INSTITUTE
OF COMMUNICATION,
INFORMATION
AND PERCEPTION
TECHNOLOGIES

Scuola Superiore
Sant'Anna

ICT COISP

Information and Communication Technologies for
Complex Industrial Systems and Processes

MULTI-AGENT SYSTEMS TO IMPROVE EFFICIENCY IN STEELWORKS

Vincenzo Iannino
Valentina Colla
Scuola Superiore Sant'Anna

INSTITUTE OF COMMUNICATION, INFORMATION AND PERCEPTION TECHNOLOGIES

Overview

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

1. Introduction

- ✓ Steel Manufacturing Industries: Features, Industry 4.0 and Challenges
- ✓ Agents as Key Enabling Technology for the Realization of Smart Steel Factories

2. Multi-Agent Systems in a Nutshell

- ✓ Distributed Artificial Intelligence
- ✓ Multi-Agent Systems Properties and Applications

3. Agent-Based Applications in Steelworks

- ✓ Case Study: Dynamic Resource Allocation (DynReAct)
- ✓ Case Study: Off-Gases Management (i3Upgrade)

5. Conclusions

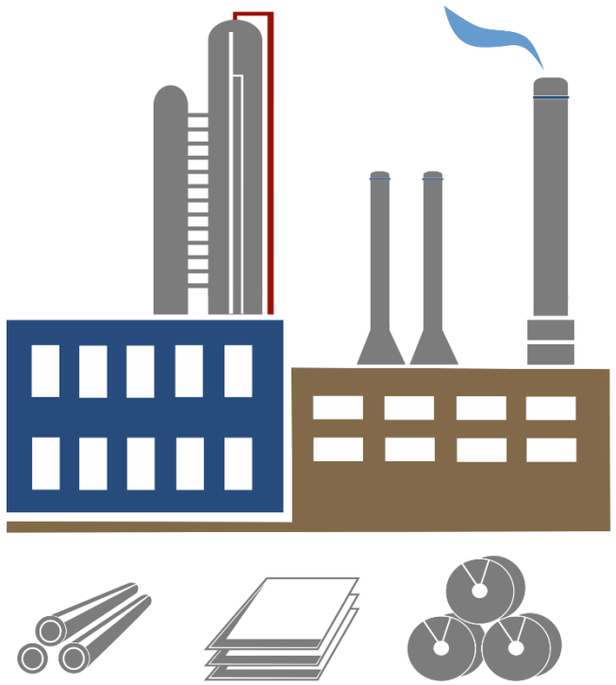
- ✓ Final Remarks About Agent-based Solutions and Their Application in Steel Industries

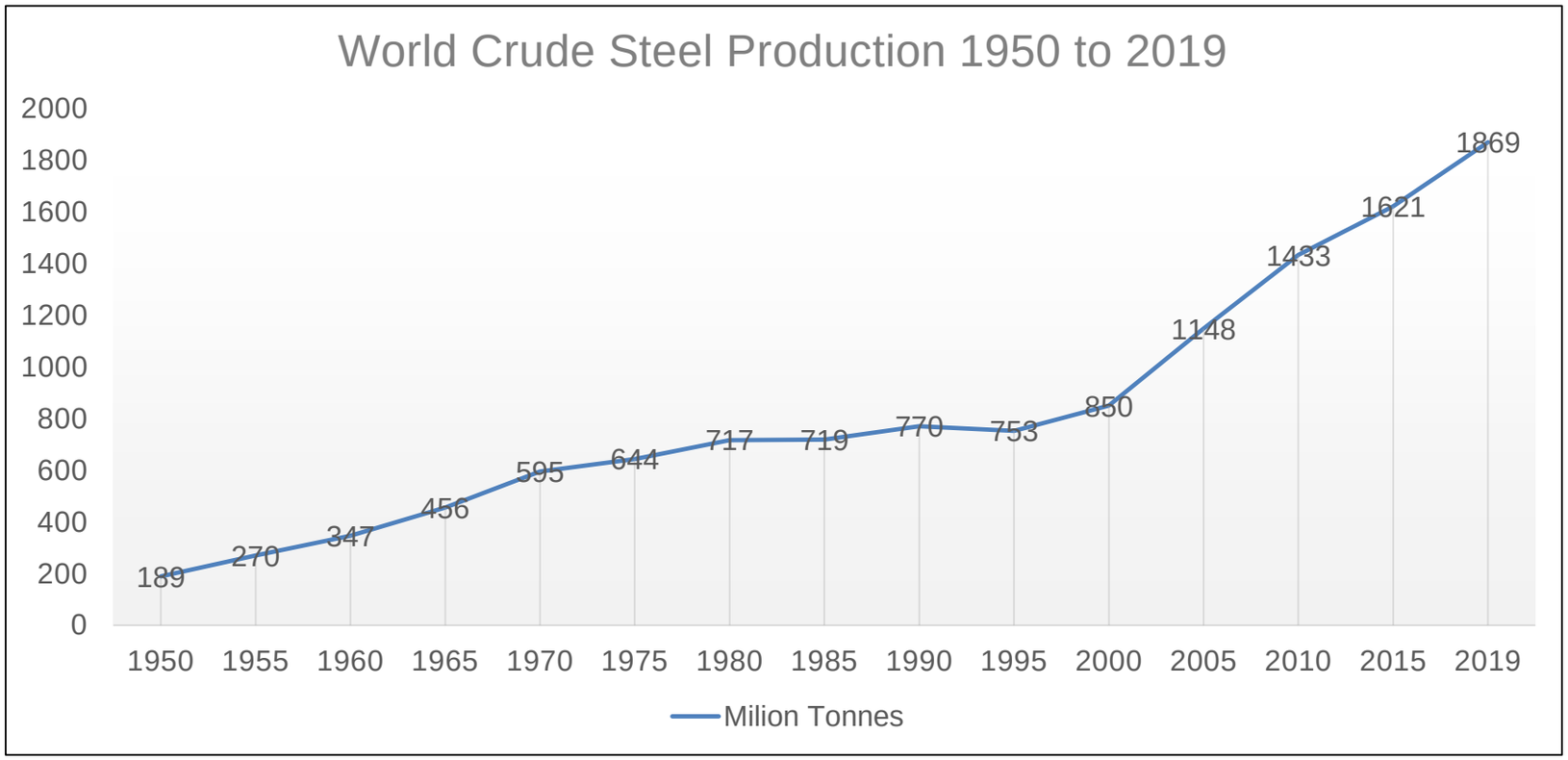
Introduction

Steel Manufacturing Industries

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

- Steel manufacturing industries are large, complex, and dynamic systems whose production processes held a strategic role in the global economy.
- Considering Europe, the steel sector has an annual turnover of EUR 166 billion and is responsible for 1.3% of EU Gross Domestic Product (GDP)*.





Source: World Steel Association – 2020 World Steel in Figures

*European Commission, "Steel: Preserving sustainable jobs and growth in Europe," 2016. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/de/MEMO_16_805.

Introduction

Steel Manufacturing Industries: Features

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

- Steelworks involve manifold and complex production steps, e.g. melting, refining, shaping coating, which are closely correlated and often seamlessly connected.
- Many of these production cycles are at least partly continuous, i.e. the production runs 24/7.
- Each production step needs multiple resources, such as materials, machineries, transport systems (e.g. cranes, forklifts).
- Unexpected events such as faults, equipment breakdowns or orders cancellation are very common, which causes e.g., delays, waste of materials or off-spec products.
- The steel industry is energy intensive, being the second-largest industrial energy consumer and one of the most relevant CO_2 emission sources.
- Not flexible automation structure.
- A variety of legacy systems needs to coexist in brownfield sectors.

