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Thematic Priority: NMP

Deliverable D5.20: – Holistic industrially oriented roadmap covering all PAC research areas

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Version [1.1]

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Dissemination Level		
PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contributing Partners:

University of Naples
Cardiff University
University of Patras
University of Manchester
Fatronik
IPA
Schneider Electric

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Executive Summary

The I*PROMS project aims to address all areas of manufacturing and deals not only with the current technologies but also prepares the way for the future so that the European manufacturing sector could remain competitive and maintain its leadership as a knowledge-intense manufacturing force in the global market rather than a labour intense manufacturing player. The clusters within the I*PROMS project are divided into four areas to cover the breadth and depth of the 21st century manufacturing processes, technologies, paradigms, platforms, concepts., tools, etc. The focus of this cluster, namely, Production Automation and Control (PAC) could be considered as the main engine room of the I*PROMS project. The vital technologies which are essential to the PAC are as follows:

- Agent Control Technology (ACT)
- Intelligent Sensor Technology (IST)
- Self diagnostic, -tuning, and –repair (STR)
- Human Machine Interaction (HMI)
- Reconfigurable Manufacturing Control (RMC)

During the first year of the project the PAC cluster conducted a detailed study of the common taxonomies and state-of-the-art review for all research areas of this cluster, and produced a catalogue of key enabling features and research roadmap covering all research areas of this cluster. During the second year of the project the PAC cluster undertook the task of updating these documents to realign the focus of I*PROMS with the European Technology Platforms (ETPs) and the Strategic Research Agenda (SRA). To this end, the I*PROMS NoE conducted an industrial survey within the European industries, academic and research communities and adopted the results of this survey as a mechanism for updating the common taxonomies, state-of-the-art review, catalogue of key enabling features and research roadmap for all research areas of this cluster.

This first updating of the roadmap was done taking into account the results of the industrial survey and the technology leaders' expert knowledge. That updated research roadmap was a refinement of the first version of the roadmap which was produced at the end of year 1 and at the same time incorporates some of the missing and emerging technologies of the future manufacturing systems. Therefore, that document could play an important role in identifying the thematic areas of research needed in the Framework Programme 7 and help the European Union and its citizens in wealth creation.

For the second update of the PAC roadmap in hand, it was taken into account that the technology planning in for production technologies is advanced in course of the new framework programme and the technology planning in various application areas become visible in the strategic research agendas. The approach of integrating an overview on the innovations in PAC areas and implementing a holistic roadmap was realised by extensive investigation of external resources, mainly from the European Technology Platforms. In this perspective, the existing roadmap was updated in a form of back coupling and analysing the impact and reactions of the previous versions in the technology scene.

1 Introduction

Manufacturers are under great pressure to comply with market changes and the constant shortening of the product life cycle. Changes on the factory floor are the order of the day. Traditional methods for production planning are no longer applicable to sustain a profitable business, whether a plant needs to be retrofitted or newly planned.

The trend shown in Figure 1[1)] may conflict with the simultaneous demand for high productivity, i.e. on production-time and/or time-to-market minimisation, on improvement of machine utilisation, and on flexibility of the whole production system, considered as a single collaborative environment [1-6].

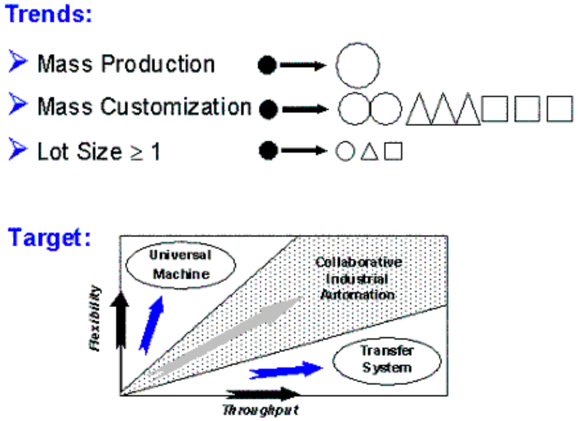

Figure 1: Trends in Manufacturing

[1)] Lot size>=1 in the Figure 1 represents the new trend called “Extreme Customisation” and indicates a high degree of reconfigurability in the complete manufacturing environment, where each customer requires the production of their own product (generally different from the product manufactured before and from that to be manufactured after).

One consequence of the deep penetration of ICT (Information and Communication Technology) into daily life is migration from conventional factory floor to intelligent manufacturing environments built around the *AmI (Ambient Intelligence* paradigm. That is, workplaces with emphasis on greater user-friendliness, more efficient service support, user-empowerment, and support for human interaction. A manufacturing environment where workforces are surrounded by a collection of reconfigurable production components (physical agents) that include mechatronics, control and intelligence (intelligent sensors and data processing units, autonomous, self-tuning and –repair machines, intuitive multi-modal human machine interfaces, etc.). In these circumstances, the challenge is to develop production automation and control systems with autonomy and intelligence capabilities for co-operative/collaborative work, agile and fast adaptation to the environment changes, robustness against the occurrence of disturbances, and the easier integration of manufacturing resources and legacy systems. In essence, the challenge is to create a PAC landscape made up of 'convivial technologies' that are easier to live with [7-9].

Under this reality and vision, and taking into consideration the developments that are happening around the five PAC-Technology Areas (ACT, RMC, IST, STR and HMI) due to the globalisation process, market evolution, user habits and various trends. the unpredictable nature of the technological changes in the PAC field hinders the reliability of predictions for the short-term time scale, i.e. 2004-2007, not to mention the long-term estimations for the timeframe of 2008-2015 – the timeframe of this study. A similar situation can easily be discovered by analysing other road mapping-activities such as references [10-26], among others. For these reasons, the PAC-cluster decided to follow a Roadmap-preparation approach based mainly on two phases: analysis of the KEFs-Catalogue generated by the partners of the cluster (broad source of predictions), and then the refinement of this catalogue and classification and timing of KEFs, identification of Key Enabling Technologies (KETs) and of Gaps performed by a group of experts selected from the cluster-consortium.

1.1 The PAC Roadmap - Preparation

A PAC-Group of experts was specially constituted for the generation of the PAC-Roadmap. For this purpose a 2-day workshop was organized and co-ordinated by Prof. Roberto Teti (University of Naples, Italy) with the participation of Mr. Michael Höpf (FhG-IPA), Dr. Armando. W. Colombo (Schneider Electric), Prof. Nikos Aspragathos (University of Patras), Mr. Jon Agirre Ibarbia (Fatronik) and Dr. Michael Packianather (Cardiff University).

For the PAC Roadmap preparation, this group of experts has gathered the main topics from the most essential Key Enabling Features KEFs (Macro KEFs) identified in each PAC-Technology Area. The analysis was conducted by a PAC-group of experts, which based its work on the contributions of all other PAC-partners, mainly the first version of the Catalogue of KEFs delivered by the cluster in June 2005. The final result is, therefore, a mixture that consists of solid background from the existing PAC-KEF-Catalogue provided by the PAC-partners, and fine-tuning of analysis using a large number of comments from the named group of experts.

1.2 The PAC Roadmap - Approach

For the first action of the workshop, all the PAC-partners developed a template for PAC Roadmap Deliverable Preparation (based on a similar document proposed by the IPROMS-Cluster APM).

The PAC-Roadmap Approach to Time Scale Estimations
The PAC-Group of experts has chosen an approach where they have tried to estimate technology development by reviewing the most important Key Enabling Features (KEFs) in the 5 PAC-Technology Areas. Initially there were 5 roadmaps possible. Some roadmaps may provide a rough estimation of the timeframe for certain technologies, but in general they propose to focus on important research and technology development issues towards 2012-2015. In some roadmaps there are more detailed connections between the technology developments and the timescales (e.g. between 2008-2010) without considering the maturity of such developments within this timeframe. Thus the background information from the roadmaps does not give insight to this aspect. Since we have no other source of information that could link maturity, technology development and time, we have chosen to present our results as they are on the roadmaps.

Template for PAC Roadmap Deliverable Preparation
The PAC-Template for PAC Roadmap Deliverable Preparation consist of two main parts, a table of PAC-Features and an explanatory introduction.

Table of PAC-Features: Based on the PAC Catalogue of Key Enabling Features (KEFs), 5 Macro-KEFs have been identified initially for each of the 5 PAC-Technology areas.
For each macro-KEF, a set of 5/6 KEFs, KETs (Key Enabling Technology) and gaps were identified and described.
Taking into consideration that each macro-KEF and its corresponding set of KEFs, KETs and gaps have first to be evaluated in terms of its "Degree of Importance for PAC", "Impact on the EU", "Limitations", "Recommended Measures" and "Forecast Materialization", each of the workshop participants was leading such action for one PAC-Technology Area. Finally, in a round-table discussion with all participants of the workshop, the names, definitions and contents of all the PAC-Features were shared and agreed.

Explanatory Introduction: Each of the 5 Macro-KEFs are explained extensively in an explanatory introduction section of this first document.

Note: By analyzing established technological and manufacturing capabilities and comparing these to existing and anticipated PAC applications across multiple market sectors and particular the 5 PAC-technology areas, the KEFs and KETs that were identified in association to the Macro-KEFs are mainly technology trends with anticipated product needs. The gaps are potential threads to industrial advancement.

Template for PAC Roadmap Deliverable

The PAC roadmap template provides a table (see example in figure 2), as follows:

1.1) each row is a macro-KEF (5 Rows per PAC Technology Area)

1.2) each column is a year -from 2008 to 2015

1.3) some entries (macro-KEF per year) are a KEF, KET or a gap in the *Table of PAC-Features* as above (when this KEF, KET or gap should be available or solved in the referenced time-period)

1.4) the column after the year 2015 is focused on the visionary results (visions / targets) at the end of the period 2008-2015. The current content of this column depicts one possible scenario in Europe and the World at the end of the period 2008-2015. The targets/visions have been proposed by the group of PAC-experts that developed the roadmap. It has to be emphasised that this set of visions is only one partial view and it should be improved or justified during the addressed time scale.

1.5) The final column shows the intellectual contents of the proposed work for each macro-KEF in each PAC technology area.

The next and more important step in the roadmap is the definition of "development-trajectories", i.e., trajectories communicating the KEFs-KETs, Gaps until one agreed visionary result was proposed by the participants (see examples in the Figure 2). Note: For each PAC-Technology there have been trajectories drawn and also for cross-technologies.

Explanatory Text for the PAC Road Mapping (Microsoft Excel file)

Since the PAC roadmap template is a big document, a set of abbreviations has been developed and used in order to facilitate the reading process of the trajectories. The abbreviations are explained in a separate document that the reader of the PAC roadmap has to use.

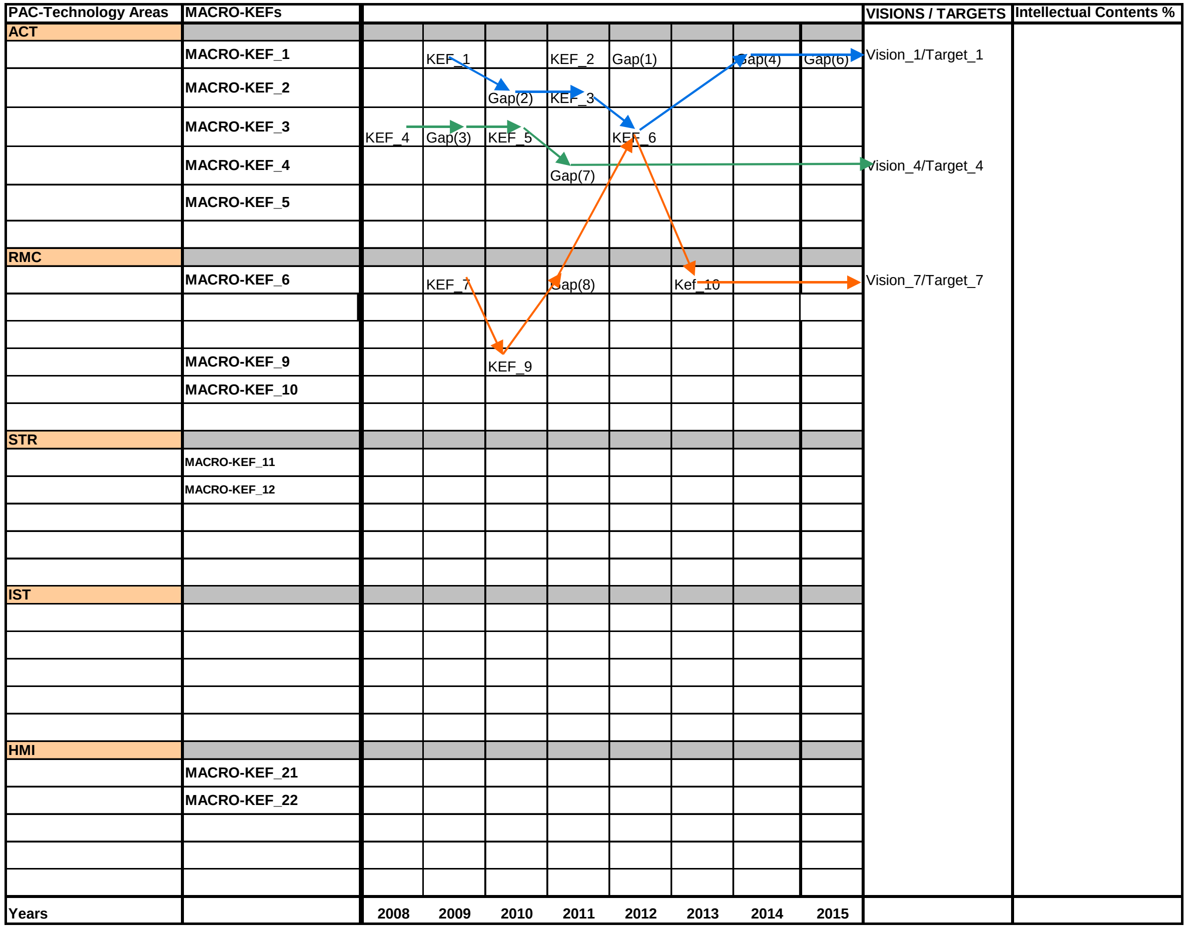

Figure 2: The PAC-Roadmap Excel-Table

1.3 The PAC holistic roadmap –The update process

In the first edition of the PAC Roadmap, the focus was on the determination of strings and timely expectations for the realisation of the previously identified key enabling features. At the end of this process, the results were intensively discussed within the manufacturing research community which was, at this time, involved in the definition process for the future European research in production technology. In course of this very high level activities, the PAC roadmapping group could successfully contribute with the content of the roadmap.

