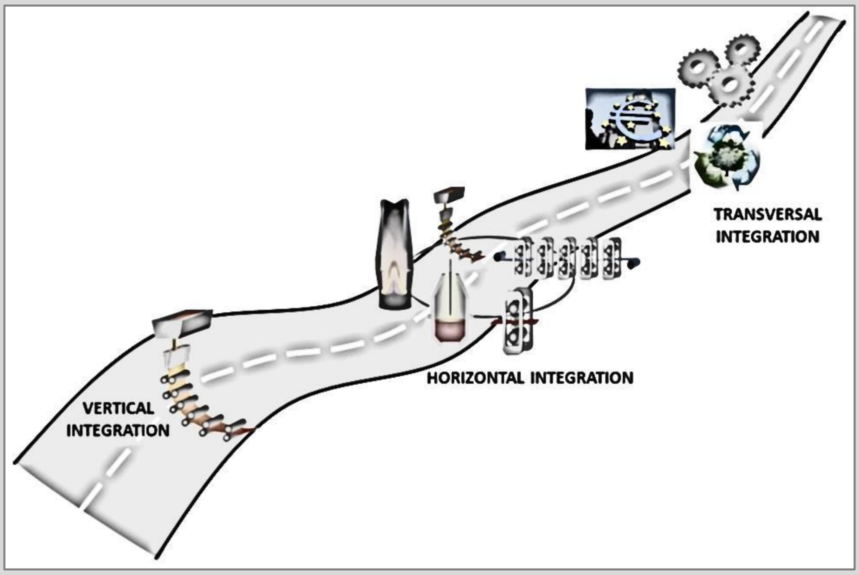
ROADMAP

"Integrated Intelligent Manufacturing (I^2M)"



Created by the Working Group "Integrated Intelligent Manufacturing (I^2M)" of ESTEP.

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Content

1 Introduction

The Integrated Intelligent Manufacturing (I²M) Working Group of the ESTEP Platform published the first edition of I²M Roadmap for European Steel Manufacturing in 2009 with a vision up to 2020, when this was an emergent concept in Steel Manufacturing. However, the development of new concepts, techniques and technologies in ICT, the increasing dynamics of globalized markets and the continuing uncertainty of the global economy suggest updating the development and implementation plan.
Strict compliancy with EU requests in terms of environmental protection, social and environmental constraints and related opportunities is mandatory as in 2009 to drive the evolution of the Steel sector in Europe /1/.

Thus, strategic objectives of the revised I²M Roadmap are the following:

- to extend the vision up to the next 20 years, representing a long term figure for ambitious expectations;
- to update technological trends, driving the Steel Manufacturing evolution according to the new conditions efficiently managing changes with ever increasing flexibility;
- to define the R&D objectives taking into account the envisaged evolution of ICT, aiming at the global optimization of operations, resource consumption decrease of the environmental footprint

The realization of the coordinated plan contributes to preserve the leading position of the European Steel Manufacturing and its economic competitiveness.

Therefore, ESTEP, by means of specific working groups and I²M WG in particular, is engaged in closing the gap within the R&D needs and the technological evolution. In fact, the prediction of the future is not in the scope of this Roadmap, it provides information and trends to support the decision makers in driving the technological evolution of their companies to implement the frame of "Smart Manufacturing" and the Integrated Intelligent Manufacturing paradigm.

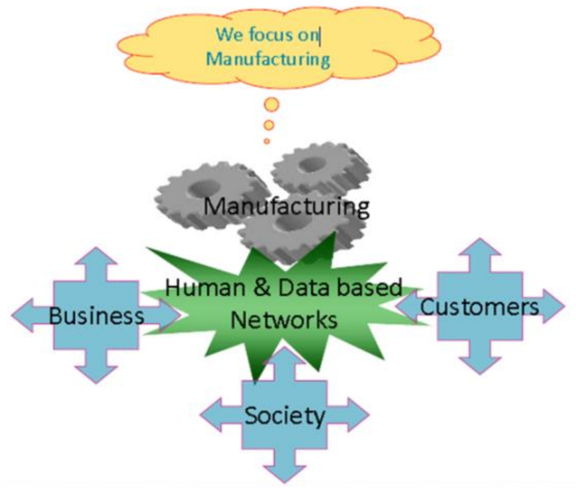
2 Industrial objectives

2.1 Needs and challenges

In order to maintain the leading role for Europe in the field of steel production, it must be both competitive and sustainable, forming an integral part of the green economy, today and in the long run. Customer and society oriented policies are part of the same global challenge to achieve profitable and sustainable business. In connection with these challenges, five top level needs will drive the future evolution of steel production:

Sustainability, Quality, Lead Time, Profitability and **Health&Safety**.

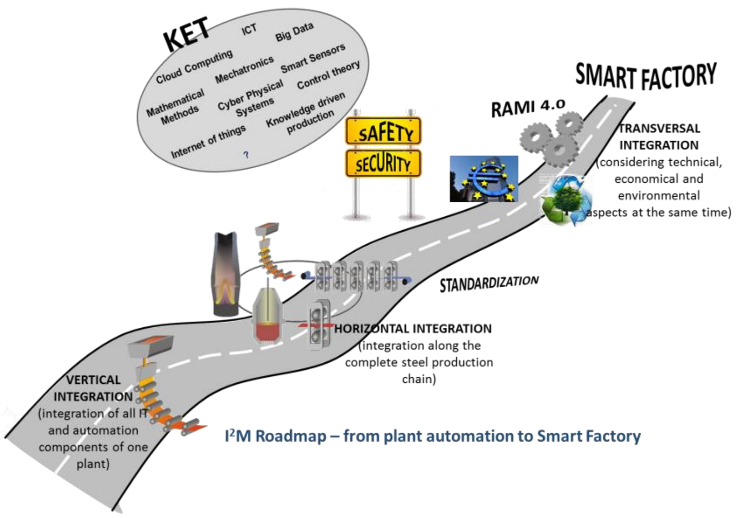
The I²M concepts are unifying in an interdependent manner three key concepts: **Vertical**, **Horizontal** and **Transversal Integration**. This evolution is enabled by the rise of disruptive information and communication technologies (ICT) such as Big Data, Internet of Things, Cloud Technologies and Cyber Physical Systems (CPS). Vertical Integration is the integration of all IT and automation components of a single plant or installation; Horizontal Integration is integration along the complete steel product chain and lastly, Transversal Integration addresses simultaneous optimization of technical, economic and environmental issues.



The three pillars of the European Steel Manufacturing competitiveness

These concepts, steered by key enabling technologies, drive us towards the realization of the final goal of implementing the **Smart Steel Factory** which represents the *intelligent*, *flexible* and *dynamic* steel production of the future. Significant efforts are needed to exploit the aforementioned techniques and technologies by extensive connection and networking between the factories, companies and the society. These and other technologies will have a huge impact on business, operation and plant management giving systems and machines collaborative capabilities similar to human beings like learning capability and self-organization. The impact on the workforce will be similarly disruptive and revolutionary.

Let’s now look to the above mentioned five top level needs driving the Integrated Intelligent Manufacturing agenda in more detail:



I^{2}M Roadmap – from plant automation to Smart Factory

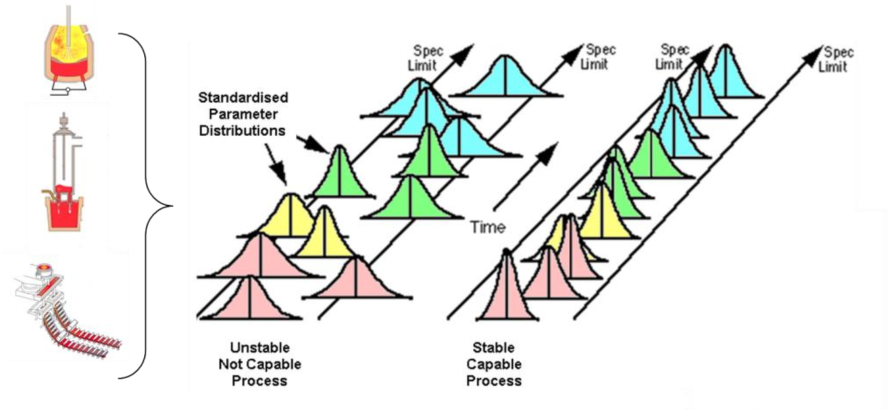
Sustainability: Sustainability optimises the relationships between the steel sector and society: Steelmaking in Europe largely depends on sharing benefits with society and minimizing risks for people and environment. Three key factors dominate this scenario, all of which require real time continuous monitoring and control of key parameters:

- Drastic abatement of greenhouse gas emissions by means of extensive continuous process monitoring, data gathering and analytics, dynamical optimization of processing and integrated surveillance systems.
- Environmental preservation is possible through the dynamical optimization of critical resources consumption like water, energy and raw materials; powerful algorithms, modelling, sensors, control and process optimization and dedicated equipment are key issues for dynamical process set up and control.
- Dynamical adjustment between steel demand and supply by means of intelligent planning and scheduling in collaboration with the capability assessment of manufacturing systems and supply chain management. Multi Objective Optimization in combination with e.g. game theory and heuristic strategies as a possible approach.