Primary Steelmaking process at Pohang Steelworks (POSCO), South Korea*

Casting process at Bruckenhausen Plant (thyssenkrupp AG), Germany*

Hot Rolling process at NLMK La Louvière (NLMK Group), Belgium*

Hot-dip galvanised coils at Bruckenhausen Plant (thyssenkrupp AG), Germany*

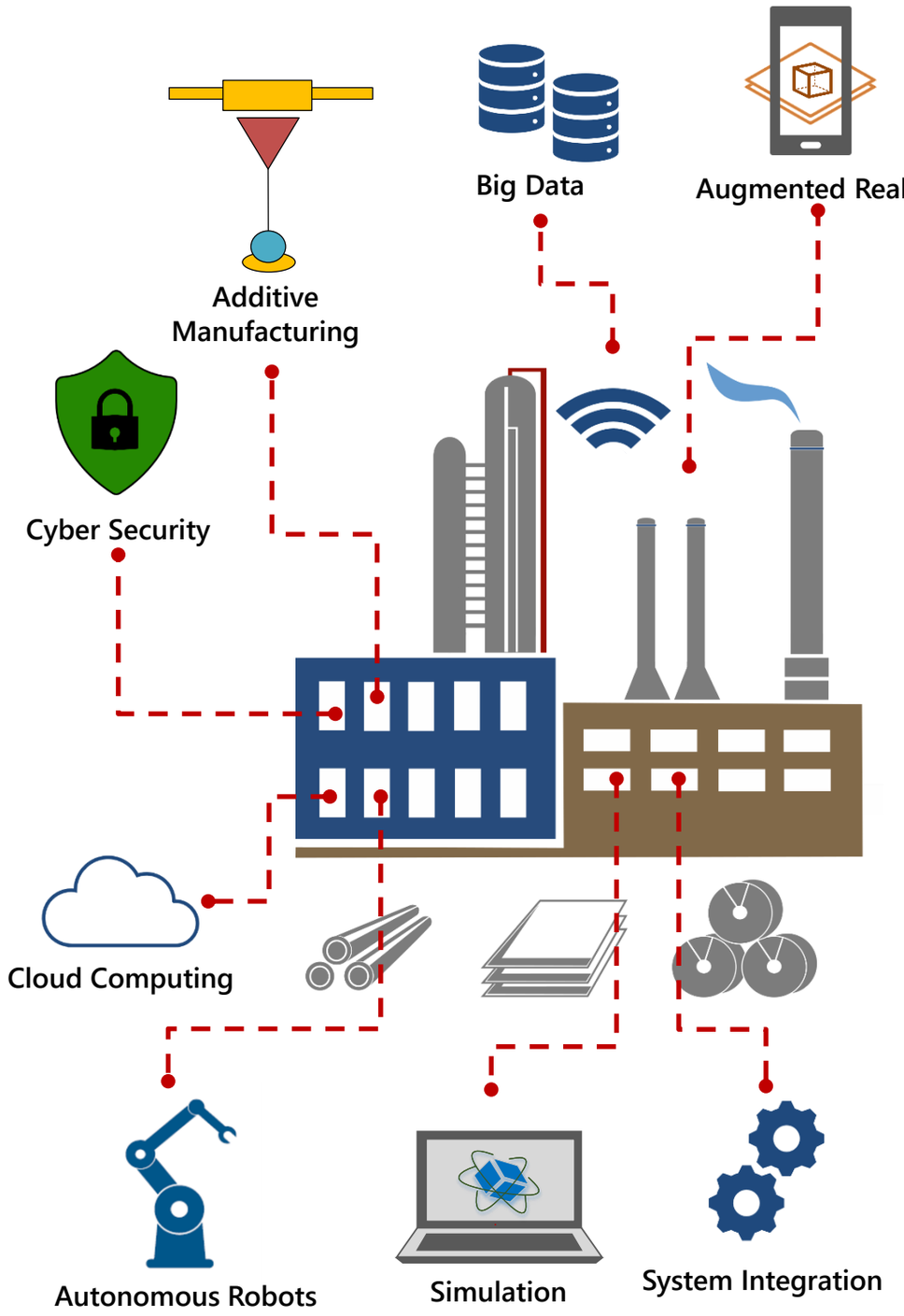
*Source: World Steel Association Website

Introduction

Steel Manufacturing Industries: Industry 4.0

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

- The massive digitalization and the innovation introduced by Industry 4.0 (I4.0) is pushing process manufacturing industries towards a new vision of production systems, the so-called **Smart Factories**:
  - ✓ Agile and flexible production structure
  - ✓ Vertical and horizontal integration of production systems through Information and Communication Technology (ICT) systems
  - ✓ Interoperability
  - ✓ Real-time reaction to changing environment conditions
- In this scenario, the Steel sector is experiencing this new transformation which opens new possibilities for implementing advanced approaches, including Artificial Intelligence (AI)-based concepts.



Introduction

Steel Manufacturing Industries: Challenges

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

- Encourage steel factories to embrace the opportunities of I4.0 technologies by addressing concerns and doubts from industrial side.

- Efficient management of process gases in order to increase the economic and environmental sustainability of the integrated steelworks production by reducing CO_2 emissions.

- Improve the current process logistics and the adopted optimization solutions in order to reduce energy consumptions and loss of efficiency in the production.

- Improve the allocation and efficient exploitation of plant resources in order to maximize the productivity by reducing waste of materials and production costs.

- Handle unexpected events in the production by promptly react to them in order to mitigate their effects.

- Enhance communication among subprocesses.

- Support common IT infrastructures and legacy systems.

Introduction

Agents as Key Enabling Technology for the Realization of Smart Steel Factories

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

How addressing steelworks challenges in I4.0 era? → **Multi-Agent Systems**

- Multi-Agent Systems (MAS) represent a suitable approach to address the new generation of flexible, digitalized, intelligent and distributed manufacturing processes[1-2].
- MAS play a major role as a fundamental technology for industrial production management and optimization[3].
- Agent-based technologies provide efficient and interesting solutions to a wide range of problems in different areas of interest.
- There exist potential advantages in using agent-based technologies in all domains of manufacturing [4], nevertheless, in steel sector MAS are not widely exploited yet.
- Agent-based solutions can be added to any brownfield scenario and their technology can be supported by the common IT infrastructures used in the steel industry.

[1] W. Shen et al., "Applications of agent-based systems in intelligent manufacturing: An updated review," Adv. Eng. Informatics, vol. 20, pp. 415–431, 2006.
[2] P. Leitão et al., "Smart Agents in Industrial Cyber-Physical Systems," Proc. IEEE, vol. 104, no. 5, pp. 1–13, 2016.
[3] V. Gorodetsky et al., "Conceptual Model of Digital Platform for Enterprises of Industry 5.0," in *Intelligent Distributed Computing XIII*, Springer, Cham, 2020, pp. 35-40.
[4] L. Monostori et al., "Agent-based systems for manufacturing," CIRP Ann. - Manuf. Technol., vol. 55, no. 2, pp. 697–720, 2006.

