Production Paradigms Ontology (PPO): a Response to the Need of Managing Knowledge in High-Tech Manufacturing

Augusta Maria Paci[1], **Maria Stella Chiacchio**[2], **Cecilia Lalle**[3]

Emerging Production Paradigms Laboratory (EPPLab) of Institute of Industrial Technologies and Automation (ITIA) of Consiglio Nazionale delle Ricerche (CNR), Via dei Taurini, 19 – 00185 Roma – Italy
augusta.paci@itia.cnr.it, maria.chiacchio@itia.cnr.it, cecilia.lalle@itia.cnr.it

Abstract Innovation issues require knowledge management to support the innovation process towards the new industrial goals. The Mass Customization and the High Value Added products & processes paradigms constitute the target of the most important innovation initiatives. These two manufacturing paradigms have been deeply analyzed in relation to both Technology and Market & Society, driving forces of the industrial innovation. The research object is to develop a top-down ontology approach – the Production Paradigms Ontology (PPO) – to enable Knowledge Management to support the innovation process towards Mass Customization and HVA products and processes for competitiveness and sustainability of industry. This paper consists of three parts concerning the Production Paradigm Ontology approach, the macro-categories and three study cases. PPO approach implies relevant elements that are the Time Horizon, the Driving Forces Technology and Society & Market, the Enabling Factors of the Innovation process life-cycle (design, implementation, use and reconfiguration) and the Infrastructure Level. The macro-categories describe real entities. The three study cases, analyzed through the three phases of the innovation process (implementation, use and reconfiguration), show how PPO could support knowledge management in the innovation process that each organization is carrying on to respond to turbulent and competitive markets.

Keywords: Innovation process ontology; Knowledge management; HVA products and processes; Best practices

---

[1] Dr. A.M. Paci is the main author. She wrote chapters 1, 2, 3, 3.1, 3.2 and 4.
[2] Ing. M.S. Chiacchio has contributed to chapter 3.2.
[3] Dr. C. Lalle wrote chapters 2.1 and 3.3.

A. Bernard, S. Tichkiewitch (eds.),
Methods and Tools for Effective Knowledge Life-Cycle-Management,
DOI: 10.1007/978-3-540-78431-9_13, © Springer 2008

1 Introduction

Companies are becoming aware of the importance of the industrial transformation to High Value Added (HVA) products, processes and services to keep their business competitive through an innovation process.

This innovation process is considered the enabler of the achievement of the transformation within complex organizations. Innovation issues require knowledge management to support the innovation process towards the new industrial goals.

The Mass Customization and the HVA products & processes paradigms constitute the target of the most important innovation initiatives.

These innovation initiatives are due to shortened product/process life-cycle, rapid progress in technologies and turbulent business environment. Therefore, high-tech manufacturing involves great investments in innovation especially in knowledge management through different layers of the organization: multiple industrial locations, different industrial departments/divisions, methods for supporting industrial products and processes, methods and tools to motivate employees, tools for measuring performance.

To respond to the users' innovation needs and to maximize the use of knowledge within organizations, it becomes essential to develop an ontology that enables to link what the company shares and reuses – as already known – and what the company should learn and know to achieve higher levels of innovation.

The Production Paradigm Ontology (PPO) allows categorizing innovation activities according to a system approach needed in complex transformation processes. This approach permits:

- at company level, the introduction of several types of innovation-oriented activities into operative industrial processes;
- at stakeholders level, to relate different organizations (i. e. public, private) that collaborate to achieve shortened time-to-market of products and processes through bridging the gap among science, industry and market.

The PPO is a contribution to the governance of innovation providing trial applications. It allows on one side to define the evolution towards the main objectives of the industrial transformation and on the other side to provide the control mechanisms of the innovation processes. These two aspects are fundamental to rule the shortened life-cycle of innovation processes in complex contexts.

The research background are the Production Paradigms that – inside Production Engineering area – are conceptual tools that aim to identify the driving forces that influence technology developments and industrial transformations in the past and in the future [1]. Nowadays, "Mass Customization" is the paradigm of the industrial strategies to survive to the market challenges started in the '90.

Looking towards 2020, the new emerging “High Value Added paradigm” states the need to integrate R&D knowledge into the continuous generation of HVA products/processes.

