}^{(\tau)}(d_{kjt}^{\uparrow} - q_{kjt}^{\downarrow}) + \mu_{kjt}^{(\tau)}(d_{kjt}^{\downarrow} - q_{kjt}^{\uparrow})\right]$$

- N. Mignoni, P. Scarabaggio, R. Carli, and M. Dotoli, "Control frameworks for transactive energy storage services in energy communities", Control Engineering Practice, vol. 130, Art. n. 105364, pp. 1–11, 2022
- Carli, R. and Dotoli, M., "Decentralized Control for Residential Energy Management of a Smart Users' Microgrid with Renewable Energy Exchange," IEEE/CAA Journal of Automatica Sinica, vol. 6, no. 3, pp. 641-656, 2019.

A1 - Management and Control of Energy Systems

A1.3- Optimal Power Grid Operation

- Aim and motivation:
  - noncooperative control framework to allow prosumers to contribute to the grid optimization process leveraging on their demand flexibility, dispatchable generation capability, and/or energy storage potential
  - considering physical constraints in energy markets: noncooperative Optimal Power Flow (OPF)
- Methodologies:
  - decentralized optimization and game theory
  - nonconvex game theory

e-distribuzione

$$\frac{\partial P_{br}}{\partial \theta_h} = \begin{cases} 0 & \text{if } h \neq r, h \neq b \\ |V_n||V_r||y_{br}| \sin(\theta_n - \theta_r - \theta_{br}) & \text{if } h = b \\ -|V_n||V_r||y_{br}| \sin(\theta_n - \theta_r - \theta_{br}) & \text{if } h = r \end{cases}$$

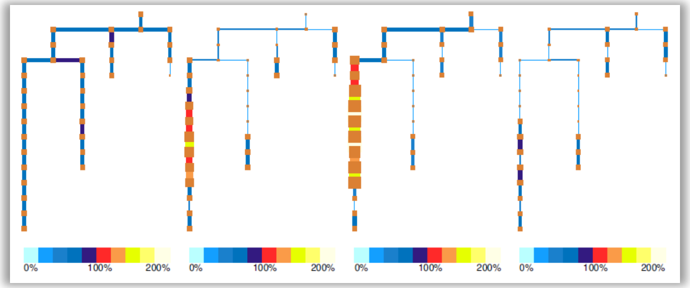
$$\frac{\partial P_{br}}{\partial |V_h|} = \begin{cases} 0 & \text{if } h \neq r, h \neq b \\ 2\,|V_n||y_{br}| \cos(\theta_{br}) & \\ \quad - |V_r||y_{br}| \cos(\theta_n - \theta_r - \theta_{br}) & \text{if } h = b \\ -|V_n||y_{br}| \cos(\theta_n - \theta_r - \theta_{br}) & \text{if } h = r. \end{cases}$$

$$\begin{bmatrix} \partial P_{br}/\partial P_1 \\ \vdots \\ \partial P_{br}/\partial P_N \\ \partial P_{br}/\partial Q_1 \\ \vdots \\ \partial P_{br}/\partial Q_N \end{bmatrix} = (J^\top)^{-1} \begin{bmatrix} \partial P_{br}/\partial \theta_1 \\ \vdots \\ \partial P_{br}/\partial \theta_N \\ \partial P_{br}/\partial |V_1| \\ \vdots \\ \partial P_{br}/\partial |V_N| \end{bmatrix}, \ \forall (b,r) \in \mathcal{E}$$

$$|V_b| \sum_{r \in \mathcal{B}} |V_r||Y_{br}| \cos(\theta_{br} + \theta_r - \theta_b) - P_b = 0, \ \forall b \in \mathcal{B}$$

$$-|V_b| \sum_{r \in \mathcal{B}} |V_r||Y_{br}| \sin(\theta_{br} + \theta_r - \theta_b) - Q_b = 0, \ \forall b \in \mathcal{B}.$$

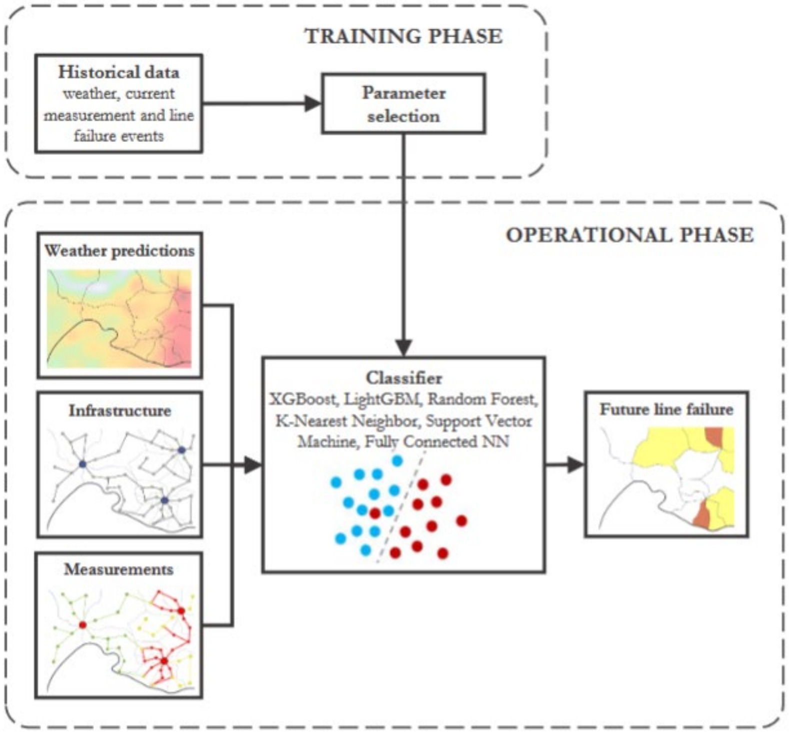
- Advantages:
  - participation of users in regulating the grid operation in a safe and secure way
- Future research directions:
  - multiple market equilibria with different characteristics



- P. Scarabaggio, R. Carli, and M. Dotoli, “Noncooperative Equilibrium Seeking in Distributed Energy Systems Under AC Power Flow Nonlinear Constraints”, IEEE Transactions on Control of Network Systems, vol. 9, no. 4, pp. 1731–1742, 2022.

A1.4 Power grids condition monitoring

- **Aim:**
  - addressed the issue of predicting failures in power distribution grids due to heatwaves
- **Methodologies:**
  - structured methods to predict distribution grid disruptions caused by heatwaves
  - methods based on machine learning to analyse previous failure data and forecast power grid outages using operational and meteorological information
- **Advantages**
  - understanding the nature of heatwaves and forecasting their impact on power distribution systems can be useful to anticipate them and accelerate the reaction, possibly avoiding negative impacts on power systems and customers

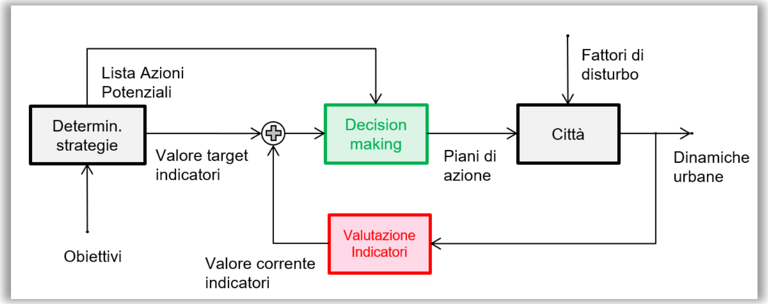


- M. Atrigna, A. Buonanno, R. Carli, G. Cavone, P. Scarabaggio, M. Valenti, G. Graditi, and M. Dotoli, "Power Distribution Grids Condition Monitoring under Heatwaves: a Machine Learning Approach to Fault Prediction", *IEEE Transactions on Industry Applications* (under review)
- M. Atrigna, A. Buonanno, R. Carli, G. Cavone, P. Scarabaggio, M. Valenti, G. Graditi, and M. Dotoli, "Effects of Heatwaves on the Failure of Power Distribution Grids: a Fault Prediction System Based on Machine Learning", in *2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I CPS Europe)*, 2021, pp. 1–5

A2 Management and Control of Complex Systems

A2.1- Smart Cities (1/2)

- Two main tools to develop city smartness:
  - the measure and monitoring of the smart city performance
  - the definition of strategic action programs as result of decision making and planning



- Benchmarking of metropolitan areas
  - Development of a multi-criteria technique to support the Public Administration in the analysis and benchmarking of the sustainability of energy/water/environment systems in metropolitan areas
- Energy retrofit of urban sectors
  - Determine the optimal set of actions to be implemented in the given existing urban system in order to reduce energy consumption, maintaining the required comfort, protecting the environment, while not exceeding the given budget constraint
    - e.g., street lighting system –

      retrofit actions: Luminaire replacement, Energy harvesting module installation, Zonal dimming device installation