Multi-Agent Systems in a Nutshell

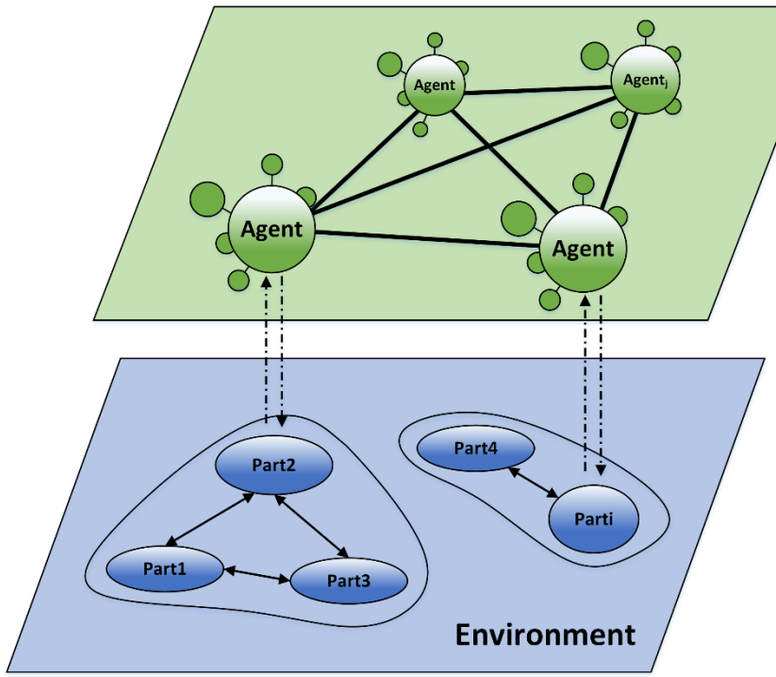
Distributed Artificial Intelligence

Parallel AI

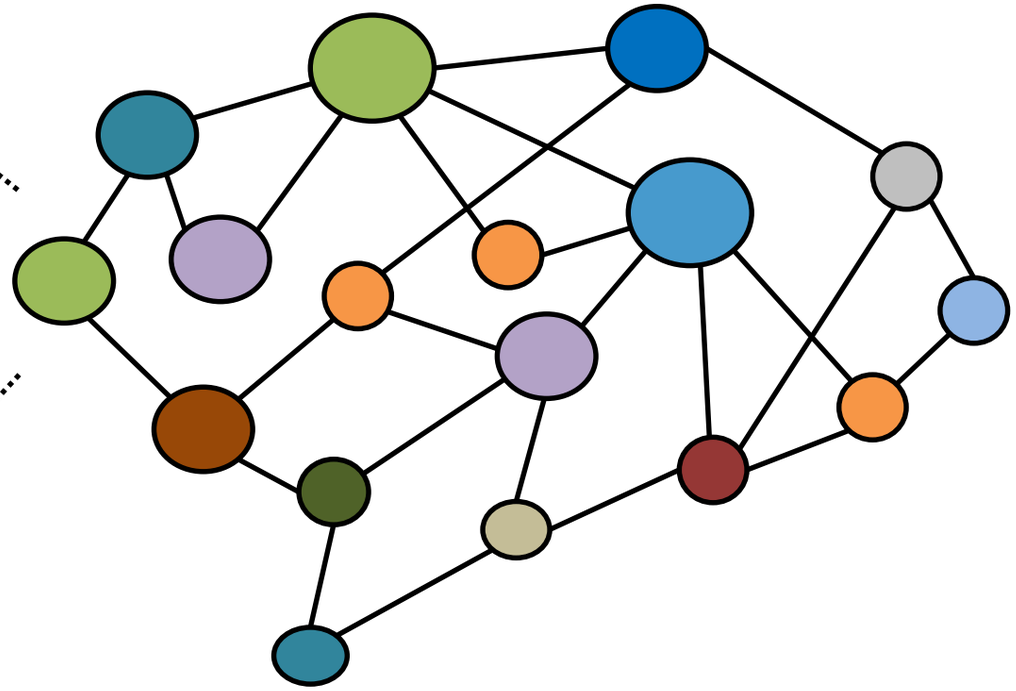
Complex problem situations can be accelerated by their distribution to a larger number of resources (parallel hardware and software processes)

Distributed Problem Solving

Complex problems can be solved by the assignment to modules that cooperate with each other by exchanging their knowledge



Distributed Artificial Intelligence (mid-1980)



Multi-Agent Systems

Distributed autonomous intelligent agents that communicate with each other and interact in order to solve problems that are beyond their individual capabilities or knowledge of each individual

Multi-Agent Systems in a Nutshell

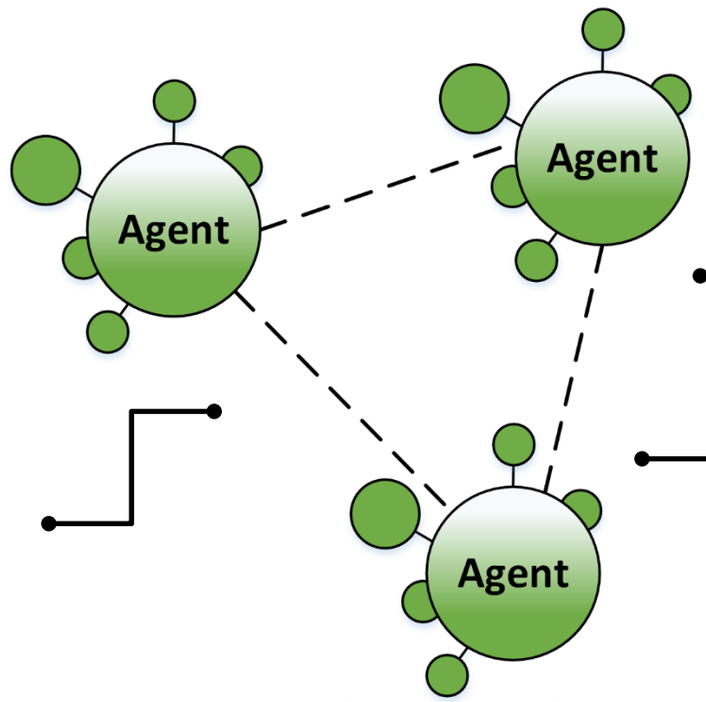
Properties

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

Autonomy

they are at least to some extent capable of deciding to for themselves



Decentralization

they are distributed and connected through a network

Flexibility

they are able to react to unexpected events and adapt to the changing environment conditions

Robustness

they provide a high level of robustness and fault-tolerance

Cooperation, Coordination, Self-organization

they are capable of interacting with each other and self-organized in order to satisfy their design objectives

Intelligence

learning capability is used to adapt and/or anticipate environment changing conditions

Multi-Agent Systems in a Nutshell

Applications

Energy
grid management and distribution (e.g. smart grid)

Manufacturing and Process Industry
production process optimization (e.g. cooperative robots, smart factories)

Networking
high scalability and self-healing networks (e.g. load balancers)

Transportation
distributed traffic management (e.g. autonomous vehicles)

Infrastructure
safety, energy management (e.g. smart buildings)

Multi-Agent Systems in a Nutshell

Applications

Two exemplar applications in steelworks:

- Dynamic Resource Allocation
- Off-gases management and valorization through hydrogen enrichment for methane and methanol synthesis

Agent-Based Applications in Steelworks

Dynamic Resource Allocation

ICT COISP

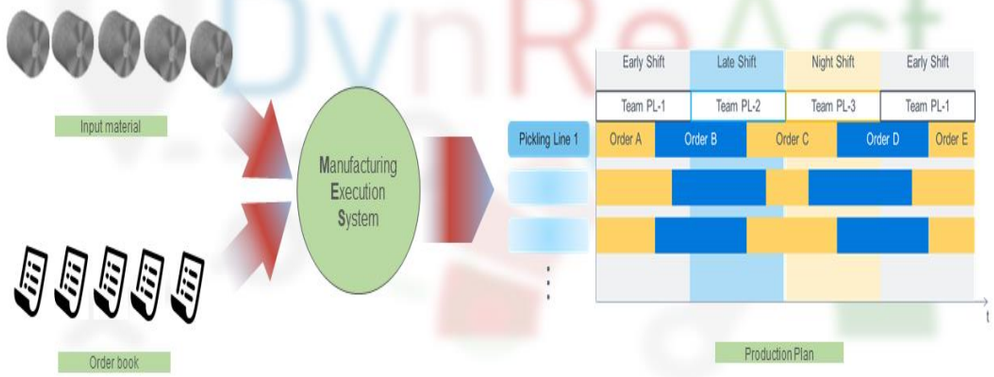
Information and Communication Technologies for Complex Industrial Systems and Processes

European Commission

Research Fund for Coal and Steel (RFCS)

Project name:

Refinement of production scheduling through dynamic product routing, considering real-time plant monitoring and optimal reaction strategies (DynReAct). The project started on June 1st 2019 and will end on December 31st 2022.



Objective:

Improve flexibility of production scheduling in flat steel production through embedded real-time analytics of all available information coming from each plant involved and optimal scheduling.