For this second update the intention was to realise an holistic approach by verifying to what extend the PAC roadmap elements have been introduced in the technology planning of the community and to feedback roadmap elements and data from strategic agendas.
For this purpose, all research agendas issued by the European Technology Platforms until July 2008 were examined, to what extend they contain PAC-technology relevant information on roadmap elements and implementation forecasts.

The ETP Documents were ranked according this findings and the following score- and linklist produced:

Linklist for the PAC Roadmap update

Most Important

- MANUFUTURE Future Manufacturing Technologies
- EUROP Robotics -
- ERTRAC European Road Transport Research Advisory Council
- ARTEMIS Embedded Computing Systems -

Important

- European Technology Platform for Wind Energy - TPWind secretariat@windplatform.eu
- Food for Life - Food v.rimbert@ciaa.eu
- European Space Technology Platform - ESTP estp-space@esa.int
- Advanced Engineering Materials and Technologies - EuMaT toe@dgm.de
- Water Supply and Sanitation Technology Platform - WSSTP info@wsstp.org
- Waterborne ETP - Waterborne cesa.research@skynet.be
- Future Textiles and Clothing - FTC info@euratex.org
- Hydrogen and Fuel Cell Platform - HFP secretariat@HFPeurope.org
- Industrial Safety ETP - IndustrialSafety rgowland-epsc@icheme.org.uk

Considerable

- Forest based sector Technology Platform - Forestry andreas.kleinschmit@cei-bois.org
- European Steel Technology Platform - ESTEP jean-claude.charbonnier@steelresearch-ESTEP.org
- European Nanoelectronics Initiative Advisory Council - ENIAC eniacoffice@eniac.eu

- Advisory Council for Aeronautics Research in Europe - ACARE luigi.bottasso@asd-europe.org
- Mobile and Wireless Communications - eMobility fiona.williams@ericsson.com
- ! Photonics21 - Photonics secretariat@photonics21.org
- Photovoltaics - Photovoltaics secretariat@eupvplatform.org
- Sustainable Chemistry - SusChem suschem@suschem.org

Out of scope

- Networked and Electronic Media - NEM info@nem-initiative.org
- Nanotechnologies for Medical Applications - NanoMedicine
- Integral Satcom Initiative - ISI Isi-info@deis.unibo.it
- European Biofuels Technology Platform - Biofuels info@biofuelstp.eu
- European Rail Research Advisory Council - ERRAC errac@unife.org
- European Construction Technology Platform - ECTP secretariat.ectp@cstb.fr
- European Technology Platform for the Electricity Networks of the Future - SmartGrids
- European Technology Platform on Smart Systems Integration - EPoSS
- Networked European Software and Services Initiative - NESSI

- Innovative Medicines Initiative - IMI
- Zero Emission Fossil Fuel Power Plants - ZEP
- Plants for the Future - Plants PlantTP@epsomail.org

For the following integration process only the important and considerable ETP research agendas were used. A remarkable result is, that two third of the ETPs have introduced at least some considerations on production technologies and manufacturing control related topics.

In the PAC roadmap group these findings were then compared with the actual version of PAC Roadmap. The results were discussed with the technology experts and, where appropriate, led to a modification of the PAC roadmap.

In this way, the PAC roadmap in hand now represents a holistic perspective of the industrial production research community in Europe as far PAC technologies are concerned.

2 Template for PAC Roadmap

PAC Technologies are as follows:

- Agent Control Technology (ACT)
- Intelligent Sensor Technology (IST)
- Self diagnostic, -tuning, and –repair (STR)
- Human Machine Interaction (HMI)
- Reconfigurable Manufacturing Control (RMC)

A separate table (shown below) is used for each of the technology areas together with an explanatory introduction.

Technology:					
Technology sub-areas♣	**Degree of importance**	**Impact on EU**	**Limitations**	**Recommended measures**	**Forecast materialization**
Speech recognition		•	•	•	•
		•	•	•	•
:		•	•	•	•

Notes for filling in the form:

- **Degree of importance:** e.g. very high, high, medium, low, very low,..
  is the technology considered as an important one for the future scientific and technological development of production automation and control.
- **Impact on EU:** possible impact on competitiveness, sustainability,…to what extent this contributes to global competitiveness
- **Forecast materialization:** forecast date when this technology may mature in the form of prototypes/demonstrators ready for industrial use, e.g. 2015

- **Limitations:** what are the factors that are not allowing this technology to be used? Are they scientific and technological, environmental, economic ? Or research, the use of the technology in industry, availability of training and information, cost and complexity.
- **Recommended measures:** what should be done to encourage the development/use of this technology? E.g. More research, collaboration between academia and industry, new regulations, what should be done to overcome the limitations identified ?

This document is based on the previous PAC roadmap deliverable D5.13, "Updated research roadmap covering all PAC research areas".

♣ **Refer to the taxonomies, state-of-the-art review and key enabling features deliverables**.

2.1 Explanatory introduction to the preparatory template for the ACT roadmap

Based on the State-of-the-Art-Analysis and the Taxonomies generated by the PAC-cluster, let´s consider that

- Agents in production are distributed physical agents (a production unit composed of mechatronics, control (intelligence) and communication capabilities) while most of the current technology is dealing with software agents.
- Agent-Systems in production are inhomogeneous multi-agent-systems while the so far realised applications are either homogenous or single agent systems.
- Each agent in production requires a dynamic and controllable decision core to enable agile line adaptation and (re)-configuration, and support decision rule development.
- Each agent in production is a self-reconfiguring, intelligent distributed automation element that has to operate in a stochastic environment, where hard real-time constraints must be met to achieve reliable system operation, while the software multi-agent-systems developed so far do not consider time as a problem at all.

Then these characteristics describe the transition from software agent-systems to ACT-based Production.

Although it is not easy to introduce a new technology in the conservative control and automation markets, it is extremely necessary from the marketing aspects of the ACT to have identifiable agent-based automation products with added value, and from the economical perspective to provide economical solutions avoiding additional hardware costs. Fortunately in control technology there is already a trend to integrate different control technologies customised on standard hardware platforms. A prospective marketing strategy can use this trend to create product scenarios for applications to guide the technical development of platforms under the perspective of agent controlled manufacturing networks.

On one side, agent control for manufacturing is a system technology in contrary to the conventional process oriented control technology. Under the customers perspective the migration is therefore not a step-by-step process of continuos improvement but a radical change in the manufacturing line design and operation. The development and application of migration techniques, methods and tools matching the newest production automation and control paradigms should be the main challenge for researchers, production control technology developers and also end-users. Control manufacturers have therefore to provide a complete system technology adaptable to a variety of processes and manufacturing structures.

On the other side, a roadmap for ACT-based products must take into account, that there is no market need for singular control products. To offer profitable solutions a complete system technology including suitable platforms must be developed in the next 10-15 years time span.

In the following section, the main Macro Key Enabling Features (KEFs), with the associated scientific- and technology-factors, challenges and visions, which were identified by the PAC-partners are described.

Remark: The main 5 Macro KEFs for ACT include now the integration of the KEFs presented in a previous deliverable and a new sub-set of KEFs that mainly appear from the results of the Delphi Study performed in I*PROMS and also from an analysis of the latest research work in this technology area plus escential material generated during the last couple of years in different European Technology Platforms (ETPs), such as Manufuture (linked to the EU FP7 NMP Program), ARTEMIS (linked to the EU FP7 ICT Program), etc.

Agent Control Technology (ACT) Engineering Platform

In the first step it is sufficient to define specification of mechanisms to develop Agent-Controlled Production Systems in order to obtain new interdisciplinary engineering technologies. In addition the definition of service interface functions for the processes, to ensure independence from low-level implementation details of communication links and protocols is necessary for the creation of plug-and-play functional middleware. At the same time the definition of Human-Machine-Interfaces (HMIs) to integrate appropriately human skills at all functional levels of the ACT-based architecture as well as the definition of Human-Agent-interfaces to incorporate human workplaces within the production system should be considered.

Then, the actions will be:

- Mature software/hardware development of new interdisciplinary engineering methodologies and tools.
- Encapsulation of hardware (mechatronics), control software and intelligence, and communication capabilities in production environments that will allow:
  - Automatic reconfiguration of processes by simply plugging new devices into the shop floor.
  - Updating production-equipment step by step. New modules could be capable to simulate old production equipment. Or the rest of the system is able to adjust to the new possibilities the new module introduces.
  - Easy maintenance and therefore better-maintained equipment. Intelligent modules know their internal state, and recognise error states.

- Real-time distributed simulation methods and tools for ACT-based production: structure, behavior and communication specifications, i.e. Integration of Mechatronics, Information, Control and Communication.
- User-interface for decision support in the planing, implementation and operation phases of ACT-Systems.
- Integration of ACT-based components in the digital factory offering wireless communication and internet technologies.

ACT-based Production Systems Engineering
(Definition, Specification and Implementation of ACT-based Production Systems / Agent domain specific problem solving functions.
How to aggregate machines, especially new generation of intelligent machinery and systems, manual work places and material found on a shop floor to production units which are optimal to take over the role of agent-based control and automation units?
Then, the actions will be:

- Developing an engineering, and control environment approach to support the implementation of an intelligent distributed architecture with real-time “shop-floor” distributed control and dynamic scheduling functions. Remark: This action is closed related to the Macro KEF (Service oriented control and interoperability) of the Roadmap for RMC.
- Developing an engineering framework for agent-based controls in different industrial application domains based on already existing solutions.
- Definition of Granularity of ACT-based production systems, from an intelligent sensor (that can act as an agent) throughout an intelligent machine (that can act as an agent) till the upper levels of an Enterprise (that can act as an agent). Defining the granularity it is possible the identify What“ an agent is in the production environment.
- Methods and Tools for the Agentification of Industrial Production Scenarios. Analysis of the production process at the shop floor and designing an environment that lets end-user easily add ACT-Systems to the shop floor, i.e., agentification of production scenarios across Europe.
- Providing knowledge and initial tools for successful, safe and efficient migration of intelligent agent-based automation and control techniques in a variety of European production scenarios.
- Consider new production control, management and organization paradigms like Holonic Enterprise, Collaborative Manufacturing Model (CMM) in order to create sufficient systems’ architecture.
- Gaining knowledge on the design, behavior and benefits of intelligent agent-based production control systems.
- Develop new tasks and functionalities for Multi-agent-systems such as change agents for adaptive manufacturing or entrepreneurial agents.
- New services and business models for agent based applications.

ACT-Integration with Legacy Systems

Due to the fact that there are existing ERP and MES systems are widely used in the industry and these systems set already common standards there is a need for ACT integration.

- Evaluating the integration aspects of the new technology in a variety of customer production scenarios.
- Matching new production control, management and organization paradigms like Holonic Enterprise, Collaborative Manufacturing Model (CMM). The granularity of agent-based production systems is close related to the Holonic Enterprise paradigm and also to the Collaborative Manufacturing Model (CMM) paradigm that are being considered in the Roadmap of the cluster IPROMS POM. Migration technologies and methods from traditional production control architectures to the new addressed above, integrating ACT-based production components with existing ERP and MES systems.
- Support of existent intelligent supervisory control functions and components with agent-based decision support systems: Inventory control, diagnosis, monitoring, maintenance, etc.
- Develop hybrid system architectures and investigate an appropriate grade of decentralization. Basically the integration of CMM-based, Holonic-based and Service-oriented architecture (SoA)-based systems.

ACT-based Components Interoperability

The variation of interfaces and components used in industies leads to the need for standardisation and interoperability especially for the acceptance of ACT.

- Providing knowledge, methods and tools to facilitate the interoperability of different ACT-Systems to finally reach a plug-and play functionality.
- Providing reference ontologies for ACT-based production systems in different industrial scenarios.
- Comparison between particular ontologies and development of methods and tools to facilitate successful communication between ACT Systems with disparate ontologies. Facilitation of interoperability of ACT-Systems produced/generated by different vendors.
- Develop communication standards for ontologies, standardised functional units/modules especially for the field of production systems.
- Establish a certain group/society which is responsible for standardisation.

Confidence and Trust in ACT-Systems.

Marketing of ACT-based Production Systems

The majority of controls today are process-oriented systems where the PLCs are dominating the market. They are offered and used in a large variety of performance and characteristics. Other important process oriented controllers are NC and CNC, regulators and drives. The direct implementation of agent-based collaborative automation technology to these types of controllers would lead to an exploding catalogue of components. Even with this high number of individual products most of the applications would not be realisable because of the lack of a general agent-based control system to represent physical units which are not controlled in conventional technology. Also the interoperability required for agent manufacturing systems is expensive to achieve for this very different hardware concepts and the necessary standards are difficult to be integrated.