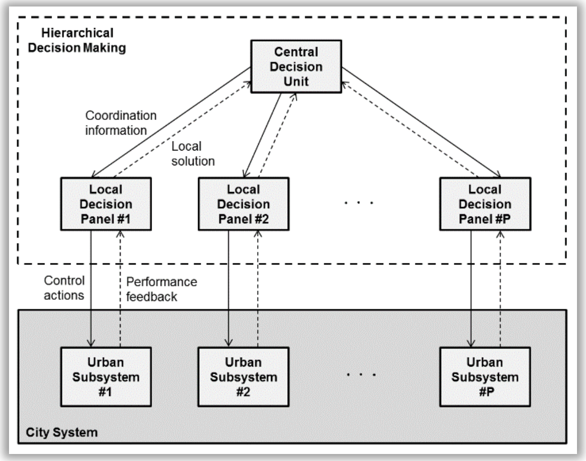
      criteria: energy saving, light pollution reduction, drivers comfort improvement

- Carli, R. and Dotoli, M., “A dynamic programming approach for the decentralized control of energy retrofit planning in large-scale street lighting systems,” IEEE Transactions on Automation Science and Engineering (TASE), vol. 17, no. 3, pp. 1140-1157, July 2020.
- Carli, R.; Dotoli, M.; Pellegrino, R., “Multi-criteria Decision-Making for Sustainable Metropolitan Cities Assessment,” Journal of Environmental Management, vol. 226, pp. 46-61, 2018.

A2- Management and Control of Complex Systems

A2.1- Smart Cities (2/2)

- Decision support for energy use at an urban level
  - most works address the problem of city monitoring/management from the perspective of a single urban sector, or for case studies
  - a city is a complex system: urban elements are interrelated and must be cross-optimized



$$\max_{\mathbf{Y}} \mathbf{F}(\mathbf{Y},\mathbf{X}^1,\ldots,\mathbf{X}^p,\ldots,\mathbf{X}^P)$$
$$\text{s.t. } \mathbf{G}(\mathbf{Y},\mathbf{X}^1,\ldots,\mathbf{X}^p,\ldots,\mathbf{X}^P) \le 0$$

Upper-level decision problem
-> Central Decision Unit

where each $\mathbf{X}^p$ (p=1,…,P) solves:

$$\max_{\mathbf{X}^p} \mathbf{f}^p(\mathbf{Y},\mathbf{X}^p)$$
$$\text{s.t. } \mathbf{g}^p(\mathbf{Y},\mathbf{X}^p) \le 0$$

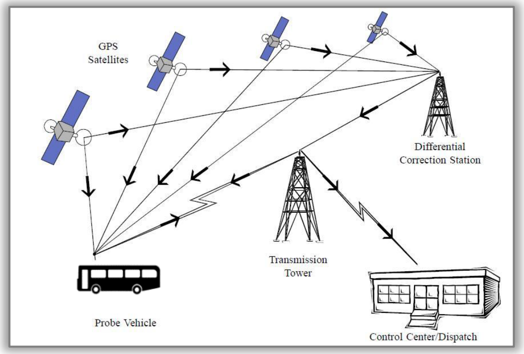
Lower-level decision problem -> Local Decision Panels

$\mathbf{Y}$: Central unit decision variables
$\mathbf{F}$ $\mathbf{G}$: Central unit objective / constraint functions
$\mathbf{X}^p$: Local unit decision variables
$\mathbf{f}^p$ $\mathbf{g}^p$: Local unit objective / constraint functions
P : Number of local units

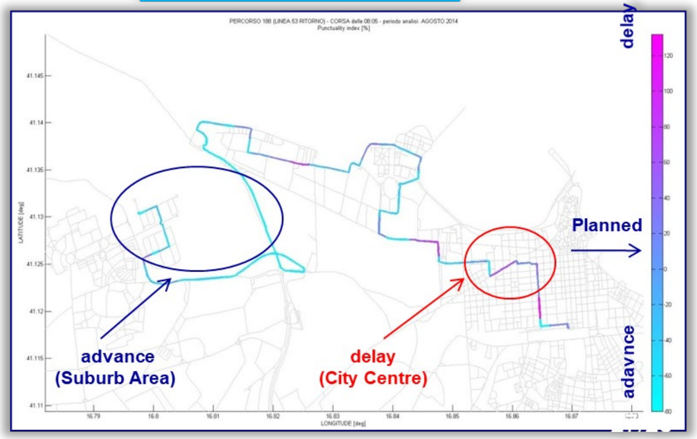
- Carli, R.; Dotoli, M.; Pellegrino, R., “A decision-making tool for energy efficiency optimization of street lighting,” Computers and Operations Research (COR), vol. 96, pp. 223-235, August 2018.
- Carli, R., Dotoli, M., Pellegrino, R.; Ranieri, L., “A decision making technique to optimize a building stock energy efficiency”, IEEE SMC-A (Transactions on Systems, Man and Cybernetics: Systems), vol. 47, no. 5, pp. 794-807, May 2017.
- Carli, R., Dotoli, M., Pellegrino, R., “A Hierarchical Decision Making Strategy for the Energy Management of Smart Cities”, IEEE TASE (Transactions on Automation Science and Engineering), vol. 14, no. 2, pp. 505-523, April 2017.

A2.2- Smart Mobility

- Aim:
- definition of an ICT system to provide the citizens and the Public Administration of a smart city with useful information about urban mobility.
- Results: Three levels of analysis
  - real time monitoring of urban traffic congestion
  - analysis of urban traffic characteristics
  - analysis of local public transport bus services
- Methodology:
  - «bus-as-probe», Data source: local bus fleet monitored by GPS signals (100 tracked buses/die; 120.000 GPS traces/die)
- Advantages:
  - low cost of setup and implementation, automatic data storage, scalability to other probe vehicles.



Punctuality Index



- Carli, R.; Dotoli, M.; Epicoco, N., “Monitoring traffic congestion in urban areas through probe vehicles: A case study analysis,” Internet Technology Letters, 2017

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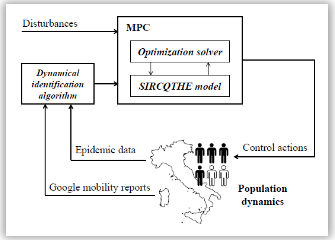
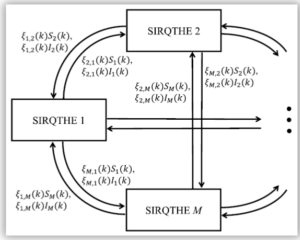
A2.3- Covid-19 Pandemic (1/2)

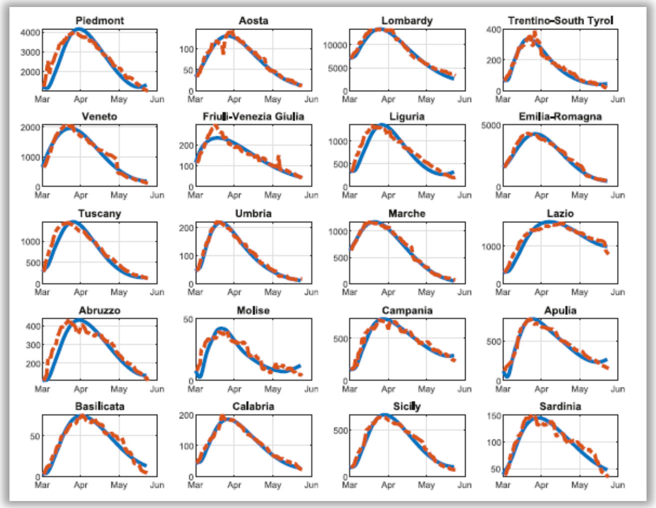
- **Aim and motivation:**
  - select proper non-pharmaceutical interventions to mitigate the COVID-19 spread

$$
\begin{aligned}
&\tilde{S}_i(k+1) = \tilde{S}_i(k) - \beta_i(k)\,\tilde{I}_i(k)\tilde{S}_i(k) + \sum_{j=1}^{M} \xi_{i,j}(k)\tilde{S}_j(k)\\
&\tilde{I}_i(k+1) = \tilde{I}_i(k) + \beta_i(k)\,\tilde{I}_i(k)\tilde{S}_i(k) - (\gamma_i + \theta_i + \lambda_i)\,\tilde{I}_i(k) + \sum_{j=1}^{M} \xi_{i,j}(k)\tilde{I}_j(k)\\
&\tilde{R}_i(k+1) = \tilde{R}_i(k) + \gamma_i \tilde{I}_i(k)\\
&Q_i(k+1) = Q(k)_i + \theta_i\,\tilde{I}_i(k) - (\delta_i + \mu_i)\,Q_i(k)\\
&T_i(k+1) = T_i(k) + \mu_i\,Q_i(k) + \lambda_i\,I_i(k) - (\pi_i(k) + \varepsilon_i(k))\,T_i(k)\\
&H_i(k+1) = H_i(k) + \delta_i\,Q_i(k) + \pi_i(k)\,T_i(k)\\
&E_i(k+1) = E_i(k) + \varepsilon_i(k)\,T_i(k).
\end{aligned}
$$