The research elaborates, in the ontology perspective, the published frame of production demand/response paradigms (Fig. 1) that maps the history of industrial developments to respond to the demand of new products and processes [1, 2]. The two mentioned manufacturing paradigms are currently deeply analyzed in relation to both Technology and Society & Market as driving forces of the industrial innovation and are discussed in strategic research agendas, foresight studies and roadmaps carried on at European level to assure the manufacturing in Europe [3, 4].

In detail, it exploits part of the frame, focusing on Customization and Innovation industrial research areas as the basis for the proposed innovation oriented ontology for new production engineering. Therefore, the research aim is to develop an ontology approach – the Production Paradigms Ontology – to enable Knowledge Management to address the innovation process towards Mass Customization and HVA products & processes for sustainability.

This paper consists of three parts concerning the Production Paradigm Ontology approach, the PPO macro-categories and three study cases related to the phases (Design, Use, Implementation and Reconfiguration) of the innovation process.

2 The PPO Approach

The research object is to develop an ontology approach – the Production Paradigms Ontology (PPO) – as a “domain ontology” for high-tech research-based manufacturing in the knowledge economy [5].

This Ontology can support Knowledge Management in the innovation process towards Mass Customization and HVA products & processes paradigms, as strategic innovation industrial areas, for competitiveness and sustainability of industry.

The PPO approach has been built upon the reference frame published in 2003 and reported in Fig. 1.

The architecture of the Production Paradigms Ontology (Table 1) allows encapsulating and handling core concepts of high-tech manufacturing strategies managing dynamically the current meanings that are generated and used in the innovation process of the company.

Table 1 is the basic architecture for industrial innovation as a response to market competitiveness relating the two new paradigms to the four elements of the PPO time horizon, the driving forces of the innovation process (Technology and Society & Market), the enabling factors, the infrastructure level. These four elements are described below:

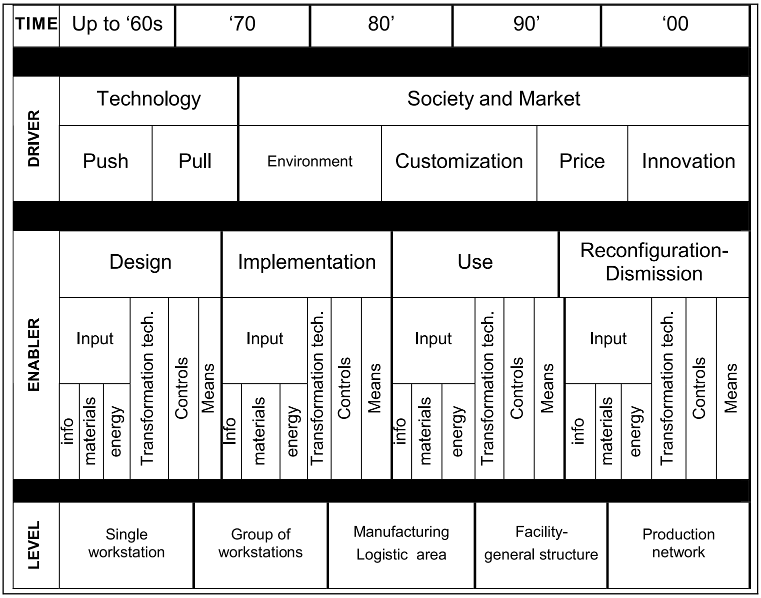

Fig. 1 NEST context demand Paradigms and Industrial Response Paradigms (Source [1])

Table 1 PPO approach to High-Tech Manufacturing Paradigms

PARADIGMS / ELEMENTS	*Mass Customization*	*HVA Product & Process*
TIME HORIZON	Nowadays	2020
DRIVING FORCES TECHNOLOGY	Push & Pull technologies	Emerging Technologies
DRIVING FORCES SOCIETY & MARKET	Environment Product Customization Price	Environment HVA Product & Customization Price Continuous Innovation
ENABLING FACTORS	Innovation process life-cycle (design, implementation, use, reconfiguration)	Innovation process life-cycle (design, implementation, use, reconfiguration)
INFRASTRUCTURE LEVEL	Infrastructure Facility	Production Network

Time Horizon: defined by Visions and Strategic Research Agendas documents issued by the European Technology Platforms.

Driving forces: are Technology and Society & Market influencing the need of the industry to change.