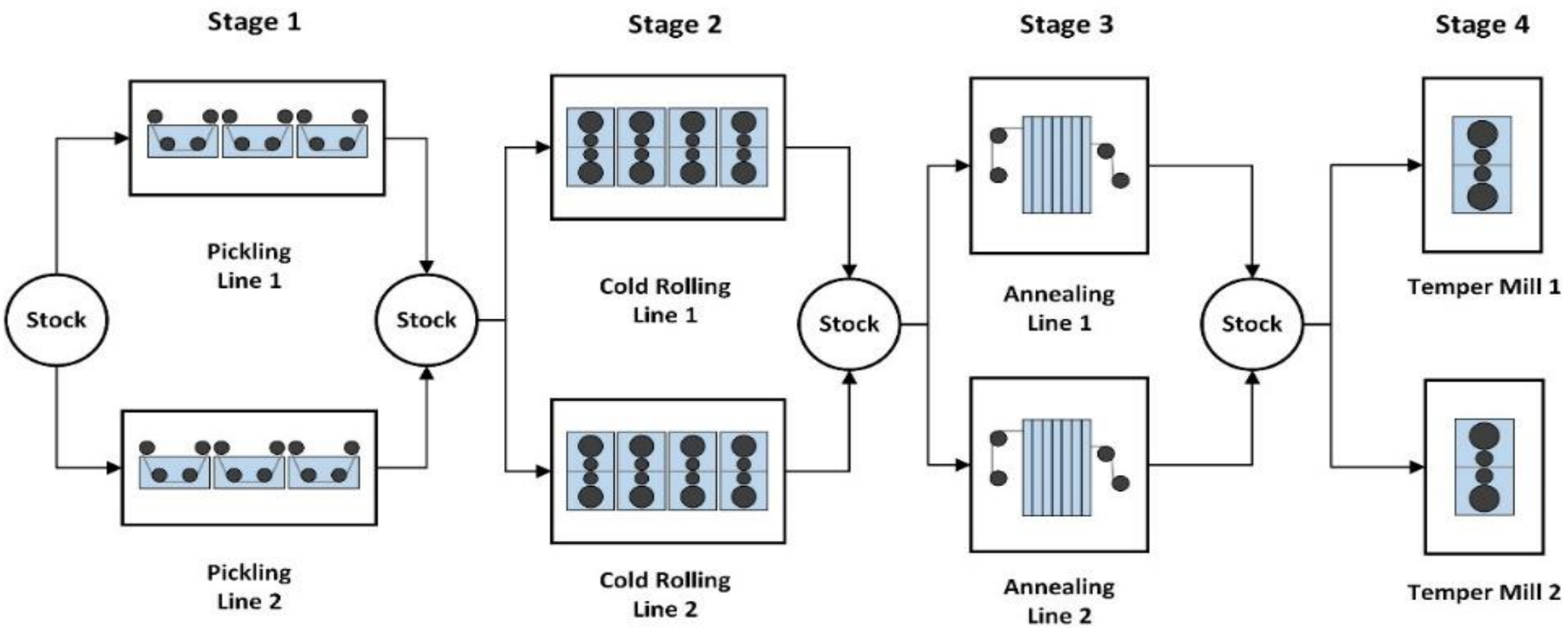
Agent-Based Applications in Steelworks

Dynamic Resource Allocation: Case Study

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

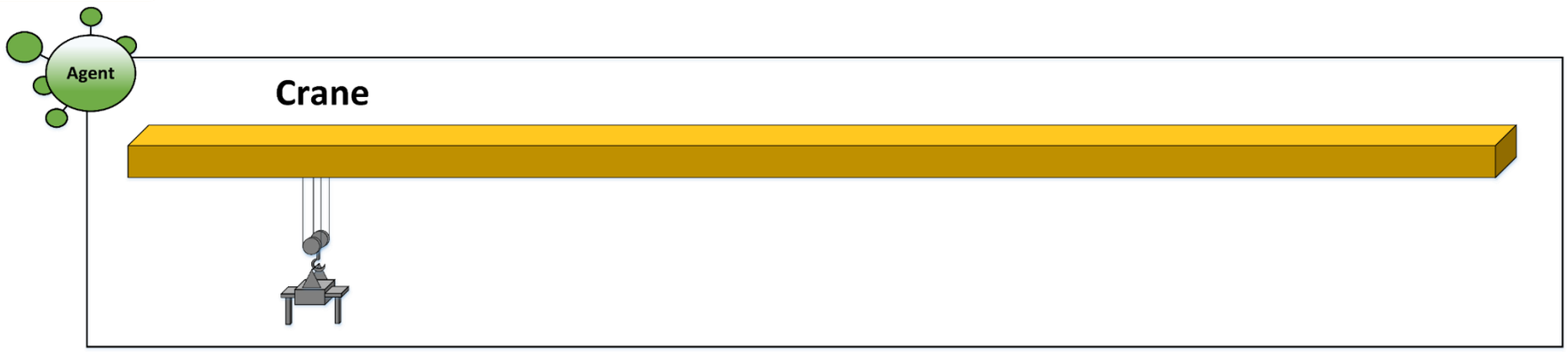
- Four stages and each of them is composed of two parallel machines.
- Strips are transported from one stock to a machine by means of a crane.
- Each production step has one crane.
- Semi-finished products are always stocked between subsequent process steps.
- Breakdowns and special maintenance operations can affect the normal production flow.
- The allocation is done to optimize the overall plant utilization.



Agent-Based Applications in Steelworks

Dynamic Resource Allocation: MAS Model

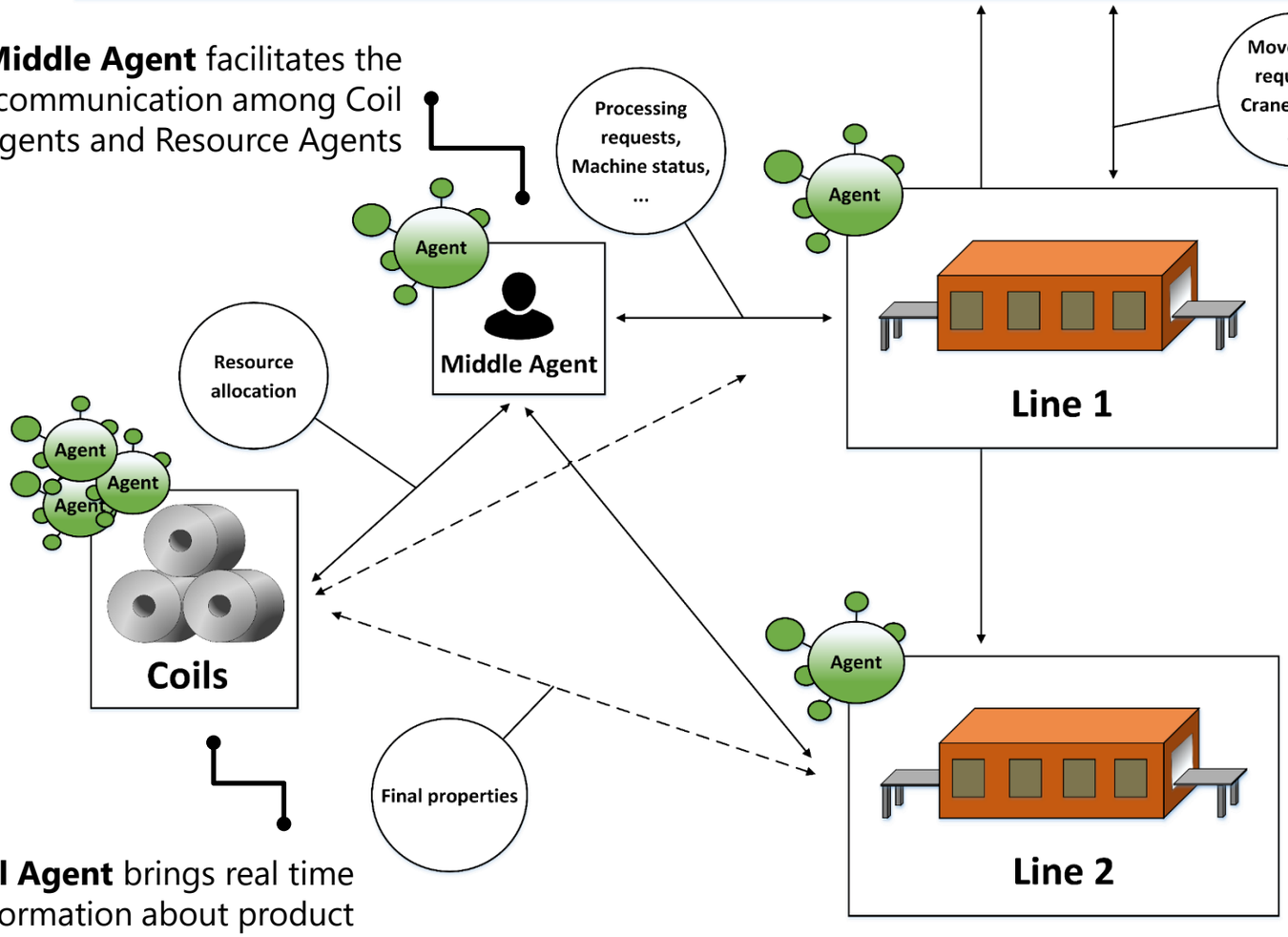
ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes