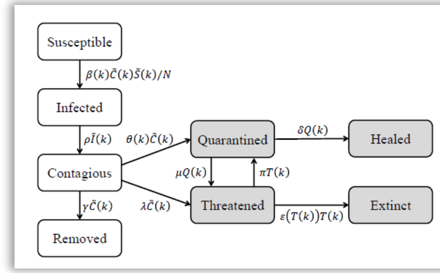
- **Methodologies:**
  - multi-region compartmental model (SIRQTHE) and a nonlinear Model Predictive Control (MPC) approach



- **Advantages:**
  - select the optimal control actions (i.e., intra and extra region mobility limitations) in terms of number of hospitalized people and socio-economic costs
- **Future research directions:**
  - centralized computation of the regional optimal control policies neglecting uncoordinated behaviour of individual regions

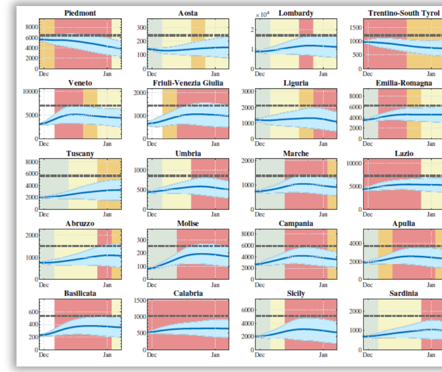
- R. Carli, G. Cavone, N. Epicoco, P. Scarabaggio, and M. Dotoli, “Model Predictive Control to Mitigate the COVID-19 Outbreak in a Multi-region Scenario”, Annual Reviews in Control, vol. 50, pp. 373–393, 2020

A2.3- Covid-19 Pandemic (2/2)

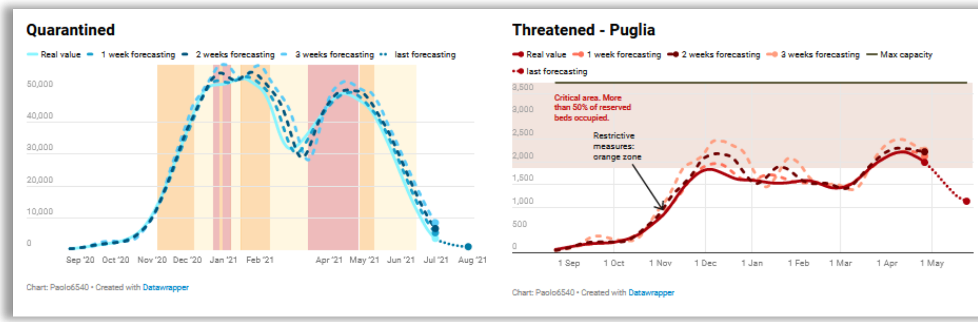


- **Aim and motivation:**
  - select interventions to mitigate the COVID-19 spread considering uncertainty (unknown infection rate and asymptomatic people)
- **Methodologies:**
  - Improved multi-region compartmental model and stochastic MPC approach leveraging the Google mobility reports to better describe the time dependency of the infection rate

$$
\begin{aligned}
&\min_{\mathbf{u}} \; J(\bar{\mathbf{u}}, \mathbf{u}) \\
&\text{s.t.} \quad \text{SIRCQTHE model (1a)-(1h)} \quad \forall k \in \mathcal{K}(h) \\
&\qquad \text{constraints (4)-(5)} \quad \forall k \in \mathcal{K}(h) \\
&\qquad \mathbf{T} - T^{\max}\,\mathbf{1}_K \leq \mathbf{0}_K
\end{aligned}
$$



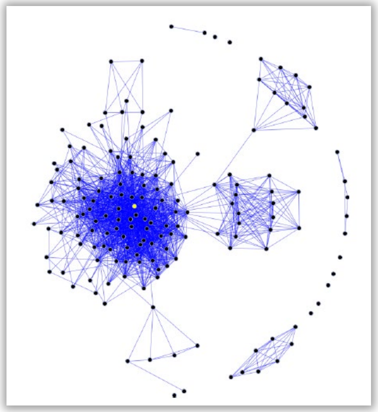
- **Advantages:**
  - control actions affect mobility levels associated with different socioeconomic categories and implying a different economic impact to different restrictive measures
- **Future research directions:**
  - Absence of vaccination effects



- P. Scarabaggio, R. Carli, G. Cavone, N. Epicoco, and M. Dotoli, “Nonpharmaceutical Stochastic Optimal Control Strategies to Mitigate the COVID-19 Spread”, IEEE Transaction on Automation Science and Engineering, vol. 19, no. 2, pp. 560–575, 2022,

A2- Management and Control of Complex Systems

A2.4- Influence maximization problem in large scale networks



- Aim and motivation:
  - Many heuristic approaches have aimed at decreasing the running time of the influence maximization problem

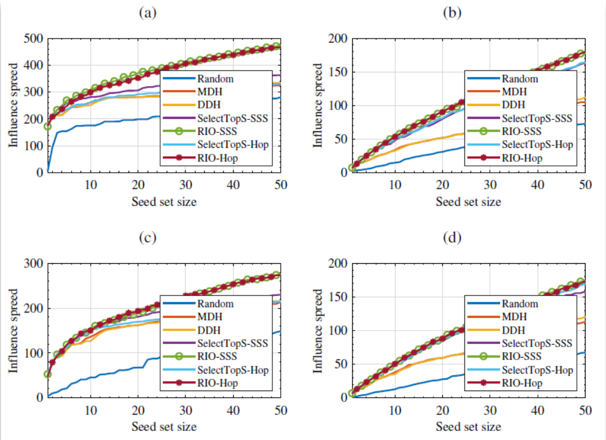
The problem is to find S initial nodes that maximize the influence spread through the network, i.e.:

$$\phi_0 = \underset{\phi \subseteq \mathcal{V}}{\operatorname{argmax}} \{\sigma(\phi) \,|\, |\phi| = S\}$$

where S is the chosen cardinality for the seed set.

- Methodologies:
  - novel low-complexity and highly accurate algorithms for large-scale networks based on the reduction of influence overlapping and leveraging on the joint probability of activations

$$\pi_j^+(\phi_0) = \begin{cases} 1 & \text{if } j \in \phi_0 \\ 1 - \prod\limits_{i \in N_j^{in}} (1 - \pi_i(\phi_0)\, p_{i,j}) & \text{if } j \notin \phi_0 \end{cases}$$



- Advantages:
  - near-optimal solutions outperforming state-of-the-art approaches in terms of running time and influence spread
- Future research directions:
  - scalability of the approach algorithm

- P. Scarabaggio, R. Carli, and M. Dotoli, “On Fast and Effective Influence Spread Maximization in Social Networks”, IEEE Transactions on Systems, Man, and Cybernetics: Systems (under review)