Technology is considered a key-driver for high-tech manufacturing. Infact, existing taxonomies for manufacturing technologies are at a critical point. Technologies' descriptions, used in current taxonomies, are unable to group complex phenomena related to continuous development (i. e. the IMTI taxonomy for Manufacturing sector, which has been a major source, is now under deep revision). The five new *main* Research & Development Areas identified by the Manu*Future* Strategic Research Agenda are [6, 7]:

1. New business models
2. Adaptive manufacturing
3. Networking in manufacturing
4. Digital, knowledge-based engineering
5. Emerging technologies

Technology may be divided in:

- a large number of push/pull enabling technologies described in the above mentioned transectoral Roadmaps;
- innovation time scale strategies to be worked out by single enterprise and collective projects.

The Driver Society & Market is considered another Key Driver for high-tech manufacturing and refers to:

- Eco-sustainability
- Socio economic environment
- Regulation
- Values-public acceptability

Enabling Factors: are the innovation process phases (Design, Implementation, Use and Reconfiguration/Dismission) – with related input/output controls and means. The enabling factors characterize the life cycle of engineering and manufacturing issues of products/services, processes and enterprises.

Infrastructure Level: this element refers to the level of infrastructure innovation (single Process/Work Station, component/Group, Machine/Area, Factory/Facility, and Network) and is characterized by hard & soft technology and ICT development.

Summing up, PPO elements in real cases, moving towards the new production paradigms, provide the support for the definition of:

- first, the concepts behind the company strategic goals (environmental, price, customization, push/pull innovation) to be related to the driving forces Technology and Society & Market;
- second, the meanings related to the Enabling Factors that form the planning of the innovation process life-cycle (design, implementation, use and reconfiguration with the appropriate controls and means);

- third, the expected output of the innovation process for the company strategic transformation related to the Infrastructure Level.

In this perspective, PPO allows to handle the whole innovation process and the continuous introduction of new technologies for business that involve the complex manufacturing and production chain [2].

The Production Paradigms Ontology strength is to influence the company context and the communication process within the organization, facilitating the internalization and externalization of knowledge towards the innovation goals around the specific targets of Mass Customization and HVA products & processes paradigms [8, 9]. In this way, PPO enables to transform a company knowledge system into a High Value Added communication context able to respond to continuous innovation needs in specific production domains [10].

2.1 The PPO Macro-Categories

PPO for high-tech manufacturing can enable Knowledge Management to describe real entities and a new mode of knowledge generation transfer, maintenance and reconfiguration in time.

This approach, with macro-categories, allows:

- to categorize several types of innovation-oriented activities inside the company;
- to relate and match all the innovation-oriented activities across different public and private organizations.

The scope of macro-categories is to specify several innovation oriented activities and to define the relationship among innovation processes life-cycle.

The innovation oriented activities generate knowledge useful in the operative industrial processes. The relationship among innovation processes life-cycle are carried on by different stakeholders, bridging the gap among science, industry and market.

The PPO macro-categories are: concepts, properties, quality, status, roles. These macro-categories enable to describe high-tech manufacturing innovation-oriented activities, as reported in Table 2.

Each macro-category is characterized by components of high-tech manufacturing paradigms following the PPO approach (see Table 1).

The components of macro-category *Concepts* correspond to the driving forces (Technology and Society & Market) as identified by the two paradigms (Mass Customization and HVA products & processes). The components of the other macro-categories correspond respectively: *Properties* to Infrastructure level; *Quality* to type of paradigm, *Status* to Enabling Factors.

The components of *Roles* correspond to the objective of the organization's innovation process.

Table 2 PPO macro-categories

CONCEPTS (G) Driving forces	PROPERTIES (S) Infrastructure levels	QUALITY (G) Response paradigm	STATUS (S) Innovation Process Life-cycle	ROLES (G) Target
• Innovation • Environment • Competition • Customization • Push/Pull technologies • Sustainability • Price	• Infrastructure Facility • Production Network	• Mass Customization • HVA Products & Processes • Mass Customization and HVA Products & Processes	• Phase 1 – Design • Phase 2 – Implementation • Phase 3 – Use • Phase 4 – Reconfiguration	• Market Leadership • Survival

Concepts, *Quality* and *Roles* contain general components (G) of the transformation process, while *Properties* and *Status* focus the actions and the process phases of the single innovation initiative with specific and detailed components (S).

