Moving toward the digital factory in raw material resources area

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This paper presents our concept proposal of objectives to reach the challenges of some new European concepts: The Factories of the Future (FoF) initiative and The Intelligent Deep Mine (IDM) initiative launched to respond to the global economic crisis. These concepts aims at helping EU manufacturing and mining enterprises, to adapt to global competitive pressures by improving the technological base of production across a broad range of sectors. The ICT contribution to these initiatives should improve the efficiency, adaptability and sustainability of production systems as well as their better integration within business processes in an increasingly globalised industrial context. The challenges include the areas of digital factories, virtual factories and enterprises and finally smart factories. Next research should address these challenges in particular and will encourage international cooperation under the Intelligent Manufacturing Systems concepts.

Key words: *Digital Factory, Digital Manufacturing, Smart Factory, Virtual factory and enterprise, Enterprise Management System (EMS), Advanced Manufacturing Systems (AMS), lean principles, Service Oriented Architecture (SOA)*

Introduction

Nowadays in the industrial sector and especially in mineral resources industry, globalization and technical innovation are changing the way companies produce, distribute and support their products. Globalization and economic crisis has opened up markets and sourcing opportunities for producers everywhere. It has brought new customers and increased sales, along with new competitors, unfamiliar customer expectations, relentless margin pressure, and the complexities of global supply and distribution. To adapt within this borderless market environment, producers have adopted lean principles, continuous improvement and other process disciplines aimed at increasing efficiency, improving quality, reducing waste, lowering costs and abbreviating development cycles.

To implement these disciplines consistently across globally-distributed operations, manufacturers and producers are aggressively pushing information and communication technologies into non-traditional areas, adding intelligence to every area of their operations and even into the products themselves. By distributing sensors, processors and communication capabilities throughout the enterprise and linking them to an integrated infrastructure, they are creating end-to-end visibility across previously discrete processes. The result is an advanced technology and something that it is called the *digital factory*.

Digital and advanced technologies add intelligence to every stage of the product lifecycle. These new embedded technologies are transforming manufacturing and mineral resources industry today. ICT solutions and support are the core elements of this transformation [1]. By capturing raw data from distributed events and delivering actionable information to users and distributed decision points, these solutions create end-to-end visibility to enable lean operations. The ICT contribution to these solutions aims at improving the efficiency, adaptability and sustainability of manufacturing and mineral processing systems as well as their better integration within business processes in an increasingly globalised industrial context. The challenges of ICT contribution are fully dedicated to supporting the following areas of advanced technology:

- Digital Factory - or “digital manufacturing” including products life cycle management, modelling, design and optimisation.
- Virtual factories and enterprises - addressing end-to-end integrated ICT allowing for innovation and higher management efficiency in networked operations and supporting the emergence of 'smarter' virtual factories and enterprises.
- Smart Factory - including application experiments of control and sensor-based systems, laser systems and industrial robots.

The advanced technologies and materials are the basis of the future priority to improve European industrial competitiveness. The top-ranking technologies are the part of ***Advanced Manufacturing Systems*** leading to improvements in terms of new product properties, production speed, cost, energy and materials consumption, operating precision, waste and pollution management. The advanced technologies in mining industry will be based on marketable knowledge-based systems and the related services (e.g. simulation of automated robotics, extraction and finishing lines) with strong ICT support. Advanced technologies can be applied in all

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(Review and revised version 13. 1. 2011)

manufacturing and processing industries and form an important element in the supply chain of many high value industrial businesses [5].

Designing the infrastructure of Digital Factory

In the digital factory concept each stage in the product lifecycle is transparent to every other. Information flows automatically between systems and processes, constrained only by policy. Real-time information and actionable insight replace latency and uncertainty, eliminating the most common sources of waste and inefficiency, setting the stage for automation. It's a transformational development made possible by open, standards-based IT infrastructures that share several core features:

- An integrated application and data management software platforms.
- A scalable hardware infrastructure based on high-performance platforms.
- A service-oriented infrastructure design that delivers software and data as services, organizes hardware as virtualized resources and offers services that cross firewalls.
- Portable or wireless solutions that keep the enterprise securely and continuously connected to its material resources, production systems, employees, partners and products through a combination of local and wide-area wireless broadband technologies.