A3 Modelling, Control, and Optimization for Industry 4.0 Applications

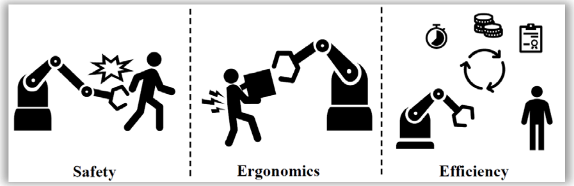
A3.1 Collaborative Robotics

A3.2 Smart Manufacturing Process Control

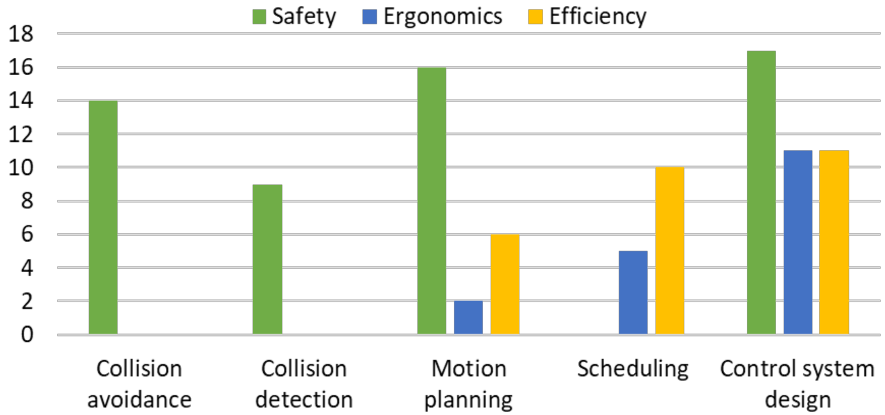
A3.3 Digital Twin

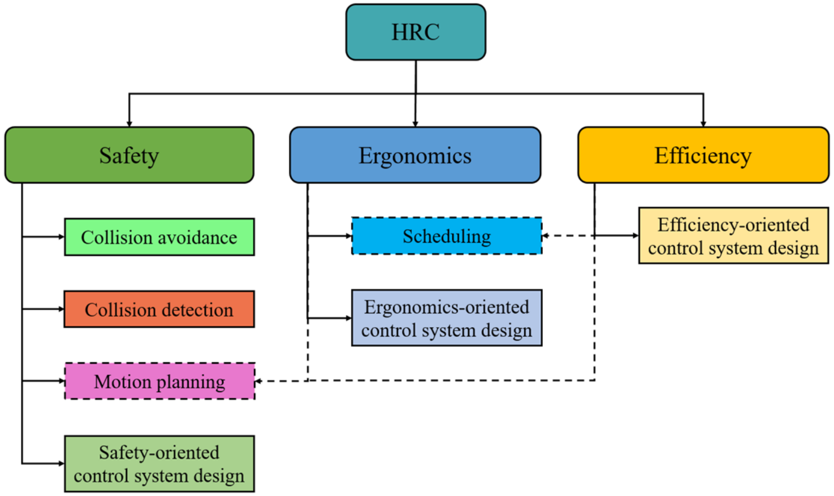
A3.4 Virtual Reality

A3.1- Collaborative Robotics (1/3)



- Human-Robot Collaboration
  - Review of the control techniques used in collaborative robotics
    - Identification and categorization of the existing control techniques used in Human-Robot Collaboration (HRC) according to three pivotal targets that are safety, ergonomics, and efficiency with the aim of improving the current methodologies, seeking alternative solutions, and developing advanced control algorithms for cobots

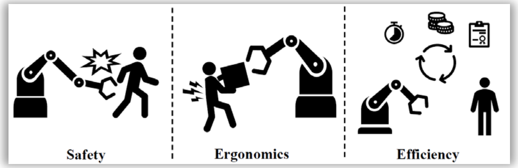




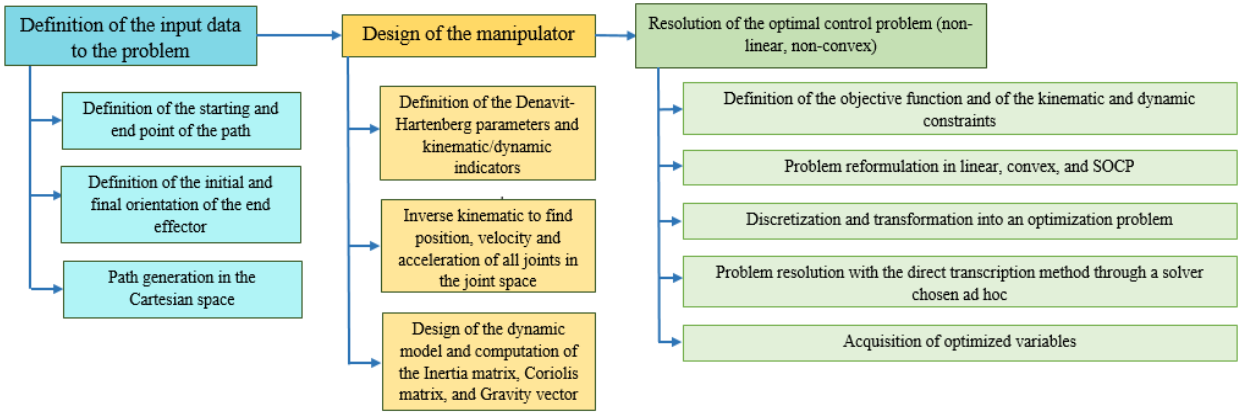
- Proia, S.; Carli, R.; Cavone, G.; Dotoli, M., “Control Techniques for Safe, Ergonomic, and Efficient Human-Robot Collaboration in the Digital Industry: a Survey,” in IEEE Transactions on Automation Science and Engineering (TASE), 2022. in press.
- Proia, S.; Carli, R.; Cavone, G.; Dotoli, M., "A Literature Review on Control Techniques for Collaborative Robotics in Industrial Applications." 2021 IEEE 17th International Conference on Automation Science and Engineering (CASE). IEEE, 2021.

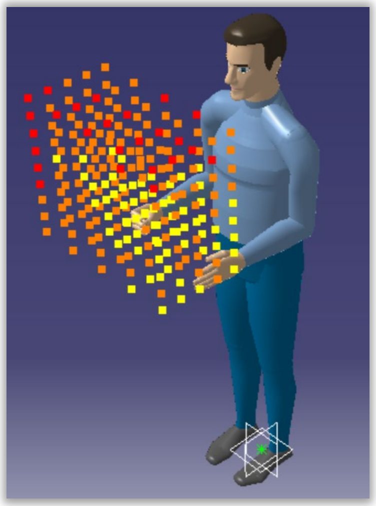
A3- Modelling, Control, and Optimization for Industry 4.0 Applications

A3.1- Collaborative Robotics (2/3)



- Human-Robot Collaboration
  - Safe, ergonomic, and efficient trajectory planning
    - None of the reviewed articles is simultaneously focused on all the three targets (i.e., safety, ergonomics, and efficiency)
    - Multi-objective optimization problem for the trajectory planning in safe and ergonomic HRC manufacturing scenario:
      - Minimization of RULA (ergonomics)
      - Optimization of time (efficiency)
      - ISO requirements compliance (safety)
      - Application: pick and place, accurate assembly, material removal, etc.

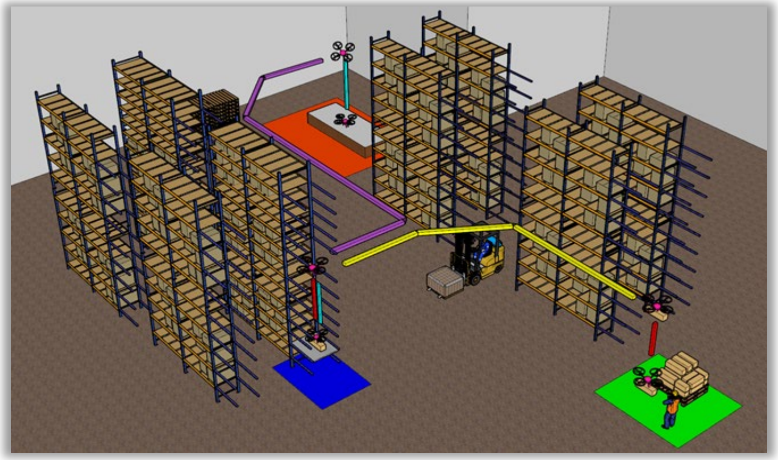


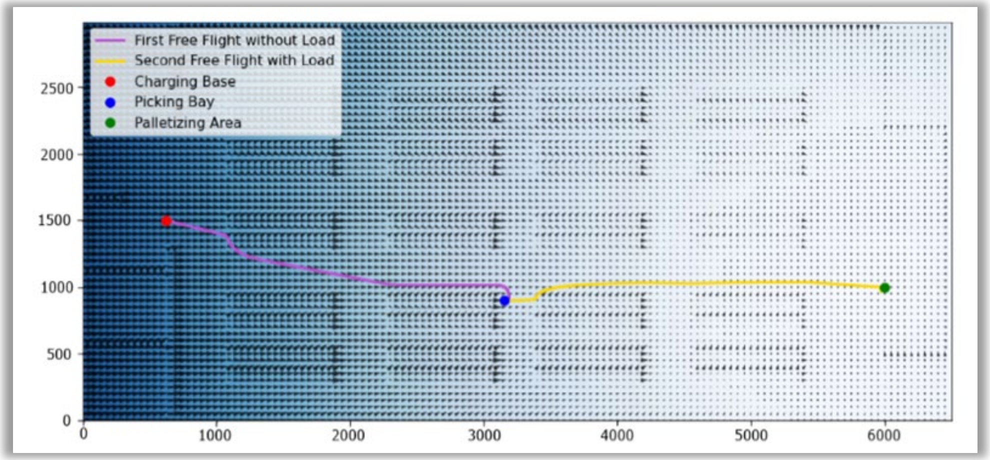


- Proia, S.; Carli, R.; Cavone, G.; Dotoli, M., "A Trajectory Planning Optimization Approach for a Safe and Ergonomic Human-Robot Collaboration." 2022 IEEE 18th International Conference on Automation Science and Engineering (CASE). IEEE, 2022 (submitted).

