Flagship Project
“Factory of the Future
National Manufacturing Platform”

Scientific and Technological Challenges
Foreword

The Flagship Project “Factory of the Future” was approved by the Interministerial Committee for Economic Planning (CIPE) within the Italian National Research Programme for 2011-2013 (Piano Nazionale della Ricerca) and will be coordinated by the Italian National Research Council (CNR).

The Flagship Project foresees the participation in research activities of CNR institutes, universities, research institutions and consortia, local institutions, governmental institutions, companies and industrial consortia, private persons. The project favours the scientific community’s and the manufacturing system’s participation in the research topics foreseen, also through research funding according to evaluation procedures.

According to the Legislative Decree 213/2009 (art. 9.1), the Flagship Project “Factory of the Future” refers to CNR Department of Engineering, ICT and Technologies for Energy and Transport. The Department coordinators supervise the carrying out of the project on behalf of CNR Board of Directors and reports their evaluation to it.

Prof. Tullio Antonio Maria TOLIO (ITIA-CNR) and Dr.ssa Federica ROSSI (IBIMET-CNR) have been appointed Manager and Assistant Manager of Flagship Project “Factory of the Future” according to Decision n. 110/2011-Minute 177 of 11/5/2011 and will be assisted by the Executive Committee, according to Decision n. 166/2011- Minute 184 of 13/7/2011.

By taking into account the Italian manufacturing system distinctive features and the evolution of the European and global industrial contexts, the Flagship Project aims at setting up important research initiatives in order to increase competitiveness of the Italian industry and, especially, of “Made in Italy” products within the global context. The Project foresees several types of initiatives which, besides generating strategically important innovations, aim at creating a long-lasting national community, characterized by scientific excellence of research, which could outline innovation future directions within the Italian manufacturing sector and represent it in the international context.

The Executive Programme defines the Flagship Project objectives and priorities, on the basis of knowledge available at an international level and of research potential existing at a national level. It especially defines the following aspects:

- breakdown into subprojects;
- intermediate scientific objectives and their connection with final objectives;
- human resources and breakdown of financing, including the amount of research funds which will be allocated on the basis of evaluation procedures;
- expected results and the relative potential users.
Executive Summary
The Manufacturing industry is a fundamental asset for generating wealth and employment and for ensuring a better quality of life. It is also an important pillar for the services, as, on the one hand, it produces those goods which are necessary for its functioning and, on the other hand, it generates new services, thus enlarging their market.

In 2009 Italy was fifth in the world ranking of manufacturing powers and second in the European ranking, following Germany. The sectors of Italian industry and of Made in Italy products (among which the machinery one ranks first in terms of export) provide jobs to about 3.9 million people and are characterized by many examples of excellence which allow Italy to rank first and second in many industrial areas (besides machinery, in mechanics, the textile and clothing industry, the furniture and nautical industries). In terms of industrial evolution, in the last few years Italian manufacturing has experienced a sectoral reorganization, shifting from traditional to more high-tech sectors. This situation makes it even more necessary to support Italian industry and Made in Italy products through modern and advanced-innovation solutions originating from the research sector.

Due to the difficult situation characterizing global markets and to the Eurozone crisis, Italy is compelled to undergo a deep transformation, in order to be able to keep playing such a primary role within the international context. Innovation in products, processes and production technologies, to be pursued by catalysing national instances of excellence towards a systemic aim, will have to act as an enabling factor for this transformation. Within this scenario the Flagship Project “Factory of the Future” is an important occasion for Italy.

The Flagship Project, whose executive programme is defined in this document, suggests to pursue five macro-objectives relative to the features which will have to characterize the factories of the future, in order to ensure Italian industrial production sustainable development. The set of these macro-objectives characterizes the notion of “Factory of the Future”:

- Factory for Customised Products.
- Evolutionary and Reconfigurable Factory.
- High-Performance Factory.
- Sustainable Factory.
- Factory for the People.

These objectives are coherent with the main trends which have been conveyed by world, European and national governments and institutions (for instance the “grand challenges” which have been identified by the EU, the “Roadmaps” and “Strategic Research Agendas” which have been developed by the European Association EFFRA – European Factories of the Future Research Association, the European Technology Platform “Manufuture”, the “American Leadership on Advanced Manufacturing” initiative, which has been promoted by the President of the United States of America and the Italian National Research Programme – PNR).

In order to carry out the “Factory of the Future”, its Executive Programme suggests to develop several typologies of enabling technologies, where by “enabling technology” we mean hardware, software and methodology solutions, whose integration will allow to reach the macro-objectives foreseen. Here follows a list of enabling technologies:

- Information and Communication Technologies (ICT) and “Digital Factory” technologies for an intelligent factory.
- Manufacturing technologies.
- De-manufacturing and material-recovery technologies.
The idea of “Factory of the Future”, characterized by its five pillars and carried out through the enabling technologies, will deeply influence from an industrial point of view several sectors of the Italian industry and of Made in Italy products, thus enhancing traditional quality, flexibility and customization traditional performances through innovative solutions.

The Executive Programme is divided into two subprojects, each consisting of work packages and tasks. The subprojects propose an organic mixture of research activities belonging to different typologies in terms of impact and actors involved and aiming at the development of the enabling technologies relative to the macro-objectives pursued. Through this set of research activities the project intends to guarantee the systemic involvement and enhancement of all the national actors who can contribute to the promoting of innovation in different ways and at different levels. CNR acts both as a research developer through its internal competences, as a body integrating different actors and as a catalyser of activities towards the strategic objectives defined. Each subproject includes, within the contents it deals with, the activities which are necessary to promote the “Factory of the Future” culture with the stakeholders and to disseminate research results in a proactive way. The project, therefore, aims to set up a national community of excellence which should be able to develop successful manufacturing strategies for the future basing on the results achieved during a project duration of three years.

