Manufacturing integration challenges: Top-down interoperability and bottom-up comprehensiveness towards a global information backbone for smart factory

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ABSTRACT: The Manufacturing paradigm is envisioned to drastically evolve from the mechanic-based system to the computer-assisted system driven by knowledge. The end-to-end process integration towards the virtual factory could be realized if only based on a fully digital factory model composed by Product, Process, Resource and Plant and their live characterization throughout their lifecycle.

Can standards help solve this "big picture" integration issue? Knowing that the top-down integration relies on applications interoperability while the bottom-up integration starts on unstructured data collection!

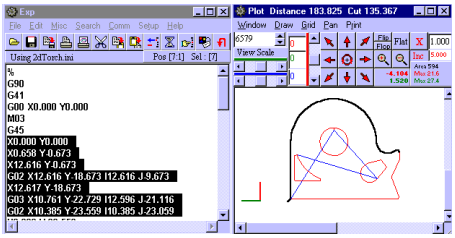
The present paper refers on the work achieved within the FOFdation project (FP7-IP-FOF-ICT), which addressed the need for the Factory of the Future to be based on an "end-to-end Digital Manufacturing Foundation" for simultaneously tackling quality, productivity and sustainability through a unique and interoperable IT platform.

1. The importance of information and knowledge in manufacturing

In the early 19th century, the industrial revolution which marked a major turning point in history, was the transition to new manufacturing processes going from hand production methods to mechanical systems. This led to the development of machine-tools that "help people to make things" by cutting and shaping metal parts. The first machine-tool was "free-handly" controlled by human who guided the tool-path manually, based on his knowledge of the part and the material he wanted to produce, but through a mechanical system that augmented his power and precision.

2. The evolution:

From automatic machine…



In the early 60's, machine-tool began to be numerically controlled and till today, the tool-paths are constrained by a NC program beforehand defined by a CAM software. Numerical control (NC) is the automation of machine tools that are operated by precisely programmed commands encoded on a storage medium, as opposed to controlled manually via hand wheels or levers, or mechanically automated via cams alone. Most NC today is computer numerical control (CNC), in which computers play an integral part of the control.

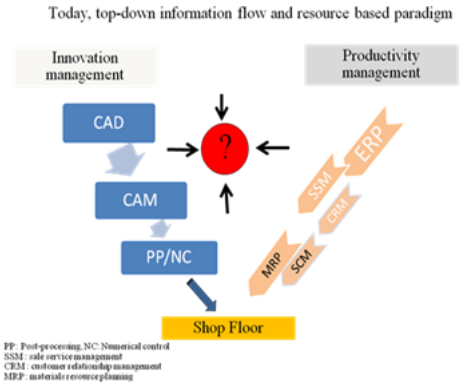
At present, machine-tool is still classified as an automatic machine: after once being set, it operates automatically and blindly follows the machining code provided and it is up to an operator to detect if a crash is about to occur, and for the operator to manually abort the cutting process. Indeed, any unforeseen condition cannot be met, and any hazard event may cause machine crash or failure, and harmful damage to the equipment and operator, despite collision detection through sensors or limiting switches that equip some modern machines.

To smart machine

In the Factory of the future, knowledge is essential and could or must be accessible everywhere, as the digital convergence will be also affecting manufacturing and allowing an interconnected web of information and production. Smart machines will collaborate with each other, with intelligent software, with tech-savvy workers, with customers, with managers all across the supply chain.

Machine-tool then can be augmented with new capabilities such as global awareness of human goals, perception of sensory and contextual information and decision for self-optimization capability.

3. The Technologies of Smart factory integration …



Previously, the industrial value chain, including product design, production planning, production engineering, production execution and management-finance-business services were implemented separately and operated as isolated applications-islands such as PLM, MES, NC-controller and automation, ERP, CRM... By making these systems interoperable or able to communicate at the semantic level, industry can leverage them for supporting shorter innovation cycles, awareness and transparency in manufacturing operations, raising productivity through knowledge sharing and minimizing risk through predictability assessment.

The key to making smart factory work is to create a dense mesh of technologies that are integrated and able to cooperating into a smarter and more efficient whole. Mobile Internet, Automation of knowledge work, the Internet of things and Cloud technology are the key disruptive technologies that sustain this new manufacturing paradigm.

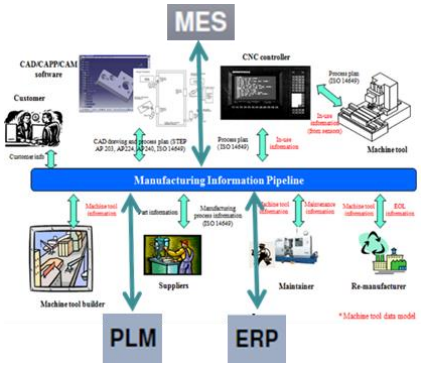
4. But the key challenge is still the semantic meaning of data…

To ensure downstream applications while preserving human's design intent to machine.

