Factories of the Future Beyond 2013.
Which Role for ICT?

Workshop
Brussels, 14 October 2010

Synthesis of Submissions
Dr John Cosgrove
Limerick Institute of Technology, Ireland

October 2010
INDEX

Section One – Executive Summary .......................................................................................... 4
  Recommendations ................................................................................................................ 5
Section Two - Context ........................................................................................................... 8
  The Lund Declaration .......................................................................................................... 8
  Europe 2020 ..................................................................................................................... 9
    Flagship Initiative: "A Digital Agenda for Europe" ...................................................... 10
    Flagship Initiative: "Innovation Union" ....................................................................... 10
    Flagship Initiative: "An Integrated Industrial Policy for the Globalisation Era" ............ 11
  European Manufacturing and ICT ................................................................................. 12
  The Factories of the Future Multi-annual Roadmap ...................................................... 12
    ICT-enabled Intelligent Manufacturing ..................................................................... 13
Section Three – Keynote Presentations ............................................................................ 16
  An ICT Industry View: Synergies in Factories of the Future and Future Internet ......... 17
  A View from Research: There Is a role for ICT! ......................................................... 18
Section Four – Summary of Workshop Contributions ...................................................... 21
  Design Inputs ................................................................................................................. 21
  Product and Process Design ......................................................................................... 22
  Product Lifecycle Management (PLM) ......................................................................... 23
  Time Constrained Automation ..................................................................................... 24
  Non Time Constrained Control .................................................................................... 25
  Collaboration .................................................................................................................. 27
  Sustainability Metrics .................................................................................................... 28
  Manufacturing Services ................................................................................................. 29
Appendix 1 – References and Contributions .................................................................... 31
  Bibliography .................................................................................................................. 31
  Workshop Contributions ............................................................................................... 31
Appendix 2 – Agenda ......................................................................................................... 33
Appendix 3 – Participants List .......................................................................................... 34
Section One – Executive Summary

Two priorities set out in Europe 2020 are *smart growth*, developing an economy based on knowledge and innovation, and *sustainable growth*, promoting a more resource efficient, greener and more competitive economy. Amongst other things, these require making full use of information and communication technologies (ICT). The "Digital Agenda for Europe", one of the Flagship Initiatives of Europe 2020, promotes increased support of ICT in order to reinforce Europe's technology strengths. Another Flagship Initiative is the "Innovation Union" which aims to improve conditions and access to finance for research and innovation and to ensure that innovative ideas can be turned into products and services that create growth and jobs. A third Flagship Initiative, "An Integrated Industrial Policy for the Globalisation Era", identifies manufacturing as a vital activity area of the European economy with significant potential for transformation to new business models supported by ICT.

Factories of the Future have emerged as an R&D initiative driven by a multi-annual roadmap defined by industry which, in its ICT sub-domain, aims to interlink three concepts of the role of ICT in factories of the future: Digital, Smart and Virtual Factories. In *Digital Factories*, all knowledge, design and decisions are based on digital data. The *Smart Factories* concept encompasses the vertical integration of intelligent applications throughout the manufacturing process. *Virtual Factories* incorporate effective management of complex global supply chains to support manufacturing.

The workshop *Factories of the Future Beyond 2013: Which Role for ICT?* set out to discuss key ingredients for a future vision for the role of ICT in manufacturing and to chart the areas where research progress must be made. These include:

- **Digital Factories**: Standardised data ensuring interoperability between simulation and modelling tools and computer aided applications in general. Semantic technologies can help capture information from dedicated (social) networks and help mine large quantities of production data in real-time. Sustainable product life cycle management systems are required to manage obsolescence, reduce waste and promote recycling/remanufacturing.
Smart Factories: Low-cost automation and information solutions are needed to support SME users in particular. Process automation, energy efficiency and maintenance systems need to be developed further on the basis of modular system components and architectures, open control platforms and standardised interfaces ("plug & produce"). Also stepping up developments in sensing for cognitive machines is needed. Robots will increasingly be deployed with an emphasis on assisting and supporting human abilities in manufacturing and beyond.

Virtual Factories: Complex business relationships with global supply chain actors can efficiently be managed via shared platforms and data. Standardisation is needed to also trace the full carbon footprint of products (including their service components). Manufacturing services based on high-speed broadband and cloud computing will become prominent.

**Recommendations**

**Recommendation 1:**

Manufacturing must identify ways to add value, to reduce production times and to increase the level of customisation in the design, manufacture and supply of products.

**Recommendation 2:**

Manufacturing must lead the development of suitable semantic technologies capture information from dedicated (social) networks. This will facilitate the further integration of consumer needs into manufacturing design and drive more responsive and flexible production.

**Recommendation 3:**

Manufacturing must develop a standardised set of core meta-data that could be inherited by any relevant software tool (CAM, CAD, Modelling, etc.) without the need for translators.
Recommendation 4:
Manufacturing must develop techniques and models for new areas of manufacturing where typically large quantities of production data are available in real-time and from multiple sources.

Recommendation 5:
Manufacturing must develop tracing systems for product life cycle management. These must be based on long-term ICT solutions and sustainable operating systems.

Recommendation 6:
Manufacturing must develop automatically generated software and adaptive methods for distributed deterministic control systems. For regulated production, autonomous verification and validation of process code is vital.

Recommendation 7:
Manufacturing must facilitate the integration of robotics where they can assist and support human abilities in the manufacturing process and beyond.

Recommendation 8:
Manufacturing must develop low-cost automation solutions with modular system architectures, open control platforms and plug & produce interfacing standards to ensure that all benefits of automation are made available to SMEs.

Recommendation 9:
Manufacturing must implement integrated factory automation and energy management systems that can demonstrate the total per unit carbon cost of any product in near real-time.

Recommendation 10:
Manufacturing must implement intelligent maintenance systems which drive intervention when required and not just when scheduled.
Recommendation 11:
Manufacturing must adopt a capability-centric approach which integrates manufacturing and supply chains effectively at supplier and sub-suppliers (typically SME) level.

Recommendation 12:
Manufacturing and its supply chains must develop transparent standardised business performance indicators which include energy consumption and carbon cost per product labelling of products and services.

Recommendation 13:
Manufacturing must embrace new service-integrated manufacturing models and specifically opportunities to provide on-demand functionality for business processes and services.
Section Two - Context

The Lund Declaration

In July 2009, the Lund Declaration [LUND, 2009] was agreed by EU policy makers at the initiative of the Swedish EU presidency. The declaration sets out the need for cooperation in research and innovation across different sectors in society and the economy. The major Grand Challenges identified are: global warming, tightening supplies of energy, water and food, ageing societies, public health, pandemics and security. The overarching challenge will be to turn Europe into an eco-efficient economy.