**Subproject 1: “Factory of the Future: towards reality”**

Subproject 1 aims to combine CNR internal competences in order to promote frontier innovation and bring it closer to industrial dimension. Subproject 1 foresees three typologies of research projects:

- **S1.A** Towards the carrying-out of innovative products.
- **S1.C** Towards new frameworks for factory design and management.

Project results will belong to different types depending on the distance existing between laboratory process and industrial application. They include general and/or detailed projects relative to: factories manufacturing products and innovative technologies, economic and environmental feasibility studies relative to new factories, new frameworks for the design of the factories of the future and of industrial demonstrators which foresee a tangible implementation of the factory project and/or the use of new technologies within the system. The selection of projects will take place on the basis of an evaluation process of the proposals submitted within a thematic call for project proposals.

Subproject 1 foresees specific activities for the promoting and disseminating of the results achieved.
Subproject 2: “Promotion of innovation supporting the Factory of the Future”

Subproject 2 intends to develop different types of innovation which are consistent with the Flagship Project scientific topics through an organic set of initiatives aiming to:

- Strengthen cooperation between Universities, research institutions and industry.
- Enhance the role of local actors such as advanced-technology districts, national technological platforms and hubs of national excellence in innovation cycle.
- Support human resources of excellence in the development of their research projects.
- Promote training initiatives dealing with the “Factory of the Future”.

Within Subproject 2 CNR will therefore act as a “hub” directing and structuring research activities of excellence carried out at a national level and relative to the macro-objectives of the Flagship project. Accordingly four main activity typologies will be supported:

- S2.A Research projects for the development of medium to long-term innovation.
- S2.B Research projects for the development of short to medium-term innovation.
- S2.C Research projects supporting the relaunch of human capital devoted to research.
- S2.D Training projects dealing with the “Factory of the Future”.

Projects belonging to typologies S2.A and S2.B will be addressed to consortia composed by at least one partner belonging to the following categories: industrial companies, universities, research institutions. Industrial partners can be individual companies, consortia and consortium companies, science and technology parks, industrial associations. Multidisciplinarity of consortia and representation of Made in Italy sectors will be rewarded. Projects belonging to typology S2.C will be addressed to young researchers of age under 35 working in public research institutions connected with the Italian Ministry of Education, University and Research (MIUR) and in Italian universities. Projects belonging to typology S2.D will be addressed to individual participants as well.

Project participation will take place on the basis of a selection procedure of the proposals submitted within thematic calls for proposals.

Subproject 2 foresees specific activities for the promoting and disseminating of the results achieved.

Thanks to organic structuring, to the design of a set of complementary actions which can involve and enhance Italian forms of excellence, to coherence with the international competitive scenario and to an approach foreseeing the dissemination of a new manufacturing innovation culture able to set up a national community of excellence, the Flagship Project “Factory of the Future” is an important occasion to support the future Italian competitiveness, featuring CNR as a crucial actor in the promotion of innovation.
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1. REFERENCE SCENARIO

1.1. The Italian Manufacturing Industry in the world: industrial challenges and the role of research

In 2009 Italy was the world’s fifth manufacturing power with 3.9% of the global manufacturing production. At a European level Italy comes second in the ranking of manufacturing countries, following Germany, which in the last few years has kept its leadership role by protecting its competitive advantage. France and the United Kingdom lost out to Italy and rank respectively seventh (3.6%) and tenth (2.3%). Within the global scenario, China shot to the top of the charts (21.5% of manufacturing production), outranking USA and Japan, which come respectively second and third. Although the change in the absolute production volume of these countries is limited, in terms of percentages, in the last ten years, they have been cutting nearly by half their contribution to global manufacturing (totalling respectively 15.1% and 8.5% in 2009), because of emerging economies’ remarkable growth. South Korea, India and Brazil, ranking respectively sixth (3.6%), eighth (2.9%) and ninth (2.7%), are hot on Italy’s heels, although Italy defends its position (Table 1).

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<tr>
<th>Paesi produttori</th>
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<th>2000</th>
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Table 1 – Ranking of the 20 most important countries in terms of manufacturing production [Confindustria, 2010]

Italy’s vocation for manufacturing is even more evident if we consider manufacturing per-capita production. According to this indicator Italy is the world’s second most industrialized country, below Germany. Japan and the U.S.A. rank immediately below Italy (Figure 1).
In terms of contribution to the added value globally produced in Italy, in 2010 manufacturing production accounted for 17% (Eurostat data). The manufacturing industry should not be considered as a sector which is able to produce wealth and employment as such. It should instead be considered as a basic pillar of modern economy, as, on the one hand, its absence would make the service sector be unable to provide its offer and, on the other hand, it would lose part of its marketing area. As a matter of fact, industry requires services for its functioning and its growth fosters the development of the service sector (“pull” effect). According to estimates, each job in the manufacturing sector creates about two supplementary jobs within the services [European Parliament, 2010]. Besides, industry provides products and semi-finished products which are necessary to service companies for the offering of performances (“push” effect), thus actively defining product quality and the opportunities relative to their offer. As a “supplier” the Italian manufacturing sector devotes about 11% of overall production to the functioning of the service sector [European Commission, 2009]. Figure 2 represents the connection described above.

These data show that factories pull the national and European overall economies, both by producing the goods and services used in other sectors and by acting as marketing areas for them. Turnover and added value relative to 2010 referring to those fields the Italian manufacturing sector consists of, listed according to NACE classification of industrial sectors, are represented in Figure 3.