The Knowledge Management, supported by the PPO macro-categories, could handle information priorities at a higher level than day-by-day operations.

The development of the PPO macro-categories will address basic issues in the following sub-domains of high-tech manufacturing:

- Products/Services:
  - Focus on product innovation needs
  - Capitalization of knowledge concerning processes and technologies
  - Exploitation of pertinent knowledge
- Processes:
  - Focus on processes innovation needs
  - Integration of knowledge into processes
  - Convergence of business and processes
- Enterprises:
  - Focus on business models
  - Collaboration networked
  - Knowledge sharing in networks

PPO ontology and macro-categories can be applied to current and future paradigms as stated in [1] "*It is clear that the various paradigms are rarely applied individually in the various manufacturing sectors and actually few of them coexist according to the drivers that are applicable to the sector at a specific moment in time and location. Location is also an important factor because the same paradigm could be applied in a certain region of the globe but not in another*".

In the following paragraph, the approach is applied to three study cases. The PPO macro-categories and related components are used to describe innovation oriented activities carried on by the selected organization.

The PPO analysis of the study cases adds a common view of different innovation experiences across different public and private organizations and different process phases.

3 Presentation of Study Cases

Three study cases of industrial research for innovation initiatives are presented to show how PPO can support Knowledge Management in three different innovation processes. Each of these cases adopts a response strategy that may be interpreted as a paradigm (Mass Customization, HVA products & processes) (Table 3).

The first case presents the footwear laboratory for HVA products; the second one refers to leading high-tech products and services; the third reflects knowledge products for collaborative research networks.

Then each case has been analysed and described through the PPO macro-categories (Concepts, Properties, Quality, Status, Roles). Properties and Status characterize the actions and the innovation process life-cycle of the single initiatives.

This exercise shows the PPO approach and representation as capable to handle heterogeneous contexts and compare strategies in different types of organizations.

These real cases report highly different context in managing knowledge and share the common objective of organization to integrate RTD base innovation.

Table 3 PPO common view of study cases

STUDY CASES / **ELEMENTS and PARADIGMS**	***D&MC-LAB***	***MindSh@re***	***Expanded Network***
DRIVING FORCES	• Technology • Society & Market	• Technology • Society & Market	• Technology • Society & Market
ENABLING FACTORS	Phase 3 – Use	Phase 2 – Implementation	Phase 4 – Reconfiguration
INFRASTRUCTURE LEVEL	• Infrastructure Facility • Production Network	• Infrastructure Facility • Production Network	• Infrastructure Facility • Production Network
TARGETED PARADIGMS	• Mass Customisation • HVA Product & Process	• HVA Product & Process	• HVA Product & Process

3.1 Design & Mass Customization Laboratory (D&MC-LAB)

The Design & Mass Customization Laboratory (D&MC-LAB) is the research unit of Institute of Industrial Technologies and Automation (ITIA) of Consiglio Nazionale delle Ricerche (CNR) and started up officially on the 29th of January, 2002, in Vigevano (Italy) [11]. The D&MC-LAB activities of research and development focus on the manufacturing paradigm of "Mass Customization" with specific reference to the footwear sector. Currently the Laboratory hosts an integrated and automated pilot plant for the conception and production of shoes. In order to reach the prefixed objective, the Laboratory of Vigevano makes use of four different Operative Units:

- Scientific and Research Activities, dedicated to the management of research projects.
- Technical Activities, dedicated to guarantee the effectiveness and functionality of the plant and related equipments.
- Production Activities, dedicated to take care of the proper functioning of the pilot plant for experimental manufacturing of shoes.
- Education Activities, to which is assigned the conception and management of internal and external didactic initiatives.

According to the ontology approach, the D&MC-LAB moves towards both mass customisation and high value added paradigms for the innovation of the footwear sector: the chief direction of the Laboratory is "Consumer and Environment at the Centre".

Table 4 PPO analysis of D&MC-LAB

Consumer and Environment at the Centre				
CONCEPTS Driving forces	**PROPERTIES** Infrastructure levels	**QUALITY** Response strategy	**STATUS** Innovation Process Life-cycle	**ROLES** Target
• High Value Innovation of the footwear sector • Environment • Competition • Customization • Push/Pull technologies • Sustainability	• Infrastructure Facility: Design and Mass Customization laboratory of ITIA-CNR • Production Network: Automated Pilot Plant Operative Units	• Mass Customization • HVA Products & Processes • Mass Customization and HVA Products & Processes	• Phase 1 – Design: Large scale collaborative projects • Phase 2 – Implementation: Ability to design and manufacture the shoe for the individual consumer • Phase 3 – Use: Pilot plant for experimental production	• Market Leadership • Survival

The findings of applying the PPO macro-categories to this case are reported in table 4.