Meeting the Grand Challenges requires:

1. Strengthening frontier research initiated by the research community itself. It is fundamentally important to create knowledge diversity, endowing the European Union with expertise, especially when confronted with unforeseen Grand Challenges and “shocks”. Competition among researchers will ensure that research carried out in Europe is of international excellence.

2. Taking a global lead in the development of enabling technologies such as biotechnology, information technology, materials and nanotechnologies.

3. Bringing together supply- and demand-side measures to support both business development and public policy goals. Measures are needed to maximise the economic and societal impact of new knowledge in areas such as industrial, environmental and social policies, agriculture and regional development. Links between these policy areas and research policies must be strongly improved. Supply-oriented research and innovation policies should be more strongly supported by demand-oriented policies, such as lead market initiatives, public procurement, problem- and issue-driven policies and priority setting.

4. Excellence and well-networked knowledge institutions. Modernisation of universities and cooperation between universities and research institutions is a key element for enhancing the competitiveness of European research. There is a need to develop instruments to stimulate and support initiatives for cross-
border cooperation between knowledge-building institutions in creating peak of excellence environments including for less developed research institutions.

5. The creation and maintenance of world-class research infrastructures in Europe including installations for big science as well as those serving the needs of social sciences and humanities.

6. A risk-tolerant and trust-based approach in research funding entailing actions for necessary changes in the Union's Financial Regulation and Rules for Participation and Dissemination.

**Europe 2020**

In September 2009 the President of the European Commission, Mr. José Manuel Barroso, summarised his objectives for the new Commission ahead of his appointment by the European Parliament [Barroso, 2009]. The challenges posed by global warming, a sustainable economy, energy efficiency, an ageing population, health and research and innovation were identified as key priorities.

This resulted in an agreed 10-year policy framework for the European Union: “Europe 2020 - A European strategy for smart, sustainable and inclusive growth” [COM, 2010a]. Europe 2020 sets out a vision of Europe's social market economy for the 21st century and how it can turn the EU into a smart, sustainable and inclusive economy delivering high levels of employment, productivity and social cohesion.

Europe 2020 puts forward three mutually reinforcing priorities:

- **Smart growth**: developing an economy based on knowledge and innovation.

- **Sustainable growth**: promoting a more resource efficient, greener and more competitive economy.

- **Inclusive growth**: fostering a high-employment economy delivering social and territorial cohesion.

At the launch of the new EU strategy smart growth is identified as being based on strengthening knowledge and innovation as drivers of future growth. Amongst other things, this requires making full use of information and communication technologies.
Europe 2020 proposes headline targets to be achieved by 2020 including: reducing greenhouse gas emissions by at least 20% compared to 1990 levels or by 30% (if international agreement is forthcoming); increasing the share of renewable energy sources in Europe's final energy consumption to 20%; and a 20% increase in energy efficiency.

These targets are representative of the three priorities of smart, sustainable and inclusive growth but they are not exhaustive: a wide range of actions at national, EU and international levels will be necessary to underpin them. The Commission is putting forward seven flagship initiatives to catalyse progress under each priority theme. These initiatives, are described [COM, 2010c] as “powerful tools to hand in the shape of new economic governance, supported by the internal market, our budget, our trade and external economic policy and the disciplines and support of economic and monetary union.”

**Flagship Initiative: "A Digital Agenda for Europe"**

The adoption of the Commission Communication on 19 May 2010 [COM, 2010d], proposing a "Digital Agenda for Europe" sets out the actions to take at EU and national levels to tackle bottlenecks and deliver on the Europe 2020 priorities.

These include measures to increase and reorganise research and innovation funds and further increase support of ICT to reinforce Europe's technological strength in key strategic fields as well as to create the conditions for high growth SMEs to lead emerging markets and stimulate ICT innovation across all business sectors.

The initiative acknowledges the importance of the Digital Agenda for Europe and the need to encourage the digital economy to use its enabling and cross-sectoral capability to increase productivity and competitiveness of other sectors as well as to take advantage of ICT to better meet global challenges, such as the transformation to a low carbon, resource-efficient economy and the creation of more and better jobs.

**Flagship Initiative: "Innovation Union"**

The "Innovation Union" Flagship aims to improve conditions and access to finance for research and innovation and to ensure that innovative ideas can be turned into products and services that create growth and jobs. In particular, the initiative aims to
re-focus R&D and innovation policy on the challenges facing our society, such as climate change, energy and resource efficiency, health and demographic change. Every link should be strengthened in the innovation chain, from 'blue sky' research to commercialisation [COM, 2010b].

At EU level, the Commission is working towards completing the European Research Area, and developing a strategic research agenda focused on the grand challenges, including such as energy security, climate change and resource efficiency, transport and environmentally-friendly production methods. With a view to achieve the Europe 2020 objective of smart, sustainable and inclusive growth, the Commission intends to launch European Innovation Partnerships in key areas addressing major societal challenges. One of the first such innovation partnerships will be based on the key enabling technologies to shape Europe's industrial future.

**Flagship Initiative: "An Integrated Industrial Policy for the Globalisation Era"

This initiative is entitled further: "Putting competitiveness and sustainability at centre stage". It highlights the need for industry to play a key role if Europe is to remain a leading economic power. The main policy document [COM, 2010e] is accompanied by a report on the competitiveness performance of the Member States, and the European Competitiveness Report 2010.

The report also confirms that the promotion of creative industries, activities at the crossroads of arts, business and technology, can enhance growth and innovation. Extremely fast growing, creative industries are key inputs for the development of other sectors. Activities such as design or software programming are able to reshape the process and product innovations of EU manufacturing industries.

Multi-purpose and forward looking, key-enabling technologies also have the potential to increase growth and productivity. EU’s competitiveness in nanotechnology, micro- and nanoelectronics (including semiconductors), industrial biotechnology, photonics, advanced materials, and advanced manufacturing technologies is remarkable, as is the potential world market for their applications. However, factors such as skills, R&D, venture capital, maintaining a manufacturing base and appropriate regulation will be crucial for the future development of key enabling technology applications in Europe.
European Manufacturing and ICT

Manufacturing is a vital activity to be supported if European society wants to survive these global challenges. Many jobs in Europe are dependent on manufacturing and downstream services. There are over 250,000 companies involved in manufacturing and production in Europe. These companies employ approximately 35 million people directly in manufacturing with over 70 million employed in ancillary or downstream services.