The relevant cross-section shows that the first sector in terms of both turnover and added value is mechanics, followed by machinery, the chemical-pharmaceutical and rubber-and-plastics industries, the foodstuff sector and the textile and clothing industry. “Made in Italy” sectors are traditionally represented in Italian by the “Four As”: Automazione (Automation), Alimentare (Foodstuff), Abbigliamento (Clothing), Arredo (Furniture) [Fondazione Edison, 2009].
These data confirm the trend relative to the sectoral restructuring of Italian economy which has been already pointed out by Confindustria and which consists of a shift from more traditional sectors, such as tanning and shoemaking industries, the furniture industry and clothing and textile industries towards heavier sectors characterized by higher technological content, such as the machine tool industry and manufacturing systems, mechanics and the metal industry, the automotive and chemical-rubber-plastics industries.

This reorganization requires more sophisticated industrial solutions characterized by greater innovation which could be used in the manufacturing of more complex industrial products and which could more efficiently support those traditional industrial types of production which have to adopt more efficacious and advanced practices, in order to maintain their competitiveness.

It is necessary to point out that, despite this sectoral reorganization, Italy keeps occupying the first position in Europe in those sectors in which it can count on solid traditions and unquestioned style, thanks to an increase in the efficiency companies operating within these sectors have been compelled to achieve. Table 2 shows how, besides ranking first in Europe in the textile-clothing-leather industry, Italy is second in Europe as concerns industrial machinery, metals and non-metal production, metal products, wood and paper, furniture (according to data relative to 2006). Because of their limited size, niches of excellence such as the nautical industry and the luxury boats sector do not currently contribute to the overall industrial production. Nonetheless, they point out Italy’s world leadership in those sectors requiring a combination of technology and design.
In terms of employment, Italian manufacturing production activities provide jobs to about 3.9 million people, who are distributed in industrial sectors as it is shown in Figure 4. The figure relative to employment in the services connected to manufacturing is about 6.5 million people (this figure equals the number of people working in Public Administration and the social services) (Eurostat data relative to 2010).
Export of “Made in Italy” products is represented in Picture 5, which has been drawn up by using 2008 data provided by the Foreign Trade Institute (ICE). Machinery is first in the ranking of Italian export and is followed by the chemical-pharmaceutical-rubber-plastics, textile-clothing and foodstuff industries.

1.2. EU and Italian institutional and keynote framework
The Flagship Project structure cannot abstract from on-going research and innovation initiatives in the manufacturing sector both at a national and a European level. These initiatives are chronologically summarised below. In the early 2000s the European Platform “ManuFuture” was set up in order to face the challenges characterizing the modern industrial scenario. The Platform embodies the main manufacturing actions and initiatives carried out at European, national and regional levels, in order to support the European manufacturing sector. After several working groups’ meetings, in which ITIA Director took part as “High-level Group” and “Implementation Support Group” member, in 2006 “ManuFuture” marked the need for modifying the European competitive model, which was no longer suitable for facing the new global situation [Manufuture, 2006]. On the one hand, the European manufacturing sector’s most advanced-technology segments are suffering from fierce competition by other industrialized countries’, such as Korea for instance. On the other hand, production activities in more traditional sectors are gradually shifting towards countries characterized by lower labour costs with which structural conditions do not allow to compete. The strategic solution suggested by this platform consists in the shifting of competition to high added-value and knowledge-content products and activities, which should occupy a central position in the manufacturing sector innovation. The Platform, in particular, has identified the following five pillars of the manufacturing industry of the future:

- New high added-value product-service systems.
- New business models.
- Adoption of industrial engineering advanced solutions.
- Development of manufacturing knowledge and technologies.
- Innovation in research infrastructure and education system.
The economic crisis which has been characterizing the period after 2006 has marked even more the crucial role of the manufacturing sector as a pillar of economies. At a European level, the “recovery plan” the President of the European Commission Mr. Barroso launched in 2008, foresaw the setting-up of “Public Private Partnerships” between the European Commission and private actors, in order to foster investment in strategic sectors and activities. In particular, an overall budget of 1.2 billion euros was allocated for the manufacturing sector [Barroso 2008] [European Commission 2008]. This led to the establishment of the “European Association for the Factories of the Future” (EFFRA), a European-level private association which was set up within Manufuture and which is composed by companies, trade associations and research centres. Accordingly with EU plans, EFFRA aims to act as a private negotiator which, by cooperating with the public representative (EU), can engage in the carrying-out of a Public-Private Partnership (PPP) dealing with the topic “Factories of the Future”. EFFRA has produced a “Strategic multiannual roadmap”, to which the National Research Council Institute of Industrial Technologies and Automation (ITIA-CNR) made its contribution as a member of the “Industrial Research Advisory Group” [EFFRA 2010]. This roadmap outlines the guidelines of research activities and European innovation within manufacturing as they have been proposed by industrial stakeholders. They belong to four basic classes:

- Sustainable manufacturing (from an environmental, economic and social point of view).
- ICT-enabled intelligent manufacturing.
- High-performance manufacturing.
- Exploitation of new materials through manufacturing.

The topics proposed by EFFRA strategic roadmap have been the basis for the development of “call for proposals” of on-going European research projects.

During the last year, the importance of the manufacturing industry and the need for considering it as a core factor for the defining of the European future policies relative to economy, industry, infrastructure and new technologies were confirmed by a few reports addressed by the European Commission Directorates-General “Enterprise and Industry”, “Research and Innovation” and “Information Society and Media” to the European Parliament [European Commission 2010 (a) (b) (c) (d)].