Status macro-category highlights that the first three innovation process life-cycles are covered.

3.2 MindSh@re of FINMECCANICA (FNM)

Finmeccanica (FNM) is the main Italian high-tech industrial group operating globally in the aerospace, defence and security sectors. It is also one of the world's leading groups in the field of helicopters and defence electronics, as well as being the European leader for satellite and space services.

Finmeccanica believes that innovation must take a central role to guarantee the longevity of the organization, to support its vocation for technological excellence and successfully meet the challenges presented by markets [12].

The MindSh@re project – designed as "Unconventional engine for value innovation" – can be considered a key driver in this direction.

This large innovation project operates as a network for knowledge management and for technology and innovation governance. This project multiplies the possibilities for new ideas generation and their implementation in Value Innovation. In this way, the network have created a common language supporting the dynamic development of knowledge management.

Real exchange junctions of shared knowledge are the 7 Communities that concern specific innovation areas such as Radar, Homeland Security, Software & Capability Maturity Model Integration, Materials, Simulation for Training, Integrated Environment for Design & Development, Logistics & Services.

Within the MindSh@re mission, each Community is required to act as: the engine able to give value to innovation; the animator of a cooperative and interconnected network involving other Mindsh@re communities; the stakeholder representing the FNM companies; the interface with complementary suppliers (market competitors and clients) and research structures (public research centres and universities).

In 2007, the project comprised a total of 540 people, 30 FNM companies, 24 centres of excellence, 7 Communities with 39 focus groups. Knowledge management activities counted 1 Mindsh@re event, 3 conferences, 15 workshops and seminars. The last Mindsh@re event was held on February 2008 with more 1000 effective participants (among FNM people, defence institutions, university and research centres).

According to the PPO approach, the MindSh@re initiative moves towards the high value added paradigm.

The findings of applying the PPO macro-categories to this case are reported in the following Table 5.

Table 5 PPO analysis of MindSh@re Community Logistics & Services

Unconventional Engine for Value Innovation				
CONCEPTS Driving forces	**PROPERTIES** Infrastructure levels	**QUALITY** Response strategy	**STATUS** Innovation Process Life-cycle	**ROLES** Target
• High Value Innovation • Competition • Push/Pull technologies • Sustainability	• Infrastructure Facility: 30 Finmeccanica companies Web portal 7 Communities with 39 Focus Groups Governance structures Annual Community "Big Event" 15 Workshops and Seminars in 2007 • Production Network: Product/Process Collaborative Systems Engineering Laboratory Other laboratories	• HVA Products & Processes	• Phase 1 – Design: finished • Phase 2 – Implementation: one year activity	• Market Leadership

Status macro-category highlights that the first two innovation process life-cycles are covered.

3.3 *Expanded Network of Emerging Production Paradigms Laboratory (EPPLab ITIA-CNR)*

The Emerging Production Paradigms Laboratory (EPPLab) is a research unit of the Institute of Industrial Technologies and Automation of Italian Consiglio Nazionale delle Ricerche [13]. The activities are dedicated to strategic studies for new production, fostering industrial applications of knowledge-based production models applying the Manu*Future* strategy. This study case operates in the field of European and international collaborative research in the Production System area.

The Expanded Network comprises, in 2007, a total of about 250 researchers, 10 European research organizations and several companies.

This project carried on Knowledge Management activities in 2006/2007 through a cycle of 3 seminars, 3 websites design & running, micro databases and management/scientific reports.

The Expanded Network applies a research-industry collaboration model with the following objectives for HVA innovation:

- alignment to a common language focussed on advanced manufacturing for strategic interests;
- exchange of knowledge related to industrial research for manufacturing sectors to improve collaborative activities;
- transfer a new concept of R&D to industries.

According to the ontology approach, the Expanded Network initiative moves towards the high value added paradigm; in the context of the Manu*Future* initiative, the chief direction is "Bridging the gap" in knowledge transfer.