As Europe is facing a relative decline in manufacturing industries, new manufacturing business models based on services and supported by ICT present an opportunity for the transformation of industry. There are many drivers for the impact of ICT in manufacturing, these include: Managing increased complexity, shorter product development cycles, faster, more responsive and flexible processes, increased regulatory and environmental requirements and greater requirements for corporate accountability particularly across distributed global manufacturing systems.

Areas that have been identified with high economic potential include lifecycle management, knowledge-based engineering, industrial internet and intelligent manufacturing. Future development of ICT systems for manufacturing must incorporate the following key features: collaborative, digital from end to end, available in real-time and accessible across many platforms, including mobile.

As stated in the Lund Declaration, Europe should take a global lead in the development of enabling technologies such as information technology.

The Factories of the Future Multi-annual Roadmap

Under the Factories of the Future PPP an Ad-hoc Industrial Advisory Group has assisted the Commission in preparing a strategic multi-annual roadmap [FoF Roadmap 2010]. Developed through a process of workshops and strategic discussions between stakeholders from manufacturing industries and the related research community, the following strategic sub-domains were identified:

- Sustainable Manufacturing
ICT-enabled Intelligent Manufacturing

High-performance manufacturing

Exploiting new materials through manufacturing

The research areas described in the roadmap are expected to satisfy the following criteria: a clear enabling character, a specific focus on production technologies and, last but not least, an evident cross-sectoral application potential. Project results are expected to be implemented as improvements in production processes shortly after the conclusion of the projects, with commercial solutions leading to wealth creation through a competitive market position and added value generation.

**ICT-enabled Intelligent Manufacturing**

The contribution of ICT to manufacturing aims to improve the efficiency, adaptability and sustainability of production systems and their integration within agile business models and processes in an increasingly globalised industry, requiring continuous change of processes, products and production volumes. Also the further integration of any newly developed ICT into the production lines and the industrial environments requires complementary research and innovation efforts. These integration aspects will play a key role for generating and using smart production systems for factories in different industrial sectors. [FoF Roadmap 2010]

The existing roadmap follows the following structure:

**Smart Factories:**

Agile manufacturing and customisation involving process automation control, planning, simulation and optimisation technologies, robotics, and tools for sustainable manufacturing. Sub-topics include:

- Adaptive and fault tolerant process automation, control and optimisation technologies and tools
- Intelligent production machines and “plug & produce” automation equipment
- Large-scale validation of robotics-based and other automated manufacturing
- Intelligent cooperative automation and robotic control systems
Laser applications

New metrology tools and methods for large-scale and real-time manufacturing.

**Virtual Factories:**

Value creation from global networked operations involving global supply chain management, product-service linkage and management of distributed manufacturing assets. Sub-topics include:

- Increasing management efficiency of global networked manufacturing
- ICT for sustaining the value of products
- Product/service systems
- Managing volatile manufacturing assets.

**Digital factories:** Manufacturing design and product lifecycle management

A better understanding and design of production and manufacturing systems for better product life cycle management involving simulation, modelling and knowledge management from the product conception level down to manufacturing, maintenance and disassembly/recycling. Sub-topics include:

- Knowledge and analysis
- Enhanced, interoperable models for products and processes
- Design environments
- Lifecycle management.

The structures identified in the FoF Roadmap with respect to Digital, Smart and Virtual Factories capture the essence of the different strands of manufacturing that are particularly relevant to the application or development of ICT. However, it is important to recognise that there are strong overlaps and that any specific factory, enterprise or industry may incorporate some or all of these structures.
In specifying or developing the factories of the future it is imperative that all knowledge, design and decisions be based on digital data. Thus Digital Factories is a ubiquitous notion and underpins advances in the other areas. The digital factories could be seen as the first step on the road to the factories of the future. It is particularly important for SMEs to move towards end-to-end digitisation in order to add value and to leverage advances in all the three ICT domains.

The Smart Factories of the future encompass the vertical integration of intelligent applications throughout the manufacturing process. These intelligent applications should ensure the optimisation of resources, facilities and energy in all aspects of the manufacturing process.

Virtual Factories acknowledge that most modern manufacturing encompasses some level of supply chain external to the process. In some enterprises up to 100% of the process may be external. Whatever the level, the effective management of complex, global supply chains to support European manufacturing will be critical to the factories of the future. The carbon accounting in product logistics and the total carbon cost for the supply of goods and services will increasingly come to public attention.
Section Three – Keynote Presentations

An ICT End User's View: Can ICT Help Reduce Manufacturing Complexity?

In his presentation, Dr Jean-Bernard Hentz, CAD/CAM/PDM Research and Technology at Airbus SAS, France stated how ICT influences all manufacturing processes and represents an enabler for factories of the future:

“ICT is a trusted business partner capable of enabling and even driving strategic change in the use of innovative processes, technologies and solutions”.

Some of the challenges identified by Airbus include: reducing development lead time, increasing production ramp-up and managing work sharing with suppliers. In particular, the volume of data and the variety of applications that are used across the full supply chain poses a source of risk. Even where fully integrated solutions have been developed, problems reside in the scalability of the solution. The complexity and cost is prohibitive to move down to supplier and sub-supplier level (typically SMEs).

Recent application of best practice in "product-centric model" approaches to the development of manufacturing facilities has demonstrated impressive results in reducing product cycle times by 30%. A Product Lifecycle Management (PLM) approach incorporating fully integrated 3D tools and MRP with simulation capability ensures a strong relationship between engineering and manufacturing. Further benefits are seen from an earlier involvement of manufacturing engineers into the design process, including improvements in cost and quality of the tools in manufacturing. The 3D approach assisted in accelerating the ramp-up of competence with 3D simulations used for demonstrations, communication, training and risk analysis.

A future challenge for Airbus will be in the move towards a "manufacturing capability-centric" approach. Standardisation will be a key ingredient, along with flexibility in the manufacturing process and an Integration Architecture based on a "cloud" of databases inside the whole supply chain.
Where a fully integrated PLM approach has been adopted, issues have been identified with the growing complexity, unchecked data models, uncontrolled data duplication and critical data dissemination. This needs to be addressed with a standards-driven ‘out-of-the-box’ PLM platform using an optimised critical data model.

IT obsolescence is a challenge in PLM, where the product lifecycle exceeds the IT cycle time, for example 30 years for an aircraft vs. 5 years for an IT platform. This leads to high migration costs and constant upgrades in IT systems. Longer-term ICT solutions are needed that are based on sustainable operating systems and middleware. Longer-term maintenance of product data is a vital asset also for the recycling/ remanufacturing and end-of-life aspects of a product.