Quality: Customers perceive quality as a key issue for stable and effective relationships. In this context, shared standardization and “defectology” approaches facilitate the explicit relating of a steel product to its final use such as it currently applies in specific sectors like Automotive and Buildings realisation. Product tracking and tracing systems are essential. Such systems, able to withstand harsh environments of steelmaking, are not yet fully available. Early detection and prediction of quality deviations activate order dynamical allocation and recovery strategies to increase first choice production rate. Systems to link markets, customers and products from the early stage of planning and scheduling are necessary.

Lead Time: Lead Time is fundamental in manufacturing efficiency and customer satisfaction. Vertical, horizontal and transversal integration implies that there is real-time co-ordination and insight in consequences of decisions on the on time delivery to customers in dealing with release, rejection and reclassifications and rerouting at the various levels of local plants, through process routes and businesses. Factors like awareness of the equipment status offer big opportunities to increase efficiency through their local and total control allowed by the development and deployment of predictive tools to prevent unexpected breakages, increasing equipment availability at the same time. The migration from the planned maintenance model to condition based monitoring and predictive maintenance plays a crucial role in improving efficiency and increasing overall equipment effectiveness.

Profitability: General and specific manufacturing efficiency on one side and the possibility to establish win-win relationships with markets and customers on the other, largely influence the profitability. Optimal exploitation of intelligent manufacturing technologies is required to realise new business and manufacturing models such as efficient product allocation and re-allocation taking into account the relevant characteristics, flexibility in planning and scheduling, active cost optimization and synchronous connection with markets and customers.
Stability and repeatability of processes is the key factor to decrease defect ratio in product manufacturing. Workers, operators, commercial people, managers can take benefit from scenario analysis, event forecasting and early stage recognition of events coming from primary steel market and secondary markets, like the energy market for example.



Increased stability and repetability of process will contribute to decrease defect ratio

Health & Safety: Total safety, zero lost time injuries and zero impact on health are priorities driving current and future policy for working environment re-design and worker and neighbour community's health and well-being. Development and deployment of sensors for continuous monitoring of air and water quality, of pollutant contents in waste and gas give rise to crucial environmental benefits. An integrated view of the working organization and control systems, considering the central role of the human being in an increasingly autonomous environment (***Human-in-the-loop*** approach), is fundamental for achieving complete safety in operations and eliminating direct contacts with hazardous equipment and operations. Simulation tools for embedding health & safety, coupled with wearable devices to extend situation awareness will combine with real-time data analytics linking functional areas, mode of operations and workers.

2.2 Themes and R&D requirements

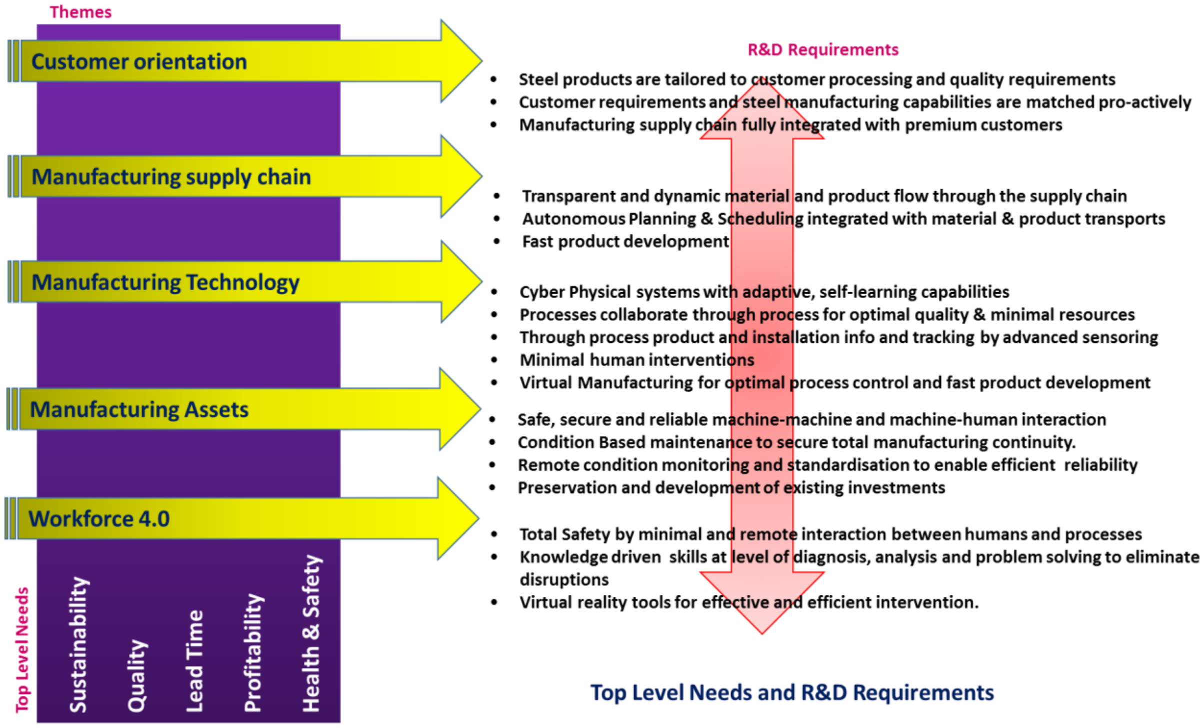
Technological themes for development can be specified in relationship with the mentioned Top Level Needs that serve to settle specific R&D requirements to realize the Smart Steel factory. A matrix view among Top Level Needs, Themes and R&D Requirements is presented and expanded in the following.
Such a matrix drives future development of tangible and intangible assets as processes, plants, equipment, control systems, business models and organization design. It guides the definition of the R&D strategic programs and, on the other hand, exposes R&D thematic areas where inter-industry cooperation is necessary. Development and deployment can accelerate through non-competitive collaborations, in-house developments and technology transfer from other industrial sectors, sharing risks among the whole Process Industry. The matrix contains the following main components:

Customer Orientation: Proactive connection between steel manufacturing and customer demand, in particular with premium customers, enables customer pull on orders, whilst managing stocks, etc. and delivers flexibility in planning and tailoring of products according to the customer processing capabilities and quality requirements.

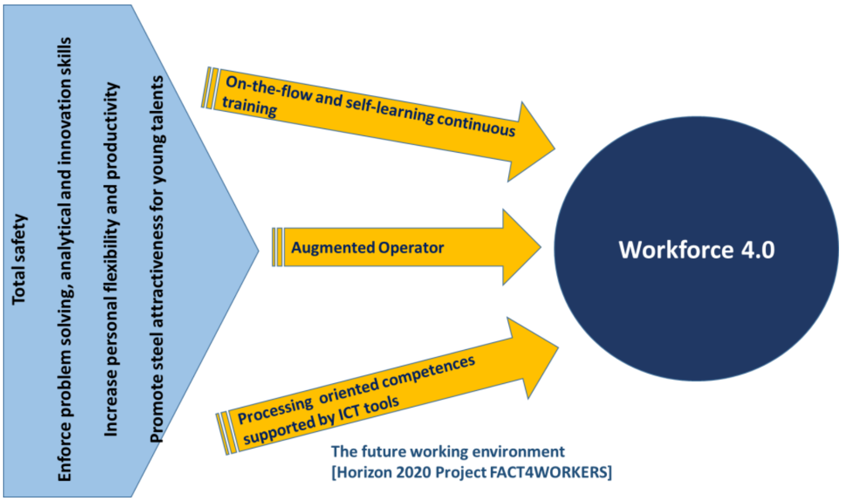
Manufacturing supply chain: The integration of the supply chain from steel processing up to end user applications requires transparent connection and dynamic product flow management through all the manufacturing stages, including yard control. Sharing of production plans in the supply chain enables autonomous Planning and Scheduling integrated with material and product logistics. Enhanced multi-physics and multi-scale simulation tools, based on fast computing networks, and rapid prototyping technologies for in-field testing and end user applications will shorten the time-to-market of new steel grades with superior surface and bulk characteristics strengthening the steel competitiveness.

Manufacturing Technology: Cyber Physical Systems with adaptive, self-learning capabilities will enable through-process collaborative control for optimal quality with minimum resources. Simultaneously, product quality parameters will benefit from the through-process information and material micro-tracking obtained by advanced sensors with minimal human interventions. Virtual Factory and Real Factory will run and be maintained in parallel for off line multi-objective optimization strategy design, fast tuning and deployment of results.