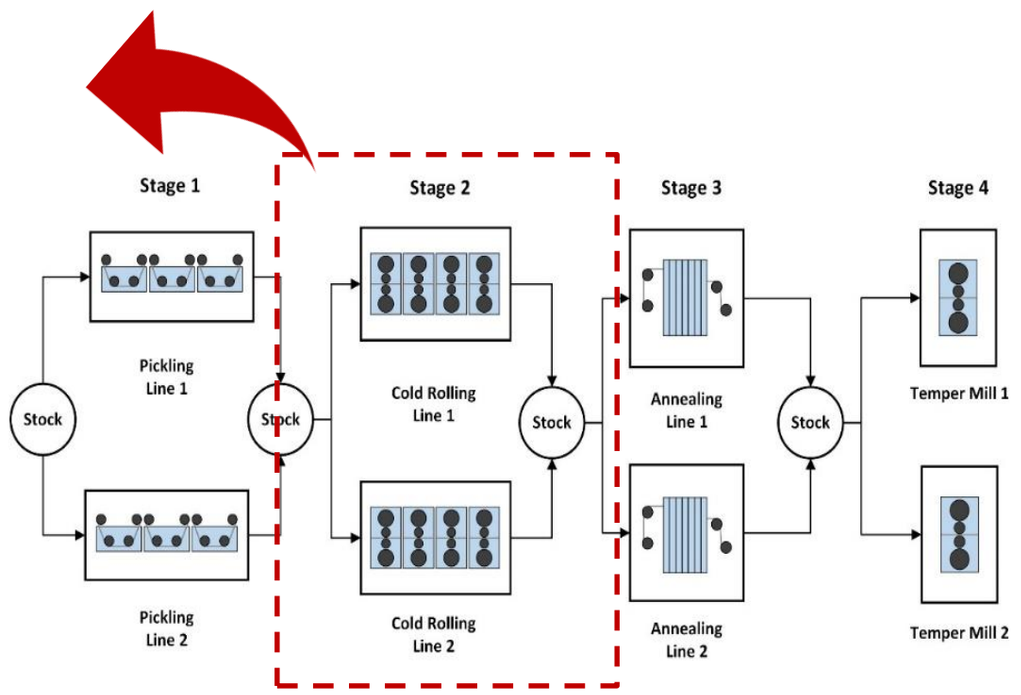
Crane Resource agent oversees the loading of coils into machines.

Middle Agent facilitates the communication among Coil Agents and Resource Agents

Machine Resource Agent implements smart production line and handles a particular machine within a production stage



Coil Agent brings real time information about product



V. Iannino, C. Mocci, and V. Colla, "A Brokering-Based Interaction Protocol for Dynamic Resource Allocation in Steel Production Processes", in Trends and Applications in Information Systems and Technologies, Springer, Cham, 2021, pp. 119-129.

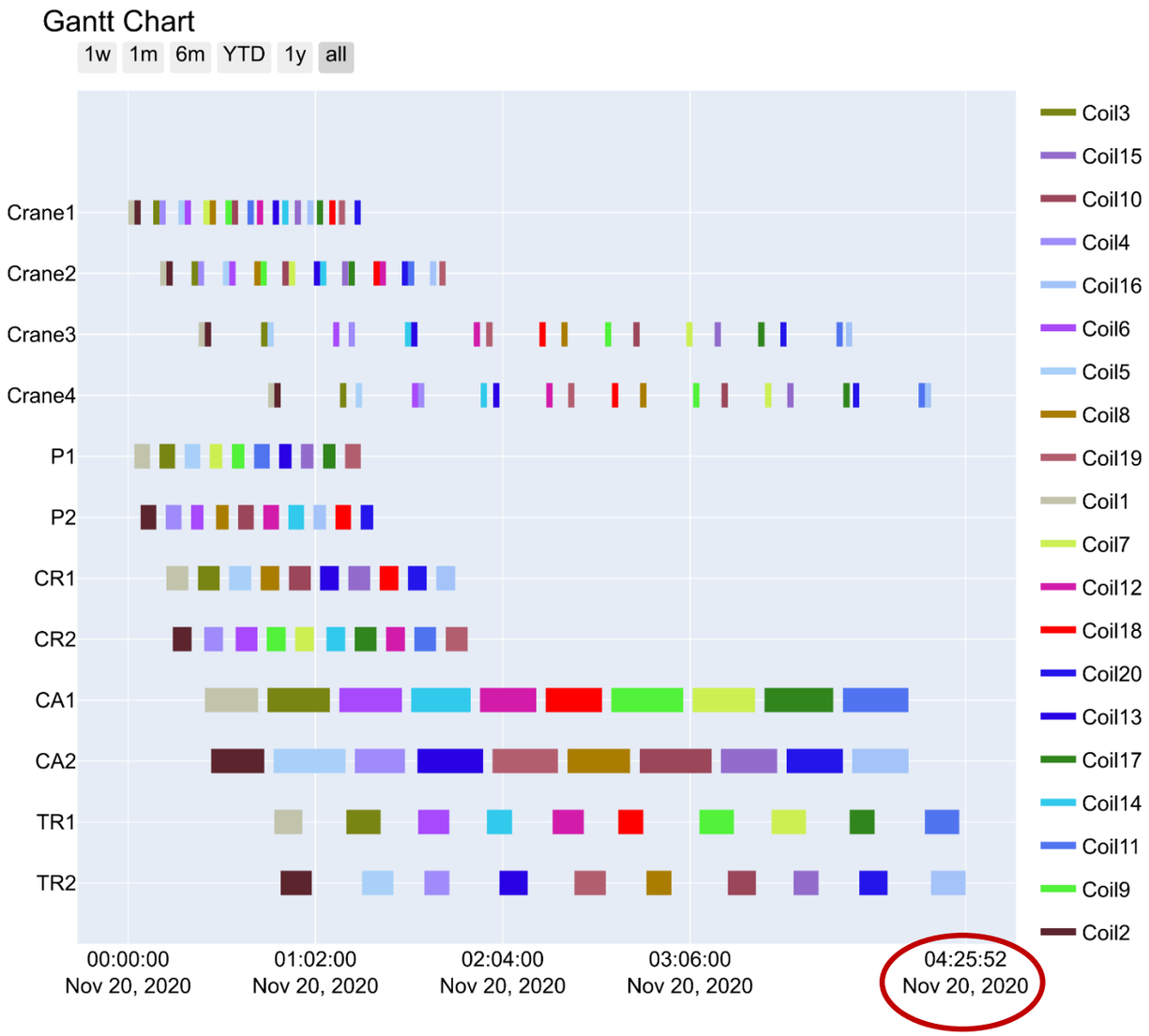
V. Iannino, C. Mocci, and V. Colla, "A Hybrid Peer-to-Peer Architecture for Agent-Based Steel Manufacturing Processes", in Proc. 17th IFAC Symposium on Information Control Problems in Manufacturing, 2021.