Therefore the marketing for agent-based collaborative controls must include the perspective of a new type of controls where the different physical functionality of a manufacturing module can be realised on a set of common platforms with unique architecture. An agent control product program must consist of a series of controllers, which are configurable to control a broad range of different physical processes and can combine the traditional functions of industrial controllers with new concepts like MMI, quality monitoring and control and extensive data processing. The product differentiation for agent controls is by performance under the perspective of a generalised profile instead of different physical control categories.

Then the actions will be:

- Generation of a catalogue that will provide an overview on the European and world-wide status on ACT-based applications.
- ACT monitoring process. Providing a structure and data on existing ACT-based technologies and systems, both in industry and appliedresearch.
- Industrial-oriented research with strong collaboration between academia e industry. Agentification methods based on existent industrialexperiences
- Providing knowledge and initial tools for successful, safe and efficient migration of intelligent agent-based automation and controltechniques, applying the new Taxonomies for ACT-based production in a variety of European production scenarios.
- Building demonstrator environments. These should be the base on which the European industry will be able to build a final product, where Control of manufacturing sequences by means of negotiation and autonomous decision incorporated as an inherent co-ordination function in manufacturing entities like machines and manual workplaces. These new functions of ACT-based production components replace the logical programming of manufacturing sequences and supervisory functions.
- Develop new methods of software testing and -benchmarking, and investigate possibilities to predict the emergent characteristics of agents.
- Making decision making of Multi-agent systems transparent
- Develop business models for new network/software solutions

As a main result of the actions addressed above, in the next 5-10 years:

- Innovative control system components and services will be developed and put into the market to answer fast changing demands and markets – 2006 CAGR 25%.
- The European ACT-development industry will be able to build a final product based on ACT. Then Innovative control system components and services will be used to answer fast changing demands and markets – increasing the current compound annual growth rate (CAGR) of the industrial automation software market from its current 25% to values above the 50%.
- The European Production Industry will be able to implement ACT-based production systems.
- Gain a leading role in software products in future
- Enables a fast reaction to changing environments and markets based on ACT.

Technology: Agent Control Technology (ACT)					
Technology sub-areas[♣]	**Degree of importance**	**Impact on EU**	**Limitations**	**Recommended measures**	**Forecast materialization**
ACT Engineering Platform	Very high	• Competitiveness in control technology	• Scientific and Technological factors. • Very few number of people know the meaning of such a platform (scientific and technological challenge). • Technology maturity	• More basic and applied research in engineering of ACT • Strong collaboration between simulation systems developers and ACT-developers.	• 2012
Interdisciplinary engineering methodologies and tools	high	• Enables industry to develop new solutions	• Task for several disciplines • Very few number of people know the meaning of such methods and tools.	• Number of interdisciplinary research programms	• 2010
Encapsulation of hardware(mechatronics), control software and intelligence	Very high	• Integration of scientific and technological areas.	• Separated scientific and technological areas at academic, research and industrial levels	• New university programs integrating the different aspects	• 2010
Real-time **distributed simulation**	Very High	• Competitiveness in control technology	• Very few number of people know the meaning of such methods and tools. There are not positive experiences yet. • Technology maturity	• Involvement of big simulation system developers, who can influence the market	• 2012
Agent-interface of ACT-Systems	Very high	• Competitiveness in control technology	• Only few and isolated labour experiences are known till today. • Technology maturity	• Exchange of information and experiences among main players	• 2012

[♣] **Refer to the taxonomies, state-of-the-art review and key enabling features deliverables**.

Integration of ACT-based components in the **digital factory**	Medium	• Competitiveness in control and production technology	• There are not known experiences yet. Technology maturity	• Bringing together both main development trends: digital factory and ACT	• 2012
ACT-based Production Systems Engineering	Very high	• Sustainability • Customisation of Production following the trends of the markets. • Competitiveness in production technology	• Very few experiences with real production environments. • Not enough availability of training and information. • Approaches maturity.	• Close work between research / academia and industry (end users and developers of the ACT)	• 2010
Agentification of Industrial Production Scenarios.	Very high	• Sustainability • Customisation of Production following the trends of the markets. • Competitiveness in production technology	• The market for ACT is too traditional. ACT means a complete different form of thinking about production control. • Approaches maturity.	• Close work between research / academia and industry (end users coming from different production areas, e.g., manufacturing, electronic assembly, process, etc., and developers of the ACT)	• 2010
Migration in a variety of European production scenarios.	High	• Sustainability • Competitiveness in production technology	• Not enough availability of training and information. • Only one European industrial experience till now. • Approaches maturity.	• Close work between research / academia and industry (end users coming from different production areas, e.g., manufacturing, electronic assembly, process, etc., and developers of the ACT)	• 2012

Consideration of management paradigms	Very high	• Acceptions of ACT • Holistic approach	• Cultural change in thinking is necessary • Concepts are not well known	• Number of publications in this field	• 2012
G**ranularity of ACT**-based production systems	Very high	• Sustainability • Competitiveness in production technology	• Only one European industrial experience. • Approaches maturity.	• Availability of training and information.	• 2010
New tasks and functionalities for Multi-agent-systems	High	• Identify new applications and markets	• Acceptance • Traditional market behaviour	• Number of new ACT products in specific markets • Number of publications	• 2015
New services and business models for agent based applications.	High	• Identify new applications and markets	• Acceptance • Traditional market behaviour	• Number of new ACT products in specific markets • Number of publications	• 2015
ACT-Integration with Legacy Systems	High	• Integration in the global market	• Only 1 European industrial experience till today. • Fear of Legacy System developers	• Generation of measurable integration aspects involving Legacy System developers.	• 2015
Evaluating the integration aspects in a variety of European production scenarios	High	• Integration in the global market	• Only 1 European industrial experience till today. • Fear of Legacy System developers. • Not enough availability of training and information	• Generation of measurable integration aspects involving Legacy System developers.	• 2015

Integrating ACT-based production components **with existing ERP and MES systems**.	Very high	• Integration in the global market	• Only 1 European industrial experience till today. • Fear of Legacy System developers. • Not enough availability of training and information	• Generation of measurable integration aspects involving Legacy System developers.	• 2015
Support of existent intelligent **supervisory control functions and components.**	Medium	• Integration in the global market	• Only 1 European industrial experience till today. • Fear of Legacy System developers • Not enough availability of training and information	• Generation of measurable integration aspects involving Legacy System developers.	• 2015
Hybrid system architectures	Very high	• Integration in the global market	• Fear of Legacy System developers • Not enough availability of training and information • Few case studies and systems are known	• Generation of measurable integration aspects involving Legacy System developers.	• 2010
ACT-based Components Interoperability	Very high	• Competitiveness. in control technology (Better Positioning in front of USA and Japan)	• Missing co-operability between ACT vendors. Trend of ACT-vendors to monopolise the market. • Technology Maturity	• More cross-regional co-operation between Europe and USA/Japan. • New standardisation activities with Cross regional standardisation bodies (FIPA, IEEE)	• 2015

Providing **knowledge, methods and tools** to facilitate the interoperability of different ACT-Systems.	Very high	• Positioning in front of USA and Japan	• Missing co-operability between ACT vendors. Trend of ACT-vendors to monopolise the market. • Technology Maturity	• More cross-regional co-operation between Europe and USA/Japan. • New standardisation activities with Cross regional standardisation bodies (FIPA, IEEE)	• 2015
Providing **reference ontologies** for ACT-based production systems in different industrial scenarios	Very high	• Positioning in front of USA and Japan	• Missing co-operability between ACT vendors. Trend of ACT-vendors to monopolise the market. • Concept maturity	• More cross-regional co-operation between Europe and USA/Japan. • New standardisation activities with Cross regional standardisation bodies (FIPA, IEEE)	• 2015
Facilitation of interoperability of ACT-Systems produced/generated by different vendors	Very high	• Positioning in front of USA and Japan	• Missing co-operability between ACT vendors. Trend of ACT-vendors to monopolise the market • Concept maturity	• More cross-regional co-operation between Europe and USA/Japan. • New standardisation activities with Cross regional standardisation bodies (FIPA, IEEE)	• 2015

Standardisation	high	• Positioning ahead of USA and Japan • Acceptance of new technology	• Missing co-operation between ACT vendors. Trend of ACT-vendors to monopolise the market • Concept maturity	• More cross-regional co-operation between Europe and USA/Japan. • New standardisation activities with Cross regional standardisation bodies (FIPA, IEEE)	• 2012
Establish a certain group/society for standardisation.	medium	• Positioning ahead of USA and Japan • Acceptance of new technology	• Missing co-operation between ACT vendors. Trend of ACT-vendors to monopolise the market • Concept maturity	• More cross-regional co-operation between Europe and USA/Japan. • New standardisation activities with Cross regional standardisation bodies (FIPA, IEEE)	• 2012
Confidence and Trust in ACT-Systems	High	• Competitiveness in production technology. • International Market dominance.	• Fear of End-users to change to new technologies. Market for ACT is too conservative. • Not enough availability of training and information about existent solutions	• Involvement of End-Users in development activities. • Demonstrators implemented at industrial level	• 2015

Generation of a **catalogue**	High	• Competitiveness in production technology • International Market dominance in some ACT-application areas (e.g., manufacturing).	• Fear of End-users to change to new technologies. Market for ACT is too conservative. • Not enough availability of training and information about existent solutions.	• Conduction of periodic survey performed by research/academia and involving representative industrial End-Users of ACT	• 2010
ACT monitoring process.	High	• Competitiveness in production technology. • International Market dominance in some ACT-application areas (e.g., manufacturing)..	• Not enough availability of training and information about existent solutions	• Conduction of periodic survey performed by research/academia and involving representative industrial End-Users of ACT	• 2012
New benchmarking methods	Very high	• Positioning ahead of USA and Japan • Acceptance of new technology	• Unrealistic scenarios • Few case studies in industry • Systematic measurement	• Number of publications in this field	• 2010
Transparency in decision making	Very high	• Positioning ahead of USA and Japan • Acceptance of new technology	• Due to prototype solutions	• Number of publications in this field	• 2012
Business models for new network/software solutions	High	• Positioning ahead of USA and Japan • Acceptance of new technology • Identify new applications and markets	• Fear of End-users to change to new technologies. Market for ACT is too conservative. • Not enough availability of training and information about existent solutions.	• Number of publications in this field • Number of new ACT products in specific markets •	• 2010

Applying the new Taxonomies for ACT-based production in a variety of European production scenarios.	High	• Competitiveness in production technology. • International Market dominance in some ACT-application areas (e.g., manufacturing)..	• Weak coupling between research, academia and industry	• Close work between research / academia and industry (end users coming from different production areas, e.g., manufacturing, electronic assembly, process, etc., and developers of the ACT)	• 2014
Building demonstrator environments..	Very high	• Competitiveness in production technology. • International Market dominance in some ACT-application areas (e.g., manufacturing)..	• Amount of Investment for demonstrators	• More support from official RTD-programs like the ERA and from big control developers	• 2015
Build **a final European product based on ACT**	High	• Competitiveness in production technology	• Fear reaction of markets to technology bifurcation	• Active dissemination in fairs and industrial oriented workshops. • Exploitation plans supported by the official RTD-programs.	• 2015

Implementation of ACT-based production systems	Very High	• Competitiveness in production technology. • International Market dominance in some ACT-application areas (e.g., manufacturing).	• Initial Investment too high due to necessary redundancy of hardware • Concepts and approaches maturity	• Generation of economic study (between development and marketing departments) showing return of initial investment due to the high performance, high-customisation of products and flexible behaviour of ACT-based production systems	• 2015

2.2 Explanatory introduction to the preparatory template for the IST roadmap

The main key enabling features (Meta-KEFs) for the IST Technology Area, selected from the KEFs presented in the D5.3 PAC deliverable for this technology, are:

New Sensors and Sensor Systems:

The KEFs of this Meta-KEF are: (1) New stand alone sensors with power harvesting, (2) LEGO sensors, (3) Intelligent sensor components interfaces including gesture and haptic aspects, (4) Multi sensor paradigms, (5) Wearable sensor devices, (6) New sensor systems, (7) Sensor for harsh environment, (8) Embedded micro-nanosensors, , (9) Low cost sensors, (10) Cluster sensors.
The degree of importance of these KEFs is considered to be very high.
The impact of the development of these KEFs on the PAC field of activity in the European Union refers to improvements in (a) competitiveness and (b) sustainability. As regards competitiveness, the following advances are expected: improved productivity; increased unmanned production capability; improved reliability, robustness, accuracy; cost and time reduction; maintenance reduction; scrap reduction. As regards sustainability, the following advances are expected: environmental impact reduction; material waste reduction; improved working environment safety.
The envisaged limitations for the development of these KEFs are: (a) lack or scarcity of advanced sensors, (b) lack or scarcity of advanced sensor systems, (c) high cost of existing advanced sensors and sensor systems, (d) Measurement in challenging environments.
The proposed recommended measures to achieve the roadmap IST targets are: (a) more basic and applied research in new sensors, (b) more basic and applied research in sensor intelligence, (c) collaboration between academia and industry for identification of real needs for new sensors and sensors systems e.g. large frequency bands MEMS accelerometers, non-intrusive current and voltage MEMS sensors,…etc.
The forecast materialisation of the roadmap targets for these KEFs is expected to occur in 2008 – 10.
In general it is expected that more than half of the manufacturing systems will have new sensors & sensor systems (Ref PAC Delphi study); It is part of the ARTEMIS Research Strategy, annual work programme 2008, section 3.2.3, 3.2.5
Ubiquitous systems which include change in environmental parameters (EUROP) and overall system capability to reconfigure (e.g. actuation) to accommodate the dynamic changes with respect to user specifications (see STR in the Road map and MANUFUTURE).
It is expected to engender new generation of autoreconfigurable sensors/actuators with embedded intelligence to host multiple changes that are sometimes predictable but not systematic.
Power harvesting is a key aspect for stand alone sensors.