Manufacturing assets: Equipment, machines and systems must ensure safe, secure and reliable cooperation among them (M2M) and with humans (H2M). New systems will be compatible with existing ones integrating and progressively replacing them in order to achieve maximum value from previous investments. In addition, new approaches and technology like Remote Condition Monitoring and Condition Based Maintenance will secure total manufacturing continuity and equipment availability. In connection, standardization will enable efficiency, reliability and transferability of new systems, equipment and models.
Workforce 4.0: New technologies with extended connectivity and fast access to information will ask for novel workforce and working environments. Safety will benefit from the minimal and remote in-



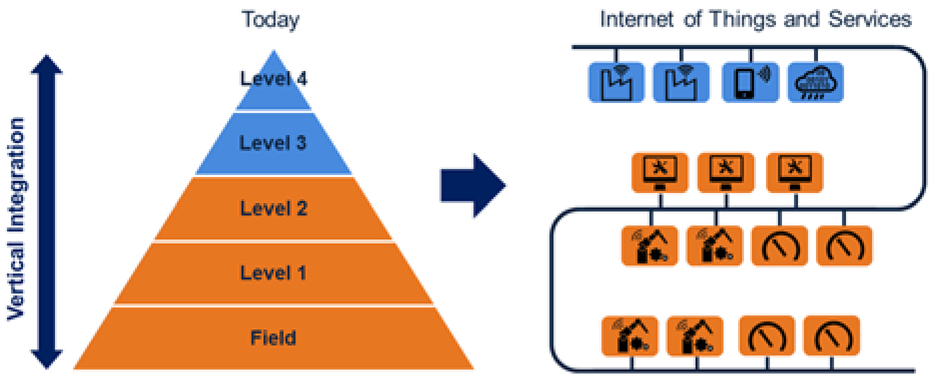
teractions in harsh environments by means of intelligent systems and robots, both autonomous and piloted by humans while local and global monitoring of plants and workplaces will guarantee health to workers and surrounding communities. Operator skills will be more oriented to maintaining manufacturing trajectory and correcting deviations rather than manual operations. Total safety, comfortable workplace, with high technology systems will increase satisfaction of workers and attract more young talents to the factory manufacturing environment and a new generation of operators skilled in both ICT and steel processing. They will be flexible and rapidly adaptable in carrying out their tasks using augmented and virtual reality and in-situ training systems using immersive pulpits. Automation will decrease routine and repetitive jobs while fostering significant increase in job places for systems design, ICT and application of Data Science. At the same time, transparency, communication and consensual cooperation between social and industrial stakeholders will promote acceptance and cooperation between companies and communities at local and regional level. Leadership and management will be posed new challenges in terms of and the quality and skills to attract manage and sustain this new digitally enabled workforce.



3 Concepts of future „Smart Steel Industry“

3.1 Vertical integration

In the frame of Integrated Intelligent Manufacturing the Vertical Integration means the integration of all IT and automation systems which are related to one plant and which are running on the different levels of the automation pyramid (see figure). The solution therefore will be based on Cyber-Physical Systems, which can be considered as the next evolution step of process automation. The consequences of the more and more usage of CPS will be an increased de-centralization and a significant de-hierarchisation. Vertical Integration and CPS call for a technical structural transformation in IT and automation. Today's hierarchical automation pyramid will be replaced by a flat structure of intelligent, flexible and autonomous units. In the Internet-of-Things, every unit can communicate directly with other units such as Smart Sensors. This means that the pyramid levels and the related organizational and technical barriers will be overcome.



This practically enables the total integration of data and functions, e.g. of machines, automation, monitoring, products, services, knowledge etc. In addition it enables the fast and efficient implementation of service-oriented functionality. The vertical integration becomes reality. The next generation of process automation and IT systems will provide the required infrastructure.

Further trends and visions for process automation which are in direct relation to the Vertical Integration are the following:

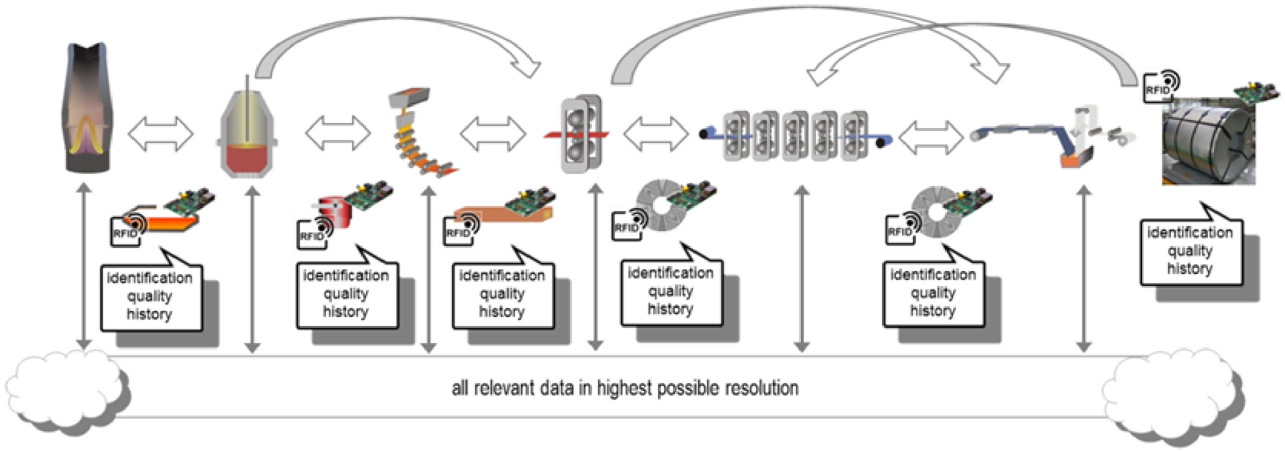
- Openness of Systems
- Platform Independency of Applications
- Highly modular and decentralized systems
- Embedded Systems (i.e. part of Mechatronic) combined with Internet Services
- Cloud Storage and Cloud Computing
- Industrial Apps, SaaS
- Uniform communication infrastructure M2M, M2B
- De-hierarchisation
- Through-going Data Management
- Virtualization

- Digital Shadow of Production in real-time
- Simulation, Analysis and Decision Support in real-time
- Intuitive multimodal HMI
- Augmented Reality
- Mobile Computing, any data – anywhere – anytime

The prerequisite for a fast transition into this type of next-generation process automation are commonly accepted industrial standards and proven IT security standards. A long co-existence with existing legacy systems can be expected. Some of the above listed trends and the just mentioned aspects will be discussed in more detail in later chapters of this document.

3.2 Horizontal integration

Along the complete chain of steel production a strong communication between all participating processes has to be guaranteed in future. This has not only to be true for neighboured plants but for all plants along the process chain. Additionally a 100% material tracking including a full material genealogy taking into account all possible transformation of material (liquid to solid, cutting, welding, coiling, length changes, etc.) is necessary for a complete horizontal integration. Therefore it has to be possible to identify all types of intermediate and final products and sensors or indicators are necessary to follow all possible material transformations.



Data coming from different process steps and different information levels (refer to chapter “vertical integration”) have to be stored in such a way, that they are available at any time and from any location in the company. A possible solution to realise such a type of data storage could be a company cloud. Furthermore information from raw material suppliers as well as information coming from customers have to be integrated here. Horizontal integration is on the one hand the basis for the connection of automation solutions of neighboured plants (e.g. optimal setup of a cold rolling mill based on the input geometry of the hot rolled coil to optimise overall flatness of the final product, etc.) but also necessary to realise quality control loops on a very high abstraction level e.g. based on suitable decision support tools.

3.3 Transversal integration

Transversal integration means to take at all decisions which have to be made during the long chain of steel production the aspects of technical solution, economic benefit and environmental aspects into account at the same time. Only on that way it is possible to find the best solution for each decision making process based on the overall strategy of the steel producing company. In the following some aspects are discussed to underline the need to look for such multi-criteria solutions based on I²M technologies.

Steel production is an energy intensive industry. According to Word Steel Association since 1960 a reductions of about 60% in energy required to produce a tonne of crude steel has been achieved. Further reduction can be still reached both in a single process step and in the whole production chain through an intelligent management of existing energy sources and enhanced and sustainable energy efficiency. The recovery and valorisation of energy sources which are currently not exploited can lead to a significant economic advantage. A smart interaction with the energy grid and distribution systems outside the boundaries of the company can also contribute to improve overall energy efficiency leading also to economic benefits.

The just described solutions will need to be fully integrated and managed in an "intelligent" way in the energy network of the steelworks, to provide maximum benefits to the company as well as to the surrounding community.

Circular economy promotes zero waste, a reduction in the amount of materials used and encourages the reuse and recycling of materials. These are fundamental advantages of steel, which is reusable and 100% recyclable. The circular economy requires action at all stages of the life cycle of products: from the extraction of raw materials, through material and product design, production, distribution and consumption of goods, repair, remanufacturing and re-use schemes, to waste management and recycling. Improvements in terms of resource and energy efficiency in steel production go in this direction.

Among resources, water is essential for the production of crude steel. Most of the water in the steel industry is used for cooling. Steel factories use very different quantities of water, depending on their access this resource, the available technologies to treat and reuse it as well as on local regulations. A world survey of steel mills by Word Steel Association showed that the spread of figures ranged from 1 to over 148 m3 of water per ton of crude steel. Having this in mind it is clear that both economic and environmental drives are pushing towards innovative management of water and related energy exploiting new technologies not only in terms of advanced treatments, but also of sensors, data handling and interpretation and optimization strategies.