The findings of applying the PPO macro-categories to this case are reported in Table 6.

Status macro-category highlights that all four innovation process life-cycles are covered.

Table 6 PPO analysis of EPPLab

Bridging the gap				
CONCEPTS Driving forces	**PROPERTIES** Infrastructure levels	**QUALITY** Response strategy	**STATUS** Innovation Process Life-cycle	**ROLES** Target
• High Value Innovation • Competition • Customization • Push/Pull technologies • Sustainability	• Infrastructure Facility: Emerging Production Paradigm Laboratory of ITIA-CNR for Foresight and Roadmapping 3 Seminars in 2006 3 Web sites Micro databases Management and scientific reports • Production Network: Networks of 50 researchers in production systems in Italy and about 200 roadmappers in Europe	• HVA Products & Processes	• Phase 1 – Design: Strategic Research Agenda of the Manu*Future* Platform, 2005 • Phase 2 – Implementation: Leadership SSA project for supporting the Manu*Future* roadmaps, 2006 • Phase 3 – Use: Leadership support of the Manu*Future* Implementation Plan, 2007 • Phase 4 – Reconfiguration: Monitoring and Exploitation of results for new activities	• Market Leadership

4 Concluding Remarks

Considering that the most important innovation initiatives aim at achieving Mass Customization and HVA products & processes paradigms, the Production Paradigms Ontology (PPO) approach may support Knowledge Management in the innovation process for competitiveness and sustainability of industry.

The PPO approach shows that the driving forces Technology and Society & Market are the broad influencing factors and the life-cycle (design, implementation, use and reconfiguration) orientation is the enabling factor of the innovation process.

The three study cases illustrate how PPO could support knowledge management in the innovation process that each organization is carrying on to respond to turbulent and competitive markets.

Therefore, PPO approach permits to build a common view of different and complex innovation initiatives that are carried on by public and private organizations with the aim to shorten time-to-market of products and processes and bridge the gap among science, industry and market.

The PPO is a contribution to the governance of HVA innovation with trial application. It allows on one side to define the evolution towards the main objectives of the industrial transformation and on the other side to provide the control mechanisms of the innovation processes. These two aspects are fundamental to rule the shortened life-cycle of innovation processes in complex contexts.

References

1. Jovane F, Koren Y, Boer CR (2003) A present and future of flexible automation: towards new paradigms in Annals of the CIRP, Page. 18, Vol. 53(2003), n. 1.
2. Andersson Pl H, Salminen KI (2007) FMS in 2010 and beyond in Manufacturing Summit, Tampere, Finland, 6–7 June.
3. European Commission Manu*Future* Platform (2006) Manu*Future* Strategic Research Agenda: Assuring the future of manufacturing in Europe (Report of the High Level Group), Luxembourg, September 2006, ISBN 92-79-01026-3.
4. Paci AM (2008) Manufacturing Roadmaps as Information Modelling Tools in the Knowledge Economy, in Information Modelling and Knowledge Bases XIX, H. Jaakkola, Y. Kiyoki, T. Tokuda (eds), IOS Press, Amsterdam, pp. 354–358.
5. Mostefai S, Bouras A (2006) What ontologies for PLM: a critical analysis, in Proceedings: 12th International Conference on Concurrent Enterprising, Milan, Italy, 26–28 June 2006, pp. 423–430.
6. Westkaemper E (2006) Manu*Future* RTD Roadmaps: from vision to implementation, Manu*Future* Conference, Tampere, October http://manufuture2006.fi/presentations/
7. Paci AM (2006) Towards the new global production in the knowledge economy, Working Paper for CIRP Working Group Manufacturing Paradigms – Assessment & Future, August.
8. IMS-NoE SIG 3 (2005) Network Future human factors research needs to increase manufacturing productivity and employability, in TNO Report, 28 November.
9. Nonaka I (1998) The Knowledge-Creating Company, in: Harvard Business Review on Knowledge Management. Harvard Business School Press, pp. 21–45.

10. ITEA (2004) Technology Roadmap for Software Intensive Systems, 2nd edition, May.
11. Vigevano Laboratory http://www.itia.cnr.it/en/index.php?sez=7&ssez=5
12. Finmeccanica Group (2006) MindSh@re event Rome, 22–23 November.
13. EPPLab http://www.itia.cnr.it/en/index.php?sez=7&ssez=3