Intelligent Sensor Signal and Data Processing:

The KEFs of this Meta-KEF are: (1) Innovative sensor signal processing, (2) Sensor fusion, (3) Communication of sensor information (high frequency signals, wireless communication), (4) Auto reconfiguring sensors, (5) Decision making systems.
The degree of importance of these KEFs is considered to be very high.
The impact of the development of these KEFs on the PAC field of activity in the European Union refers to improvements in (a) competitiveness and (b) sustainability. As regards competitiveness, the following advances are expected: improved productivity; increased unmanned production capability; improved reliability, robustness, accuracy; cost and time reduction; maintenance reduction; scrap reduction. As regards sustainability, the following advances are expected: environmental impact reduction; material waste reduction; improved working environment safety.
The envisaged limitations for the development of these KEFs are: (a) lack, scarcity or inadequacy of intelligent sensor signal and data processing, (b) insufficient reliability of decision making procedures, (c) need for skilled operators, (d) high development costs.
The proposed recommended measures to achieve the roadmap IST targets are: (a) more applied research in advanced sensor signal and data processing, (b) more basic and applied research in decision making system development, (c) more interdisciplinary research (manufacturing technology, electronics, informatics, AI, …), training and formation of skilled operators, the forecast materialisation of the roadmap targets for these KEFs is expected to occur in 2008 – 09.

Intelligent Sensor Monitoring Applications:

The KEFs of this Meta-KEF are: (1) Real-time process monitoring, (2) Tool condition monitoring, (3) Chip form monitoring, (4) Work material condition monitoring, (5) Other monitoring applications such as required by reconfigurable machines , (6) Imaging sensing applications.
The degree of importance of these KEFs is considered to be very high.
The impact of the development of these KEFs on the PAC field of activity in the European Union refers to improvements in (a) competitiveness and (b) sustainability. As regards competitiveness, the following advances are expected: improved productivity; increased unmanned production capability; improved reliability, robustness, accuracy; cost and time reduction; maintenance reduction; scrap reduction. As regards sustainability, the following advances are expected: environmental impact reduction; material waste reduction; improved working environment safety.
The envisaged limitations for the development of these KEFs are: (a) lack, scarcity or inadequacy of intelligent sensor monitoring methodologies, (b) lack of standardisation, (c) high development costs, (d) need for skilled operators, (e) low acceptability in industrial environments, (f) ambiguity in feature extraction.

The proposed recommended measures to achieve the roadmap IST targets are: (a) more applied research in intelligent sensor monitoring applications (process, tool condition, work material state, …), (b) development of high performance equipment, (c) efforts in the direction of standardisation, (d) promotion with industry, (e) Robust feature recognition algorithm with intelligent identification.
Training and formation of skilled operators in intelligent sensor monitoring.
The forecast materialisation of the roadmap targets for these KEFs is expected to occur in 2009 – 10.

Technology: INTELLIGENT SENSOR TECHNOLOGY (IST)					
Technology sub-areas[♣]	**Degree of importance**	**Impact on EU**	**Limitations**	**Recommended measures**	**Forecast materialization**
New Sensors and Sensor Systems	**Very high**	• Competitiveness (improved productivity; increased unmanned production capability; improved reliability, robustness, accuracy; cost and time reduction; maintenance reduction; scrap reduction) • Sustainability (environmental impact reduction; material waste reduction; improved working environment safety)	• Lack or scarcity of advanced sensors • Lack or scarcity of advanced sensor systems • High cost of existing advanced sensors and sensor systems	• More basic and applied research in new sensors • More basic and applied research in sensor intelligence • Collaboration between academia and industry for identification of real needs for new sensors and sensors systems	• 2008 - 2009

[♣] **Refer to the taxonomies, state-of-the-art review and key enabling features deliverables**.

- New stand alone sensors with power harvesting	Very high	•	• Performance and measurements range	• More high performance MEMS at low cost e.g. large band accelerometers and non-intrusive voltage and current measurements.	• 2008 - 10
- LEGO sensors	High	•	•	•	• 2009
- Intelligent sensor components interfaces including gesture and haptic aspects	Very high	• Ease of new machine reconfiguration paradigm	•	•	• 2009
- Multi sensor paradigms	Very high	•	•	•	• 2008 - 10
- Wearable sensor devices	High	•	•	•	• 2009
- New sensor systems	Very high	•	•	•	• 2008 - 10
Sensors for harsh environment	High	• Environments for most manufacturing tasks are harsh and need advanced sensor systems that can cope with them.	• Measurement of critical data is currently difficult in harsh environments	• New sensor materials, packaging techniques and communication methods.	• 2010

Embedded micro/nano sensors	Very high	• Next generation innovative products and processes with intelligence capabilities which can provide niche market for EU depends on these sensors.	• Micro/nano technologies for realising these sensors are still in their infancy	• Monitoring of the developments in the micro/nanotechnologies required and quick adaptation.	• 2010
Stand alone sensors	Very high	• These are innovative systems which will provide economic benefits because of new market opportunities and improve performance of various technological processes.	• challenging environment requiring sensors for unreachable locations	• Self powering, wireless communications. Large-scale communication(GPS), real time plug and play techniques	• 2010

Intelligent Sensor Signal and Data Processing	**Very high**	• Competitiveness (improved productivity; increased unmanned production capability; improved reliability, robustness, accuracy; cost and time reduction; maintenance reduction; scrap reduction) • Sustainability (environmental impact reduction; material reduction; material waste reduction; improved working environment safety)	• Lack, scarcity or inadequacy of intelligent sensor signal and data processing • Insufficient reliability of decision making procedures • Need for skilled operators • High development costs	• More applied research in advanced sensor signal and data processing • More basic and applied research in decision making system development • More interdisciplinary research (manufacturing technology, electronics, informatics, AI, …) • Training and formation of skilled operators	• 2008 - 09

- Innovative sensor signal processing	Very high	•	•	• More local signal processing within sensors in network for fast alarms and monitoring.	• 2008 - 09
- Sensor fusion	Very high	•	•	•	• 2008 - 09
- Communication of sensor information (high frequency signals, wireless communication, …)	Very high	•	•	•	• 2008 - 09
- Auto reconfiguration of sensor in network	Very high	• High reliability in continuous monitoring especially in complex environment.	•	• Auto-reconfiguration of sensor network.	•
- Decision making systems	Very high	•	•	• Sensor embedded decision making	• 2008 - 09

Intelligent Sensor Monitoring Applications	Very high	• Competitiveness (improved productivity; increased unmanned production capability; improved reliability, robustness, accuracy; cost and time reduction; maintenance reduction; scrap reduction) • Sustainability (environmental impact reduction; material waste reduction; improved working environment safety)	• Lack, scarcity or inadequacy of intelligent sensor monitoring methodologies • Lack of standardisation • High development costs • Need for skilled operators • Low acceptability in industrial environments	• More applied research in intelligent sensor monitoring applications (process, tool condition, work material state, …) • Development of high performance equipment • Efforts in the direction of standardisation • Promotion with industry • Training and formation of skilled operators in intelligent sensor monitoring	• 2009 - 2010
- Real-time process monitoring	Very high	•	•	•	• 2009 - 10
- Tool condition monitoring	Very high	•	•	•	• 2009 - 10
- Chip form monitoring	Very high	•	•	•	• 2009 - 10
- Work material condition monitoring	Very high	•	•	•	• 2009 - 10

- Other monitoring applications	Very high	•	•	•	• 2009 - 10
-Imaging sensing applications	Very High	• EU products such as machine tools with this technology have more competitive edge over those of the competition. • Employment of the technology results in more precise and low/zero waste.	• Ambiguities in feature extraction and pattern recognition	• Robust feature extraction and pattern recognition techniques using multiple algorithms and intelligent techniques	• 2008-2009

2.3 Explanatory introduction to the preparatory template for the STR roadmap

The main key enabling features for the STR have been worked from the KEFs presented in the previous deliverable for this technology :

The progressive incorporation of increasingly complex information architecture, microchips and software into a wide variety of machines - from computing devices to automobiles, robots, and industrial machinery has led to a proliferation of **intelligent machines**. The Center for Intelligent Machines (CIM), at McGill University offers a concise definition of intelligent machines: "Intelligent machines are capable of adapting their goal-oriented behaviour by sensing and interpreting their environment, making decisions and plans, and then carrying out those plans using physical actions"

The concept of “smart or intelligent” machine tools is under discussion, but an intelligent machine tool should display some of the same characteristics as human intelligence:

- Adaptation to changing conditions, i.e. the ability to learn from experience and use different processes in the future.
- Integration of sensory input with stored models. Our eyes, ears etc. provide input, which is interpreted, based on a stored world model.
- Extensive information processing capability.
- A sophisticated storing knowledge system.

There is a tremendous gap between current machine tool technology and these qualities. By the development and application of techniques from the Artificial Intelligence (AI) research area, the objective of producing useful machines to automate human tasks requiring intelligent behaviour will become possible. This roadmap intent to establish some bases to materialise the "Intelligent Machine Tool", improving the accuracy, reliability and productivity of machining operations.
Following we describe the four main key enabling features that we have selected :

Smart (easy) machines. A smart / easy machine provides capabilities in order to offer **proactive assistance to the operators**, taking into account their needs, capabilities and skill level. The objective of making the machine easier from the operation point of view will be achieve by the development and application of techniques from the **Artificial Intelligence** (AI), Cognitive systems and Knowledge Management / Data Mining research areas.

Adaptive machines. By this feature we describe what is related to the improvement of the **machining process**. We consider two phases : firstly the Self-tuning, a off-line optimisation of the parameters involved in the process (machining parameters) and machine (control parameters). Secondly, Adaptronics - a real-time on-line optimisation and adaptation to the variable conditions of the process through the Intelligent Process Monitoring & Control. An overall adaptronic system consists of integrated multi-functional sensors and actuators, with the associated electronics and an adaptive control system capable of acting in real time.

Autonomous machines. By this feature we describe what is related to the **machine**, assuring that the machine is able to detect failures and provide a diagnosis of the failure cause, including the detection of the involved component or subsystem. And is able to take care of the failure by **Self-Repairing**. So, the machine has a Intelligent Machine Monitoring, that uses information coming from a wide variety of data sources integrated by the Data Fusion and a **Diagnosis** system based in different approaches as Model-Based Diagnosis (MBD), Rule-Based Diagnosis (RBD) or Case-Based Diagnosis (CBM). Failure prediction, **Maintenance and end of life management** systems are features that contribute to the materialization of an autonomous machine. The generalisation of the Life Cycle Units (LCU) concept in each machine component will offer a very rich source of historical information about the operation and working conditions of the components in the machines. The Teleservice feature also contributes to the general autonomous machine feature.

AmI in manufacturing machines (Environment awareness)
AmI technologies offer also tremendous opportunities for broad industrial change. The research will focus in new features for the machines to allow them to be integrated in an Ami manufacturing scenario, as defined in the "Annex 5: Towards Industrial AmI applications" of the "ISTAG

: Scenarios for Ambient Intelligence 2010" report. Collaborative working environment between Robots and Humans sharing time and space, assuring the safety and avoiding any situation that are harmful to people, property or itself damage.

Technology: Self diagnostic, -tuning and –repair					
Technology sub-areas[♣]	**Degree of importance**	**Impact on EU**	**Limitations**	**Recommended measures**	**Forecast materialization**
Smart (easy) machines	Very high	• Competitiveness	• Industrial applicability	• Smaller start-up applications	2012
Artificial Intelligence	Very high	• Competitiveness • Production quality	• Industrial applicability	• Applications / Techniques matrix	2009
Cognitive systems	High	• Competitiveness	• Technology maturity	• Smaller start-up applications	2012
Knowledge Management / Data Mining	Very high	• Competitiveness • Productivity	• Availability of training and information	• Prototypes demonstration and dissemination	2008
Proactive assistance to operator	Very high	• Competitiveness • Productivity	• Technology maturity	• Smaller start-up applications	2014
		•	•	•	
Adaptive machines Intelligent Process Monitoring & Control	Very high	• Competitiveness • Production quality	• Industrial applicability	• Smaller start-up applications	2012

[♣] **Refer to the taxonomies, state-of-the-art review and key enabling features deliverables**.