Being the steel industry a highly energy- and resource- intensive sector, profit and efficiency are not the only targets: the responsibility toward society in terms of environmental impact is clearly and deeply accounted. Overall the global impact Indicator (“Eco-efficiency”, “Green Growth” and “Resource Efficiency”) appears in the EU Roadmap toward a Resource Efficient Europe.

Smart systems are expected to allow multi-objective production planning enabling to optimize productivity (in both qualitative and quantitative terms), by reducing energy and materials consumptions, with obvious benefits in terms of environmental impact and cost.

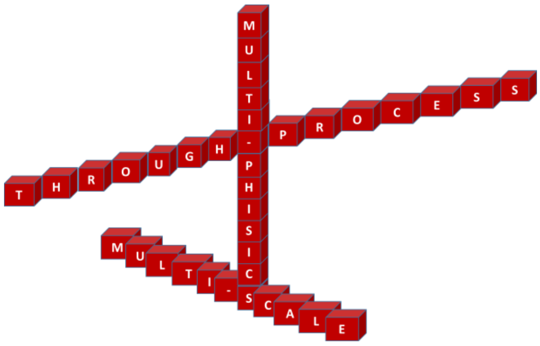
Dynamic switching between different available energy, material and water sources is just an exemplar case of application of intelligent systems for transversal integration and through process optimization. Such systems must allow flexibility during the scheduling phase and real time reaction based on multi-objective criteria: In fact, in the case of energy, large development of intermittent renewable energy sources (and the new targets of the 2030 EU climate and energy policy entail a further development of renewable sources) is expected to have a strong impact on steel production.

For all the above mentioned aims, suitable tools and technologies have to be developed as a basis for the adoption of advanced operating practices. Integrated Intelligent Manufacturing will play a fundamental role allowing effective support to the decision makers in creating Transversal Integration in steel industries, as well on the level of daily operation as on the long term perspectives.

3.4 Virtual/Digitalised factory, especially modelling and simulation

Modelling has been a key pillar since the development of the metal science and the disruption created by the ICT growth. In the Industry 4.0 era it has also confirmed its role in the digitalization path towards the Smart Factory. There is a traditional strong involvement of the steel industry, in cooperation with Academia and research institutions in the continuous development of ever reliable and performant models in domains of knowledge which are relevant to this business. Today, aspects like enhanced connectivity, fast storage and high performance computing (both supported by cloud technologies) draw the attention and the efforts to the need of integration of models according to three main directions (see the aside picture):

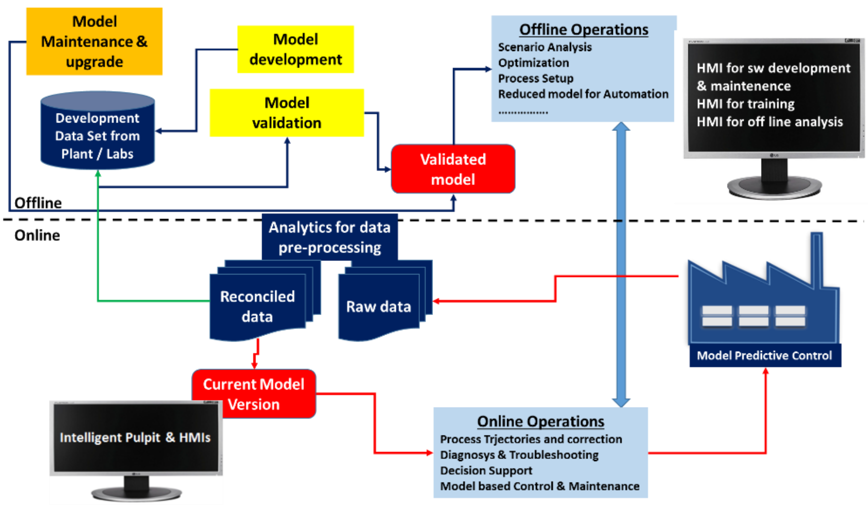
- Multi-scale modelling and simulation, for coupling non-linear processes phenomena at the micrometric scale and less, like for example metallurgical transformation or chemical reactions between molten steel and slag, with the complex Fluid Dynamics in the bath at the scale of meters. Specifically, a need for further development is the simulation of highly dynamics phenomena which are today simulated by means of piecewise steady-state analysis.
- Multi-Physics modelling, for coupling different complex interacting phenomena. Here, needs are the development of robust and reliable methods for convergence and precision and approaches like multi-zonal analysis, i.e. the possibility to automatically detect and manage the discretization domain in high gradient areas.
- Through-Process modelling, considering interacting logistics, process sequence, scheduling, supply chain, business can be considered in unique flowsheets. Here, each step is the I/O of the neighbours. This is the typical domain of multi-objective optimization with specific modelling techniques like flow-sheeting analysis, to optimize resources and energy demand. Here, needs are efficient HMIs for data selection and processing using methods belonging to the domain of Cognitive Engineering as well as to the specific technical aspects.



Large efforts are concentrated in the model development although a huge number of models are still available today. Thus, steel research is engaged in tailoring existing or incoming techniques and models developing specific aspects taking benefits from the natural directions in which scientific community is running. In addition, there are general needs throughout the industrial sectors to overcome the complexity of the management of models by the automation of specific operations and post-processing of simulation results. Moreover, costs and efforts required for model development imply the reusability of model components, i.e. the possibility to use or adapt parts in the context of other modelling applications.

Specific needs from the process industry are mentioned in the following. First, the development of architectures dedicated to such large integrated models: in process simulation for multi-scale and multi-physics approach the connection of models (i.e. the “Internet of Models”), is considered both in public and private contexts with the needs of necessary security and reliability. Thus, the attention is focused on the development of such efficient infrastructures where each node of the “network of models” has different complexity generating also a “system of systems” according to the IoT paradigm with which this approach has some similarity. The need of generality is also necessary, developing a taxonomy for the different classes of applications, facilitated by the implementation of semantic tools for fast linking and development, accessing to each necessary node in the network.

Some aspects of model development and model usage are illustrated in the figure aside.



4 Key Enabling technologies

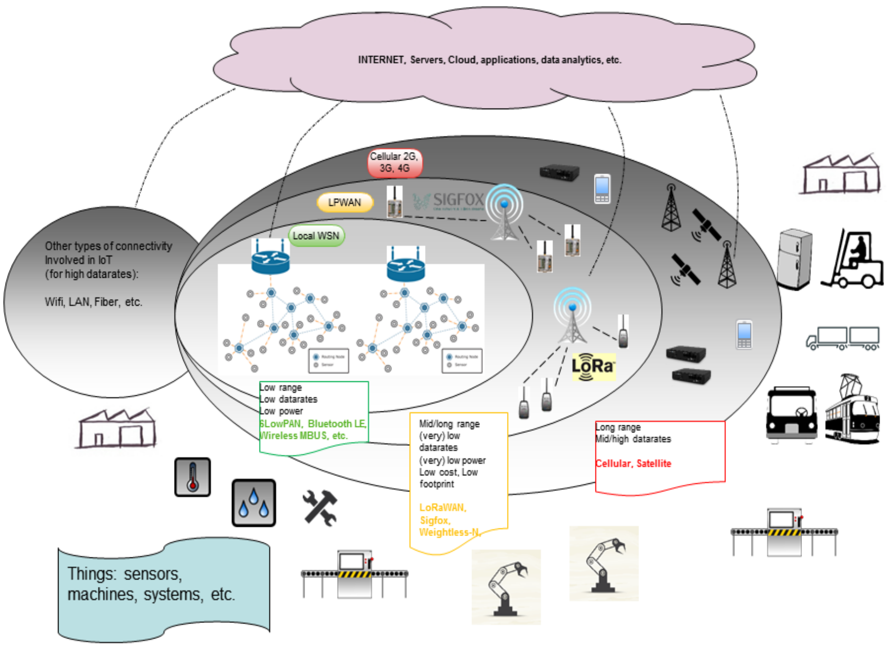
Additionally to the above described concepts of a future “Smart Steel Industry” different technologies will become necessary to realise such concepts. These technologies are mainly driven by new developments in the field of information technologies (IT), process automation and sensors and called in this document “key enabling technologies”.

Because in the just mentioned fields the developments are running extremely fast in the last years it is necessary to always follow them in detail and to check their suitability for the realisation of smart industry concepts. Here now the most important key enabling technologies to realise Integrated Intelligent Manufacturing solutions will be discussed.

4.1 Internet of Things (IoT)

Nowadays, IoT is usually presented as being the ongoing revolution that will largely influence our live in a way similar to the impact of the global wide- spreading of Internet or mobile communications. While lot of hype and marketing communication is associated with the term “IoT”, by the way making it somehow a bit confusing, the main technology trends fostering its quickly growing adoption are well known.