Real-time information and collaboration is essential to remaining competitive. Integrated and interconnected enterprise can enhance collaboration and reduce cost, waste and inefficiency throughout the product lifecycle - producing immediate productivity improvements from the shop floor to the top floor. Advanced communication technologies provide two critical capabilities in the digital factory - distributed data acquisition by enterprise management systems, automated workflows, and ubiquitous access to that data by mobile employees. Interconnection is the key factor to succeed in economically driven business environment. If a specialist leaves the site to get to a PC, the company incurs significant delays and lost productivity. But if the has point-of-use access to inventory information through a wireless device, the customer is back in production sooner and at lower cost. If the product can monitor its own operating state and communicate its status, the maintenance personal can substitute the required parts, reducing downtime and service expense even further.

Advanced ICT solutions across the Life Cycle

Advanced ICT solutions that combine embedded intelligence and wireless communications capabilities can deliver improvements at every phase of the product and customer life cycle, helping to reduce waste, shorten cycle times and bring real value to end-customers.

a) **Factory automation and autonomous equipment** - advanced ICT solution that combines intelligence and wireless communications capabilities, provide a continuous link between shop floor personnel, workstations, autonomous equipment, local process control systems and the enterprise management systems (EMS) that coordinate and manage production. They provide an ideal conduit for modern advanced signaling to synchronize just-in-time material deliveries, optimize work-in-progress levels, and orchestrate end-to-end process automation. Production workers can receive work orders and review instructions on the spot. *Production optimization* is enabled via integrated data collection and alert notification. In the ICT- enabled digital factory, production information gets into the system quickly so line managers can track problems and make faster, better informed decisions. Team leaders with access to the latest information can quickly switch workers from one task to another, respond to quality issues, provide electronic signatures, and react immediately if a machine or assembly line is reconfigured.

b) **Product development** - with advanced ICT solution working teams and marketing managers can use ICT to access the information they need, they can also collaborate more efficiently with team members, customers, and suppliers, more easily involving customers and suppliers in the development process. This ability to share ideas and data more broadly and in a more timely fashion enhances innovation, leads to more efficient design cycles and adds value for the customer. Efficient collaboration can also avoid expensive rework by identifying potential design and manufacturing problems earlier.

c) **Sales and order management** - field sales reps equipped with ICT solutions can access company databases to answer questions and place orders wherever they are. In many cases, the sale can be accomplished in a single visit rather than requiring repeated trips to the customer site. When mobilized sales staff enters orders directly throughout the day, they avoid duplicate effort and gain more time for selling. This can increase sales volumes and improve customer satisfaction by meeting customer needs faster.

d) **Supply chain** – ICT advanced solutions let manufacturers monitor supply pipelines in real time, replacing inventory safety stocks with accurate, up-to-the-minute information on material availability, location and delivery schedules. RFID tags on pallets and shipping containers, combined with scanners on warehouse loading docks and storage racks, track inbound and outbound shipments and monitor current inventory levels. All workers can now be fully connected.

e) **Service and product support** - for many manufacturers, ongoing *maintenance repair and operations* (MRO) activities are a significant cost center that offers extensive opportunities for savings in time and money. Empowered with ICT solutions, technicians can be more effective and enhance customer satisfaction. Field service staff can obtain work orders remotely and arrive at the customer site with a record of the customer's service history. They can refer to diagnostics databases, check asset lifecycle management databases for warranty coverage, order parts and check part availability on the spot.

Designing the platform for Service Oriented Architecture

Within the framework of a Service Oriented Enterprise, Service Oriented Architecture (SOA) helps manufacturing organizations benefit from right information. With advanced ICT solutions, combining embedded intelligence and wireless communications capabilities, and implemented on a robust SOA, data can be accessible to authorized users throughout the Digital Factory and its value chain. SOA extends the principles of modularization and standardization used to build today's Internet and Web environment and integrates the best elements of many emerging initiatives: utility computing, grid computing, on-demand computing, policy-based computing, organic ICT and others. SOA contrasts with the current generation of distributed computing in several important ways:

- **Hardware as virtualized resources -** resources are virtual and dynamically allocated, providing flexibility meeting peak demands cost-effectively.
- **Data as services -** a composite set of services that runs on a variety of execution platforms, giving users access to data located anywhere and at any time.
- **Services across firewalls -** secure delivery across firewalls makes it possible to extend mobile initiatives to external customers, partners and vendors.
- **Autonomic data sources -** sensors and devices can respond to real-world events by initiating immediate actions based on user-defined rules.
- **Embedded intelligence and wireless network applications -** wireless network applications work together seamlessly, distributing services and data across the network to facilitate real-time decision-making.