Technology: Self diagnostic, -tuning and –repair					
Technology sub-areas*	**Degree of importance**	**Impact on EU**	**Limitations**	**Recommended measures**	**Forecast materialization**
Self-tuning	High	• Competitiveness • Production quality	• Openness of the controllers for data availability (sample rate) • Complexity	• Control openness : data access at the control loop • Prototypes	2012
Adaptronics	Very high	• Competitiveness • Production quality • Productivity	• Openness of the controllers for data availability (sample rate) • Complexity	• Control openness at the control loop level • Prototypes	2010
		•	•	•	
Autonomous machines Intelligent Machine/Tool Monitoring & Diagnosis	High	• Competitiveness • Productivity	• Dissimilarity between the machines at the plc level (small series) • Difficult to industrialise diagnosis solutions	• Research on AI techniques to automate model generation • Use ICT for creating historical data repositories	2012
Monitoring : Data Fusion / Model based monitoring / …	High	• Competitiveness • Production quality	• Research on applicability	• Prototypes demonstration and dissemination	2009
Failure prediction	High	• Competitiveness • Productivity	• Availability of historical data	• Use ICT for creating historical data repositories	2009

Technology: Self diagnostic, -tuning and –repair					
Technology sub-areas*	**Degree of importance**	**Impact on EU**	**Limitations**	**Recommended measures**	**Forecast materialization**
Self-Repair	High	• Competitiveness • Productivity	• Technology maturity	• Smaller start-up applications	2012
Maintenance & end of life management : machine components as Life Cycle Units (LCU)	Very high	• Competitiveness • Ecological	• Availability of training and information • Legal directives for sustainability	• Prototypes demonstration and dissemination • Setting up legal directives for sustainability	2010
Teleservice	Very high	• Competitiveness • Productivity	• Secure external access to internal network	• Secure access certificated by third party entities • Prototypes demonstration and dissemination • 3g independent access	2008
Collaboration Working Environments – CWE	Very high	• Competitiveness • Productivity	• New business models • Assure / Limit information secure access to the different actors	• Smaller start-up applications	2010
		•	•	•	

Technology: Self diagnostic, -tuning and –repair					
Technology sub-areas*	**Degree of importance**	**Impact on EU**	**Limitations**	**Recommended measures**	**Forecast materialization**
AmI in manufacturing machines Environment awareness	Very high	• Competitiveness • Productivity • Operator's safety	• Technology maturity	• Smaller start-up applications	2010
AMI in manufacturing	Very high	• Competitiveness • Productivity	• Research on applicability	• Prototypes demonstration and dissemination	2010
Collaborative Robots / Sharing working environment (Robot-Human) / Safety / Damage	High	• Competitiveness • Productivity • Operator's safety	• Technology maturity	• Smaller start-up applications	2015

Conclusions drawn from the ManuFuture and EUROP ETPs
The following references extracted from the last version of the ManuFuture Roadmap[2] (June 2007), the EUROP Strategic Research Agenda [3] (May 2006) and some ISTAG reports enhance the importance of the previously described technologies for each of the main key enabling features.

Smart machine :
Reference 1 : "*Besides them the usability / intuitional operator guidance must be taken into account*".
Reference 2 : "*A gradual migration path from operator advisory systems to full self-optimization should be the intent*".
Reference 3 : "*User interfaces should reduce complexity for the operator but simultaneously maintain the full extent of the system's control*".
Reference 4 : "*The development of an integrated framework for networked "Multimodal collaboration in manufacturing environments" aims at enhance the interfaces human-machine-machine through new and innovative easy and friendly mode of interaction*".

Adaptive machine :

[2] Leadership (ManuFuture SSA) - Overall Manufuture Roadmap. http://www.leadership-ssa.net
[3] EUROP ETP : http://www.robotics-platform.eu

Reference 5 : *"The "Adaptive Production Systems, Machines and Processes" aims to the development of adaptive assembly modules, the implementation of the reconfigurability of the machines and the using of smart materials for the fabrication of plug and play components employed in the high precision manufacturing. The embedding of the "Intelligence for enhanced processes" aim at the development of cost-efficient monitoring systems, which improve the prognostic capabilities, the reliability and performance of the monitoring systems". On medium term with high priority as well, the enabling technologies grouped here aim at implementing the responsive factories through cooperative, self-organised and self-optimised behaviour of the process control systems, and through embedded electronics and sensor-actuators systems, as well".*
Reference 6 : *"The main objective is then to create radically new, self-adaptive machine structures with online self-optimisation, based on mechatronic modules. The knowledge-based and/or self-learning intelligent systems can feature multi-layer control, sensing and actuator structures with a high level of redundancy, which guarantees a high level of reliability and allows optimal performance of a production system under different conditions"; "development of "adaptronic" modules and their integration into intelligent manufacturing equipment …".*
Reference 7 : *"enabling advanced automatic process control"; "enable knowledge-based, self-learning systems through the development of multi-layer controls and model based real-time compensation routines, embedding machining process knowledge…".*
Reference 8 : *"Intelligence-based process capability enhancement"; "Manufacturing processes are instable because of the high number of dynamic influencing factors (deviations of material, wear, dynamic of machines, etc). Manufacturing Instabilities combined with the inaccuracy of measurement are compensated by the tolerance system".*

Autonomous machines :
Reference 9 : *"development of self-learning, self-optimizing and cooperative control systems".*
Reference 10 : *"Self-learning, self-optimising factory control systems"; "One of the main objectives of the adaptive production systems is the development of intelligent, scalable and flexible production systems and factories by employing methods of self-learning and self optimizing control and multi-sensor systems".*
Reference 11 : *"Research should focus on self-sufficient, self-sensing and self-actuating intelligent plug- and-play components based on smart materials. Such systems should easily implement and self-adapt their range of properties, depending on the changing process conditions".*
Reference 12 : *"and finally one which assumes radical new concepts in which the monitoring system is used to modify the behaviour of actuators and to maintain the performance envelope for the longest possible time (self-optimising over a short to mid-tem time period)".*
Reference 13 : *"Main outcomes of the above presented enabling technology represent the push of the manufacturing quality towards zero defects in processes and process chains and realise intelligent self-optimising manufacturing systems".*

AmI in manufacturing machines :

Several references on Ambient Intelligence in Manufacturing in ISTAG Report “IST Advisory Group - Ambient Intelligence: from vision to reality”[4]
Several references in ISTAG Report “Scenarios for Ambient Intelligence in 2010”, annex 5 - Towards Industrial AmI applications.[5]
Several references in the EUROP SRA (May 2006).

[4] ISTAG Report – Ambient Intelligence : from vision to reality. ftp://ftp.cordis.europa.eu/pub/ist/docs/istag-ist2003_consolidated_report.pdf
[5] ISTAG Report “Scenarios for Ambient Intelligence in 2010”, annex 5 - Towards Industrial AmI applications ftp://ftp.cordis.europa.eu/pub/ist/docs/istagscenarios2010.pdf

2.4 Explanatory introduction to the preparatory template for the HMI roadmap

The target of an effective interaction between operators and machines in automation processes makes it essential to provide broadly applicable and safe communication channels. The machine should understand human modes of communication and interaction and should permit the operator to stay as close as possible to the work area. Mass-market input devices are highly desirable for user interaction to allow low-cost and easy to use commanding that meets existing safety standards. The programming effort for manufacturing plants is tremendous and drastically increases the life cycle costs for a typical process, therefore the aim is to implement methodologies, that make it an easy to perform task as the input device itself takes into account further environmental entities than a pure command. Complex structures and algorithms for interpreting operations chains as well as highly innovate technologies for the perception and measurement of the industrial environment need to be developed and integrated to enable further competitiveness of European manufacturing industries.

In the following section, the main 2 Macro Key Enabling Features (KEFs), with the associated scientific- and technology-factors, challenges and visions, that were identified by the PAC-partners are described.

Advanced physical Interaction Mechanisms for machine control
It is necessary to develop systems and methods for an intuitive process commanding without explicit programming for machine processes itself, as well as for machine interaction. These systems and methodologies will focus on the following

1. For realising the new technologies in future manufacturing processes, one operator will be not only responsible for one machine in the process, but for a process covering a whole production chain. Tele-control will therefore provide the exchange of data with different devices using several communication channels. Remote operation should be performed by wireless equipment and use virtual and augmented reality.
2. To allow a most human-like instruction, speech recognition will have to be included as an input device. Therefore new robust systems have to be built covering the large application field in industry where robustness against background noise is required.
3. Gesture recognition offers the possibility to pass simple commands like ‘start’ and ‘start’ as well as passing directions to the machine that can be translated influencing the ongoing project without a long training process of the operator. Also Human machine co-operation through physical guidance and advanced force feedback control is required.
4. Based on object recognition methods scene analysis or scene integration may generate a sequence of functions resulting on these identified objects. This interpretation allows the machine to react not only on a single given command, but to apply it on the whole process.

5. The above mentioned devices together with the state-of-the-art input devices need to be supplied in combined Multimodal Interfaces to coordinate different user input, translating them over different output channels for the process.
6. Optical recognition at long distance: Eye tracking, Person recognition. Gesture recognition etc. (touchless interaction) in factory, planning and public areas – all without carried equipment but seamless ("ambient") integration of technology into workplaces. Increasing safety, security, device independent interaction for European Industry

Intelligent Interaction Technologies

The physical input device itself is only one necessary feature of innovative human machine interaction that has to be further provided with intelligent technology, such as

1. Self adaptive and Learning input devices that are capably of interpreting the giving command by connecting the reaction to their execution context. They are not only designed for one specific application but can be adapted according to the specific operation and to the specific user profile. Most important context information to be regarded are the identification of the user/operator and his physical location.
2. The context sensitivity of interaction devices are needed to implement contextual information that can be gained from the environment and the whole process chain to be included in each operation.
3. To appropriate integrate the user and its skill into the manufacturing process virtual operation interaction devices have to be developed. They realise a profit of both the operator's and the machine's intelligence to contribute to an efficient production process. Enhanced Human/Machine interfaces will also have to include the production information systems with innovative technologies to access product life-cycle information.
4. Further behaviour sensitive interaction devices will be able to predict the outcome of the process chain at each place of the interaction between the human and the operation, controlling the process as a whole, taking into account further knowledge than the operator itself might achieve at that part of the operation, without being highly skilled and experienced. This will be realized with knowledge based technologies.
5. Mobile Augmented Reality: mobile usage of mixed, augmented and extended reality. Increasing SME competitiveness, faster productivity of new employees.
6. "Extended Memory" paradigm: Storage and semantic structuring of personal percipiences / cognitions, physiological and social data.

7. Platform- and modality-spanning design patterns: intuitive components for partially automated generation of high quality dynamic user interfaces, necessary for rapid reconfiguration / adaptation. Highly improved learning curve for personnel; faster reaction to changes (reconfigurations etc.).

Technology: Human machine interaction					
Technology sub-areas[♣]	**Degree of importance**	**Impact on EU**	**Limitations**	**Recommended measures**	**Forecast materialization**
Advanced physical Interaction Mechanisms for machine control	high	• integration, knowledge based manufacturing, mobility, competitive manufacturing	• acceptance, technological, complexity, costs	• safety technology, training, joint research, advanced technology, training, standardization	• 2015
Telecontrol	high	• integration of new technologies in the human machine interaction	• low acceptance by companies due to assumed lack of safety and confidentiality on date transfer	• information on current technology to raise acceptance	• 2008
Speech recognition	medium	• knowledge based manufacturing	• technological fragmentation • systems on the market not applicable in industry	• advanced technology to develop robust systems for industrial environment	• 2008
Gesture recognition	low	• knowledge based manufacturing	• technology with required accuracy and in acceptable price range not available, • low acceptance	• joint activity between industry and research to deploy the possibilities and raise acceptance	• 2015

[♣] **Refer to the taxonomies, state-of-the-art review and key enabling features deliverables**.

Scene analysis	medium	• mobility and knowledge based manufacturing	• complexity and costs of environment perception systems	• standardized high performance equipment has to be developed	• 2015
Multimodal Interfaces	high	• competitive manufacturing	• high complexity for the integration and coordination of input and output	• standardized high performance equipment has to be developed	• 2010
Optical recognition at long distance	High	• mobility and knowledge based manufacturing, integration of new technologies in the human machine interaction, competitive manufacturing, safety	• Algorithms • High-resolution capturing technology	• Integration and improvement of recognition technology	• 2011
Intelligent Interaction Technologies	very high	• competitive manufacturing, safety	• scientific, skilled operators, technological, acceptance	• joint research, training, promotion	• 2012
Self adaptive / Learning	very high	• competitiveness manufacturing with enhanced reliability in manufacturing process	• scientific methodologies • skilled operators	• joint research within the scientific community • training of operators	• 2010
Context sensitivity	very high	• competitiveness in manufacturing	• scientific methods • technological development of devices	• joint research scientific community and producers	• 2009
Virtual operation	very high	• competitiveness in manufacturing	• acceptance of industry • skilled workers	• training for operators • promotion for specific applications	• 2009

Behaviour sensitivity	very high	• competitiveness in manufacturing with enhanced reliability in commanding systems	• scientific • technological • safety aspects	• strengthen applied research in technology for industry	• 2012
Mobile Augmented Reality	Medium	• integration of new technologies in the human machine, interaction mobility and knowledge based manufacturing	• Recognition and visualization technology • Models	• Development of standardized meta-models for mobile AR, technology improvement	• 2012
“Extended Memory” paradigm	Medium	• mobility and knowledge based manufacturing, integration of new technologies in the human machine interaction, competitive manufacturing,	• acceptance • scientific and technological restrictions	• fusion of HCI and engineering research towards “extended memory”, enhanced technology development	• 2018
Platform- and modality-spanning design patterns	Very high	• mobility and knowledge based manufacturing, integration of new technologies in the human machine interaction, competitive manufacturing	• Scientific • Skilled system developers • Differences in technology and interfaces of devices	• Integration of interaction patterns into the concept of rapid reconfiguration	• 2010

2.5 Explanatory introduction to the preparatory template for the RMC roadmap

The main key enabling features for RMC are selected from the KEFs presented in a previous deliverable. The initial selection is updated twice and this is the final update based mainly on the results of the Delphi Study and on the latest research work in this technology area and taking into account relevant material from ETPs:

Service oriented control architecture and interoperability: Capabilities provided by a manufacturing device should be advertised as services, not as objects. A service should be entirely described by its interface, i.e. the format of the messages flowing into and out of the device, the implementation of this interface being totally opaque. Message exchanges should be asynchronous. This enables platform-neutrality. It increases flexibility, adaptability and scalability to respond in changes. It reduces development cost and time as re-use is facilitated. It enables new device networking paradigms through peer-to-peer communications. It allows real time access to the necessary information and knowledge.
Plug-and-play enables devices to be connected to a network and be automatically recognized by other devices towards higher agility and rapid reconfiguration. The interoperability of control systems and mechatronic components is necessary to allow integration of components from various vendors. For the realization of an "open automation platform" for easy integration of software modules we need a communication framework enabling the integration of external real-time critical and non real-time critical control components; also the methodologies, algorithms and tools that support the structured specification, analysis, design, testing, project work, configuration, maintenance and recycle of the whole control system.
The control architecture should have the ability to support the symbiotic manufacturing systems where robots and workers collaborate in a less structured workplace, as well as to coordinate multiple mobile processing machines. In this environments new issues for safety will emerge.
For the development of adaptive service oriented control schemes that resolve uncertainty, new methods based on Artificial Intelligent should be elaborated. Learning Algorithms will enable the controller to process the information acquired from the working environment in order to update the intelligence base and cognitive ability.