IoT overview: things and types of connectivity



IoT involves a broad set of technologies that enable things (not only computers) to be connected. “Things” range from the very small and simple objects like basic sensors to complex and compound systems (computers, servers, machines, satellites, etc.). To be integrated to IoT, “things” should at least be able to communicate (receive and/or transmit) data to other “things” within a network. This is not essentially new, since existing industrial networks, M2M communications, IT infrastructures and many others may already be considered as IoT ones. Nevertheless, IoT involves further aspects: (1) new communication standards and protocols allowing for interconnecting/interfacing a whole range of devices especially in a wireless way (2) higher computation capabilities (thanks to advances in embedded processing in terms of performance, low power, low cost and miniaturisation) at the end devices affording for much more “smartness” (ability to locally implement advanced processing, algorithms, etc.) at all levels of network hardware (end devices, gateways, servers) (3) advancements in power efficiency (power efficient communication protocols, ultralow power electronics, etc.) and energy provisioning (battery technologies, energy harvesting techniques, etc.) allowing the integration of devices that can now operate for much longer periods and even autonomously over their life time (4) novel software architectures and platforms that help operating and managing and exploiting IoT networks, data and applications.

IoT is triggering deep changes in almost all application domains: Healthcare, home automation, industrial automation, Transport & logistics, life sciences, Energy, agriculture, consumer, etc.

As for steel industry, and particularly in the scope of Integrated Intelligent Manufacturing, IoT impact is foreseen to be particularly important in:

- Manufacturing/maintenance processes optimization by leveraging the collected information enabled by intelligent sensors that are more widely deployed within factories and giving ac-

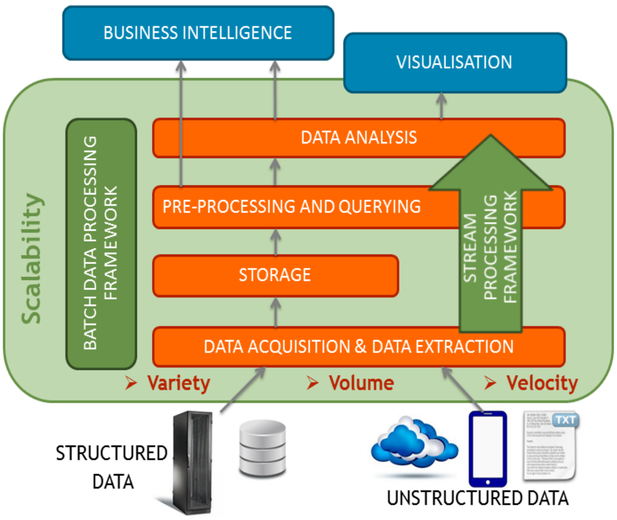
cess to data that was not accessible or monitored before (because of constraints on range, power, size)
- Network convergence based on IPv6 protocol leveraging the wide range of specialized sensor networks supporting this core protocol either natively (such in 6LowPAN, Zigbee, Bluetooth) or through dedicated gateways or infrastructures (M-Bus, wirelessHART, LoRa, Sigfox,etc.)
- Relationship strengthening with other closely linked downstream industries implementing IoT at their level (such as automotive, mechanical engineering, construction, etc.) on aspects such as traceability, logistics,
- Energy consumption monitoring and management through a global and fine-grain data collection and analysis throughout factory plant
- Productivity enhancements by enabling the integration of mobile and virtual reality (VR) applications interacting in real time with objects, materials, machines and information system.

Nevertheless, IoT still has to address strong challenges especially related to security and reliability.

4.2 Big Data technologies

The term Big Data has been widely used and it seems to correspond nowadays to a large part of the IT industry and it is therefore necessary to recall what it means. A generally agreed definition of Big Data is based on the characteristics of data: **V**olume of data to handle is huge. Data have to be processed with high **V**elocity. Data sets are made of data of a great **V**ariety of formats. In the scope of steel industry and notably of I^{2}M, Value comes from multiple criteria of Big Data. By managing huge **Volume** and **Variety** of data, it is possible to take into account several data sources build a powerful data analysis system. By managing data **Velocity**, it is possible to predictive systems, real-time monitoring systems, and reactive systems. Finally, **Visualisation** brings patterns and trends detection by human actors.

The concepts of Big Data are implemented into a data processing software stack which is made of the following layers (see the figure below).



To implement a Big Data solution as part of I^{2}M roadmap, many challenges should be considered at each layer of the software stack as well as globally with the need for **scalability**: being able to use always larger IT resource pools and in proportion of the amount of data to process.

Big Data acquisition. The data acquisition is the first level of a Big Data system. In this level, data should be collected, filtered, pre-processed, and integrated from heterogeneous data sources such as sensors, existing information system, or external sources. The integration of such heterogeneous data is a really big issue.

Big Data Storage. New technological approaches have emerged to deal with large-scale datasets while ensuring the availability of data accessing and analysis of large amounts of data. Those solutions are dubbed NoSQL databases because they complement traditional relational databases by exploiting the kind of data to store, such as time series or graphs, or the way data are accessed and used, in order to meet performance (speed), volume and variety (semi-structured data) goals.

Big Data Pre-Processing and Querying. The data pre-processing allows filtering data to focus only on trusted data and improve data quality. During pre-processing, formats, methods and tools are also used to identify concepts behind data. In turn, data querying have to provide an optimised data access to ensure the availability of data. This can be done by relying on an expressive and easy-to-use language and by using meanings of data generated during pre-processing.

Data Quality. High-quality data is an important aspect for analysing Big Data and ensuring the data value. To guarantee data quality, many issues should be addressed in order to deal with the 3V characteristics of Big Data: Huge data volumes make it difficult to analyse the data quality within a reasonable amount of time. The variety of data sources leads to diversity of data types and heterogeneous data formats, which increases the difficulty of data integration. The data velocity implies very fast data change and requires new processing technologies. In addition to these issues, the data quality analysis process should be enabled to detect and deal with several data quality factors including. Data integrity refers to whether all necessary data are available for the user need. Data accuracy refers to the data that represent the reality where they are verifiable from an external source. Data consistency refers to whether the logical relationship between correlated data is correct and complete. Several technical solutions should be investigated to implement the data quality analysis process including: Data analysis approach allows detecting the kind and the origin of the data inconsistencies, a detailed data analysis is required. This analysis can be done based on statistical approaches (distributional techniques, goodness of fit tests, control charts), model-based-methods (1st principle models, linear, logistic regression) or cluster analysis (distance-based, density-based). Transformation based approaches assume to develop a large number of data transformation and cleaning scripts.

Big Data Analysis. Big Data analysis is the software layer where we can get benefit from the stored and pre-processed data by extracting potential values or knowledge and providing suggestions or decisions. Even if several analytical techniques and tools exist, it is suitable to explore, in the context of I^{2}M, others analytical techniques out of the classical data analysis approach (e.g. process mining techniques).

Big Data Visualisation. Due to the Volume of processed data, it is necessary to display potentially a large number of values while keeping the result meaningful. Big Data Visualisation mechanisms have to take into account the temporal dimension in information display (Data Velocity), which requires to adapt visualisation tools in order to highlight or make visible the diversity of data types.

Big Data Processing and Streaming Frameworks. The data analysis workflow is driven by programming frameworks which mobilise each layer of the data processing stack. These frameworks distribute data processing load in parallel among pools of computers and data storage resources in order to manage and analyse huge amount data in a “reasonable” time. The challenge for such programming frameworks is now to gain in efficiency of resource use, and sometimes in scalability. Furthermore commercial frameworks do no fulfil demands of steel industry because of its long process chain with highly different types of processes and its complex material tracking and material genealogy needs. Here steel specific solutions will become necessary.

4.3 Cyber Physical Systems (CPS)

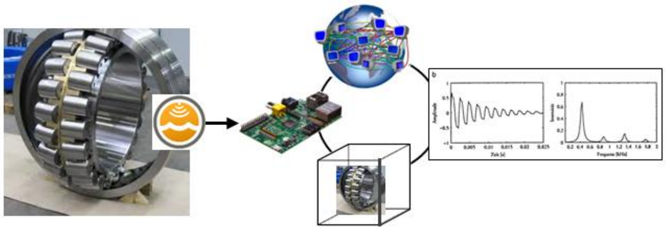
The formal definition of CPS, coming from the German working group 7.21 of VDI/VDE-GMA is as follows:

CPS: A system, which connects real (=physical) objects and processes with information processing (=virtual) objects and processes by open, partially global and at all times interconnected information *networks. Remark: Optionally a CPS uses local or remote available services, has a Human Machine Interface and offers the possibility for a dynamic adaptation of the system at runtime.*

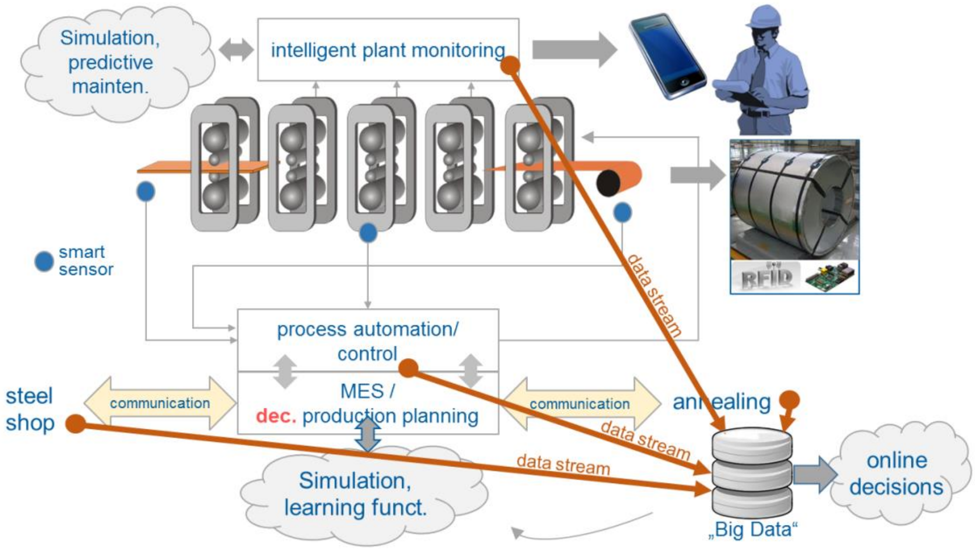
Cyber Physical Systems are <u>typically</u> based on embedded systems which

- collect physical data by sensors and influence physical processes by actuators,
- are connected with digital networks,
- use data and services,
- have Human Machine Interfaces.