Designing the Digital factory and product lifecycle management

The digital factory concept is an integrated approach to enhance the product and production engineering processes. Within this concept simulation is a key technology and can be applied in virtual models on various planning levels and stages to improve the product and process planning. In the first phase of the digital factory concept the focus is on integrated product engineering. For this application area many tools are already available in the market. The second phase includes the plant design and optimisation in a collaborative environment concurrently with the product engineering. Many tools are available for specific purposes. However, there is still a lack of open integration possibilities between tools, planning levels, and optimisation on a multi criteria level. The third phase of the digital factory concept focuses on operative production planning and control down to the factory floor. This approach requires an extremely high effort and future research is needed to develop methods and tools for this approach.

Future work will focus on open standard interfaces available for integration of various tools from different software vendors into the digital factory system architecture. The realisation of the digital factory concept needs various software components such as design and planning software, GIS or simulation tools [14]. All these have to function closely together. A single software system cannot cover the complete range of required functionalities; this can be achieved with the use of specialised software systems and their integration. Therefore, the requirements for each such a system include:

- Networked system and data architecture with integration of processes and product development process.
- Open system architecture with standard interfaces.
- Modular architecture for expandability.
- Efficient data management.
- Consistent 3D and 4D-visualisation platform.
- Advanced documentation and change management (DMS and CMS).

The digital factory concept or architecture requires the integration of design, engineering, planning, simulation, visualization, communication and control tools on all planning and factory levels [13]. Each of the particular tools requires specific algorithms and specific data. The digital factory approach aims at using common data for all applications on different modeling levels (figure 1) in order to enable collaboration with virtual models for different purposes and different levels of detail [2]. Therefore an open architecture is an important feature of the digital factory concept. In practical use digital factory applications require the use of diverse SW components. For the integration of suppliers into development and supplier networks, open interfaces need to be developed with the exclusion of the proprietary ones. Open interfaces and interoperability are the key factors for implementing digital manufacturing concepts [4]. Conversely, the lack of open standards within a digital factory environment creates significant integration and implementation effort for customers trying to deploy digital manufacturing. The key elements within this approach include:

- **Open Factory Backbone** - an open factory backbone (OFB) is a scalable digital enterprise backbone to transform the process of digital manufacturing. It provides an open platform for the integration of independent software solutions that seamlessly interoperate with one another in a digital factory environment. Open XML technology gives a platform for factory wide data exchange. An open factory backbone provides a technology platform that benefits producers as well as application developers from different areas to independently create specialised applications that plug into an integrated digital factory environment and to offer a fully mature, open and integrated environment.
- **Linking the Factory Floor** - for the operative production planning and control an interconnection to the factory floor is mandatory. Open interfaces based on industry standards are required to integrate the various control levels with the planning level. [6]. A multi-tier architecture design enables to deploy a wide array of flexible architectures. These can be used to build up virtual applications, from the Human-Machine Interface (HMI) system to complex and demanding Supervisory Control and Data Acquisition (SCADA) systems.
- **Linking the ERP System**- in a digital factory environment the operative production planning and control also require a link to the enterprise resource planning (ERP) level. An ERP connector shall:
  - Provide data import and export facilities for routes, consumptions, equipment and users.
  - Connect HMI, SCADA, and product management systems to the ERP-systems.
  - Update the ERP with real-time floor data.

- **Factory Data Management** - planning and execution involves a variety of complex and interconnected activities from process planning to plant design, ergonomic analysis and quality planning. Information and data from product design, process engineering and production management have to be transparently handled for all applications in the digital factory environment.
- **Factory Process Management** - Factory Process Management (FPM) tools establish the relationships and associations between product, process, plants and resources, which are the basis for the creation of a manufacturing plan. The overall goal is to allow all users to quickly assess the impact of their decisions on product, process, plant and resource requirements. Software tools are required for simulation, workflow, change management, integrated visualization, and configuration management as well as integration tools. These tools are using the open factory backbone and the factory data management.