The PAC Delphi Study revealed that the technologies for RMCs are likely to be adopted by 30% of the SME's by 2015. This is part of the ARTEMIS Research Strategy too, (see annual work programme 2008, section 3.1.1, {SP 3, SP 4 and SP 5}).

Communication/interfacing and collaborative automation: High-speed industrial networks are based on wire-line and wireless Ethernet connectivity and use protocols of the IP family. This includes both standard Ethernet connections for non real-time operations and real-time

Ethernet connections for highly time-sensitive tasks. These networks should further comprise provisions to guarantee safety. Uniform network connectivity and economy-of-scale will allow low-cost yet high-speed connections for all types of industrial devices, including for sensors and actuators. This also favors integration with higher-level manufacturing systems using similar networking infrastructure.
Interface specifications and descriptions for HW & SW interfaces of mechatronic components (building blocks) as well as their standardization are also required. Adoption of a high-level communications infrastructure that is entirely neutral with respect to implementation platforms and any other vendor-specific aspects and can work across different network media. Should also be compatible with communications infrastructure used at higher levels of the manufacturing hierarchy.
Collaborative automation is a result of the integration of three main emerging technologies/paradigms: holonic control systems utilizing agent-based technology, object-oriented approaches to software, and mechatronics. The aim is to effectively utilize these technologies and methods to achieve flexible, network–enabled collaboration between decentralized and distributed intelligent production competencies. Autonomous automation units with embedded local supervisory functionality, installed in each production site, are able to collaborate to achieve production objectives at the shop floor level, and interact / co-operate to meet global (network–wide) supervisory needs (e.g. related to control, monitoring, diagnosis, HMI, and maintenance). An innovative aspect of this approach is that the control of production sequences is achieved by means of negotiation and autonomous decision making inherent in the co-ordinated operation of the functional production automation entities (intelligent, collaborative automation units), e.g., system devices, machines and manual workstations. This collective functionality, distributed across many mechatronics system devices and machine controls, replaces the logical programming of manufacturing sequences and supervisory functions in traditional production systems.

Engineering tools and design methods: Integrated Knowledge-Based theory and practice for design and operation of Reconfigurable Manufacturing Systems, Control and Mechatronic Modules has to be developed. Design and development of low computational cost software platforms of collaborative intelligent optimal design, planning, control and simulation of RMC and mechatronic modules without iterative physical prototyping are needed. Engineering environement for collaborative distributed modeling and simulation systems as well as automatic and optimal adaptation of the reconfigurable system to task requirements should be developed.
Radically new engineering theory and fundamental knowledge for smart components, machines and manufacturing systems design is required. The ultimate target will be the development of an integrated platform for the design, planning and control of reconfigurable manufacturing systems. This platform should easily integrate new technologies in the designed reconfigurable control and manufacturing systems. A systematic investigation of reconfigurable manufacturing systems in different levels of abstraction should be carried out, in order to determine the enhanced role and design requirements for their hardware and software components. In this integrated science and practice environment a knowledge-based system for mapping the task requirements to the manufacturing system's hardware and software component topology should be developed

in order to rapidly determine the necessary configuration of the system. This system should process simultaneously qualitative and quantitative knowledge for the design, planning and control of reconfigurable manufacturing systems. In this environment the optimization of cost, performance, reliability, robustness, scalability, reusability of components and complexity should be considered.
Self-optimization of a reconfigurable system means that this system has the ability to endogenously modify in an optimal way not only its behaviour but its structure too according changing working conditions and targets. Self-optimization is far beyond current contol and adaptation theory and technology. Therefore new theory and engineering methods should be developed to be integrated in the platform for the design and operation of rconfigurable control systems.Such systems will need to switch product types or load situations in zero downtime and bring new processes and devices online to remain business and supply. In order to benefit from these new concepts a consistent support for agility and adaptation through all levels of automation has to be provided.
From the PAC Delphi Study, we can conclude that the collaborative manufacturing systems will reduce the efforts for setup and reconfiguration by 50% by 2015.

Modular machines and robots: It is necessary to create completely self–contained mechatronic modules for reconfigurable machines and robots, having high uniformity (standard and general purpose modules) while maintaining a low complexity level. This will offer a reduction of overall module size by scaling down its components (materials, actuator, power source and on board electronics) and enabling the development of reconfigurable systems composed by large numbers of modules and will increase the standard modules by a factor of 3.
Nowdays used modular equipment are not considered autonomous, intelligent or reusable to a large degree. An autonomous and reusable component would have to present self-awareness and intelligence capabilities and will have to be able to function autonomously when disconnected to the main machine or system. In the expert's mind such a technology is clearly an enabling one to be implemented in the coming decades; however, quite a significant number of the panel agreed that such a technology is either too uneconomical, unpractical or complex o implement in the near future.
Currently, almost every robot/machine manufacturer develops its own components spending time and money, so the cost of the reconfigurable systems is very high. This is one of the reasons justifying the result of the PAC Delphi Study on this issue: The majority of the experts recon that the use of autonomous and reusable components for RMS is very unlikely in the foreseeable future. Therefore mass production of self-contained mechatronic components for reconfigurable robots and manufacturing systems should be considered to reduce the cost and increase the reliability of the reconfigurable systems.
Fault tolerant modules with self–monitoring, self–diagnosis and self–repair capabilities will reduce breakdown and maintenance time and costs. The development of embedded microprocessors with greater computing power is necessary, as well as the development of simpler, solid physical connection methods for module to module docking.

Technology: Reconfigurable Manufacturing Control					
Technology sub-areas*	**Degree of importance**	**Impact on EU**	**Limitations**	**Recommended measures**	**Forecast materialization**
Service oriented control and interoperability	Very high	Advanced flexibility, Reduction of development cost	Technological and commercial	Realization of service oriented platform	2015 (PAC Delphi Study:these technologies would be adopted by 30% of the SME's by 2015)
Distributed and component-based control	High	Reduce computational cost	Complexity	Interdisciplinary research	2008
Real time reconfiguration (rapid response, seamless manufacturing)	Very high	Very high flexibility and fast response to changing demand	Technological and commercial	Interdisciplinary research	2012
Open architecture control	Very High	Higher adaptability and reconfigurability Encourage user innovation	Competition between control system suppliers	Realization of open architecture platform for easy integration of user developed modules and tools	2015
Plug and play	Very high	Higher agility and rapid reconfiguration	Low standardization of interfacing	Develop standards for interfacing and connectivity from simple to complex components	2008

* **Refer to the taxonomies, state-of-the-art review and key enabling features deliverables**.

Learning and intelligent control for adaptable and reconfigurable manufacturing	High	Higher autonomy	Scientific and technological	Develop advanced learning methods	2012
(Web-)Service-oriented architecture	Very high	Basis for the realisation of reconfigurable systems	Technological: missing standards	Develop the web-service technology and install standards	2012
Communication/interfacing and collaborative automation	Very High	Reduce integration cost	Technological: low speed and reliability networks for real time control Commercial: Due to the high competitive business area it cannot be expected that interoperable interfacing and communication will be developed.	Development of neutral infrastructure to various platforms	2020
High speed industrial networks	Very High	Reduce integration cost	Technological :low speed and reliability networks for real time control	Increase the speed and reliability of networks for Standard and real time internet connections	2008
Wireless connectivity	Very High	Easy and rapid integration and reconfiguration	High cost, low reliability for manufacturing control Short duration of power supply	To be included as a standard in mechatronic modules Energy harvesting technology	2010
Uniform, High level integration of component based systems	High	Increase the interoperability	Commercial , competition	Improve communications infrastructure	2015
Collaborative environment	High	Increase confidence to innovative control systems	Ad-hoc use of engineering tools	Training Support throughout the automation life cycle	2008

Engineering tools and design methods	Very High	Higher adaptability Fast response	Scientific and technological	Development of integrated environment for design and planning of reconfigurable manufacturing control	2012
Intelligent modeling/ simulation/virtual reality systems	Very high	Reduce the design and planning cost and time	Mostly manual design and planning Special skills are necessary	Develop Knowledge based simulation systems	2010
Optimal matching of configurations to tasks	High	Cost reduction Higher reusability	Lack of methods for automatic design and planning of reconfigurable systems	Interdisciplinary research	2012
Self-optimization, Automatic real-time optimal reconfiguration	High	Cost reduction Down-time reduction	Lack of theory and engineering methods	Interdisciplinary research	2020
Cognitive Science, AI, Agents (Knowledge-based Tools and methods)	High	Increases system autonomy and self-adaptation	Scientific and technological.	Joint research projects between manufacturing and IT people	2010
Formal methods and description languages	High	Reduce errors in the design phase	Scientific and technological	Basic research and developement	2020
Integrated science and engineering method and tools Environment for RMS	High	Established theory and practice for RMS	Scientific and technological	Basic research	2020
Modular machines and robots	Very high	Reduces cost Increases reconfigurability	Low level of integration, standardization and connectivity	Develop standard and general purpose modules. Innovative modules	2012

Integrated Embedded computer (DSP, DPWS)	Very high	Increases integration Reduces cost	Low performance, relatively high cost	Develop single chip 32-bit processor with built-in ports. Price target 5 to 10 E.	2008
Advanced characteristics (reduce size)	Very high	Reduces cost facilitates reconfiguration and reuse	Technological Low ability for integration	Develop advanced design optimisation methods	2010
Self-contained, fault tolerant, self-diagnosis and self-repairable mechatronic modules	High	Higher reliability and autonomy	Scientific and Technological	Research on cognitive methods for higher autonomy	2020 (Delphi Study: the use of autonomous and reusable components for RMC is very unlikely.)
Mass production of self-contained mechatronic components	Very High	Low cost and higher reliability for RMS	Mainly Commercial.	Standardization and open architecture control	See previous line
Self-reconfigurable manufacturing machines and robots	High	Reduces downtimes Import for the factory of the future	Enhanced complexity	Basic research	2020
Reconfigurable Micro-Manufacturing Systems	Very high	Reduces the cost of MEMS	Scientific and technological	Research on parallelism approaches	2015

3 Roadmapping Trajectories

For each PAC technology the main KEFs are shown in the second column. In the next columns the most important supporting sub technologies are presented in the corresponding year when these sub technologies should reach their maturity to enable the achievement of the visions and targets given in the last column. A trajectory is drawn showing the TIMELY development that is necessary for reaching the VISIONS and TARGETS by transiting the necessary KEFs and KETs. Some trajectories consider cross-technology-KEFs for reaching some visions/targets. The roadmapping trajectories for ACT, IST, STR, HMI and RMC are shown in sections 3.1, 3.2, 3.3, 3.4 and 3.5 respectively. The abbreviations used are also explained in the appropriate sections.

3.1 Roadmap trajectory for ACT

Encaps.: Encapsulation of hardware(mechatronics), control software and intelligence in agent-based production environments.

Platform: Real-time distributed simulation methods and tools for ACT (agent-structure, -behaviour and -communication specifications).

Interfaces: Agent-interface for decision support in the planning, implementation and operation phases of ACT-Systems

Integ-Digit: Integration of ACT-based components in the digital factory offering wireless communication and Internet technologies.

Granularity: Definition of granularity of ACT-based production systems, from an intelligent sensor (that can act as an agent) throughout an intelligent machine (that can act as an agent) till the upper levels of an Enterprise (that can act as an agent). Defining the granularity it is possible the identify What" an agent is in the production environment.

Agentific.: After defining the degree of granularity of a production system and the production components that will be considered and act as an agent, Methods and Tools for the Agentification of Industrial Production Scenarios are necessary. Analysis of the production process at the shop floor and designing an environment that lets end-user easily add ACT-Systems to the shop floor, i.e., agentification of production scenarios across Europe.

Mig-Tax.: Providing knowledge and initial tools for successful, safe and efficient migration of intelligent agent-based automation and control techniques, applying the new Taxonomies for ACT-based production in a variety of European production scenarios.

Evaluation: Evaluating the integration aspects of the new technology in a variety of customer production scenarios across Europe.

Matching: Matching new production control, management and organization paradigms like Holonic Enterprise, Collaborative Manufacturing Model (CMM). The granularity of agent-based production systems is close related to the Holonic Enterprise paradigm and also to the Collaborative Manufacturing Model (CMM) paradigm that are being considered in the Roadmap of the cluster IPROMS POM. Migration technologies and methods from traditional production control architectures to the new addressed above, integrating ACT-based production components with existing ERP and MES systems.

Supervis.: Support of existent intelligent supervisory control functions and components with agent-based decision support systems: Inventory control, diagnosis, monitoring, maintenance, etc.

Ref.-Onto.: Providing reference ontologies for ACT-based production systems in different industrial scenarios.

Meth.Tho.: Providing knowledge, methods and tools to facilitate the interoperability of different ACT-Systems.