In steel industry the question has to be answered, what a Cyber Physical System in this environment could mean. One answer would be that small components of the production machinery could become a CPS in the future: for example a bearing. If this bearing has an oscillation sensors and an embedded small computer system to evaluate the sensor data and to predict the remaining lifetime based on a suitable model and if it is connected to the global information network of the company to inform a higher level decision system about its prediction result, than it is a Cyber Physical System.

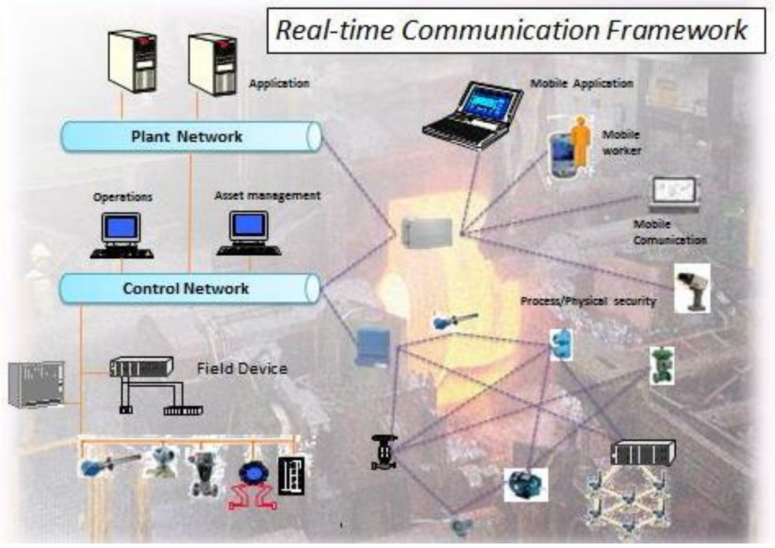


On the other hand a complete rolling mill could be defined as a Cyber Physical Production System: the mill is equipped with online and closed-loop control solutions for all important process variables and product features like rolling speed, strip tension, thickness, flatness, etc.. Therefore a lot of sensors and actuators are integrated. The online control system is directly connected with a Manufacturing Execution System which is able to use a complete set of process models to run all kinds of simulations (like “if…then…” scenarios). An integrated learning function stores all interactions and corresponding planning results as basis for a future reaction in similar situations. Furthermore a strong data and information exchange with all previous and following production steps is guaranteed. The plant is further-more equipped with smart sensors to gather the current state of the machinery, like oscillation sensors, noise detection or temperature monitoring. Based on the sensor data and based on simulations with suitable models the lifetime of components can be predicted and a predictive maintenance concept can be realised. Results are directly transferred by network and wireless communication to the relevant people in the plant. All variables are gathered with high sampling rates and stored in full resolution in such a way, that everybody at every time can use the data for his own purpose. Of course material tracking and complete genealogy is integrated. Big Data analytics can be applied to detect cause&effect relationships or to realise online quality decisions e.g. connected to material allocation topics based on large incoming data streams. The product itself can be identified all along the production chain, e.g. by RFID technologies (or others). Such a rolling mill is nothing else than a Cyber Physical Production System (=a CPS which is applied in production).



4.4 Real-time sensing and networking

Today there is an absolute need of real-time measurement of any parameter of interest, anywhere in an operating industrial process, to increase knowledge and improve automation performance. Intense competition at a global level intensifies the need for efficiency and productivity improvements in all manufacturing sectors. New sensing technologies are an inherent part of this industrial renewal, as their unique capabilities make them valuable tools for helping to reach these goals.
At present process measurements are still sometimes made in offline batches, thus limiting the possibility for using the information in real-time control situations. In cases where online measurement technology exists, it is primarily founded on conventional static fieldbus technologies that require converters and mediators to make communication between different buses and communication networks possible. This makes the technology expensive and limits the potential of real-time online measurement systems.
New monitoring and control system needs to be smarter than a collection of conventional single variable control algorithms, both in terms of reliability, response time, and multivariate information.
An advanced Monitoring and Control System will take charge of the proper and advantageous use of all information coming from the plant/process/product through a distributed sensors/micro-sensors network.



A real-time communication framework, which provides efficient communication and coordination among sensors and actuators, is essential to achieve a timely reaction. Such a framework relies on a low latency communication in the event reporting process from sensors to actuators, and a well-organised coordination algorithm that ensures a quick move to the event area by the actuators. Future steel industries will be focused not only on optimized process and quality issues but also they must comply with flexibility, fast plant reconfiguration and last but not least with safety and environment. Therefore new generation of measurement devices and, more important, a suitable sensor network is needed. Production planning, maintenance operation as well as through process quality control will be based on intelligent elaboration coming from dedicated sensors. Sensor type will depend on the severity of the industrial environment: solution ranges from heavy duty devices to disposable ones equipped with short/long term energy supply to provide relevant information.
Sensors based on wireless techno-logy, once overtaken communication with the sensing device, will allow to follow the product at each process stage; sensors network will be used by a multi-variable and multi-purpose control algorithm which can act with local loops for immediate counter-measures assuring the respect the final quality.
Moreover, emerging malfunction can be detected at an earlier stage, and planned stops can be used to replace defect components before they break down and cause expensive unplanned stops.
As well, unmanned ad-hoc “sensor-dressed” vehicles and robotic automation have to be seen as a major enabler for maintenance operation thus increasing productivity and reducing costs; more and more industrial sectors are looking to leverage such possibilities to their advantage.

4.5 Knowledge Management

Personnel’s know how is among the most important drivers of the competitiveness of any industrial sector, in particular in steel manufacturing. However, the knowledge which lay in the hands of the process managers, engineers and technicians, can only be extracted, implemented and applied when suitable ways and means to effectively preserve, enforce, expand, share and transmit such knowledge are available. Storage and processing of knowledge has been realised in the past e.g. by rule based technologies in the form of “IF…THEN...ELSE…” structures. Expert systems were an example for such a solution using inference engines to process the above rules. After a first enthusiasm about this technique in the early nineteens of the last century the reality had shown, that not many use cases in industry exist for this methodology. In the meantime explicit knowledge coming from Human Beings can also be stored in so-called Ontologies which are a semantic technique to store and to processed knowledge. First applications in the last 5-10 years were very promising. Nevertheless a lot of further research will be necessary in the future to make this technique a standard solution for knowledge processing.

Another possibility to generate knowledge is its extraction out of huge amounts of data. The idea here is to automatically extract, document and store knowledge by means of proper technologies and to create afterwards training tools for the new generations of employees. New technologies belonging to cognitive technology domains, Human Machine and Process Interfaces, as done before in the field of robotics and discrete manufacturing, coupled with IoT and Big Data paradigms can provide a great support to this task, considering the ever increasing degree of confidence of new generations with IT tools and techniques. Therefore the acquisition and smart interpretation of data coming from operations, sensors, markets etc. require ever increasing application of Big Data technologies, considering the complexity of the process chain and of the whole manufacturing sequences. Each data source, in particular human behaviour and set of sensors, ask for its own processing to be correctly acquired, processed and stored in the I^{2}M view. Other information, coming from other sources, such as documents and videos, must also be jointly processed, for instance, to the aim of acquiring strategic awareness of the equipment/process status for monitoring and fault diagnosis purposes. A challenge for future research is not only to make suitable knowledge extraction technologies available and fruitful for the daily operating practice, but also to exploit them to formalize and preserve the knowledge for the benefits of both the experts and the newly enrolled personnel.

Finally the combination of both just mentioned approaches, processing of human knowledge and extraction of knowledge from data, will be part of future developments. This implies, on one hand, to merge large data analytics, optimization techniques, knowledge-based system and cognitive technologies in order to enhance the capability of human operators e.g. to analyse process status, to outline anomalies and/or to develop complex multi-objective optimization problems. On the other hand, tools must be provided to formalize and store the outcome of these operations so as to detect the core information and preserve such knowledge, making it available (and practically fruitful, i.e. in an operative way, not just as a report) for the rest of the company, transmitting them to future generations of workers.