A3.1- Collaborative Robotics (3/3)

- Human-Drone Interaction
  - Safe and ergonomic Human-Drone Interaction in warehouses
    - HDI architecture with quadrotor and human worker
      - Artificial Potential Field (trajectory planning)
      - Iterative Linear Quadratic Regulator (trajectory tracking)
      - Speed and Separation Monitoring (safety)
      - RULA analysis (ergonomics)
      - Application: pick and place task.

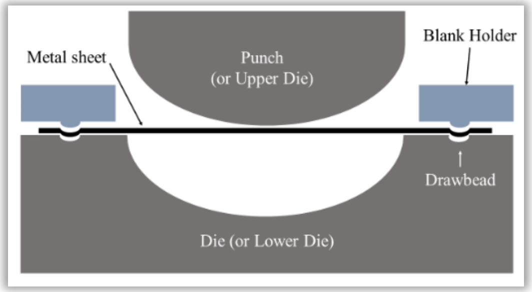


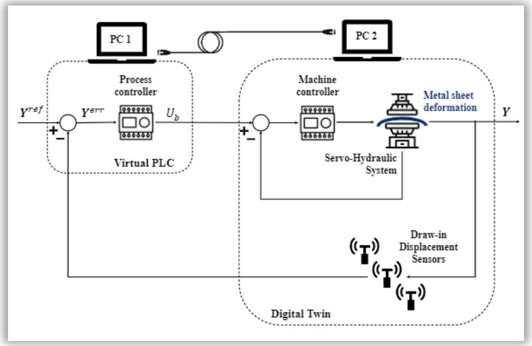


- Proia, S.; Cavone, G.; Camposeo, A.; Ceglie, F.; Carli, R.; Dotoli, M., "A Safe and Ergonomic Human-Drone Interaction in a Warehouse Environment." 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2022 (submitted).

A3.2- Smart Manufacturing Process Control

- Control of deep drawing
  - Motivation:
    - Traditionally, metal forming relies on machine control or PID based process regulator
  - Aim:
    - defining a process control architecture that considers a multi-variable system model
  - Methodologies:
    - Model predictive control
    - Process identification
  - Advantages:
    - Improving the quality of the stamped parts and implementing the zero-defect manufacturing paradigm





FIAT CHRYSLER AUTOMOBILES

- Bozza, A., Cavone, G., Carli, R., Mazzoccoli, L. & Dotoli, M. (2021) An MPC-based Approach for the Feedback Control of the Cold Sheet Metal Forming Process IN IEEE International Conference on Automation Science and Engineering., 286-291. doi:10.1109/CASE49439.2021.9551602
- Cavone, G.; Bozza, A.; Carli, R.; Dotoli, M., “MPC-based Process Control of Deep Drawing: an Industry 4.0 Case Study in Automotive”, in IEEE Transactions on Automation Science and Engineering (TASE), 2022.

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A3.3- Digital Twin

- «MASMART» Project
  - Motivation:
    - A Digital Twin (DT) refers to the building of a digital replica of a physical system. It is mostly used to simulate and understand how should work a product that a company would like to make
  - Aim:
    - Define an unsupervised predictive maintenance system of a robot station used for the quality control in the automotive sector.
  - Methodologies:
    - Build a Digital Twin of the physical system
  - Advantages:
    - The system is characterized by a completely autonomous robot station used for the quality control of delicate pieces produced in the automotive sector. The Digital Twin of the whole system will allow us to make predictions on its health and work conditions, avoiding undesirable faults.

MASMEC

A3.4- Virtual Reality

- Using Virtual Reality for the Optimal Design of Manufacturing Systems – the Case of an Electric Axles Production Line
  - Motivation:
    - In the Industry field, VR is emerging as a powerful tool to decrease design and production costs, while reducing the time needed between product conception and production.
  - Aim:
    - Provide a supporting procedure that explains step by step the transition from CAD to VR to improve the 3D model evaluation during the VR sessions
  - Methodologies:
    - Analysis of VR use in the company process
    - Study of the VR integration in the design phase.
    - Application of the VR approach to the company use case
  - Advantages:
    - Check and evaluation of the design issues

MASMEC

A4 Modelling, Control, and Optimization for Transport and Logistics

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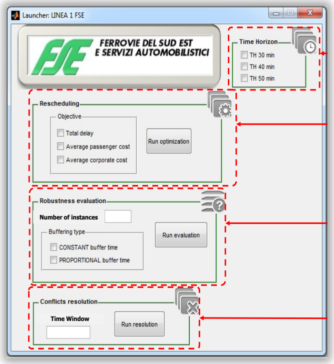
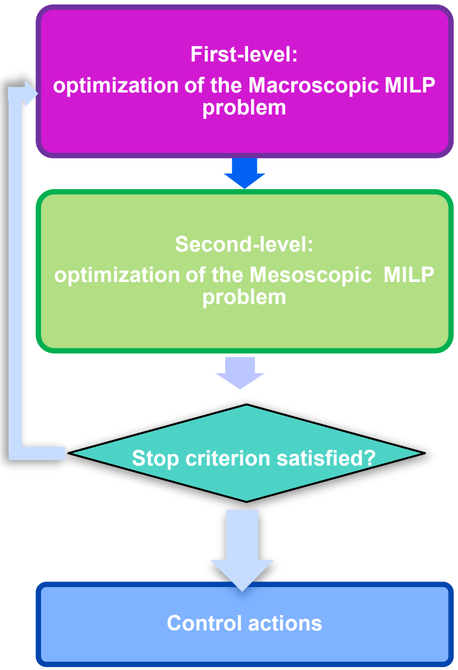
A4.1- Passengers transport (1/3)

- Railway passengers transportation
  - Aim:
    - offline scheduling of the timetable + real-time management of disturbances.
    - real-time rescheduling of railway traffic in case of disruption in large-scale networks.
  - Methodologies:
    - DEA and MILP, re-scheduling (Constraints: railway constraints + robustness).
    - MILP macroscopic mesoscopic model, bi-level rescheduling algorithm, distributed optimization, Model Predictive Control…
  - Advantages:
    - min delays + user-friendly GUI.
    - min (delays, cancellations, shuntings)+ management of stations activities





FERROVIE DEL SUD EST
E SERVIZI AUTOMOBILISTICI S.R.L.

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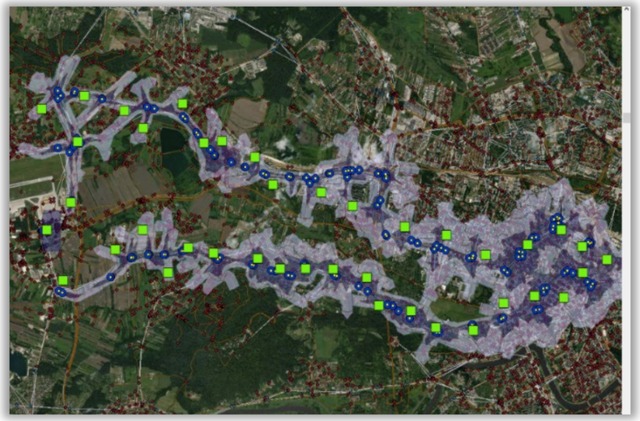
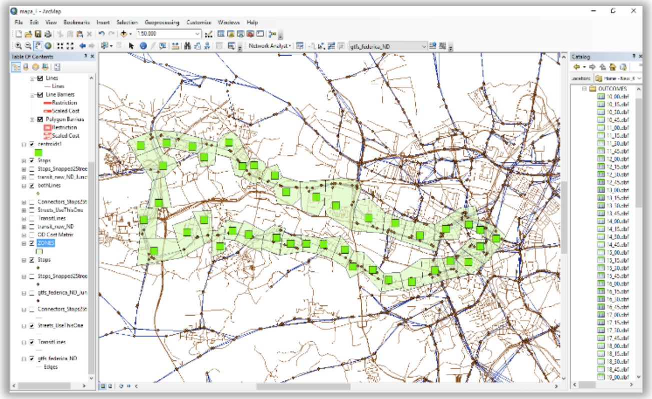
D&C Lab

A4.1- Passengers transport (2/3)

- Public Bus passengers transportation
  - Aim:
    - Dynamic accessibility assessment.
  - Methodologies:
    - real GTFS data evaluation and use of ArchGIS program.
  - Advantages:
    - support to transport management for the improvement of the transport accessibility.