Implem.: Comparison between particular ontologies and development of methods and tools to facilitate successful communication between ACT-Systems with disparate ontologies. Facilitation of interoperability of ACT-Systems produced/generated by different vendors.

ACT-Catal.: Generation of a catalogue that will provide an overview on the European and world-wide status on ACT-based applications.

ACT-Mon.: ACT monitoring process. Providing a structure and data on existing ACT-based technologies and systems, both in industry and applied research.

ACT-Coll.: **Industrial-oriented research with strong collaboration between academia e industry. Agentification methods based on existent industrial experiences.**

Demonst.: Building demonstrator environments. Gaining knowledge on the design, behavir and benefits of intelligent agent-based production control systems.

ACT-Prod.: The European ACT-development industry will be able to build a final product based on ACT.

ACT-Syst.: The European Production Industry will be able to implement ACT-based production systems.

		2008	2009	2010	2011	2012	2013	2014	2015	Target / Visions	Intellectual content of work
ACT											20%
	ACT Engineering Platform			Encaps.		Interfaces	Integ-Digit	Platform	Platform	ACT engineering platform	
	ACT-based Prod. Syst. Engineering			Granularity	Agentific.	Mig-Tax.				European agent controllers	
	ACT-Integration with Legacy Systems					Evaluation	Matching	Supervis.		European manufacturing controlled by ACT	
	ACT-based Components Interoperability		Ref.-Onto.	Ref.-Onto.	Meth.Tho.			Implem.		Increasing competitiveness by exchanging 50% of traditional production portfolio into ACT and web services by 2015 (componentisation)	
	Confidence and Trust in ACT-Systems		ACT-Catal.	ACT-Catal	ACT-Coll.	ACT-Mon.	Demonst.	ACT-Prod.	ACT -Syst.	30% reduction of down time; 20% increasing of production system utilisation; Speeding ramp up by 1 order magnitude.	
										Respond to mass customisation oriented market	
IST											20%
	New sensors & sensors Systems	sensors	sensors							Intelligent sensors and sensor systems technology	
	Intelligent Sensor Signal Data Processing	data proc	data proc							Smart sensor integration; AmI (Ambient intelligence) in manufacturing scenarios.	
	Intelligent Sensor Monitoring Applications		monitoring	monitoring						To strengthen European sensor suppliers (SMEs) in their market position by development of a smart sensor platform.	
										Less machine down time, less scraps, higher productivity, easier system operability, less false alarm, higher product quality, better knowledge about the process.	
										Safety environment	
STR											20%
	Smart (easy) machines	KBS	AI	AI		Cognitive		Assistance		Smart, adaptive and autonomous machine technology	
	Adaptive machines			adaptive		Self-Tuning				AmI (Ambient intelligence) in manufacturing scenarios; - Machines for AmI@work.	
	Autonomous machines	Teleservice	Fusion/Mod	LCU	autonom.	Self-Repair				Improve STR component capabilities by 30%	
	AmI in manufacturing machines			AmI mach.			AmI mach.		Collaborative	Double the autonomous operation time of European manufacturing systems	
										Major facilitator of convivial technology penetration in manufacturing	
HMI											35%
	Advanced physical interaction mechanisms for machine control	tele control	speech recog.	multimodal					gesture	Knowledge and skills of HMI technologies for new adaptive manufacturing control systems	
	Intelligent interaction technologies		context	self-learn.	virtual	behaviour			scene	Systems and devices to integrate human workforce into intelligent self-organising process chains	
										Innovative HMI product range designed to meet the demands of European manufacturing to contribute with 30% of the product portfolio of European PAC industry	
										Enabling European Manufacturing Industry to regain strength by using products and technologies facilitating the integration of human workforce in future manufacturing work flow	
										Aging society	
RMC											50%
	Service oriented control architecture and interoperability	Component	Plug&Play	Service					Interoperability	Engineering tools and methods for RMC	
	Communication/interfacing		Network	Comm.						Service oriented platform for RMC	
	Engineering tools and methods			Cognit	Simul	Tools				Innovative control system components and services to answer fast changing demands and markets – 2006 CAGR 25% - 2015 CAGR 50%	
	Mechatronics modules	embedded		Optimised		STR module				Mass, extreme customisation; New manufacturing paradigms and business models implementation	
										Job creation in manufacturing area	
		2008	2009	2010	2011	2012	2013	2014	2015		

3.2 Roadmap trajectory for IST

Sensors (New sensors and sensor systems). The transformation of stand-alone sensors, used primarily as diagnostic devices in a manufacturing process, to sensors that are a part of an intelligent system for process, tool or machine monitoring and control.

Data proc (Intelligent sensor signal and data processing): Advanced sensor signal and data processing techniques, supported by artificial intelligence tools and methods, for the development and application of sensors and sensing systems for manufacturing process monitoring. A new focus of much of the research on intelligent sensor signal and data processing is sensor fusion, the integration of information from several sensors to better and more robustly characterize a process, tool or machine. This addresses the critical requirement for handling ambiguous or noisy inputs. It also lays the ground work for input to machine learning schemes to capture process knowledge when the process is sufficiently complex to defy clear mathematical modelling.

Monitoring (Intelligent sensor monitoring applications): Intelligent sensor monitoring systems include, as part of their “packaging”, abilities for self-calibration and self-diagnostics, signal conditioning, and, importantly, decision making. The most important applications of this technology in manufacturing engineering refer to real-time monitoring of manufacturing processes, on-line tool condition monitoring, work material state monitoring, chip form monitoring and control.

		2008	2009	2010	2011	2012	2013	2014	2015	Target / Visions	Intellectual content of work
ACT											20%
	ACT Engineering Platform			Encaps.		Interfaces	Integ-Digit	Platform	Platform	ACT engineering platform	
	ACT-based Prod. Syst. Engineering			Granularity	Agentific.	Mig-Tax.				European agent controllers	
	ACT-Integration with Legacy Systems					Evaluation	Matching	Supervis.		European manufacturing controlled by ACT	
	ACT-based Components Interoperability		Ref.-Onto.	Ref.-Onto.	Meth.Tho.			Implem.		Increasing competitiveness by exchanging 50% of traditional production portfolio into ACT and web services by 2015 (componentisation)	
	Confidence and Trust in ACT-Systems		ACT-Catal.	ACT-Catal	ACT-Coll.	ACT-Mon.	Demonst.	ACT-Prod.	ACT -Syst.	30% reduction of down time; 20% increasing of production system utilisation; Speeding ramp up by 1 order magnitude.	
										Respond to mass customisation oriented market	
IST											20%
	New sensors & sensors Systems	sensors	sensors							Intelligent sensors and sensor systems technology	
	Intelligent Sensor Signal Data Processing	data proc	data proc							Smart sensor integration; AmI (Ambient intelligence) in manufacturing scenarios.	
	Intelligent Sensor Monitoring Applications		monitoring	monitoring						To strengthen European sensor system suppliers (SMEs) in their market position by development of a smart sensor platform	
										Less machine down time, less scraps, higher productivity, easier system operability, less false alarm, higher product quality, better knowledge about the process	
										Safety environment	
STR											20%
	Smart (easy) machines	KBS	AI	AI		Cognitive		Assistance		Smart, adaptive and autonomous machine technology	
	Adaptive machines			adaptive		self-tuning				AmI (Ambient intelligence) in manufacturing scenarios; - Machines for AmI@work.	
	Autonomous machines	Teleservice	Fusion/Mod	LCU		sel-repair				Improve STR component capabilities by 30%	
	AmI in manufacturing machines			AmI mach.			AmI mach.		Collaborative	Double the autonomous operation time of European manufacturing systems	
										Major facilitator of convivial technology penetration in manufacturing	
HMI											35%
	Advanced physical interaction mechanisms for machine control	tele control	speech recog.	multimodal					gesture	Knowledge and skills of HMI technologies for new adaptive manufacturing control systems	
	Intelligent interaction technologies		context	self-learn.	virtual	behaviour			scene	Systems and devices to integrate human workforce into intelligent self-organising process chains	
										Innovative HMI product range designed to meet the demands of European manufacturing to contribute with 30% of the product portfolio of European PAC industry	
										Enabling European Manufacturing Industry to regain strength by using products and technologies facilitating the integration of human workforce in future manufacturing work flow	
										Aging society	
RMC											50%
	Service oriented control architecture and interoperability	Component	Plug&Play	Service					Interoperability	Engineering tools and methods for RMC	
	Communication/interfacing		Network	Comm.						Service oriented platform for RMC	
	Engineering tools and methods			Cognit.	Simul	Tools				Innovative control system components and services to answer fast changing demands and markets – 2006 CAGR 25% - 2015 CAGR 50%	
	Mechatronics modules	embedded		Optimised		STR module				Mass, extreme customisation; New manufacturing paradigms and business models implementation	
										Job creation in manufacturing area	
		2008	2009	2010	2011	2012	2013	2014	2015		

3.3 Roadmap trajectory for STR

KBS : Knowledge-Based Systems.

AI : Artificial Intelligence
Cognitive : Cognitive systems. Artificial systems that can interpret data arising from real-world events and processes; acquire situated knowledge of their environment; act, make or suggest decisions and communicate with people on human terms, thereby supporting them in performing complex tasks.

Assistance : Proactive assistance to machine operator.
Adaptive : adaptive machine, real-time on-line optimisation and adaptation to the variable conditions of the process through adaptronic systems, that consists of integrated multi-functional sensors and actuators, with the associated electronics and an adaptive control system capable of acting in real time. The introduction of more intelligent machines (autonomous, adaptive,) in industry implies a change in the way of working of the machine operators. In this sense, the human centred manufacturing concepts and interaction patterns between the operators and machines must be tackled to contribute to effective use of the new features and to the radical improvement of working conditions in manufacturing workshops.

Self-tuning : a off-line optimisation of the parameters involved in the process (machining parameters) and machine (control parameters).

Teleservice : communication services allowing a Machine Tool builder's Technical Assistance service to access remotely to the machine.

Collaborative Working Environments : Collaboration aspects between groups of specialist to perform the different tasks. The new business models in the extended enterprise require stronger collaboration between different actors in the manufacturing process (e.g. operators of machines, local and external maintenance staff, service personnel from the machine builder and numerical control builder, among others). To tackle this needs Collaboration Working Environments should be addressed, including :

- Collaboration patterns including spatial and temporal aspects.
- Knowledge management and information provision aspects.
- Collaborative decision-making process, responsibility and traceability.
- IPR and security of the information in the extend enterprise and across different companies.
- Legal aspects related to the personal data information collection.

Fusion /Models : Data fusion of data coming from very wide sources of information. Models : models, rules or cases for reasoning and provide diagnosis.

LCU : Life Cycle Units, acquires and stores usage data about components through integrated sensors over the entire life span and providing for middle-of-life and end-of-live services.

Self-repair : Machine able to repair itself without outside assistance.

AmI-machines : Machines able to be integrated and interact in an AmI for manufacturing scenario.

Collaborative robots / Sharing working environments : Collaborative working environment between Robots and Humans sharing time and space, assuring the safety and avoiding any situation that are harmful to people, property or itself damage.

		2008	2009	2010	2011	2012	2013	2014	2015	Target / Visions	Intellectual content of work
ACT											20%
	ACT Engineering Platform			Encaps.		Interfaces	Integ-Digit	Platform	Platform	ACT engineering platform	
	ACT-based Prod. Syst. Engineering			Granularity	Agentific.	Mig-Tax.				European agent controllers	
	ACT-Integration with Legacy Systems					Evaluation	Matching	Supervis.		European manufacturing controlled by ACT	
	ACT-based Components Interoperability		Ref.-Onto.	Ref.-Onto.	Meth.Tho.			Implem.		Increasing competitiveness by exchanging 50% of traditional production portfolio into ACT and web services by 2015 (componentisation)	
	Confidence and Trust in ACT-Systems		ACT-Catal.	ACT-Catal	ACT-Coll.	ACT-Mon.	Demonst.	ACT-Prod.	ACT -Syst.	30% reduction of down time; 20% increasing of production system utilisation; Speeding ramp up by 1 order magnitude.	
										Respond to mass customisation oriented market	
IST											20%
	New sensors & sensors Systems	sensors	sensors							Intelligent sensors and sensor systems technology	
	Intelligent Sensor Signal Data Processing	data proc	data proc							Smart sensor integration; AmI (Ambient intelligence) in manufacturing scenarios.	
	Intelligent Sensor Monitoring Applications		monitoring	monitoring						To strengthen European sensor suppliers (SMEs) in their market position by development of a smart sensor platform	
										Less machine down time, less scraps, higher productivity, easier system operability, less false alarm, higher product quality, better knowledge about the process	
										Safety environment	
STR											20%
	Smart (easy) machines	KBS	AI	AI		Cognitive		Assistance		Smart, adaptive and autonomous machine technology	
	Adaptive machines			adaptive		self-tuning				AmI (Ambient intelligence) in manufacturing scenarios; - Machines for AmI@work.	
	Autonomous machines	Teleservice	Fusion/Mod	LCU	autonom.	sel-repair				Improve STR component capabilities by 30%	
	AmI in manufacturing machines			AmI mach.			AmI mach.		Collaborative	Double the autonomous operation time of European manufacturing systems	
										Major facilitator of convivial technology penetration in manufacturing	
HMI											35%
	Advanced physical interaction mechanisms for machine control	tele control	speech recog.	multimodal					gesture	Knowledge and skills of HMI technologies for new adaptive manufacturing control systems	
	Intelligent interaction technologies		context	self-learn.	virtual	behaviour			scene	Systems and devices to integrate human workforce into intelligent self-organising process chains	
										Innovative HMI product range designed to meet the demands of European manufacturing to contribute with 30% of the product portfolio of European PAC industry	
										Enabling European Manufacturing Industry to regain strength by using products and technologies facilitating the integration of human workforce in future manufacturing work flow	
										Aging society	
RMC											50%
	Service oriented control architecture and interoperability	Component	Plug&Play	Service					Interoperability	Engineering tools and methods for RMC	
	Communication/interfacing		Network	Comm.						Service oriented platform for RMC	
	Engineering tools and methods			Cognit.	Simul	Tools				Innovative control system components and services to answer fast changing demands and markets – 2006 CAGR 25%	
	Mechatronics modules	embedded		Optimised		STR module				Mass, extreme customisation; New manufacturing paradigms and business models implementation	
										Job creation in manufacturing area	
		2008	2009	2010	2011	2012	2013	2014	2015		

3.4 Roadmap trajectory for HMI

Tele Control: Advanced Interaction mechanism to facilitate remote control of intelligent production components using wireless technologies.