In the field of Knowledge Management a strong connection and information exchange with the ESTEP Working Group People has to be realised to assure the suitable integration and considering of the huge amount of social aspects into the more technical driven developments of I^{2}M.

4.6 „Smart Services” for steel manufacturing

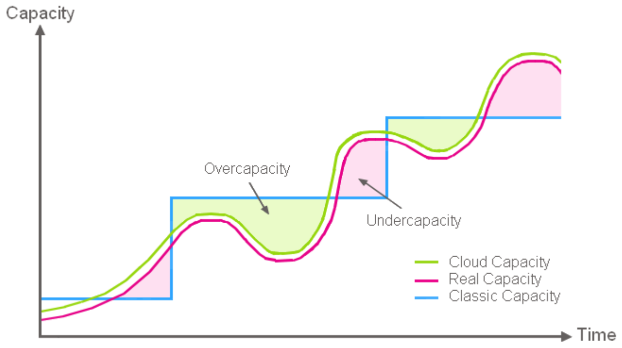
Market increased dynamic and opportunities offered by enhanced connectivity are favouring shifts from traditional serial supply chain to open supply networks. Trends to optimized in-time relationships between core entities, involved into direct added-value tasks, and services, not exclusively obtained, are emerging.

In the medium-long run, automatized services will deploy fast searches and trade-off in the network under given shared specifications for both qualified product/services and commodities. Remote negotiations have the benefit of enlarging search perimeter to optimise cost and quality in highly dynamic relationships. Furthermore, in-line relationship management inside the supply chain will transform “supplier” into “providers” characterised by their own responsibility for goods and process portions with the relevant outputs. The envisaged scenario considers also the option of negotiating between steel and plant manufacturers the warranty to produce a contractual amount of steel tons with defined quality instead of direct hardware ownership and responsibility. Condition monitoring and predictive maintenance in the same time will be optimized part of the supply, realizing an effective win-win agreement.

This enables Smart Services to manage actions just before the equipment limits following self-detection, self-diagnostic, self-corrective, or self-controlled functions through the incorporation of technologies for sensing, actuation, coordination, communication and control. Moreover, optimised self-adapting model based, data analytics and process conduction will deploy IoT concepts in practice.

4.7 Cloud Computing

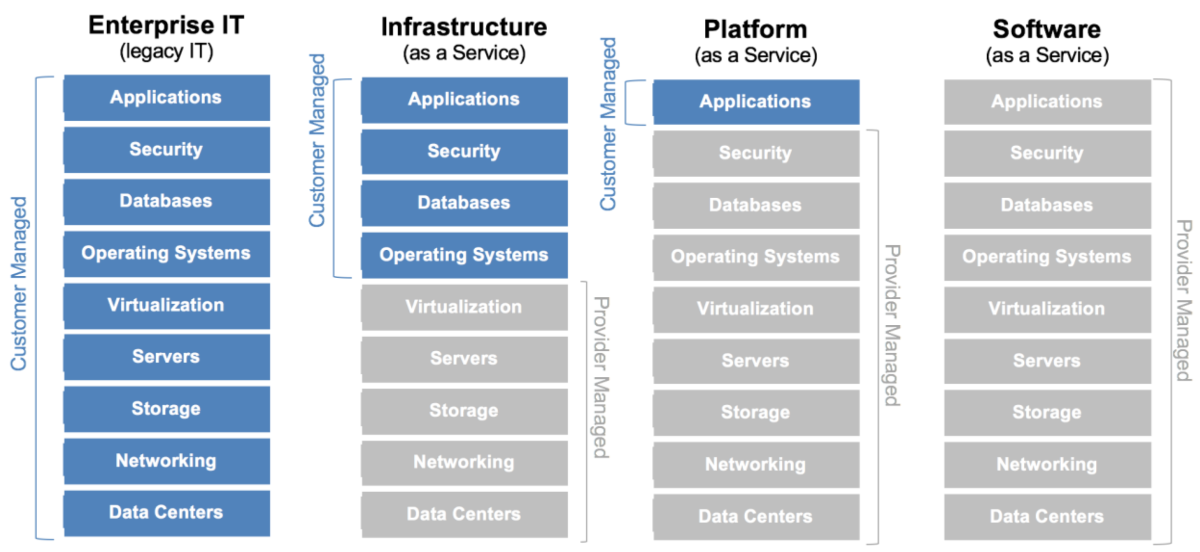
The use of the term Cloud Computing is now so widespread that it seems to be related to almost all fields of Information Technologies. Although it represents a major change in the IT industry, its nature must be specified. The US NIST proposed in 2011 a definition of Cloud Computing[1] which is still valid nowadays. For NIST, but the definition has been widely acknowledged by the IT industry, a cloud means management of IT resources in order to make them available as a service and according to five characteristics. The first one is **on demand use**: resources are available at customers' request. These IT resources are in **remote access**, usually via internet. **Resources are managed in a pool**: as long as they have been assigned to customers, they are for their sole use. It remains true until customers declare end of use, then resources are placed back in the pool and are available for other users. All **resource use is metered** and customers can be precisely charged on the resource type and duration of use. Finally, **resource allocation is elastic**, adaptable to change, so that customers can at any time and quickly change the amount of allocated resources they want to use. The later characteristic is a very important difference of the cloud compared to pre-existing IT resources providing services, like out-sourced IT resources management or hosting with coarse capacity planning, because it allows optimised use of resources over time (see figure).



This organisation of IT resources is available online at providers proposing **Public Cloud** offering or can be reproduced on premise by managing local IT resource according to cloud principles to form a **Private Cloud**, The two cases can be combined, for example to manage in public cloud temporary increase in resource needs when on premise resources are insufficient, and is then known as **hybrid Cloud**.

Cloud systems can also be divided into three groups depending on the kind of IT resources they manage and deliver to customers. In the first group, resources are basic processing (CPU, memory) and storage capacities, similar to what an IT hardware infrastructure provide, hence the name of **Infrastructure as a Service** (IaaS). Cloud offering can also deliver services and software components on top of infrastructure so that customers need only to deploy their software applications in order to use them. This second group is called **Platform as a Service** (PaaS) Cloud. Finally, customers might just want to remotely use applications pre-installed in Clouds, providing **Software as a Service** (SaaS).

[1] http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf



5 Challenges

Additional to the general I²M concepts to realise a future Smart Steel Industry and the therefore necessary Key Enabling Technologies it has to be recognised that some additional challenges have to be considered which are of technical and non-technical nature. These challenges are playing an important role regarding the question if the vision of a smart steel industry will become reality in future or not. Two examples of these challenges, one technical and one non-technical, will be discussed now.

5.1 IT Security

During the recent years, some major IT trends like internet based open architecture for communication and resource sharing, automation of decisions by software or the delocalization of information storage in the cloud have come up. At the same time, cybercrime as a “side effect” with perceived or real threats has manifested. As far as manufacturing enterprises are concerned, the main threats are

- Focus on companies and industrial espionage
- Attacks on industrial facilities
- Designed solutions for attacking process automation (sabotage)

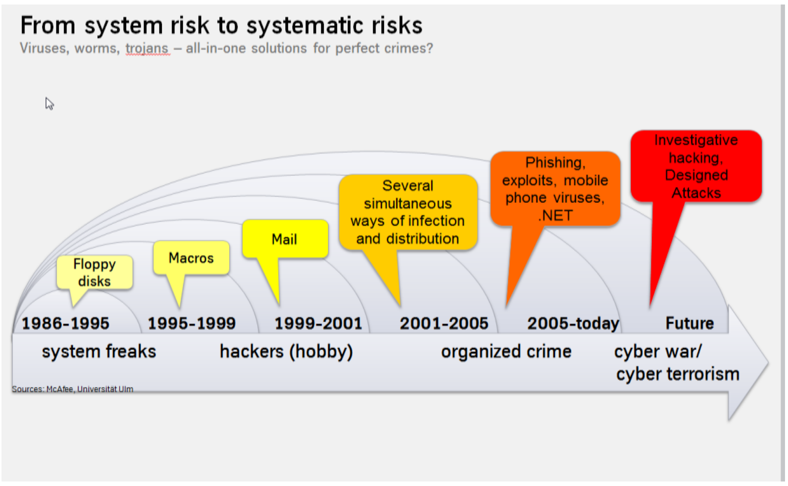
Machine control and production planning – systems are more and more communicating cross-company. Complex projects, infrastructures and systems are administrated and maintained via the internet and by use of smartphone-apps. Besides the physical security (hardware-design: encasement, printed circuit board layout, firmware), the networks (intranet) and IT-infrastructure must be secure. One of the keywords is the proof of identity of products, processes and machines/hardware.
For example, relating to automation and Cyber Physical Systems (CPS), the correctness of sensor data in view of dysfunction or a malware attack is crucial for the production process or staff safety.
The challenge for information security lies then both in the complexity and in the simultaneity of the aspects of enterprise processes to consider:

- Individualization of products under condition of large-volume production
- Process integration of customers and business partners
- Monitoring and real time control of process/supply chains
- Inspection and services by external staff (remote maintenance)
- Cost reduction
- Transit from old to new systems/machines, interfaces between them, existing security gaps on old systems/machines

- Implementation of change management processes

The new quality of threat: The rise of attacks on IT system is also the advent of new approaches of attack and more structured methods leading to cyber war and weaponized software tools.
While the common malware often uses simple exploits for initial infection (social engineering), is designed to communicate information to attackers and includes mechanisms for persistent operation even if detected, weaponized malware uses more sophisticated attack vectors for initial infection (social engineering, internal network or USB ports), is designed to operate in isolation, without remote command nor control and holds mechanisms for persistent operation or even reinfection if detected.