[Cracow bus service extract]



[ArchGIS for the centroids identification]

Cracow University of Technology

Politecnico di Bari

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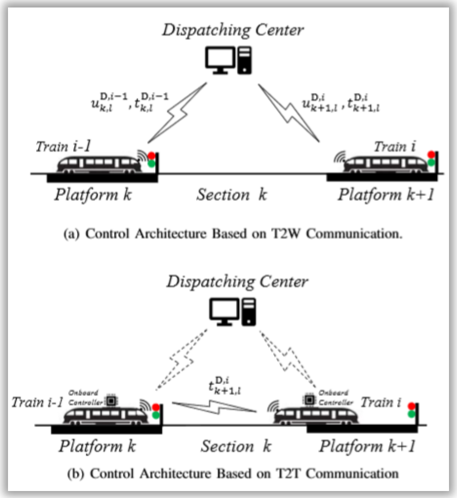
A4.1- Passengers transport (3/3)

Metro passenger transportation

- Aim:
  - service-oriented metro traffic rescheduling
  - metro traffic rescheduling in case of disruptions with backup trains allocation
  - distributed communication based control of metro networks.
- Methodologies:
  - event driven regulation strategy based on trains and passengers' flow models.
  - state space model of the train traffic and Model Predictive Control
  - Distributed Model Predictive Control.
- Advantages:
  - service-oriented regulation that minimizes the passengers’ waiting time by optimally rescheduling the trains’ headway time in case of delays and large increased passenger flow in a metro line.
  - metro traffic rescheduling in case of disruptions with an integrated MPC approach that automatically regulates the traffic and allocates backup trains based on the current state of the system
  - real-time control of metro traffic is distributed among trains that can communicate with each other, thus alleviating the computation burden of the central traffic controller.



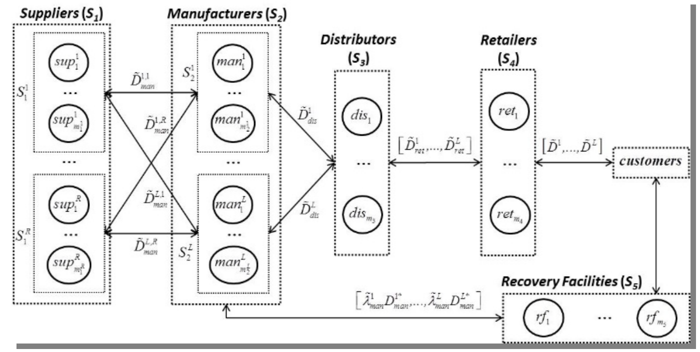
(a) Control Architecture Based on T2W Communication.

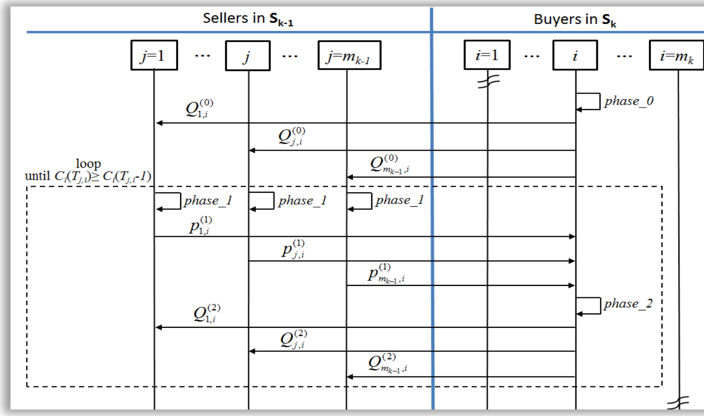
(b) Control Architecture Based on T2T Communication

SOUTHWEST JIAOTONG UNIVERSITY

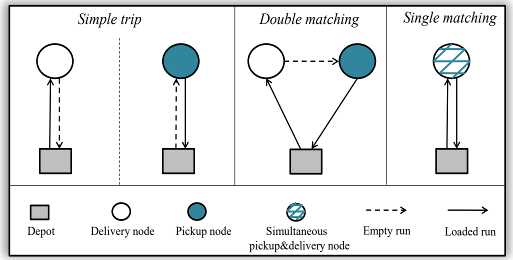
A4.2- External logistics (1/7)

- Freight transport
  - Aim:
    - strategic design of an agile Supply Chain Network (SCN) multi-buyer multi-seller under multi-objective and uncertain parameters, performance evaluation, resource management
  - Methodologies:
    - cross-efficiency fuzzy/stochastic DEA + fuzzy bargaining game.
  - Advantages:
    - flexible and efficient SCN + cooperation and competitiveness among stakeholders + time and cost reduction + what-if analysis





A4.2- External logistics (2/7)



- Road Paths
  - Aim:
    - matching of delivery and pick-up requests (first/last miles).
  - Methodologies:
    - CVRP(TW) (Constraints: max 2 clients per visit; discharge before loading).
  - Advantages:
    - combination of load/unload activities, savings (times, costs, resources).

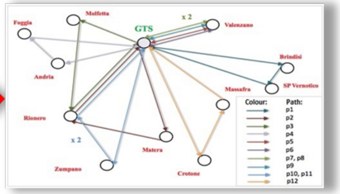
Path	Match	Delivery	Pick Up	Km	t_k [min]
Routes for customers' ITUs (run time 21.04 sec)					
p_1	double	Putignano	Brindisi	224	344
p_2	double	Gravina	Massafra	179	299
p_3	double	Melfi	M. Savoia	208	328
p_4	double	Foggia	M. Savoia	229	349
p_5	double	Valenzano	Monopoli	92	212
p_6	simple trip	Modugno	/	12	72
p_7	simple trip	Valenzano	/	18	78
p_8	double	Buccino	Statte	359	479
Routes for owned 45' ITUs (run time 41.74 sec)					
p_9	double	Trani	Buccino	284	404
p_{10}	double	Fasano	Cavallino	297	417
p_{11}	no match	/	Statte	142	202
p_{12}	single	Andria	Andria	92	212
Routes for owned 20' ITUs (run time 22.06 sec)					
p_{13}	double	Fasano	Cavallino	297	417
p_{14}	no match	/	Putignano	82	142
p_{15}	single	Andria	Andria	92	212
p_{16}	double	Policoro	Buccino	356	476

Scheduling for with customers' ITUs (run time 0.053 sec)

vehicles	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	T_v [min]	T_{over} [min]
v_1		x				x	x		449	0
v_2				x					349	0
v_3	x								344	0
v_4			x						328	0
v_5					x				212	0
v_6								x	479	0

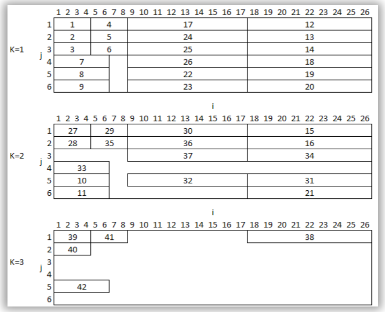
Scheduling for owned ITUs (run time 0.0517 s)

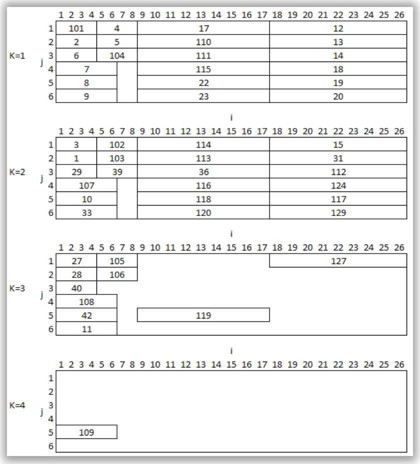
vehicles	p_9	p_{10}	p_{11}	p_{12}	p_{13}	p_{14}	p_{15}	p_{16}	T_v [min]	T_{over} [min]
v'_1			x	x					414	0
v'_2						x	x		354	0
v'_3					x				417	0
v'_4		x							417	0
v'_5	x								404	0
v'_6								x	476	0

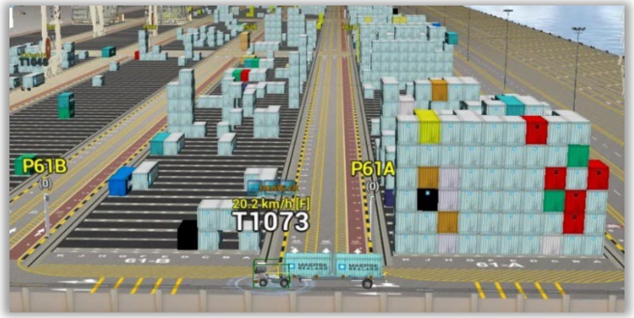


A4.2- External logistics (3/7)

- Yard Positioning
  - Aim:
    - maximize the yard fulfilment
  - Methodologies:
    - Knapsack problem (Constraints: capacity, stackability, economic and commercial value, stringency, customers importance).
  - Advantages:
    - profit increase, reduction of removals, cost, and time, informatization, better use of resources, departures/arrivals management.