Geometrical design is the first stage to represent the human's goal about the geometrical and physical aspects of the part he wants to produce and that can meet user's needs. Today digital CAD model has replaced "analog drawings", and the CAD model can be seamlessly transformed into a CAM model. But the interoperability is still not fully streamlined as the end-to-end integration of data is not yet achieved outside the integrated CAD-CAM software, and neither a machine-tool nor a simulation or monitoring software at the shop-floor level can fully understand the "as-desired" part requirements and its business context.

Despite the progress made by CAD-CAM and today's PLM software, the product design-engineering-production process and its different applications are still communicating through the data translation mechanism that might lose the semantic meaning and impoverish the data to the destined software due to its smaller focused input-output. The strategic issue is twofold and in both horizontal (between different CAD systems) and vertical dimensions (between CAD and manufacturing systems):

- Dynamic data structure for changing business environment: even when attempting to define data models that focus on specific application, the scope cannot be properly defined because of multiple needs in different sectors, and their change overtime.
- Thorough knowledge of the product design and the designer's intent, knowing that all stakeholders in manufacturing need a subset of the original model based design data which can be fortunately well structured and mathematically described with the addition of information such as process, resource, pricing, logistic and planning sequences etc…



In FOFdation, the consortium proposes a Manufacturing Information Pipeline (MIP), based on STEP and STEP-NC to demonstrate a proof of concept of the manufacturing shift that consists of fully integrating the Design-Manufacturing process. The key proposition is the Smart Manufacturing Controller (SMC) tightly coupled with the Smart Manufacturing Optimizer (SMO): this combined SMC-SMO controller will exploit interoperability enabled by MIP, as a modern Master Model, between PLM-CAD systems and machine-tool while being able to optimize the cutting process in real-time, based on the closed loop assistance of the Smart Manufacturing Optimizer.

To comprehend executive operations: bottom-up live data, resources health and work context

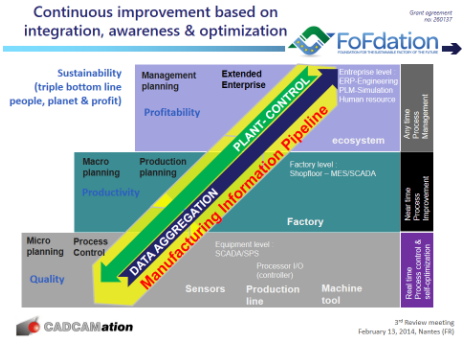
Many disruptive IT technologies are expected to help managers (and other knowledge workers) tackle overall management and planning tasks, by helping them aware of the manufacturing diagnosis through real-time information. The daily visibility of the factory shop floor health and the comprehensive awareness of the whole manufacturing eco-system (including customers and suppliers) are also primordial to the top management for taking the right decision at the right time within a global context, thus meeting the triple-bottom line objectives and requirements. Nevertheless, the bottom-up feedback process of data from the factory operational ground is still in the infancy stage today and many technologies are claimed to be the cornerstone for such innovating process like complex event processing, data pattern mining, or big data analytics… And at the data collection level, many commercial stand-alone solutions are existing on the market and can be classified into three categories:

- Dedicated data collection tools
- MES based tools

- Specialized systems for quality tracking or energy monitoring.

As a consequence of the analysis performed in FOFdation, our consortium has selected a MES system as a basis to our general monitoring solution and sustainability assessment. The data collection module (FoF-EMon) is proposed as a new feature of the extended MES (called Smart MES) which will be adapted to form a comprehensive approach for energy and resource monitoring, controlling and assessment. Such a combination leads to an improved awareness of the manufacturing operations performance through a configurable set of sustainability key performance indicators (KPIs).
The present approach is a pragmatic proposition to address a dedicated solution need: energy management or quality tracking. This might be not sufficient to address a general, real-time and permanent diagnosis in order to permanently watch after the manufacturing operations which generate huge data streams, but this could efficiently support engineering approaches towards product, process and resource characterizations that are needed to improve the optimization process reliability and correctness based on the fine-tuning of its validity scope.

5. Conclusion



This paper proposed a Manufacturing Information Pipeline framework built in a pragmatic way to support manufacturing interoperability towards global optimization.
Nevertheless, many challenges are still ahead of us and the interoperability for optimization at the forefront of innovation, in the perspective of extending the model based design, thus providing manufacturing stakeholders with complete knowledge from-design-to-manufacturing linked to business requirements. In order to continuously improve the manufacturing process at the different time scale levels for decision making and closed-loop optimization, we need to map live data (output) and goal driven data (input) thus supporting the root cause analysis.

6. Acknowledgements

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7. References

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