Guidance: Manual physical guidance for programming during human-machine-cooperation.

Speech Recog.: Speech Recognition as one data-processing mechanism for facilitating the interaction human-machine.

Context: Context Sensitivity, identification and localization of operators.

Multimodal: Multimodal Interfaces.

Self-Learn.: Self-Adaptive / -Learning.

Virtual: Virtual Operation and augmented reality.

Behaviour: Behaviour Sensitivity.

Optical Recog.: Optical Recognition with ambient integration of technology into workplaces.

Scene: Scene Analysis.

Operator Id./Loc.: Identification of the operator and its physical localisation.

Product Data: Include product life-cycle information in human/machine inerfaces.

Extended Memory: Dynamic user interfaces for fast reconfiguration/adaptation

											Intellectual content of work
ACT											20%
	ACT Engineering Platform			Encaps.		Interfaces	Integ-Digit	Platform	Platform	ACT engineering platform	
	ACT-based Prod. Syst. Engineering			Granularity	Agentific.	Mig-Tax.				European agent controllers	
	ACT-Integration with Legacy Systems					Evaluation	Matching	Supervis.		European manufacturing controlled by ACT	
	ACT-based Components Interoperability		Ref.-Onto.	Ref.-Onto.	Meth.Tho.			Implem.		Increasing competitiveness by exchanging 50% of traditional production portfolio into ACT and web services by 2015 (componentisation)	
	Confidence and Trust in ACT-Systems		ACT-Catal.	ACT-Catal	ACT-Coll.	ACT-Mon.	Demonst.	ACT-Prod.	ACT -Syst.	30% reduction of down time; 20% increasing of production system utilisation; Speeding ramp up by 1 order magnitude.	
										Respond to mass customisation oriented market	
IST											20%
	New sensors & sensors Systems	sensors	sensors							Intelligent sensors and sensor systems technology	
	Intelligent Sensor Signal Data Processing	data proc	data proc							Smart sensor integration; AmI (Ambient intelligence) in manufacturing scenarios.	
	Intelligent Sensor Monitoring Applications		monitoring	monitoring						To strengthen European sensor suppliers (SMEs) in their market position by development of a smart sensor platform	
										Less machine down time, less scraps, higher productivity, easier system operability, less false alarm, higher product quality, better knowledge about the process	
										Safety environment	
STR											20%
	Smart (easy) machines	KBS	AI	AI		Cognitive		Assistance		Smart, adaptive and autonomous machine technology	
	Adaptive machines			adaptive		Self-Tuning				AmI (Ambient intelligence) in manufacturing scenarios; - Machines for AmI@work.	
	Autonomous machines	Teleservice	Fuson/Mod	LCU	autonom.	Self-Repair				Improve STR component capabilities by 30%	
	AmI in manufacturing machines		AmI mach.				Ami mach		Collaborat	Double the autonomous operation time of European manufacturing s	
										Major facilitator of convivial technology penetration i	
HMI											35%
	Advanced physical interaction mechanisms for machine	Tele-ctrl.	Speech	Multimod	Guidance			Optical	Scene	Knowledge and safety skills of HMI technologies for new adaptive manufacturing control systems	
	Intelligent interaction technologies		Context	Self-learn.	Prod. Data	Virtual	Behaviour	Ext. Mem		Systems and devices to integrate human workforce into intelligent self-organising process chains	
					Op. Id/Loc					Innovative HMI product range designed to meet the demands of European manufacturing to contribute with 30% of the product portfolio of European PAC industry	
										Enabling European Manufacturing Industry to regain strength by using products and technologies facilitating the integration of human workforce in future manufacturing work flow	
										Aging society	
RMC											50%
	Service oriented control architecture and	Component	Plug&Play	Service					Interoperat	Engineering tools and methods for RMC	
	Communication/interfacing		Network	Comm.						Service oriented platform for RMC	
	Engineering tools and methods			Cognit	Simul	Tools				Innovative control system components and services to answer fast changing demands and markets – 2006 CAGR 25%	
	Mechatronics modules	embedded		Optimised		STR module				Mass, extreme customisation; New manufacturing paradigms and business models implementation	
										Job creation in manufacturing area	
		2008	2009	2010	2011	2012	2013	2014	2015		

3.5 Roadmap trajectory for RMC

RMS: Reconfigurable Manufacturing Systems

Component: Manufacturing device able to offer and receive services

Colab. Aut. : Collaborative Automation.

Plug&play: Enables devices to be connected and be automatically recognized

High Speed: High speed and reliable networking to support RMC

Wireless: Wireless Connectivity Communication/interfacing

Learning: Learning and intelligent control for adaptable and reconfigurable manufacturing

Uniform: Uniform, High level integration of component based systems

Cognit.: Cognitive science for knowledge-based engineering methods and tools.

Sim.: Knowledge-based simulators

Tools : Engineering tools and methods

Embedded: Embedded microprocessors with greater computing power in mechatronic modules

Integr. Env.: Integrated science and engineering method and tools environment

Optim.: Optimized mechatronic modules

(Web-)Services: Service oriented architectures and control for reconfigurable manufacturing components, machines and systems

STR modules: Self-contained intelligent mechatronic modules

Formal methods: Formal methods for verification and validation during the design phase

RMM: Reconfigurable Micro-Manufacturing

Self-reconf.: Self-reconfiguration capabilities for Reconfigurable Manufacturing Systems

Self-optim.: Automatic real-time optimal reconfiguration

											Target / Visions	Intellectual content of work
ACT												20%
	ACT Engineering Platform			Encaps.		Interfaces	Integ-Digit	Platform	Platform		ACT engineering platform	
	ACT-based Prod. Syst. Engineering			Granularity	Agentific.	Mig-Tax.					European agent controllers	
	ACT-Integration with Legacy Systems					Evaluation	Matching	Supervis.			European manufacturing controlled by ACT	
	ACT-based Components Interoperability		Ref.-Onto.	Ref.-Onto.	Meth.Tho.			Implem.			Increasing competitiveness by exchanging 50% of traditional production portfolio into ACT and web services by 2015 (componentisation)	
	Confidence and Trust in ACT-Systems		ACT-Catal.	ACT-Catal	ACT-Coll.	ACT-Mon.	Demonst.	ACT-Prod.	ACT -Syst.		30% reduction of down time; 20% increasing of production system utilisation; Speeding ramp up by 1 order magnitude.	
											Respond to mass customisation oriented market	
IST												20%
	New sensors & sensors Systems	sensors	sensors								Intelligent sensors and sensor systems technology	
	Intelligent Sensor Signal Data Processing	data proc	data proc								Smart sensor integration; AmI (Ambient intelligence) in manufacturing scenarios.	
	Intelligent Sensor Monitoring Applications		monitoring	monitoring							To strengthen European sensor suppliers (SMEs) in their market position by development of a smart sensor platform.	
											Less machine down time, less scraps, higher productivity, easier system operability, less false alarm, higher product quality, better knowledge about the process	
											Safety environment	
STR												20%
	Smart (easy) machines	KBS	AI	AI		Cognitive		Assistance			Smart, adaptive and autonomous machine technology	
	Adaptive machines			Adaptive		Self-Tuning					AmI (Ambient intelligence) in manufacturing scenarios; - Machines for AmI@work.	
	Autonomous machines	Teleservice	Fusion/Mod	LCU	autonom.	Self-Repair					Improve STR component capabilities by 30%	
	AmI in manufacturing machines			AmI mach.			AmI mach		Collaborat		Double the autonomous operation time of European manufacturing systems	
											Major facilitator of convivial technology penetration in manufacturing	
HMI												35%
	Advanced physical interaction mechanisms for machine	tele control	speech recog	multimodal					gesture		Knowledge and skills of HMI technologies for new adaptive manufacturing control systems	
	Intelligent interaction technologies		context	self-learn.	virtual	behaviour			scene		Systems and devices to integrate human workforce into intelligent self-organising process chains	
											Innovative HMI product range designed to meet the demands of European manufacturing to contribute with 30% of the product portfolio of European PAC industry	
											Enabling European Manufacturing Industry to regain strength by using products and technologies facilitating the integration of human workforce in future manufacturing work flow	
											Aging society	
RMC												50%
	Service oriented control architecture and	Component	Plug&Play	Web Service					Interoperability		Engineering tools and methods for RMC	
	Communic/interf.and collab.	High speed		Wirless				Collab. aut.	Unif.		Service oriented platform for RMC	
	Engineering tools and methods			Cognit.	Simul	Tools			Self-optim.	Integrat. Env	Innovative control system components and services to answer fast changing demands and markets – 2006 CAGR 25%	
	Mechatronics modules	embedded		Optimised		STR module			RMM	Self-reconf.	Mass, extreme customisation; New manufacturing paradigms and business models implementation	
											Job creation in manufacturing area	
		2008	2009	2010	2011	2012	2013	2014	2015	2020		

4 Conclusion

The research roadmap deliverable D5.5 has been updated based on the results obtained from industrial survey which has been conducted within the European industries, academic and research communities, and the technology leaders' expert knowledge. The updating should be seen as a continuation of the updated common taxonomies, state-of-the-art review and key enabling features. The first version of the roadmap has been refined and at the same time some of the missing and emerging technologies of the future manufacturing systems have been incorporated in this updated research roadmap.

The content of this roadmap was based on the state-of-the-art analysis carried out by the cluster in an earlier step that resulted in 5 Key Enabling Technologies as described by the PAC catalogue of Key Enabling Features (KEF). During the workshop, each of the participants evaluated one of the 5 PAC technology areas, identifying Key Enabling Technologies (sub-technologies), to classify different macro-KEFs and to fill the PAC-template that was used to improve the KEF structure to result in the final PAC technology roadmap. In a round table discussion with all participants the names, definitions and contents of the KEFs were shared and agreed for each PAC technology area and then adapted to the timeframe of the roadmap, to reflect the development process.

The technology roadmap is structured in time dependant tablets for each technology area. Each row represents a macro-KEF that is divided into columns for the year 2008 to 2015. The boxes placed behind the macro-KEF demonstrate a KEF, KET or gap belonging to this technology area, which is due to be available or solved in the year of the corresponding column.

At the workshop, for each of the technology areas, visions and targets have been identified that should be achieved with the implementation of the KEFs, KETs and/or solving the gaps. These are filled into the table in the first column after the year 2015. The last column shows the intellectual content of the envisioned work for each macro-KEF in each of the PAC technology areas. To achieve one of these targets, mostly several KEFs, KETs and gaps have to be considered. This is visualised by the trajectories that also consider cross-technologies and show the timely development that is necessary for reaching the target by transiting the necessary KEFs , KETs and gaps.

Roadmaps do not specify exactly when a certain functionality or key enabler will be realised or a gap will be solved. In the case of the PAC-Roadmap, the PAC workshop participants did use their own judgement to classify them to a different time scale, based mainly on the sources of information offered by the PAC Taxonomies, State-of-the-Art and catalogue of KEFs deliverables.

The visions presented here give the view of the IPROMS-PAC partners that have contributed to the roadmap examined in this work. Therefore, the presented visions and targets for the production automation and control in Europe are somewhat self-realising, since they are the visions presented by those entities that can hopefully influence them during the next 4 years (work plan of IPROMS) and beyond. Naturally, not all challenges or targets will become the success that is envisioned in the roadmap, but it does show the future possibilities in the road ahead.

Of course, the visions, targets and the roadmap will be updated from one IPROMS work-plan period to the next one to see which direction the developments in the 5 PAC technology areas are heading in.

One important step in the next IPROMS Period will be the evaluation of the roadmap and the identification of critical paths.

The delivery of this first version of the PAC roadmaps will also be followed by in-depth gap discussions to identify areas where common needs can be addressed through research and development, innovation, deployment and standards development.

Finally, the set of visions/targets and the corresponding timing associated to the KEFs, KETs and Gaps is only one possible scenario proposed by the PAC-group of experts Thus this roadmap, as is usual with this kind of study, must be treated with caution and should be seen as a first vision of our IPROMS-Cluster as one possible approach rather than as something that will certainly happen in detail.

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The Technology Roadmap for the PAC Cluster is initially based on the contributions of all PAC-partners that collaborated in the generation of the PAC-Catalogue of KEFs (Key Enabling Features). The current version was prepared by an expert group consisting of Mr. Michael Höpf – FhG-IPA (assisted by Miss. Susanne Oberer); Dr. Armando W Colombo – Schneider Electric; Professor R Teti (assisted by Dr. Doriana D'Addona) - University of Naples Federico II; Professor N Aspragathos - University of Patras; Dr. Michael Packianather – Cardiff University; and Mr. Jon Agirre Ibarbia – Fatronik, during a 2-day workshop.

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