According to Mr. Hentz, in the last 10 years his company has "chased functionality, whereas now sustainability needs to be pursued". This is clear to the company's top management but it also requires a change of mindset with the providers of software and the end users.

**An ICT Industry View: Synergies in Factories of the Future and Future Internet**

In his presentation, Dr. Uwe Kubach, Director of the Research Center Dresden of SAP AG, Germany presented his company as a global leader in enterprise software for manufacturing. There are strong market opportunities for manufacturing ICT, for example, growth of 6% per annum is expected for performance management and orchestration tools until 2015. The biggest challenge facing the industry is the volatility on the international markets which requires faster and more flexible solutions. The internet is driving change as customers have more power in purchasing decisions.

His company has a policy of open innovation which means that it is more beneficial to carry out research work in collaboration with other partners. For new products, research typically starts 5 years before the final solution goes to the customer. Product enhancements take 1-2 years. Overviews were presented about projects ActionPlanT, KAP and PlantCockpit. The research outcomes are typically tested in
‘living labs’ to ensure that prototypes are developed including a customer perspective.

Dr Kubach identified areas where there are overlaps with Future Internet PPP, particularly across the Internet of Services. There exist strong opportunities to leverage technologies such as:

1. Real-time business intelligence
2. Business web, social web, mobility, guaranteed service
3. Cyber-physical systems, real-time data acquisition, real-time control.

What is needed is to move from orchestration to choreography. The adaptive control systems currently available are best compared to traffic at a set of traffic lights – complex arrangements can be managed and the timing and sequences of operation can be optimised under a strict set of rules or orchestration. What is needed is to move towards a more free-flowing model (a roundabout for the traffic) which is more loosely coupled or choreographed.

One of the major challenges for manufacturing will be the increased customer requirement and regulatory accountability over sustainability and environmental impacts. According to research on energy efficiency presented by Dr. Kubach, savings of up to 60% in energy use can be achieved where there is real-time awareness of what is going on in the process, what is being consumed, what the costs are and if decisions are taken to optimise the processes around energy use.

One of Europe’s main assets is that its enterprises can manage complex systems and can deliver 24/7 solutions. Exciting opportunities exist in leveraging the social web and in delivering manufacturing tools across mobile platforms. The future will be collaborative, real-time, end-to-end and mobile.

**A View from Research: There Is a role for ICT!**

According Professor Engelbert Westkämper, Director of the Fraunhofer Institute for Production Technology and Automation (IPA) in Stuttgart, Germany, it is worth noting that the manufacturing and service industries are the biggest market sector for ICT products in Europe. Challenges lie in the current inefficiencies of ICT in day-to-day manufacturing practice. These include:
1. The management of complexity and the management of obsolescence
2. The cost of software development for special applications such as, automation solutions, programmable controllers, embedded electronics
3. The openness of application systems and IT-architecture for engineering, product management, process management, lifecycle management
4. The lack of changeability in workflows where greater flexibility is required
5. The cost of implementation, service and maintenance of IT systems where the cost of extracting data can be a factor of 20 times the benefit of the resulting improvements
6. The gap between the digital/virtual and the real world in terms of data management, the cost of data acquisition and modelling, the integration of sensor/actuator data and the suitability of human interfaces
7. The reliability and accuracy of data where the level of incomplete or incorrect records can run to 20 or 30%
8. The security of data and operations on internal and external networks.

In particular there needs to be a focus on ICT for SMEs who don’t have the critical competences to develop, customise and implement integrated IT systems for manufacturing. SMEs require low-cost solutions, modular system architectures and interface standards. SMEs also need better education, skills and qualifications for the structural change from conventional systems to knowledge-based systems.

Prof. Westkämper identified further a number of fields with high economic potential for ICT in manufacturing. These are:

- Lifecycle management: PLM systems to follow each product's life from engineering to end-of-life
- Knowledge-based engineering environments for collaborative engineering and virtual engineering
- Ubiquitous networking (IT infrastructure and standards): Industrial internet for customisation, logistics, cooperation and services
- Technical intelligence: Learning and knowledge integration, intelligent mechatronic components and self-configuring systems.
The key R&D challenge will be to move to knowledge-driven and sustainable manufacturing. This is the right time to address the gap between ICT and manufacturing.
Section Four – Summary of Workshop Contributions

Design Inputs

Recommendation 1: Manufacturing must identify ways to add value, to reduce production times and to increase the level of customisation in the design, manufacture and supply of products.

Manufacturing must move from resource-intensive to knowledge-intensive operations with added value arising from capturing the consumers’ voice in the design, manufacture and supply of products. New capability services are required, particularly for SMEs, to facilitate mass customisation through on-demand and small-batch manufacturing.

Knowledge extraction and decision support capabilities based on artificial intelligence and data mining technologies will drive developments in business intelligence tools. These must be linked to factory and process embedded monitoring in order to provide real-time visibility of material flow and resource utilisation from the shop-floor to the boardroom. Methods should be developed to close the loop and implement needed decisions.

Furthermore, better models and tools are needed to support flexibility in production, service customisation, context adaptation, demand management and geographic and/or domain services that may ultimately lead to shorter time-to-market.

Recommendation 2: Manufacturing must lead the development of suitable semantic technologies capture information from dedicated (social) networks. This will facilitate the further integration of consumer needs into manufacturing design and drive more responsive and flexible production.

The needs of the consumer and of society are constantly changing within a very dynamic world context. The internet has significantly changed the interconnection between production and the consumer. This relationship has become increasingly individualised requiring ever faster reactions on offerings and demands, ultimately down to batch sizes of one. Opportunities exist to add value from the integration of new media driving towards the personal configuration of products. The development of suitable semantic technologies to capture relevant trends would facilitate the
Further integration of consumer needs into manufacturing design. This consumer focus will require a more responsive and flexible production.

The implementation of the fully digital factory is still an aspiration. New technology frameworks are required to address future challenges and support the needs of tomorrow’s “knowledge workers”. They should provide engineers and blue-collar workers with ICT-based tools to design and operate the Factories of the Future. Investment in education, skills and qualification for the structural change from conventional systems to knowledge based systems is required.

**Product and Process Design**

*Recommendation 3: Manufacturing must develop a standardised set of core meta-data that could be inherited by any relevant software tool (CAM, CAD, Modelling, etc.) without the need for translators.*

Recent best practice applications of "product-centric model" approaches to the development of manufacturing facilities has demonstrated impressive results leading to a 30% reduction of product cycle times. A PLM approach that would incorporate fully integrated 3D tools as well as MRP systems equipped with simulation capability can ensure the much needed strong interconnection between engineering and manufacturing.