In the United States, too, President Obama has underlined the central role of the manufacturing sector and its importance as a basic factor for reconstruction following the economic crisis. Similarly to European events, the “recovery plan” launched by US president foresees a specific chapter dealing with “Manufacturing and green jobs” which establishes the setting-up of an “Advanced Manufacturing Fund” for the development of advanced manufacturing strategies, the doubling of funds allocated for innovating production technologies and improving their efficiency, besides considerable investment for the development of new technologies in the energy sector in terms of sustainability [Obama, 2010]. In order to support the operational implementation of this programme, in June 2011 the “Council of Advisors on Science and Technology” published a “Report to the President on ensuring American leadership In Advanced Manufacturing” [Advisors 2011], which suggests to allocate 0.5-1 billion dollars per year (for four years) for supporting important research initiatives in the advanced manufacturing sector, companies would not be able to undertake on their own. Here follows a list of the actions mentioned:

- development of new technologies and design methodologies supporting the production of highly innovative products and materials;
• development of design methodologies drastically reducing the time which is necessary for carrying out product manufacturing, starting from product idea;
• setting-up of private-public pre-competitive partners which should be able to develop “cutting-edge” manufacturing technologies;
• setting-up of shared infrastructures allowing small and medium companies to innovate their products and processes, in order to be more competitive globally;
• the report also defines the priorities for the setting-up of fiscal conditions favouring innovation in the manufacturing sector and the enhancing of training in technical-scientific subjects favouring an increase in competences of excellence within frontier technologies.

At a national level, institutions and the industrial world are currently greatly focusing on innovation and support to this sector. On the basis of the trends and needs thematic working tables representing different sectors and industries have pointed out (one of which specifically refers to capital goods), the Italian Research National Programme (PNR), which was drawn-up by the Government, sets up important research actions oriented towards enabling technologies, innovative industrial sectors’ development, support to existing industries aiming to improve their efficiency and competitiveness and support to new high-tech companies [PNR, 2010]. This is consistent with evolution towards a higher added-value manufacturing sector which has been promoted at EU-level.
At a regional level it is necessary to mention the initiative “Mind in Italy”, within which the National Research Council (CNR) and the Region Lombardy have recently signed a framework agreement relative to the carrying out of four research projects, one of which deals with “high-tech processes and consumer-oriented products for the Lombard manufacturing sector’s competitiveness”. This initiative foresees a budget of 40 million euros equally distributed between the Region Lombardy (20 million euros) and CNR (20 million euros) [CNR, 2006].
The Flagship Project described below is the implementation of the research trends defined within PNR and the national research community, according to on-going European and world initiatives and strategies.
2. THE ROLE OF FLAGSHIP PROJECTS IN THE RESEARCH AND INNOVATION NATIONAL SYSTEM

2.1. Factory of the Future
This chapter places the Flagship Project “Factory of the Future” within the overall framework of Italian and European manufacturing systems. It moreover defines five macro-objectives, whose achievement the initiative “Factory of the Future” intends to contribute to through two subprojects. It finally introduces the notion of “Enabling Technologies” together with the Flagship Project’s central role in the development of the five macro-objectives which are the basics of the idea of “Factory of the Future”.

The macro-objectives were defined according to the “grand-challenges” identified at a global level by the most recent strategic documents defining “Roadmaps” and “Strategic Research Agendas”, drawn up at a EU level by the European Association EFFRA, the European research programme “Factories of the Future”, the European Platform “ManuFuture”, the initiative dealing with “American Leadership on Advanced Manufacturing” promoted by the President of the United States and the initiative IMS - Intelligent Manufacturing Systems 2020. The macro-objectives are coherent with the characteristics of the Italian manufacturing market which emerged from the analyses mentioned in the previous chapter and which are part of the Italian National Research Programme (PNR) strategic and operational documents.

This process led to the defining of five macro-objectives relative to the features the factories of the future should have in order to ensure sustainable development of industrial production in Italy. Here follows a list of them:

- Factory for Customized Products.
- Evolutionary and Reconfigurable Factory.
- High-performance Factory.
- Sustainable Factory.
- Factory for the People.

The set of these macro-objectives characterizes the very idea of “Factory of the Future”.

Within the Italian context it is strategically important to favour factory evolution from mass production and mass customization models (which focus on production volumes, process repeatability, high standardization of operations and components’ modularity) towards the idea of a factory producing customized/“one of a kind” products, that is one product realised for each product code. As the analysis mentioned above has pointed out, one of the main strengths of Italian manufacturing production is the ability to provide solutions which meet each customer’s specific needs, by using product and process know-how and by relying on a deep vocation for innovation. Good examples of this ability are furniture, design and fashion products markets, mechanics. Besides, this design ability requires to be supported by flexible industrial technologies and production structures which should be able to produce small quantities of a big amount of product models, by keeping a high degree of automation and high quality in a sustainable way.

Macro-objective 1 “Factory for Customised Products” provides research with useful guidelines within this area.

Besides customization, one more meaningful typical feature characterizing high technology-content “Made in Italy” products (e.g. segments of capital goods, medical technologies,
mechanics, chemical and automotive industries) is a reduction in products’ lifecycle and their fast evolution in time. From the point of view of the factory producing these products, impact is remarkable, as the factory can no longer be a static entity characterized by unchanging design. On the contrary, it is an ever-evolving structure which has to adapt its processes and performances in order to cope with new features and materials. The factory, which is considered as an evolving entity, will have to be equipped with enabling technologies allowing to modify its configuration and processes by incurring low costs and ensuring reduced transition time from a type of configuration and the following one and great freedom in configuration modification. The need for operating in dynamic productive contexts in which demand and technologies evolve fast will require the factory to be able to react to change together with products and processes, thus modifying itself in an efficient and economically competitive way. Reconfigurability will have to emerge at different factory levels, from the single productive resource to the global logistic network. These notions have been summarized within reference texts in evolutionary, flexible and reconfigurable factory models. Macro-objective 2, “Evolutionary and Reconfigurable Factory”, focuses on the issues relative to the development of these models.