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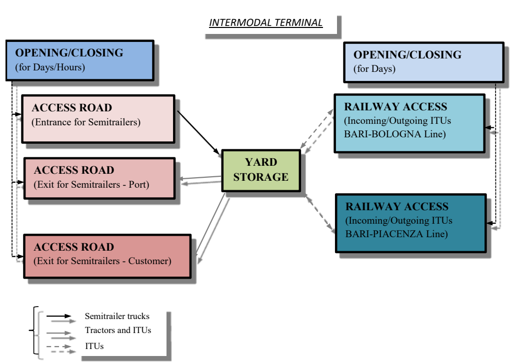
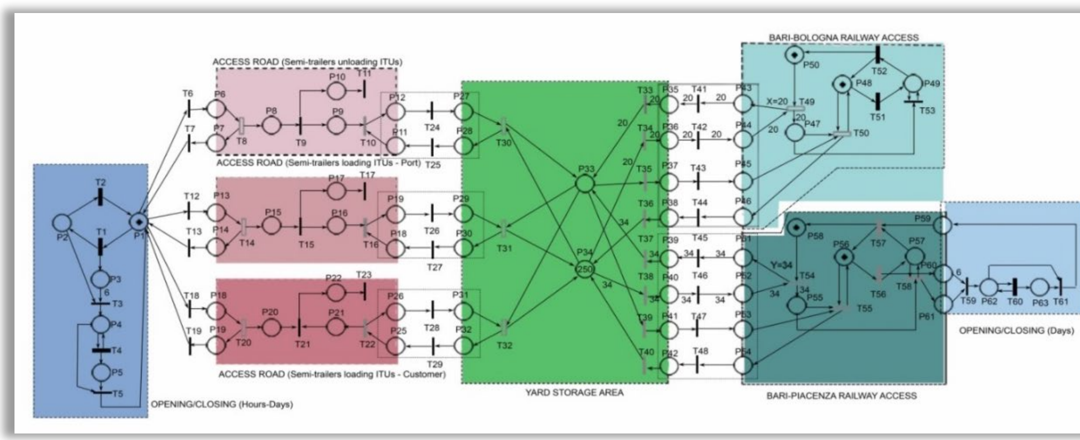
A4.2- External logistics (4/7)

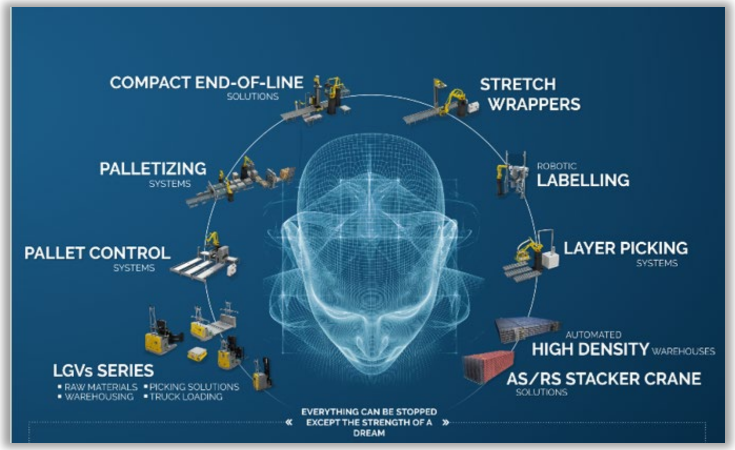
- Multimodal terminals
  - Aim:
    - strategic management of combined freight transport terminals, performance evaluation, and resource management. Also useful for process re-engineering
  - Methodologies:
    - discrete event simulation (Petri Nets: Timed Stochastic + First-Order Hybrid).
  - Advantages:
    - standardized and modular modeling + dynamic analysis + simulation and what-if analysis + application of control policies.

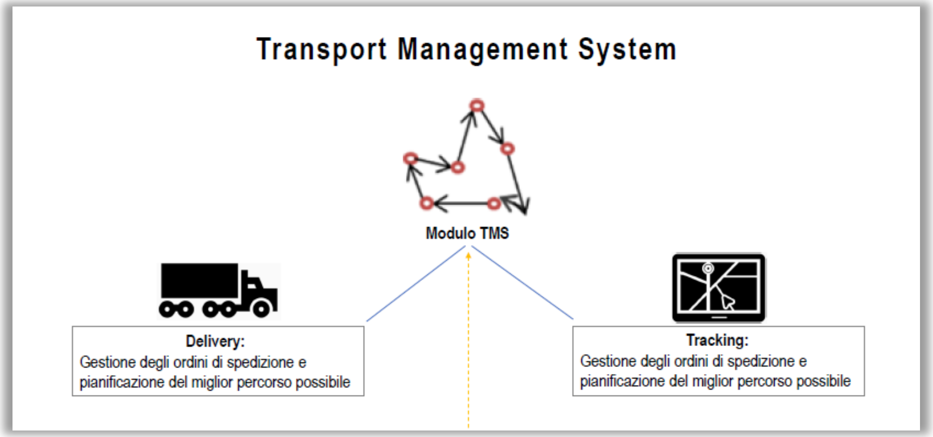




A4.2- External logistics (5/7)

- Transport Management System
  - Aim:
    - Reduce planning time and transportation costs
    - Increase the saturation of the space of the means of transport
    - Monitor the fleet and deliveries in real time
    - Fulfill any compatibility constraints between goods





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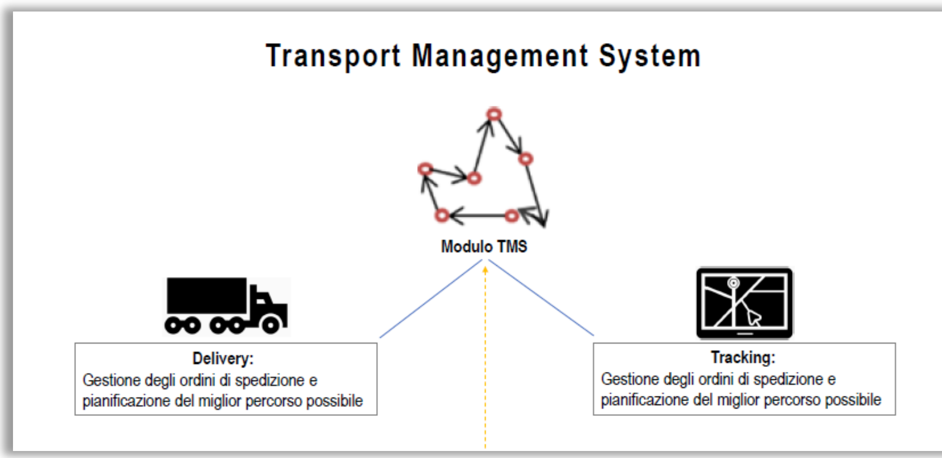
D&C Lab

A4.2- External logistics (6/7)

- Container loading problem
  - Aim:
    - determine the optimal configuration (optimization of volume and space) of bins, choosing the optimal arrangement of pallets inside the transport unit taking into account some hard rule such as the unloading order, the stability and the balancing

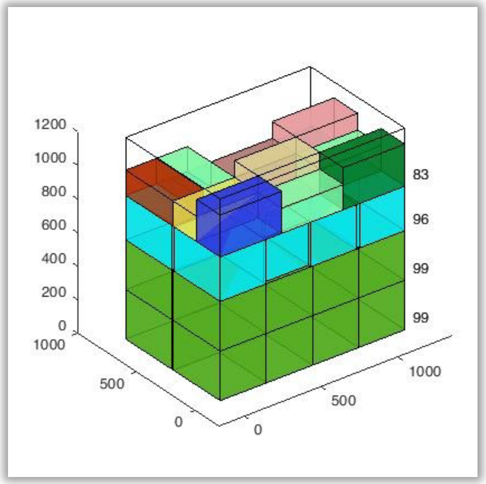
A4.2- External logistics (7/7)

- Vehicle Routing Proble,
  - Aim:
    - Determin the best routing plan, given a set of orders and clients during a workday.
    - Choice of the best transport unit among a given fleet
    - Choice of the fastest and/or the most economic route
  - An important variant of this problem is the dynamic vehicle routing which takes into account variations in the travel times during the shipments caused by various factors, such as accidents, traffic conditions, and weather conditions.