To achieve the most effective outcomes in end-to-end digitisation of production, a standardised set of core meta-data is needed that could be incorporated by suitable software tools without the need for translators. All simulation, modelling tools and computer-aided applications should be truly interoperable. This would greatly simplify interaction across the various engineering platforms and between original equipment manufacturers (OEMs) and their suppliers with significant savings for the SMEs involved.

Significant benefits have been achieved through an early involvement of manufacturing engineers in the design process leading to improvements in the cost and quality of the manufacturing process tools. A full 3D approach can assist in accelerating the ramping-up of competences with 3D simulations used for demonstrations, publishing, training and risk analysis. The benefits of a fully integrated 3D CAx environment are not yet fully exploited by European
manufacturers with approximately 60% of them still using 2D systems. Further take up measures and a higher level of use of CAx tools are required.

Another aspect is the need for tools to operate seamlessly across platforms, especially mobile platforms, without the need to change the user interface.

**Recommendation 4:** Manufacturing must develop techniques and models for new areas of manufacturing where typically large quantities of production data are available in real-time and from multiple sources.

Techniques should be developed supporting the mining of large quantities of production data in real-time from a wide range of sources; from embedded intelligence in production tools right up to computing clouds hosting database, visualisation and simulation applications. Specifications for the format and processing of such information and additional parameters such as localisation or context should be investigated. The goal should be to present the most relevant data to business intelligence and decision support tools.

Furthermore, structured methods and tools, based on formal reference models comprising system specification, design and development, set-up and commissioning have been shown to be able to reduce ramp-up times for new products by up to 30%. New manufacturing paradigms, such as the manufacture of electric vehicles need new integrated models, including design “from scratch”, the development of manufacturing and services for electric vehicle batteries and models supporting mixed electric/internal combustion vehicles involving multi-power trains.

**Product Lifecycle Management (PLM)**

**Recommendation 5:** Manufacturing must develop tracing systems for product life cycle management. These must be based on long-term ICT solutions and sustainable operating systems.

Product lifecycle management systems from engineering to end-of-life are required to manage obsolescence and to reduce waste. It is important to ensure that the move to ‘zero-defect systems’ does not increase waste.

Where a fully integrated PLM approach has been adopted problems related to a growing complexity, uncontrolled data models, uncontrolled data duplication and
critical data dissemination have been reported. These can however be addressed via standards-driven ‘out-of-the-box’ PLM platforms and optimised critical data models. IT obsolescence is a challenge in PLM where the product lifecycle exceeds the IT cycle time. There are high migration costs due to constant upgrades in IT systems. Longer-term ICT solutions are necessary based on sustainable operating systems and middleware. Longer-term maintenance of product data is a vital asset in the recycling/remanufacturing of end-of-life products.

Tracing systems and ontology-based services for the disassembly of worn out or used parts in complex products should be developed.

**Time Constrained Automation**

*Recommendation 6: Manufacturing must develop automatically generated software and adaptive methods for distributed deterministic control systems. For regulated production, autonomous verification and validation of process code is vital.*

There are many applications in manufacturing, particularly in process control and robotics, where the need for hard real-time control systems is justified. Automatically generated software and/or recipes for distributed control systems that can cope with difficulties in determinism and synchronisation will speed up the development or the re-development of control applications. For regulated production, autonomous verification and validation of process code is vital to shorten the ramp-up time of new production.

Adaptive process automation is necessary where machine learning systems and self-adjustment is based on strict closed-loop feedback mechanisms. Automatic modifications should be possible based on the core instruction set, predicted operation and actual performance.

Cost effective solutions are required, particularly by SMEs, to guarantee the compatibility of new co-operative services with existing legacy production systems. The addition of process automation and robotics can lift the value creation potential of traditional processes and services and improve the costs and efficiencies of legacy systems thereby maintaining jobs in Europe.
Recommendation 7: Manufacturing must facilitate the integration of robotics where they can assist and support human abilities in the manufacturing process and beyond.

There should be further integration of robotics with an emphasis on the robots assisting and supporting human abilities in the manufacturing process. This requires intelligent IT solutions plus advanced technologies in robotics. These should lead to greater flexibility by combining commercial off-the-shelf (COTS) sensing mechanisms with mobile platforms that are autonomous enough to operate in close proximity to workers. The challenge is cost, reliability and efficiency, the technology is there, but not the system integration process.

Advanced robot technologies such as simulation platforms for highly reconfigurable robots, robotic inference for automated reconfiguration and self-configuring systems with learning and knowledge integration should be supported. Optics-based sensory systems such as lasers can be key technologies in creating cognitive machines that are aware of their environment, self-optimising, self-rigging, adaptive and fault-tolerant. Further development is needed on core components for high power ultra-short pulse laser systems required for high-speed optical components (e.g. scanners).

**Non Time Constrained Control**

Recommendation 8: Manufacturing must develop low-cost automation solutions with modular system architectures, open control platforms and plug & produce interfacing standards to ensure that all benefits of automation are made available to SMEs.

For every control application that requires deterministic performance there are multitudes of applications in which softer real-time requirements are good enough. These include many manufacturing automation, material handling and logistic operations. Similar ‘soft’ real-time operation capability can be applied to distributed SCADA and energy management systems, plants and utility controls.

CO₂ emissions can be reduced by 20% where there is near real-time monitoring of process and energy consumption data, correlation of data and automatic shut-down of unused functionalities.
For these types of applications, low-cost solutions based on modular system architectures, standard interfaces and open methods for the development automation software and systems could be developed. Automatically generated systems would assist in the deployment of enhanced production tools particularly in smaller enterprises and those without internal technical expertise. Such control systems should be based on service-oriented architecture (SOA) systems, integrated and pervasive web-based SCADA systems, Ethernet and wireless-based autonomous intelligent components as well as web-distributed documentation.

"Plug & produce" integration of control systems, sensors, tooling, machine modules and safety systems should be delivered. Modules should be intelligent, interoperable, bus powered, self-configuring and "hot-swappable". Plug & produce technologies and open software utilities for rapid reconfiguration at different levels, from lower levels (devices, sensors and actuators) to intermediate control levels (complex machines) up to overall production lines could increase reconfiguration speed of intelligent production systems by more than 40%. Future systems should allow the validation of control software against virtual plants with distributed control architectures.

*Recommendation 9: Manufacturing must implement integrated factory automation and energy management systems that can demonstrate the total per unit carbon cost of any product in near real-time.*

There are many applications such as, energy monitoring, environmental conditions and machine operations, where the information flow is primarily in one direction, facilitated by an increased deployment of embedded sensors. For such operations, information is more important "when needed" rather than in "real-time".