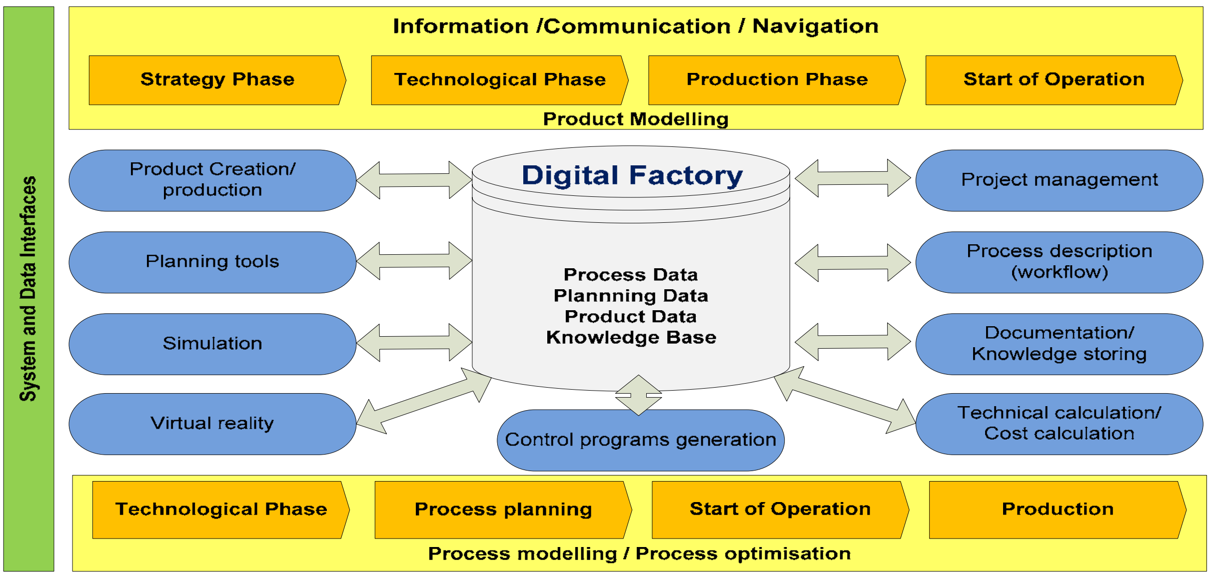

Fig. 1. The integrated design of Digital factory concept and product lifecycle management.

The future concept and architecture of Digital factory and generally manufacturing design addresses the product lifecycle management through interoperable models, engineering platforms, computer-assisted product and process development and analysis, and virtual prototyping and testing environments to reduce the need for physical mock-ups. It covers the three main areas to develop:

1. **Comprehensive engineering platforms -** that enable cross-disciplinary information sharing, workflow integration and the capture of product-relevant knowledge (e.g. manufacturing or treatment process knowledge embedded in the models and the engineering tools), supporting the reuse of knowledge across stakeholders and the product lifecycle (e.g from use to design). The product lifecycle in raw material processing area should support the focus areas covering the whole lifecycle - from exploration and extraction until reuse and recycling. It should reach processes from the exploration, the identification of valuable mineral resources to the sellable products. All steps of the supply and production chain for mineral resources should be underlined with societal issues of various kinds.
2. **User-intuitive tools for simulation and virtual prototyping with forward and backward compatibility** – that enable using of finer digital models to increase accuracy and integrating aspects such as functionality, forming, painting and assembly. The work should also aim at interoperable models enabling the use of various aspects of design and engineering, model auto-generation and robustness (e.g. automated meshing and optimisation) as well as the use of CAD-, CAE-, VR-, volume-, fluid-, structure-, polygonal- and process models in the various engineering stages. The future is the adaptation and scaling of engineering codes to next-generation of high-performance multi-core computing clusters.
3. **Tools for holistic modelling and simulation of full complex products and processes** – that enable using of multi-physics and support for tolerance changes in the models. The very important is the Digital modelling and simulation of product and process behaviour, e.g., regarding material properties from micro to macro scale (from the atomic level upwards).

Designing the intelligent mine-wide infrastructure, communication and process control

The future Intelligent Mine concept (Invisible mine, Intelligent Deep Mine, Mine of the Future) should develop a set of innovative methods, technologies, ICT tools, machines and equipment for the economical, eco-innovative, intelligent and safe exploitation of mineral raw materials in the EU including maintenance, especially in greater depths. The mine of the future (we take into account also the results of the Swedish conceptual study “Mine of the Future”), which most likely has to exploit mineral raw materials in greater depths than today, needs a completely different layout compared to today’s deep mines. This does not only include informatization, communication, planning and decision making tools but especially machinery for exploitation, transport and processing suitable to deal with the conditions of logistics. The core is to investigate into autonomous, highly selective mineral extraction processes and machinery based on new advanced (sensor) technologies as well as innovative concepts for mass flow management and transportation.