The need for customized ever-evolving products deeply influences the idea of factory “performance”, too, which is considered from two points of view. Firstly, new performance measures become remarkable: good examples of them are the factory’s ability to modify itself in order to face different features, its ability to include innovative production processes or else its ability to adapt quality levels and production rhythms to current specific conditions. On the basis of the data collected in the field, the high-performance factory will be able to implement adaptive strategies autonomously by modifying its performances, operational ways and patterns.

Secondly, the new requirements identified point out the importance of availability of new hardware and software technologies and new methodologies for an improvement of factory performances and for quality control, which could ensure the achievement of quality and productivity requirements which are requested even in small quantities’ production as well.

Within this context, it is therefore crucial for research to focus on and aim to the development of an high-performance factory of the future, which should be able to ensure the achievement of high performances, despite continuous changes affecting operational conditions. This topic is dealt with by the third macro-objective of this Flagship Project.

In the past few years, the introduction of the idea relative to “green” products, too, has had a remarkable influence at a global level and has obviously involved “Made in Italy” products as well. “Green” products not only make use of low environmental impact, recyclable, reusable or easily disposable materials. Broadly speaking and within LCA (Life Cycle Assessment) perspective, “green” products must be also characterized by reduced environmental impact and energy consumption during their production phase. This idea provides sustainable production with a crucial role as regards “Made in Italy” products. Sustainable production has to ensure reduced energy consumption of processes, systems and industrial plants, limited production of industrial waste during production, reduced consumption of water, rare materials and other crucial natural resources. The factory system will have to operate within energy consumption and emission constraints, from machinery consumption to the adjustment/control of lighting and air conditioning systems. The factory will be able to reduce its environmental impact from an energy point of view as well, by using “clean” sources of energy in an intelligent way, besides reusing each available potential source of energy. Besides being “green”, the factory will be socially sustainable, by including and using workers’ skills and socio-economic habits at best, thus contributing to the local context’s growth.

Moreover, the factory will be able to cope with the ever-growing needs relative to the management of product life cycle final phases, thus de-manufacturing, disassembling, reusing,
recycling or recovering products, generating new opportunities and resources for the labour sector. If necessary, the factory will be able to modify existing products which requires functionality upgrade or modification of technological characteristics. Flagship Project fourth macro-objective deals with the sustainable “factory of the future” model.

Finally, the fifth macro-objective identified relates to the idea relative to a factory of the future for the people. The motivation for handling this topic arises from deep social and demographic changes which in the last few years have been influencing and stimulating the global, European and Italian production contexts more and more. From a social point of view, the need for offering people jobs in the manufacturing sector within the meeting of working conditions’ requirements which are typical of the European economy is a strategic objective. Moreover, the increase in pensionable age and the global ageing of population are driving towards a deep reconsidering and, consequently, re-designing of factory environment. This topic influences, on the one hand, ergonomic and safety features of manufacturing systems and, on the other hand, those factors relating to the improvement in man/machine interaction patterns in production context, in order to enhance and stimulate the human and knowledge capital operating within the factory system. People and machines will have to cooperate, by sharing manufacturing environment in a safe way. Production environment will have to be sound and human-friendly, thus increasing workers’ perception of being working in an environment which contributes to their well-being. Only in this way, it will be possible to keep a high quality of life for Italian labour force and to contribute to assert at a national level the European knowledge-based employment basic principles, thus avoiding the loss of human capital to countries characterized by high-growing economies.

These challenges provide a new transition opportunity for the idea of factory. The initiative “Factory of the Future” intends to be a national benchmark for promoting and supporting this change.

2.1.1. Factory for Customised Products

The Italian companies’ ability for adapting their products and processes to the customers’ specific needs, in order to provide tailor-made solutions is one of the most important strengths which has allowed to keep market shares in high added value sectors and to compete with emerging countries thanks to a customized offer of products and services which are difficult to reproduce.

Advanced customisation, that is the providing of products and services which are able to adapt to specific customers’ characteristics and needs (for instance their biometric characteristics and requisites relative to non-standard size, shape and finish which are not known in advance) is an evolution of the idea of “mass customization” leading to offering different pre-established models of the same product. Keeping being leader in satisfying the demand for customized products and services is an important strategic opportunity for Italy, as this kind of demand originates from industrialized and emerging countries’ economies and shifts competition’s drivers from costs to added value.

Important “Made in Italy” sectors will take advantage of research in these areas. Good examples of them are sectors producing personal products such as shoes, glasses and accessories, clothes, prostheses and orthopaedic devices, luxury goods, and so on. Besides them, it is possible to mention also those sectors in which specialized support and design competences directing customization towards customers’ needs and preferences are needed (furniture and household accessories).

In order to keep being leader, by considering fast improvement by competitors, who are enlarging their products’ range and reducing prices more and more, it is necessary to design and implement a new innovation cycle setting up a new generation of methods and factories producing customized products. By taking into due account the current set of knowledge, infrastructure and...
production methodologies, Italian factories will have to be equipped with modern technologies and approaches, in order to further increase those characteristics relating to flexibility, efficiency and the ability to offer high added value services which will keep ensuring their competitiveness. The Factory of the Future for customized products will aim to produce high added value products which could deeply influence the user in terms of comfort, health and uniqueness. It is therefore necessary to consider and design solutions relative to “customer driven” factories which are based on the idea of tight cooperation with final users. The factories which are able to produce highly personalized products will have to be characterized by high flexibility, in order to quickly adapt technological-productive requirements to the product features. In order to support these factory characteristics it will be necessary to rely on an advanced automation framework and on structured and efficient logistics allowing an on-going information transfer between the supply chain partners, in order to satisfy users’ production requirements in a coordinated and efficient way.