These systems are critical for the vertical integration of data with business intelligence tools where they provide the raw information for statistical analysis. Formal structures should be defined for how such embedded data can be integrated right up to computing clouds hosting database, visualisation and simulation applications. Modern algorithmic techniques should be adopted to ensure that the statistical exploitation of shop floor and plant-wide data leads effectively to the optimisation of processes.
Autonomous and intelligent production tools with real-time representation of tool activity, tool simulation and comparison between models and reality should be supported. To achieve a widespread penetration of intelligence-assisted production such solutions must be low-cost with modular architectures, open control platforms and defined interface standards.

**Recommendation 10:** Manufacturing must implement intelligent maintenance systems which drive intervention when required and not just when scheduled.

Enhanced monitoring systems with visualisation design and cognitive components including perception and learning could be developed. Features such as "neighbourhood awareness" (location/orientation, services, interfaces, interactions) and "situation awareness" should contribute to improved monitoring. Enhanced human-machine interfaces should be developed specifically for highly interactive human-machine environments.

Intelligent maintenance systems are required which drive intervention when required (predicted) and not just when scheduled. Both for standard maintenance systems and the increasing number of remote servicing applications, the operation should be based on "when needed" monitoring and management systems with embedded decision making capability.

**Collaboration**

**Recommendation 11:** Manufacturing must adopt a capability-centric approach which integrates manufacturing and supply chains effectively at supplier and sub-suppliers (typically SME) level.

The challenge of integrating manufacturing and supply chain processes in a global environment are immense. The volume of data, the variety of IT platforms and the variation in engineering and simulation tools leads to great complexity and difficulties in developing flexible solutions that can be applied across the supply chain. Where fully integrated approaches have been developed, problems reside in the scalability of the solution. The complexity and cost of the solution is prohibitive for suppliers and sub-suppliers (typically SMEs).
The future challenge will be to move to a "manufacturing capability centric" approach. Standardisation will be key along with flexibility in the manufacturing process and an Integration Architecture based on a "cloud" of databases inside the whole supply chain.

Secure web-based collaboration systems and ICT platforms are required to support distributed production. Tools for international collaboration, the building of virtual teams and virtual prototyping are still needed. The challenge resides on the virtualisation of work and validation techniques that allows for rapid developments within an international context.

Development is needed on the decentralised control of intra-logistic systems using autonomous, flexibly cooperating elements situated on different control-layers. Verified modules (safety, real-time, security) are necessary to address stability, predictability and trust requirements.

**Sustainability Metrics**

**Recommendation 12: Manufacturing and its supply chains must develop transparent standardised business performance indicators which include energy consumption and carbon cost per product labelling of products and services.**

The factory of the future should be green with no pollution, waste or emissions. It should enable a sustainable world as well as fair trade. The business model should be driven by the triple bottom-line (profit, people and planet) to deliver sustainability.

Business performance indicators should include additional metrics to throughput and overall equipment effectiveness (OEE): energy consumption, energy efficiency, carbon footprint, carbon cost per product, etc. These measures should be transparent across all elements of the supply chain. Standardisation is required to define the full carbon footprint of all components and services going into a product. This will allow customer comparison and clarity in the selection of supply chains.

Intelligent Computer Integrated Manufacturing (iCIM) Systems are needed which can schedule operations taking into account effects such as the manufacturing costs, the energy needed, the materials consumed, the supply logistics and the carbon-footprint of any item of production. Optimising the energy efficiency of a
manufacturing system is still an important challenge for Enterprise Resource Planning (ERP) systems. Use case scenarios for carbon neutral manufacturing should be developed.

In addition to efforts to achieve efficiency from an energy viewpoint in current factories, the reduction of the factories footprint (or the scalability from factory-size down to product-size) by a deployment of desktop factories close to consumers may also improve sustainability. Methods of autonomous factory generator/re-generator models to meet those requirements could be developed.

**Manufacturing Services**

**Recommendation 13:** Manufacturing must embrace new service-integrated manufacturing models and specifically opportunities to provide on-demand functionality for business processes and services.

There is a trend towards the “servicification” of manufacturing industries (to use and sell more services) which requires end-to-end digitisation of product, process, resource and plant and to have all the linked factories sharing data seamlessly to design and produce anywhere. Opportunities have been identified for new business models responsible for the full lifecycle of the product, i.e. the manufacturer being responsible for the installation, operation, maintenance and de-commissioning of products.

Support is needed for on-demand functionality for new business processes and services. ICT systems (high-speed broadband and cloud computing) that can make applications available for download and use when required will become more prominent. Standards and semantics could be developed that promote service-integrated manufacturing models with defined service quality management, service compositability and service adaptability and customisation. Plug & produce integration with support systems and online libraries of applications could be developed. The safety and real-time properties required to ensure the correct functioning of distributed systems needs further development.

There is a trend towards distributed production where units are autonomous and loosely coupled. This enables quick reactions to new conditions, unknown at the time
of creation, but it introduces risk, volatility and waste if suitable tools are not available.

The next generation of intelligent remote maintenance services should result in faster diagnostics and issue resolution. Interoperability and standardisation of such systems is necessary. The integration of in-line monitoring and structured diagnosis, of automatic failure detection and recovery procedures and of predictive maintenance techniques enabled by advanced manufacturing execution systems solutions could increase equipment up-time from 85% to 95%. Web-service-based solutions are required for after sales operation and real-time remote assistance.
Appendix 1 – References and Contributions

Bibliography


Workshop Contributions

Agirre Ibarbia, J., Fatronik-Tecnalia: Towards the new Manufacturing Service Industry

Bischoff, R., Coordinator Cooperative Research Projects, KUKA Roboter GmbH

Brennan, K., Intel: Manufacturing Challenges

Celefati, P., Prima Industrie S.P.A.: ICT for the manufacturing machines - The optimization strategy

Chryssolouris, G., University of Patras: ICT for FoF: Some Ideas

Cosgrove, J., Director – ACORN Research Institute, Limerick Institute of Technology

Decubber, C., Agoria asbl, EFFRA

Hentz, J.B., CAD/CAM/PDM Research and Technology, Airbus: Can ICT Help reduce Manufacturing complexity?

Hinke, C., Photonics21, Fraunhofer-Institute for Lasertechnology: Cognitive Machine – Key photonics components from ICT.