Compared to previous targets of attacks like “know how”, “patents”, “facts and figures”, “application-code”, “research and development”, “engineering designs” or “product technology” with the main intention of economic and industrial espionage, the new malware targets “control protocols”, “functional diagrams”, “process parameters”, “quality logs”, “control system designs” or “safety controls” and is aiming on the complete control of the compromised machine and thereby on the capability of sabotage.



Related topics Safety and Data privacy: As shortly mentioned above, safety is a crucial aspect of IT-security in the age of industry 4.0 and therefore there is a close connection between security and safety. Within this chapter, we will not go deeper but reference to the Working Group People which is treating this topic in detail.
Worth mentioning in the context of the protection of data privacy is the General Data Protection Regulation (GDPR). This is a regulation by which the European Commission intends to strengthen and unify data protection for individuals within the European Union (EU). It will become effective in 2018 for each EU Member State. The neglecting of data privacy and data security will then represent a yet major business risk.

Standards for security management: Security management is a continual process within an organization or company to ensure information security. Its task is the systematic protection of an information-processing IT-cluster. A normalized strategy is enabled by the use of IT-standards like ISO/IEC 27001 or IEC 62443. The IEC 62443 series is a technical specification which defines the terminology, concepts and models for Industrial Automation and Control Systems (IACS) security.
As term for the quality assurance system for information security, security level management (SLM) has established. Its main purposes are the company-wide transparent presentation of the security status at any time and the implementation of IT-security as a measurable quantity. It belongs to the range of tasks of the Chief Security Officer or Chief Information Officer or Chief Information Security Officer (CSO, CIO, CISO), who reports on IT-security and data availability to the company management.

5.2 Work 4.0

The implementation of Industry 4.0 paradigms is running with already visible effects on human tasks. In this revolution, automation has a leading role in industrial manufacturing; its further implementation, although being mainly part of the 3.0 paradigm, also with the new advances in ICT, is still a necessary step in many industrial applications. The acceleration of this process is having an increasing impact on tasks, organization, necessary skills and communications. The diffusion of digitalization in all aspects of worker life due to the replacement of manually and analogue acquired information by digital information. First of all, manual tasks as dangerous, dirty and dull manual work is replaced by smart sensors and/or robotics, eliminating or remotising tasks in hostile environments taking benefit from the extended communication between digital systems and between digital systems and smart machines (CPSs). In consequence, business takes benefits from the elimination of lost time injuries and the decrease of often untraceable human errors.

Already necessary manual tasks will shift from plant to centralized service centres, with big influence on the organization models in manufacturing and worker skills; this will inevitably shift manual and service-oriented skills to external offered services in favour of in-house higher specialized and multiple skills workers. As it is expected, human roles in the plant cover more and more monitoring at high-level and leading improvement and optimisation initiatives like, for example, high-level diagnostics for root cause analysis and simulation tools to test such improvements. Extended Big Data infrastructures enable progressively pro-active maintenance (based on prediction) rather than reactive (failure diagnosis after the fact) and complex decisions are supported by systems inducing high flexibility to manage changes. Real-time analytics, simulations and smart HMI’s, optimized planning and decision taking are broadened from local to plant wide (vertical), through process (horizontal) and through business (transversal).

Technical Operators in the Plants in particular focus on deviations from planned production and ways to reduce the consequences over the process route, technologists focus on eliminating disturbances permanently and improving performance bases on advanced analytics and virtual, real-time simulation. In the manufacturing landscape, data-scientists, virtual reality engineers and multiple-skilled operators become an integral part of daily plant operation life and wearable augmented reality tools are normal tools for human operators.

As the real environment for the employees is more and more replaced by remote and virtualized systems, the need for continuous training, tools and new skills take place with the support of Virtual and Augmented Reality. Careers are driven by attitude to flexibility, job rotation and job relocation. In this context, the educational aspects need the strict cooperation between private and public entities, including regional and state authorities. Social bodies and industry become players of a strict cooperation to promote and support the transformation from current to future workforce. In particular, schools and universities participate with industry with new learning models focused on broader skill sets of competences, cooperating with industry in organizing and supporting student staging in industry as part of scholarship courses and IT supported teamwork as usual practice. At the end of their educational course, students are characterized by extended multi-disciplinary background in scientific disciplines, necessary for the interaction with digital systems as a premise to the familiarity with digital systems and mobile devices; they are prone and flexible in turning roles and tools by means of frequent training courses. In consequence, the increasing demand of properly skilled workers requires a new strategic approach to workforce planning and recruitment for closing the impending gap between demand and offer, providing Talent Policy in the same time. In fact, talents are capital assets for competitive advantage in innovation and fast development and deployment of Digital Technologies with their integration in Factory and Corporate scale in the same time. Such factor pushes the EU and the Member States to sustain and support entities and individuals in valorising excellences in all the digitalization related sectors, in favour of the global competitiveness of the European Industry.

6 Future research needs

At the end of this document the short, medium and long term research needs in the field of Integrated Intelligent Manufacturing shall be presented based on the above described concepts and the key enabling technologies available today. As structure therefore the diagram presented in chapter 2.2 where the industrial challenges are connected with the general R&D needs shall be used. The table below has a dynamic nature in the sense, that it will be continuously adapted and changed in the next years by the I^{2}M working group depending on new upcoming key enabling technologies on the one hand and/or in the meantime solved or overcome tasks/problems on the other hand.

Customer orientation	Timescale
Steel products are tailored to customer processing and quality requirements	
Smart Product Inventory	Medium
Customer requirements and steel manufacturing capabilities are matched pro-actively	
Automatic auction methods for product selection via Multi-Agent-Technology	Short
Manufacturing supply chain fully integrated with premium customers	
Cooperative systems for supply chain management (incl. monitoring and simulation)	Medium
Manufacturing Supply Chain	
Transparent and dynamic material and product flow through the supply chain	
Tracking, tracing, genealogy technologies for all flat and long products	Medium
Solutions to make all supply chain data available in real-time everywhere in the factory	Short
Supply chain monitoring and simulation	Medium
Autonomous Planning & Scheduling integrated with material & product transports	
Solutions for self-organised planning and scheduling based on software agent technology and taking reverse planning and maintenance aspect into account	Short
Coordination of process control of single processes with material scheduling tasks	Medium
Fast product development	
Integrated product-process modelling and simulation	Long
Manufacturing Technology	
Cyber Physical systems with adaptive, self-learning capabilities	
Integrated networks of sensors based on IoT Paradigm incl. auto-check capabilities	Medium
Extraction of knowledge from huge amounts of data by Big Data approaches (incl. data reliability improvement) and combination with experience knowledge from people	Medium
Self-learning based optimisation of real time process models	Short
VR tools for process simulation and management	Long
Processes collaborate through-process for optimal quality & minimal resources	
Through-process and model based predictive control (feedback, feed-forward)	Short
Integral optimisation of product quality parameters (surface, properties, geometry) based on through process and multi objective optimisation approaches	Medium
Through-process product and installation info and tracking by advanced sensoring	
Solutions to realise tracking and tracing of products based on sensors and CPS	Medium
Augmented Reality applied to product evolution detection and process supervision	Medium
Minimal human interventions	
Remote control of operations by robots and remotely controlled systems	Medium
Intelligent pulpit for integrated manufacturing control	Short
Virtual Manufacturing for optimal process control and fast product development	
Modelling for integrated vertical-horizontal-transversal process simulation	Long
Manufacturing Assets	
Safe, secure and reliable machine-machine and human-machine interaction	**Medium**
Condition Based maintenance to secure total manufacturing continuity	
Solutions for intelligent predictive maintenance based on combinations of 1st principle models and Big Data approaches incl. learning capabilities	Medium
Remote condition monitoring and standardisation to enable efficient reliability	**Short**
Preservation and further development of existing investments	**Long**
Workforce 4.0	
Total Safety by minimal and remote interaction between humans and processes	
Anti-collision, anti-crushing, access control and tracking systems	Short
Solutions for the use of autonomous vehicles for difficult/dangerous operations	Medium
Knowledge driven skills at level of diagnosis, analysis and problem solving	**Short**
Virtual reality tools for effective and efficient intervention	**Medium**

7 References

/1/ COM(2010) 2020 COMMUNICATION FROM THE COMMISSION - EUROPE 2020 - A strategy for smart, sustainable and inclusive growth - 3.3.2010