Agent-Based Applications in Steelworks

Dynamic Resource Allocation: Results

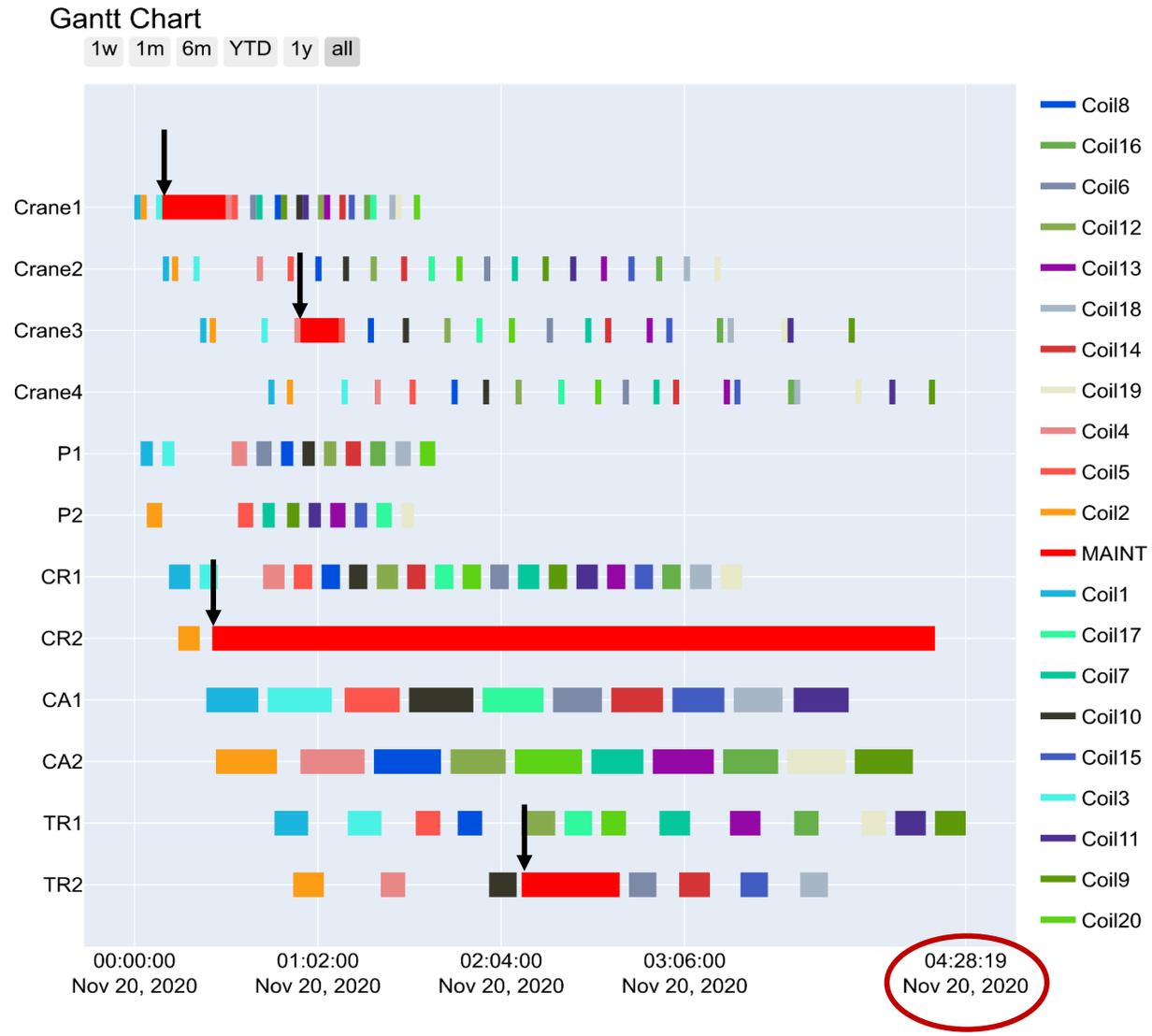
ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

Without Unexpected Events



C_{max} =04:25:52

With Unexpected Events



C_{max} =04:28:19

C_{max} is the *Makespan*, i.e. the completion time of the last job to leave the system.

Agent-Based Applications in Steelworks

Off-Gases Management

ICT COISP

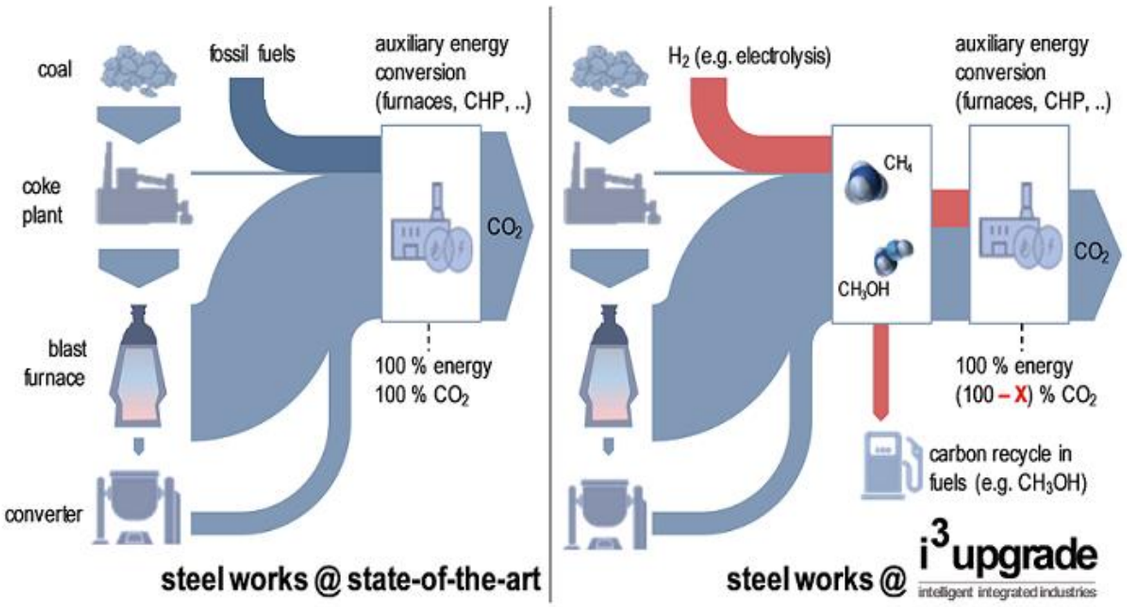
Information and Communication Technologies for Complex Industrial Systems and Processes

European Commission

Research Fund for Coal and Steel (RFCS)

Project name:

Integrated and intelligent upgrade of carbon sources through hydrogen addition for the steel industry (i3Upgrade). The project started on June 1st 2018 and will end on April 1st 2022.



Objective:

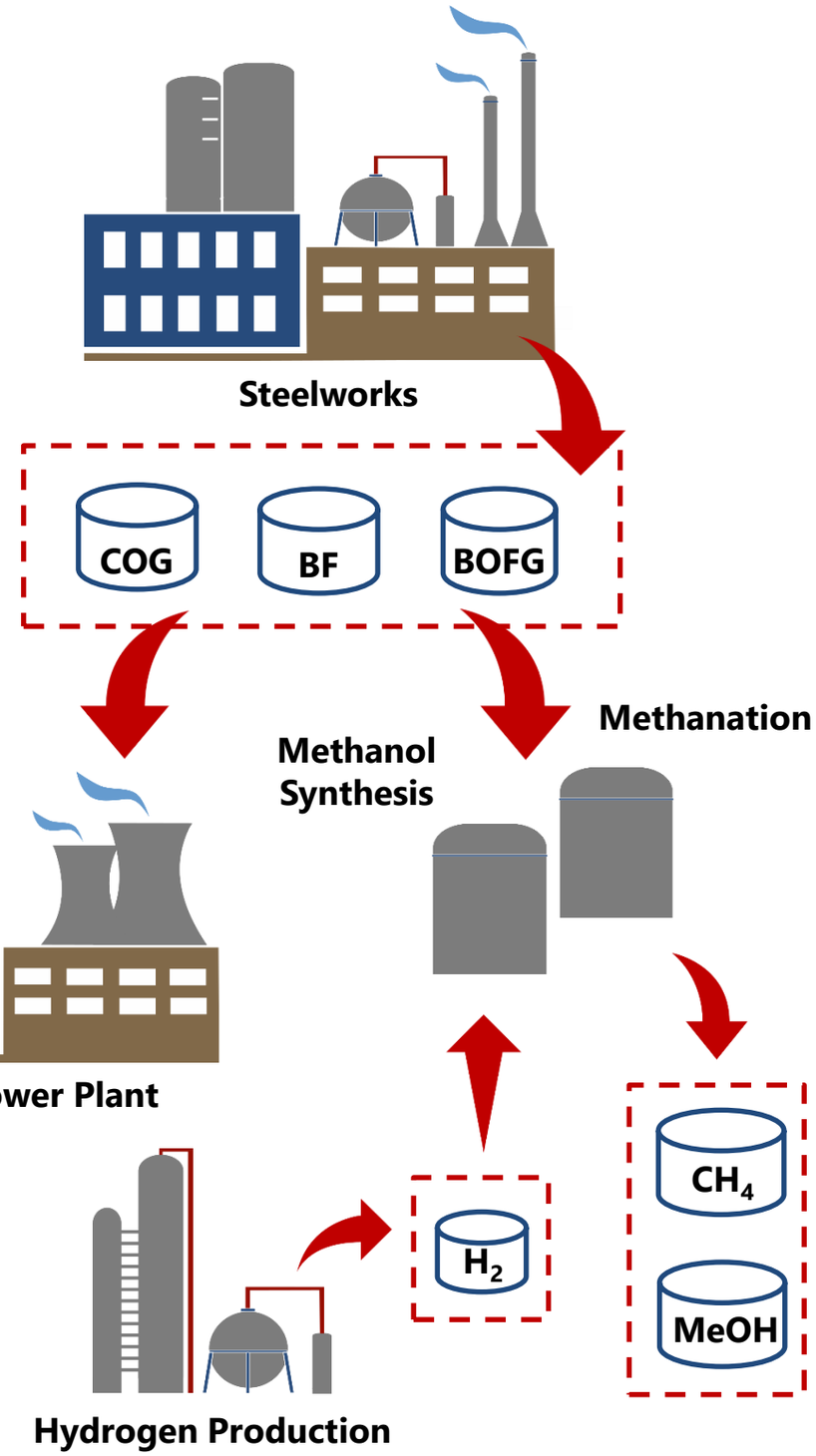
Intelligent and integrated upgrade of carbon sources in steel industries through hydrogen intensified synthesis processes and advanced process control technologies.

Agent-Based Applications in Steelworks

Off-Gases Management: Case Study

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

- An integrated steel plant produces three type of process off-gases, i.e. coke oven gas (COG), blast furnace gas (BF) and basic oxygen furnace gas (BOFG).
- Off-gases can be exploited to meet the energy demand of production processes, to produce steam and as energy sources for power plants, which can both satisfy internal electricity demand and or part of their production to the external energy market.
- A methanation and methanol synthesis reactor for the production of methane (CH_4) and methanol (MeOH).
- A hydrogen plant for the production of hydrogen (H_2).
- The management of off-gases is done to optimize the off-gases utilization, to reduce the CO_2 emissions, and minimizing Operating Expense (OPEX) and Capital Expenditure (CAPEX) costs in the emerging volatile markets.



Agent-Based Applications in Steelworks

Off-Gases Management: MAS Model

ICT COISP

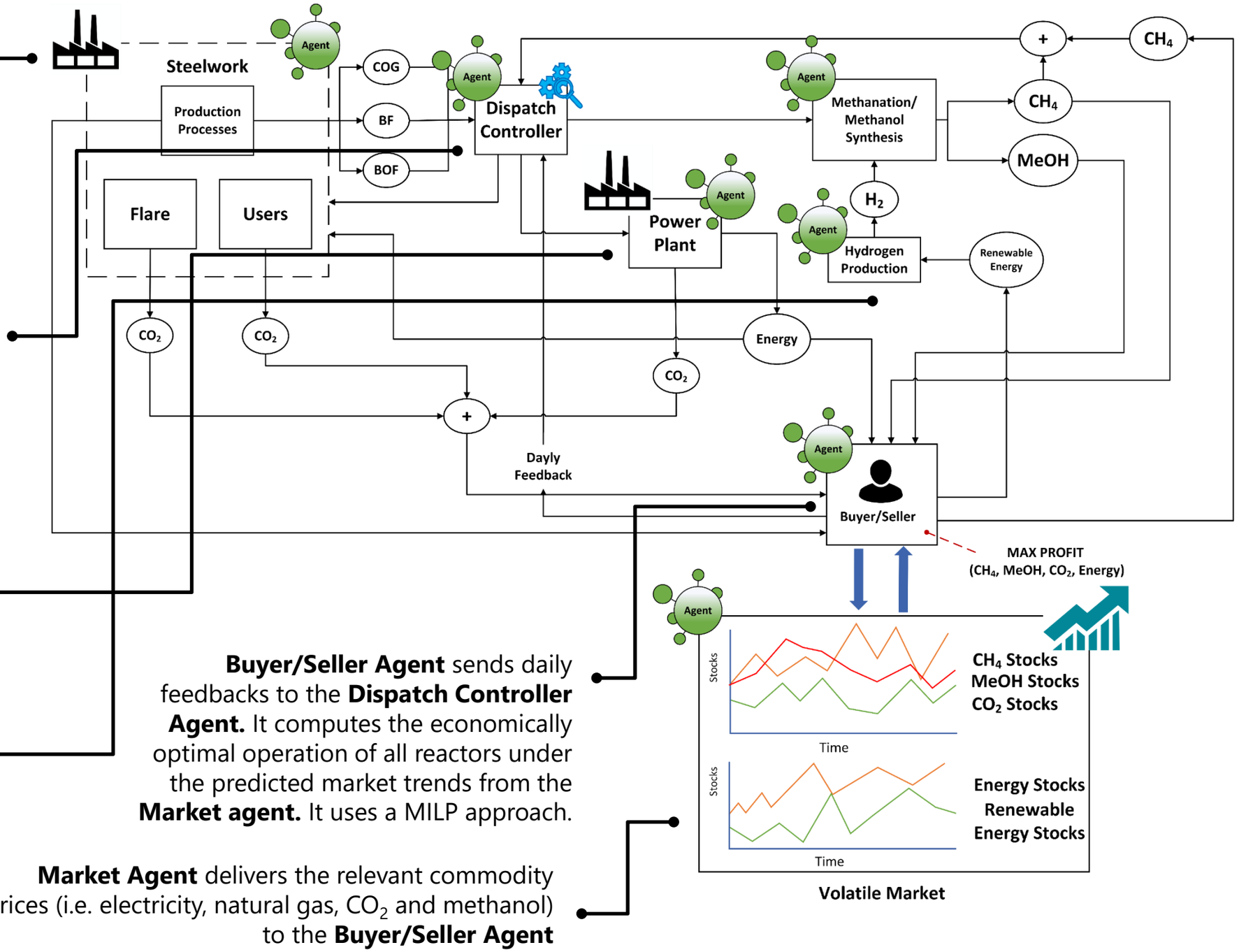
Information and Communication Technologies for Complex Industrial Systems and Processes

Steelworks Agents are responsible for providing the global amount and the main features of off-gases by exploits Echo State Neural Networks (ESN)

Dispatch Controller Agent optimizes the distribution of process off-gasses. It implements a Model Predictive Control (MPC) approach based on the solution in real time of a Mixed Integer Linear Programming (MILP). It translates the economically optimized production targets of the **Buyer/Seller Agent** into detailed instructions for the **Reactor Agents**

Power Plant Agent aims at producing electric energy by using part of the available steelworks gases

Reactors Agents represent the methanation and methanol synthesis as well as the hydrogen production units



Buyer/Seller Agent sends daily feedbacks to the **Dispatch Controller Agent.** It computes the economically optimal operation of all reactors under the predicted market trends from the **Market agent.** It uses a MILP approach.