A4.3- Internal logistics (1/2)

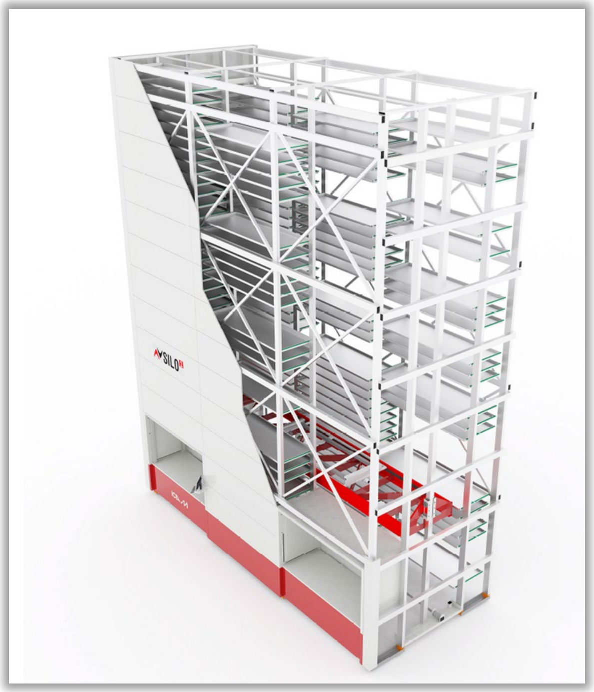
- Automating bin packing through a layer building matheuristics
  - Motivation:
    - bin packing problem is generally addressed considering geometrical constraints only and disregarding practical constraints
  - Aim:
    - defining feasible pallets configurations while taking into account the practical requirements of items’ grouping by logistic features, load bearing, stability, height homogeneity, overhang and weight limits, and robotized layer picking.
  - Methodologies:
    - Mixed Integer Linear Programming
    - Layer building heustistics
  - Advantages:
    - efficiency and effectiveness of the proposed algorithm in terms of computation time, optimization of the bins’ configuration, and stability of the bins



- Tresca, G.; Cavone, G.; Carli, R.; Cerviotti, A.; Dotoli, M., “Automating Bin Packing: a Layer Building Optimization Module for Cost Effective Logistics”, in IEEE Transactions on Automation Science and Engineering (TASE), 2021. 2nd review round.

A4.3- Internal logistics (2/2)

- Warehouse management
  - Aim:
    - determine the optimal configuration (optimization of volume and space) of the warehouse in terms of
      - tray's volume optimization
      - number of trays
      - height of trays
      - association item-trays



ICAM INTELLIGENT SPACE SOLUTIONS

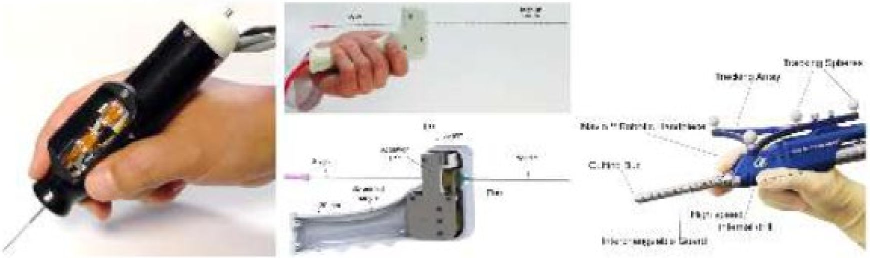
A5 Modelling, Control, and Optimization for Biomedical Application

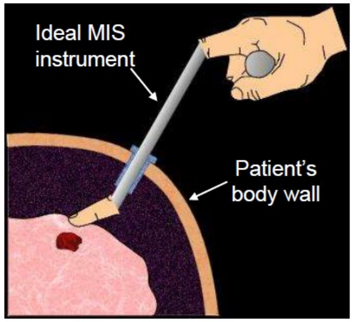
A5.1 Medical Robotics

A5- Medical Robotics

A5.1- Medical Robotics (1/3)

- Surgical robotics
  - Aim:
    - Benefits for patient
      - reduced trauma
      - post-operative pain
      - recovery time
    - Challenges for surgeons
      - limited access
      - limited sense of touch
      - recovery time

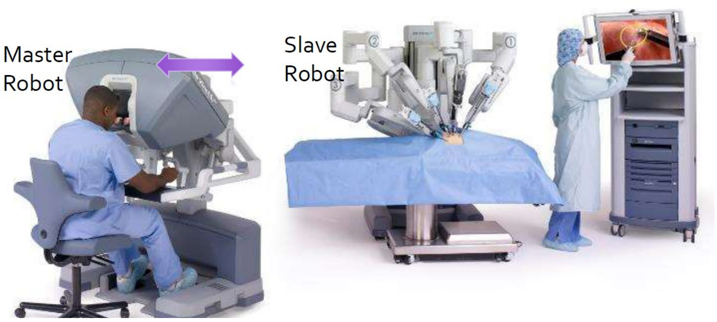




Minimally Invasive Surgery (MIS)

A5- Medical Robotics

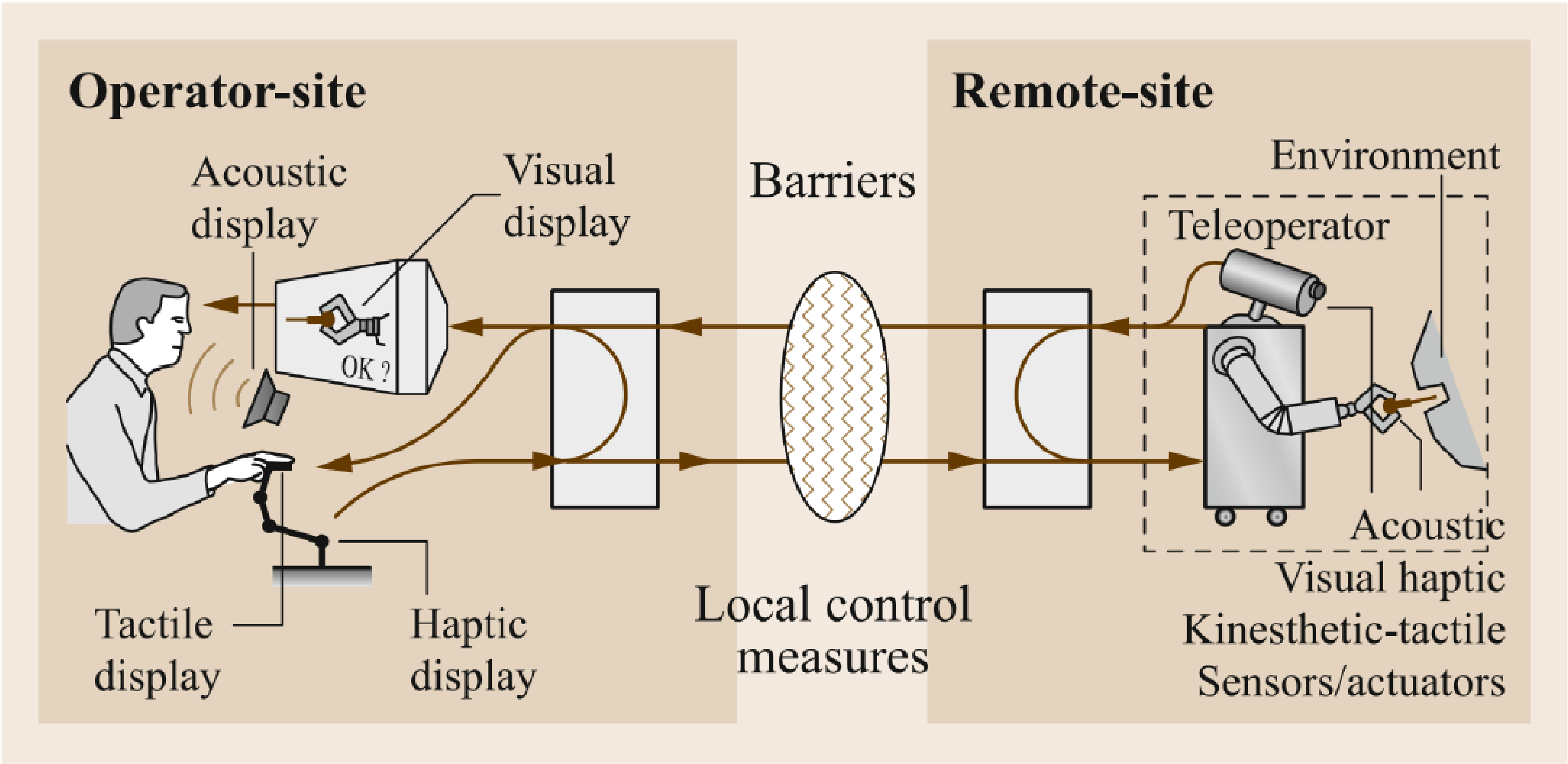
A5.1- Medical Robotics (2/3)



- Tele-operation
  - System:
    - divided into three main components:
      - master or surgeon's console
      - slave or patient-side robot with three or four manipulator arms
      - communication interface or network
    - Benefits:
      - 3D vision to provide depth perception for the surgeon
      - motion scaling to enhance accuracy
      - motion filtering to remove physiological hand tremor of the surgeon
      - augmented vision to enable detection of pathological tissues
      - delivering multiple dexterous tools through a single incision
      - Enhanced dexterity and hand-eye coordination during laparoscopic surgeries

A5.1- Medical Robotics (3/3)

- Tele-operation
  - System:



Thanks for your attention!

Research Activities

Decision & Control Laboratory

Politecnico di Bari

Website: http://dclab.poliba.it
LinkedIn: https://www.linkedin.com/company/dandclab
YouTube: https://www.youtube.com/channel/UCrroEhmYOtc2QAClCqIsOkw