Research will also have to address the improvement of processes relative to the collection and analysis of customized needs, to the design of tailor-made products and to their rapid production, by offering at the same time consumers a positive experience throughout product lifecycle. Customers’ characteristics, needs and tastes will have to be acquired, elaborated and shared through innovative technologies. These data will be transferred to the factory, which will handle manufacturing or pre-manufacturing through advanced automation and flexibility machines and systems, and will be made available to customers for testing, for any potential modifications which may follow and for final delivery. Relevant research areas will deal with the following topics:

• Innovative use of ICT tools supporting customisation (for instance virtual and augmented reality, design and simulation of products and their interaction with people, exchange of information between virtual models and the real factory).
• Design of new approaches and tools supporting machinery, equipment and system flexibility, from a physical and logical point of view.
• Set-up of innovative tools and business models supporting economic and logistical optimization for “one of a kind” product realization.
• Development of innovative approaches relative to dynamic design, management and cooperation addressed to supply chains and single companies supporting customized products’ production, by coping with frequent changes affecting demand and manufacturing systems.
• Definition of new tools and services supporting users and based on innovative monitoring and manufacturing techniques during product lifecycle.

2.1.2. Evolutionary and Reconfigurable Factory

The need for coping with more and more complex and changeable consumers’ requests, together with technological evolution of products and processes, has resulted in a drastic reduction of product lifecycle, especially in high-tech sectors supported by recent advancement within the areas of innovative materials, ICT and mechatronics. This addresses several challenges to manufacturing companies which are obliged to evolve in order to rapidly adapt their technologies to the state of the art and to follow market modifications through the offer of more and more innovative products. The need to operate in dynamic production contexts where demand and technologies evolve fast requires the factory to be able to react to change together with products and processes (co-evolution), by modifying itself efficaciously and in an economically competitive way. Factories have therefore to acquire the operational flexibility and advanced reconfiguration ability relative to their product-process-manufacturing infrastructure systems. Production systems’ skill to evolve and reconfigure will have to be evident at different factory levels, from each single production resource to the global logistical network. Their evolution will concern
modifications and reconfiguration of production resources operating within the system and of layout, modifications affecting production operational management patterns and modifications of production planning and management policies. Reconfigurability features of the factory system are therefore crucial. The merging of automation and ICT sectors plays a fundamental role in the solving of manufacturing production complexity and in the enabling of flexibility both at hardware and software level. Research and innovation will have to aim to the development and definition of transversal methodology tools which should be able to support the design of evolutionary systems embodying reconfigurability patterns of hardware and software in different timeframes, from long-term planning level to real time management of events. Research topics supporting evolutionary and adaptive factories of the future will focus on:

- Design of new approaches and tools supporting flexibility and reconfigurability of manufacturing systems, control systems, automation, machines and equipment, both from a physical and a logical point of view, in order to cope with production and quality needs.
- Development of methodologies and tools supporting the joint design of production products-processes-systems from an evolutionary point of view.
- Design of optimization approaches directed to reduction in set-up and ramp-up time of production systems.

2.1.3. High-Performance Factory

Production of complex products characterized by high quality standards and produced within the reduced delivery time required by the market is an extremely important factor of competition for Italy in the world. This leads to the defining of broadly speaking efficient production plants, from single operational resources to structured logistics. High-performance factories intend to cope with production demand by minimizing all the inefficiencies related to production which derive from the following factors: handling systems and interoperational warehouses, transformation processes and their process criteria, hardware and software used, management and resources’ maintenance policies, inspection and control techniques of qualities implemented. Through an on-going update of the information collected in the field, their elaboration through the use of innovative analysis techniques based on the knowledge of production process and system dynamics, the identification of the reasons for malfunctions and failures and for noises in the system functioning and the synthesis of improvement automatic actions and operations it will be possible to constantly operate the factory system in high efficiency and reduced faultiness conditions. Moreover, through the development of more and more efficient transformation processes characterized by high production rhythm, it will be possible to reduce cycle time relative to transformation operations carried out within the system, thus reducing production lead time and improving the factory service level. As a result, high-performance factories will be characterized by solutions consisting of advanced-system machines and architecture solutions, a complex ICT framework supporting the inspection and continuous monitoring of processes and systems and a whole series of information processing software tools aiming at the identification of continuous improvement, predictive maintenance and defect elimination policies. Solutions relative to high-performance factories will result from the examination of the following research issues:

- Development of new high-performance transformation processes and material handling systems.
- Conceiving and implementing of models and platforms for the collection of data from the field aiming at the improvement of manufacturing systems’ technical efficiency.
• Development of methodologies supporting the design of quality control system, resource maintenance policies and management, and control policies relative to production flows.
• Conceiving and designing of new hardware and software technological solutions to be used for product and process control, in order to allow system monitoring of high production rhythm and a continuous handling of the data originating from the field.

2.1.4. Sustainable Factory
The design and management of factories which should be able to carry out sustainable production require on the one hand to go into energy, social and economic issues and, at the same time, on the other hand, to follow the evolution of the regulations ruling safety, quality of working environment and environmental impact of both products and of the relative production processes. These needs contextually concern products, processes and factories. Products and processes have to be conceived and designed in a sustainable and healthy way, by selecting those raw materials and technologies which can guarantee minimum environmental-impact chemical composition both during production and throughout their lifecycle, up to their dismantling and recycling/recovery.
In order to ensure sustainable production, the Factory of the Future will have to be able to:
• Guarantee maximum energy efficiency.
• Optimise the design of products and the relative production processes.
• Embody new de-manufacturing patterns.
• Operate within a production supply chain which should be conceived in order to optimize sustainable logistics by adopting low environmental impact transport solutions.