Ibanez-Guzman, J., Renault SA Engineering: Factories of the Future: Context and Challenges

Kubach, U., SAP AG: An ICT Industry View: Synergies in Factories of the Future and Future Internet

Lai, M., Process Research, Fiat Research Centre: FoF Beyond 2013, ICT role

Martinez Lastra, J.L., Tampere University of Technology, TTY Säätiö: Social and Operational Challenges: Towards the Personal Factory
| Martinsson, P.E., Luleå University of Technology |
| Münzenmaier, A., Festo AG & Co.: Three reasons why IT is indispensable for future manufacturing |
| Newman, S.T., Nassehi, A. & Dhokia, V.G., IdMRC - Innovative Design & Manufacturing Research Centre, University of Bath |
| Nguyen, V.K., FoFdation Technical Supervisor |
| Paniti, I., MTA SZTAKI: Factories of the Future beyond 2013: Which Role for ICT? |
| Pegman, G., Managing Director, R U Robots Limited |
| Runde, C., Virtual Design Cluster |
| Rusina, F., Comau SPA |
| Schulz, W., Fraunhofer-ILT |
| Sharratt, D., C3P Manufacturing/Dimensional Analysis, Jaguar-Landrover |
| Taisch, M., Politechnico Di Milano |
| Van der Pyl, T., Director "Components and Systems", DG INFSO/G, European Commission |
| van Dongen, P. & van Delft, A., DSM: Manufacturing IT - Vision and Roadmap |
| von Bose, H., Director "Industrial Technologies", DG RTD/G, European Commission |
| Westkämper, E., Fraunhofer-Institut für Produktions technik Und Automatisierung (IPA): Factories of the Future beyond 2013, A view from Research: The role of ICT |
| Wloka, J., Audi AG Production + Automation Technologies |
Appendix 2 – Agenda

Workshop - Factories of the Future beyond 2013: Which Role for ICT?

14 October 2010
Brussels

Background:
The Factories of the Future initiative as part of the European Commission’s Economic Recovery Plan aims at helping European manufacturing enterprises to adapt to global competitive pressures by improving the technological base of manufacturing across a broad range of sectors. Following consultations with industry, the Commission has included plans in the Work Programmes of the FP7 ICT and NMP Themes to launch until 2013 annual calls for a rapid set up of industry-driven R&D projects under this initiative.

Scope:
At the meeting, stakeholders will be asked to present ideas for an effective implementation of ICT, in particular Future Internet technologies, within the context of the Factories of the Future initiative. The outcomes of this meeting will contribute to shaping a future vision of ICT in Factories of the Future.

Chair: Erastos Filos & Rolf Riemenscheider, DG INFSO

9.30 Welcome – Meeting Rationale and Objectives
Thierry Van der Pyl, Director, DG INFSO, European Commission

10.00 A View from NMP
Herbert von Bose, Director, DG RTD, European Commission

10.30 A Manufacturer’s Perspective: Can ICT help Reduce Manufacturing Complexity?
Dr Jean-Bernard Hentz, Airbus Operations SAS

11.00 An ICT Industry View: Synergies in Factories of the Future and Future Internet
Dr Uwe Kubach, Director, SAP Research, Dresden