The concept of an invisible, zero (low) - impact mine further includes operating as much as possible working steps underground in order to produce the final product of a mine. The necessary level of automation in mining operations regarding also health and safety and logistics issues can only be achieved by reaching a high level of integration and interconnection in all parts of a mine. Fully integrated underground technologies and processes for diagnosis and extraction as well as communication, health and safety issues are the key for the success of the concept. Many systems for information gathering, communication, transferring various types of data and also to some extent integrating the data flow are commercially available. The decisions necessary in the day-to-day operation are nowadays made by individuals based on their own particular experiences. There is a big need to come to decision support tools providing an already integrated view of the current situation underground, comprising of all information available related to a certain topic. The future Intelligent Mine concept would provide the following developments beyond the state-of-the-art:

- An intelligent decision making tool that would determine the best possible production strategy with the highest likelihood of success. Resulting in increased productivity and reduced energy consumption.
- Reference model and digital engineering tool for performance, risk and cost analysis in long-term mining planning, connected to the developed intelligent using a standardized data exchange.
- Novel transport and logistics systems based on centralized plant design, underground pre-concentration using minimal underground infrastructure required due to plant capable of being installed vertically (gravity methods) and an intelligent technological logistics system design through the whole production process (production life cycle).
- A location, maintenance, monitoring system for autonomous vehicles as input to production management platform.
- A new hardware and software platform so-called “e-Intelligent Monitoring Network”, dedicated to ground stability control of mine development.

- A mine-wide sensing, monitoring and information system for on-line detection of mine activities like seismic movements passage of vehicles, blasting etc.

Mines and factories of mineral resources sphere are complex long life products which have to be adapted permanently to the changes of products, technologies and markets. The engineering of next-generation companies along all life cycle phases from investment planning to ramp-up and operation requires digital manufacturing technologies and tools. From the point of ICT support the research needs to focuses on development and applying the methods, instruments and tools for modeling, simulation, visualization and optimization of products, factories, manufacturing resources and processes [15]. The aim is the state-of-the-art ICT environment for integration and distribution of data, models, engineering tools, simulation applications and computing resources. The comprehensive research area should include:

- **Factory Life Cycle Management:**
  - A reference model for holistic and continuously integrated factory and process planning - Factory Life Cycle model.
  - A design for rapid manufacturing of products and resources - engineering in hybrid and complex environments.
  - An evaluation of factory performance from the complex view.

- **Factory Data Management:**
  - Modeling of networked, mine-wide and knowledge-based factories.
  - Reference factory data model for systematic and continuously data management.

- **Digital Engineering Tools:**
  - Development, applying and integration of innovative and advanced digital engineering tools.
  - RFID-based identification and localization of factory objects-context-aware applications.
  - Workflow management systems for factory lifecycle and knowledge-based factory operation.
  - Virtual Reality (VR) applications and intuitive interfaces (speech recognition, and 3D-input devices).

- **Advanced Engineering for Processing:**
  - Advanced technology - based distribution and networking of data, models, tools and computing resources.
  - ICT - integration platform for the continuously integrated and multi-scale modeling and simulation.

Conclusion

Business challenges demand that manufacturers and producers within mining and manufacturing industry streamline their operations, accelerate the pace of business, reduce waste and enhance product quality. Intelligent advanced solutions (Digital Factory, Virtual Factory, SMART Factory) play a crucial role in meeting these demands when deployed as part of an integrated, service-oriented ICT infrastructure. Connectivity between a manufacturer's enterprise management systems and its distributed work processes, supply inventories, employees and products provides the basis for continuous data capture and access. It enables real-time distillation of raw data into actionable information, and makes those insights available at any decision point, at any time.

As we stated above, the advanced technologies and materials are the basis of the future priority to improve European industrial competitiveness. Inteligent top-ranking technologies lead to improvements in terms of new product properties, production speed, cost, energy and materials consumption, operating precision, waste and pollution management. The advanced technologies supported by advanced ICT solutions in mining industry will be based on marketable knowledge-based systems and the related services (e.g. simulation of automated robotics, extraction and finishing lines). Advanced technologies can be applied in all manufacturing and processing industries and form an important element in the supply chain of many high value industrial businesses. They make up some 10.5 % of EU industrial productions and provide some 2.2 million jobs and account for 19 % of EU exports and over 40 % of EU private sector R&D expenditure [8].

Acknowledgement: *This contribution/publication is the result of the project implementation Research excellence centre on earth sources, extraction and treatment supported by the Research & Development Operational Programme funded by the ERDF.*

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