From an energy efficiency point of view, the Factory of the Future will be supported by energy consumption reduction strategies carried out by both by the manufacturing system and by the plants, within productivity and cheapness requirements. This will lead, on the one hand, to the studying and optimizing of energy impact of the technologies used and, on the other hand, to the including in the factory of energy co-generation systems based on renewable sources of energy and of systems dealing with energy and waste materials’ recovery.
Sustainable production factories will use technologies characterized by minimum environmental impact in terms of emission and production waste. Together with technologies, products will also have to be conceived and designed within sustainability, by selecting raw materials and semi-finished products according to criteria which consider their healthiness and chemical-physical properties.
Together with manufacturing factories, a new generation of sustainable factories will have to be conceived and developed in order to support the repairing/upgrading of components both throughout their lifecycle and during the recycling phase. De-manufacturing factories will be able to efficiently disassemble, repair and recycle components and assembled products from an environmental point of view, by separating also those parts which have to be disposed of according to special procedures.
Both manufacturing and de-manufacturing factories will have to operate within an overall sustainable production network in which each partner shares transport and sustainable production patterns.
The research guidelines to be examined will deal with:
• Definition of new materials and innovative production technologies which can make use of green and renewable sources of energy and which allow an efficient re-use of material waste and processes’ emissions from an environmental and an economic point of view.
• Development of ICT tools supporting the factory integrated control and optimal management both of production systems and buildings, by considering energy, environment and maintenance aspects.
• Development of methods and tools supporting the design and management of process, machine, system and factory solutions embodying sustainability patterns and an efficient use of resources at optimized costs.
• Definition of new business models supporting a more efficient use of production resources through maximization of their efficiency, the lengthening of their lifecycle, the providing of services aiming at a more efficient use of them, structured manufacturing/de-manufacturing strategies, and so on.
• Development of methods and tools supporting the design and management of de-manufacturing factories.

2.1.5. Factory for the People

The factory of the future has to examine new forms of interaction between manufacturing processes, machines and human beings which could guarantee operators and employees a comfortable and challenging working environment.

The potential of current and future technologies can be thoroughly used only if the education of people who have to manage the factory and work in it is taken special care of. Moreover, issues as safety and ergonomics will no longer have to be dealt with as a reaction to new regulations coming into force. On the contrary, these issues will have to be considered as basic stimuli for the improvement in the factory productivity and profitability.

Factories for the people will have to be designed and implemented by taking into due account the on-going social and demographic trends. The increase in average life expectancy and in pensionable age will have to affect the design of machines, technologies and workspaces which should suit not only young people but also more experienced ones.

The history of the manufacturing sector shows how culture, know-how and personal skills play a crucial role for success. Therefore, decisions concerning factory design and location will not have to be taken by following only economic patterns aiming to minimize production costs in the short-term. It will also be necessary to thoroughly examine the social and economic impact involved by such phenomena as production relocation.

New factories will have to provide people with a working environment allowing to cope with difficult production contexts characterized by short lifecycle products and frequent revisions, which therefore require a rapid adaptation of production capacity and the development of new knowledge. On the one hand, operators will have to be characterised by multidisciplinary training, which is required in order to be able to manage planning and functioning of complex production plants in a flexible way. On the other hand, the high rhythm at which products become obsolete requires to focus on production resources’ easiness of use, thus underlining (or re-underlining) the crucial role of people within the factory environment.

The development of the factory for the people will go in depth into several research issues (covering sociological, organisational, psychological and technological fields).

Research issues will mostly relate to the following fields:
• Study of socio-economic features, in order to evaluate knowledge and technology impact, by examining the factors influencing their use (for example ethics, standardization, “gender-gap”, etc.).
• Study of technologies allowing to improve people’s working conditions through studies on ergonomics aiming to a reduction of noise emissions/waste and of risks relative to dangerous
processes, thanks to a higher degree of automation and use of tele-control, virtual and augmented reality, tele-work technologies, etc.

- Study of interactive cooperation between machines and human beings within advanced factory environments, in order to thoroughly use human skills and intuition even within changing working conditions, minimize human contribution to low added value activities and use machine skill for managing possible operators’ mistakes, which should be quickly identified and isolated thanks to intelligent devices and sensors.
- Development of man/machine adaptive and reactive communication interfaces (using for instance voice recognition, understanding of gestures and language, machinery skill to move in an autonomous way) which should allow efficient cooperation and offer satisfactory workspaces for employees/operators.
- Study of business models supporting choices for factory location, by considering all the relative socio-economic-cultural aspects.
2.2. Enabling Technologies
The term “enabling technologies” defines those advanced-knowledge and capital technologies which relate to meaningful research and development activities. They are characterized by fast and highly-structured innovation cycles and by a meaningful involvement of highly competent human capital. They are defined as “enabling” as their influence is remarkable and allows widespread innovation, by involving products, processes, systems and services. These technologies are strategically important at systemic, multidisciplinary and cross-sectoral levels. They embody those competences deriving from different scientific-technological areas tending to converge and the ability to lead to structural changes and to break with the state-of-the-art solutions.

“Enabling technologies” are crucial within the Flagship Project basic objectives which have been defined in the previous chapter: they represent the pre-conditions and the bases on which the new idea of “Made in Italy” suggested and the “factory of the future” macro-objectives identified can be based. For this reason, within the Flagship Project” enabling technologies will play a crucial role.