11.30 ICT for FoF beyond 2013
Presentations (3 slides/3 minutes) of participants and Q&A

13.00 (Net)working Lunch

14.00 Factories of the Future beyond 2013 – Which Role for ICT?
Discussion – Moderated by Rolf Riemenscheider

15.00 A View from Research: There is a Role for ICT
Professor Dr. Engelbert Westkämper, Director, Fraunhofer IPA

15.30 Rapporteur’s Summary & Conclusions
John Cosgrove & Erastos Filos

16.00 End of Meeting
Appendix 3 – Participants List

<table>
<thead>
<tr>
<th>First Name</th>
<th>Surname</th>
<th>Institution</th>
<th>Function</th>
<th>e-mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jon</td>
<td>Agirre</td>
<td>Fatronik Tecnalia</td>
<td>FoF AIAG</td>
<td><a href="mailto:jagirre@fatronik.com">jagirre@fatronik.com</a></td>
</tr>
<tr>
<td>Karl</td>
<td>Brennan</td>
<td>Intel Ireland</td>
<td>FoF Project KAP</td>
<td><a href="mailto:karl.g.brennan@intel.com">karl.g.brennan@intel.com</a></td>
</tr>
<tr>
<td>Paolo</td>
<td>Celefati</td>
<td>Prima Industrie s.p.A.</td>
<td></td>
<td><a href="mailto:p.calefati@primaindustrie.com">p.calefati@primaindustrie.com</a></td>
</tr>
<tr>
<td>George</td>
<td>Chryssolouris</td>
<td>University of Patras</td>
<td>FoF Project ActionPlant</td>
<td><a href="mailto:xrisol@lms.mech.upatras.gr">xrisol@lms.mech.upatras.gr</a></td>
</tr>
<tr>
<td>John</td>
<td>Cosgrove</td>
<td>Limerick Institute of Technology</td>
<td>Rapporteur</td>
<td><a href="mailto:John.Cosgrove@lit.ie">John.Cosgrove@lit.ie</a></td>
</tr>
<tr>
<td>Carmen</td>
<td>Constantinescu</td>
<td>Fraunhofer-IPA Stuttgart</td>
<td>Digital Factory</td>
<td><a href="mailto:CLC@iff.uni-stuttgart.de">CLC@iff.uni-stuttgart.de</a></td>
</tr>
<tr>
<td>Chris</td>
<td>Decubber</td>
<td>Agoria asbl</td>
<td>EFFRA</td>
<td><a href="mailto:chris.deubber@agoria.be">chris.deubber@agoria.be</a></td>
</tr>
<tr>
<td>Jean-Bernard</td>
<td>Hentz</td>
<td>Airbus SAS</td>
<td>FoF Project FoFDation</td>
<td><a href="mailto:jean-bernard.hentz@airbus.com">jean-bernard.hentz@airbus.com</a></td>
</tr>
<tr>
<td>Javier</td>
<td>Ibanez-Guzman</td>
<td>Renault SA</td>
<td>Engineering</td>
<td><a href="mailto:javier.ibanez.guzman@gmail.com">javier.ibanez.guzman@gmail.com</a></td>
</tr>
<tr>
<td>Uwe</td>
<td>Kubach</td>
<td>SAP AG</td>
<td>FoF AIAG</td>
<td><a href="mailto:uwe.kubach@sap.com">uwe.kubach@sap.com</a></td>
</tr>
<tr>
<td>Manuel</td>
<td>Lai</td>
<td>Fiat Research Centre</td>
<td>FoF AIAG</td>
<td><a href="mailto:manuel.lai@crf.it">manuel.lai@crf.it</a></td>
</tr>
<tr>
<td>José</td>
<td>Lastra</td>
<td>Tampere University of Technology</td>
<td>ARTEMIS</td>
<td><a href="mailto:jose.lastra@tut.fi">jose.lastra@tut.fi</a></td>
</tr>
<tr>
<td>Pär Erik</td>
<td>Martinsson</td>
<td>Luleå University of Technology</td>
<td>Process IT Innovations</td>
<td><a href="mailto:par-erik.martinsson@itu.se">par-erik.martinsson@itu.se</a></td>
</tr>
<tr>
<td>Andreas</td>
<td>Münzenmaier</td>
<td>FESTO</td>
<td>FoF AIAG</td>
<td><a href="mailto:mmm@de.festo.com">mmm@de.festo.com</a></td>
</tr>
<tr>
<td>Steve</td>
<td>Newman</td>
<td>University of Bath</td>
<td>Innovative Manufacturing Technology</td>
<td><a href="mailto:s.t.newman@bath.ac.uk">s.t.newman@bath.ac.uk</a></td>
</tr>
<tr>
<td>Van Khai</td>
<td>Nguyen</td>
<td>FoFdation</td>
<td>Technical Supervisor</td>
<td><a href="mailto:vknguyen@cadcamation.ch">vknguyen@cadcamation.ch</a></td>
</tr>
<tr>
<td>Imre</td>
<td>Paniti</td>
<td>MTA-SZTAKI</td>
<td>MANUFACTURE</td>
<td><a href="mailto:paniti@sztaki.hu">paniti@sztaki.hu</a></td>
</tr>
<tr>
<td>Geoff</td>
<td>Pegman</td>
<td>RU Robots Ltd</td>
<td>FoF AIAG</td>
<td><a href="mailto:geoff.pegman@rurobots.co.uk">geoff.pegman@rurobots.co.uk</a></td>
</tr>
<tr>
<td>Christoph</td>
<td>Runde</td>
<td>Virtual Design Cluster Stuttgart</td>
<td>Head of VDC</td>
<td><a href="mailto:christoph.runde@vdc-fellbach.de">christoph.runde@vdc-fellbach.de</a></td>
</tr>
<tr>
<td>Fulvio</td>
<td>Rusina</td>
<td>Comau</td>
<td>EFFRA</td>
<td><a href="mailto:fulvio.rusina@comau.com">fulvio.rusina@comau.com</a></td>
</tr>
<tr>
<td>Wolfgang</td>
<td>Schulz</td>
<td>Fraunhofer-ILT Aachen</td>
<td>Photonics21</td>
<td><a href="mailto:wolfgang.schulz@ilt.fraunhofer.de">wolfgang.schulz@ilt.fraunhofer.de</a></td>
</tr>
<tr>
<td>Name</td>
<td>Position</td>
<td>Organization</td>
<td>Email</td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------------------------</td>
<td>--------------------</td>
<td>------------------------------</td>
<td></td>
</tr>
<tr>
<td>Franz-Josef Stewing</td>
<td>Chief Engineer</td>
<td>Materna GmbH</td>
<td><a href="mailto:Franz-Josef.Stewing@materna.de">Franz-Josef.Stewing@materna.de</a></td>
<td></td>
</tr>
<tr>
<td>Marco Taisch</td>
<td>FoF Project ActionPlanT</td>
<td>Politecnico Di Milano</td>
<td><a href="mailto:marco.taisch@polimi.it">marco.taisch@polimi.it</a></td>
<td></td>
</tr>
<tr>
<td>Engelbert Westkämper</td>
<td>IPA Director, MANUFUTURE</td>
<td>Fraunhofer-IPA Stuttgart</td>
<td><a href="mailto:engelbert.westkaemper@ipa.fraunhofer.de">engelbert.westkaemper@ipa.fraunhofer.de</a></td>
<td></td>
</tr>
<tr>
<td>Joachim Wloka</td>
<td>Production + Automation Technologies</td>
<td>Audi AG</td>
<td><a href="mailto:joachim-peter.wloka@audi.de">joachim-peter.wloka@audi.de</a></td>
<td></td>
</tr>
<tr>
<td>Thierry Van der Pyl</td>
<td>Director &quot;Components and Systems&quot;</td>
<td>European Commission INFSO/G</td>
<td><a href="mailto:thierry.vanderpyl@ec.europa.eu">thierry.vanderpyl@ec.europa.eu</a></td>
<td></td>
</tr>
<tr>
<td>Herbert von Bose</td>
<td>Director &quot;Industrial Technologies&quot;</td>
<td>European Commission RTD/G</td>
<td><a href="mailto:herbert.von-bose@ec.europa.eu">herbert.von-bose@ec.europa.eu</a></td>
<td></td>
</tr>
<tr>
<td>José-Lorenzo Vallés</td>
<td>Head of Unit &quot;Production Technologies&quot;</td>
<td>European Commission RTD/G</td>
<td><a href="mailto:jose-lorenzo.valles@ec.europa.eu">jose-lorenzo.valles@ec.europa.eu</a></td>
<td></td>
</tr>
<tr>
<td>Augusto de Albuquerque</td>
<td>Head of Unit &quot;Microsystems&quot;</td>
<td>European Commission INFSO/G</td>
<td><a href="mailto:augustodealbuquerque@ec.europa.eu">augustodealbuquerque@ec.europa.eu</a></td>
<td></td>
</tr>
<tr>
<td>Andrea Gentili</td>
<td>FoF NMP</td>
<td>European Commission RTD/G</td>
<td><a href="mailto:andrea.gentili@ec.europa.eu">andrea.gentili@ec.europa.eu</a></td>
<td></td>
</tr>
<tr>
<td>Rolf Riemenschneider</td>
<td>FoF ICT</td>
<td>European Commission INFSO/G</td>
<td><a href="mailto:rolf.riemenschneider@ec.europa.eu">rolf.riemenschneider@ec.europa.eu</a></td>
<td></td>
</tr>
<tr>
<td>Laszlo Csernak</td>
<td>FoF ICT</td>
<td>European Commission INFSO/G</td>
<td><a href="mailto:laszlo.csernak@ec.europa.eu">laszlo.csernak@ec.europa.eu</a></td>
<td></td>
</tr>
<tr>
<td>Erastos Filos</td>
<td>FoF ICT</td>
<td>European Commission INFSO/G</td>
<td><a href="mailto:erastos.filos@ec.europa.eu">erastos.filos@ec.europa.eu</a></td>
<td></td>
</tr>
</tbody>
</table>