Market Agent delivers the relevant commodity prices (i.e. electricity, natural gas, CO_2 and methanol) to the **Buyer/Seller Agent**

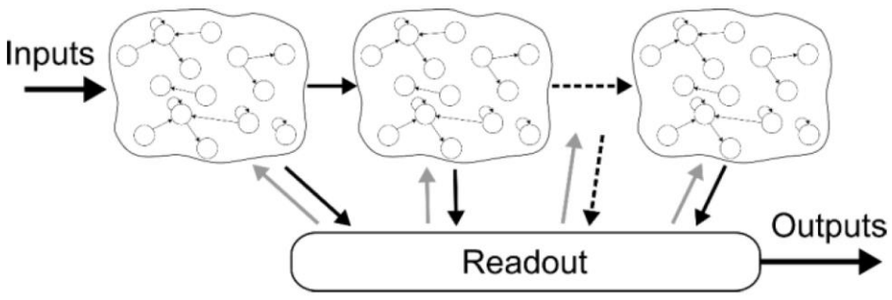
A. Zaccara et al., "Renewable Hydrogen Production Processes for the Off-Gas Valorization in Integrated Steelworks through Hydrogen Intensified Methane and Methanol Syntheses", *Metals*, vol. 10, no. 11, pp. 1-24, 2020.

I. Matino et al., "Application of Echo State Neural Networks to forecast blast furnace gas production: pave the way to off-gas optimized management", *Energy Procedia*, vol. 158, pp. 4037-4042, 2019.

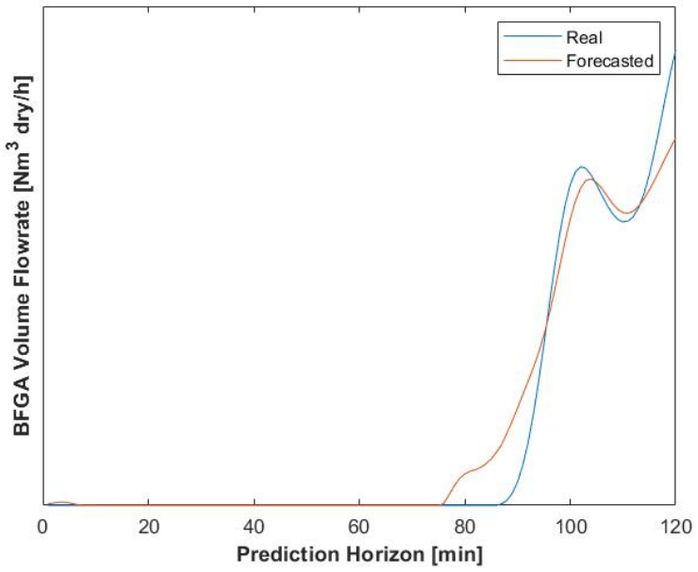
Agent-Based Applications in Steelworks

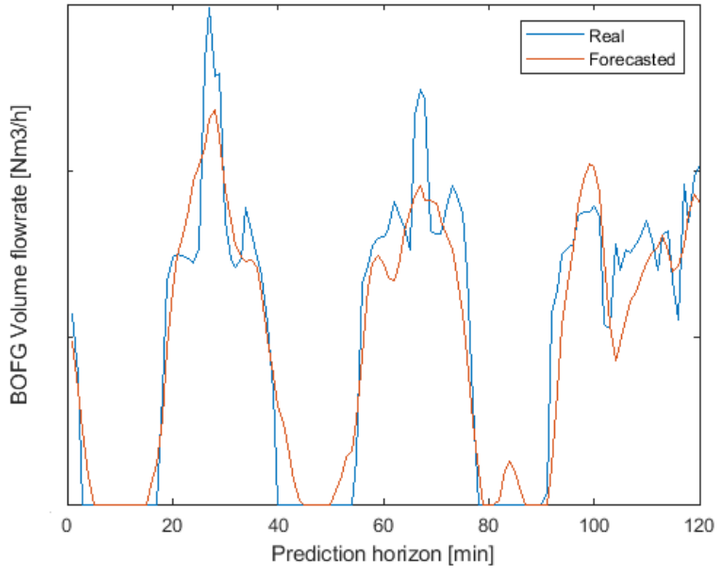
Off-Gases Management: Results

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes



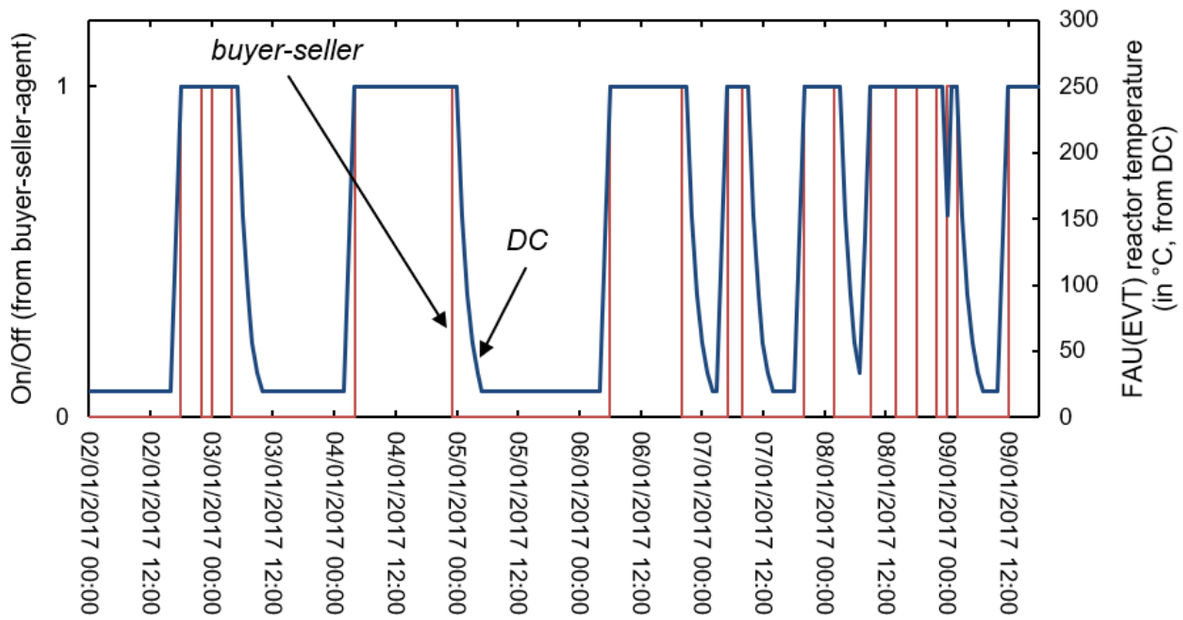
Steelworks Agent (ESN Forecasting)





Dispatch Controller Agent (Off-Gases Management)

Buyer/Seller Agent (Daily Feedback) and Dispatch Controller Agent Action



Conclusions

- Industry 4.0 exploits technologies which pave the way to the transformation of a traditional process industry into a Smart Factory.

- Steel manufacturing industries are undergoing relevant transformation through digital transformation and Industry 4.0.

- The use of MAS in process manufacturing industry offers several advantages in terms of quality, reliability, efficiency, robustness, autonomy, time, and costs in comparison to classic production systems.

- Agent-based technology is very promising and represents a realistic solution for the set of industrial challenges, especially the steel industrial ones.

- A systematic use of MAS in the steel sector may increase its production efficiency and its sustainability.

- The smooth introduction of MAS in steel production systems by testing and demonstrating the technology through simulation tools may be the solution to address concerns and doubts from industrial side.

INSTITUTE
OF COMMUNICATION,
INFORMATION
AND PERCEPTION
TECHNOLOGIES

Scuola Superiore
Sant'Anna

ICT COISP

Information and Communication Technologies for
Complex Industrial Systems and Processes

THANK YOU FOR YOUR ATTENTION!

Vincenzo Iannino
Scuola Superiore Sant'Anna

Phone: +39 050 88 2334
Mobile: +39 331 80 66 026
E-mail: v.iannino@santannapisa.it
Linkedin: https://www.linkedin.com/in/vincenzo-iannino-b936ab155/
Researchgate: https://www.researchgate.net/profile/Vincenzo_Iannino