Enabling technologies’ impact will become evident at a more widespread and national level. As a matter of fact, as leading-edge technologies, enabling technologies are the bases for innovation in several industrial sectors and play a crucial role in making new products and services available to the whole population. “Enabling technologies” are foreseen to be able to meaningfully contribute to Italian economy, by offering a wide range of uses within a big amount of applications and sectors, and to contribute to energy efficiency, through new materials, processes, technologies and applications.

Here follows a list of the “enabling technologies” which have been identified to support the Flagship Project “Factory of the Future” five macro-objectives:
• Information and Communication Technologies (ICT) and “Digital Factory” technologies for an intelligent factory.
• Manufacturing technologies.
• De-manufacturing and material-recovery technologies.
• Resource- and system-control technologies.
• Factory-reconfiguration technologies.
• Resource management and maintenance technologies.
• Monitoring and quality-control technologies.
• Man-machine interaction technologies.

Here follows a description of these technologies, with special reference to the most innovative solutions which will have to be investigated in order to support the “factory of the future”.

2.2.1. Information and Communication Technologies (ICT) and “Digital Factory” technologies for an intelligent factory
The use of Information and Communication Technologies (ICT) within the manufacturing sector can meaningfully contribute to increase the efficiency, adaptability and sustainability of manufacturing systems and their integration with lean business models and processes. Due to production context complexity, these methods and tools are usually conceived in order to assist the carrying out of specific and limited activities which are therefore not so efficient within a structured factory. Nevertheless, the decision of facing engineer problems in an organic and structured way, by considering different kind of issues, such as modelling of product, process and manufacturing system design often requires the defining of a multidisciplinary cooperation
network. On these occasions, the main challenge consists in structuring and harmonizing company knowledge through the use of different methods and software tools which have to overcome the heterogeneous character of the information relative to products, processes and production resources which have to be managed in time. Moreover, there is an evident need for ICT architectures which should be structured and open, in order to ensure a correct use of software tools and the management of information flow through the factory. Interoperability of software tools is crucial for the sharing and transferring of data aiming to identify production system management strategies which should not be local solutions, but should be undertaken by considering the system overall behaviour (for instance energy consumption, production rhythm, reliability of machinery).

The complexity of the problems which should be faced requires the assistance of support tools for all the factory lifecycle phases: for instance structured and interoperable solutions for supporting the flow of heterogeneous data within the factory of the future, including Product Lifecycle Management (PLM) software (level product), platforms for Life-Cycle Assessment (LCA) (process level), wireless sensors and resources’ remote monitoring solutions, CAE (Computer Aided Engineering), CAD (Computer Aided Design), CAM (Computer Aided Manufacturing), CAPP (Computer Aided Process Planning) solutions and advanced models for the simulation of processes and machine tools (manufacturing system level), software for the evaluation of manufacturing systems’ performances, for the simulation of multi-level and reconfigurable factories, for the cooperative design of factories basing on virtual reality (VR) and augmented reality (AR) and theories relative to a conceptual modelling of the factory and its elements.

2.2.2. Manufacturing technologies
The development of new transformation technologies is crucial within a sustainable production factory, a reconfigurable factory and an high-performance factory. The factory of the future will have to embody transformation technologies which should allow resources’ efficient use and be based on “clean” processes. It is therefore necessary to identify new processes, which are characterized by low energy consumption, which make use of renewable sources of energy, besides examining how to increase efficiency and reduce emissions during manufacturing processes. Moreover, the factory of the future will have to efficiently include, from the point of view of production performances, new transformation resources characterized by more and more reduced cycle time and by high precision, for both micro- and macro-scale products. Finally, it will be necessary to develop new modular and flexible technologies, in order to allow manufacturing of changeable products even in small batches.

A few examples of manufacturing enabling technologies therefore concern high-speed machining transformation technologies, modular, reconfigurable and performing handling technologies, fastening adaptive systems and tools, high-performance tools, unconventional transformation technologies (laser, plasma, water jet, ultrasonic machining – USM), micro-manufacturing, micro-assembling and micro-factories, robotized assembling cells and focused flexibility manufacturing systems.

2.2.3. De-manufacturing and material-recovery technologies
Production sustainability involves both product manufacturing phase and the management phases relative to lifecycle and reuse of the materials and the components used during manufacturing, within closed-loop management. In this field, contribution by automatized remanufacturing technologies and robotized disassembling technologies can play a key role in the improving of industrial production sustainability. Similarly, materials’ separation and crushing advanced technologies aiming to a recovery of rare secondary raw materials characterized by a remarkable
commercial value are strategically important for sustainable production. Finally, new techniques and procedures aiming to simplify the use of secondary materials recovered are important opportunities to make product processing at the end of their lifecycle more sustainable.

2.2.4. Resource- and system-control technologies
Within the new industrial context, automation plays a basic role in the solving of manufacturing production complexity. Recent innovation in the field of IPMCS (Industrial Process, Measurement and Control Systems) such as the introduction of advanced communication techniques relative to fieldbuses and intelligent devices, embodying microprocessors and programmable hardware, allowed the defining of control systems distributed within a network consisting of heterogeneous devices. As a result, the defining of general methodology and application tools which are able to support real time design of control environments for distributed systems is crucial. Distributed control technologies are based on decentralised forms of control intended for distributed and highly interconnected control systems. Traditional modelling techniques, which are based on IEC 61131 standard and PLCs are unsuitable for distributed systems and do not allow to satisfy the requirements relative to reusability, flexibility and reconfigurability in the development of control applications. Therefore, research dealing with distributed and reconfigurable types of control will rely on IEC 61499 standards, which are specifically devoted to reconfigurable distributed systems for industrial control and measure supporting automation SW project.

2.2.5. Factory-reconfiguration technologies
The need for defining new architectures relative to systems and machine tools, which should be reconfigurable from the point of view of hardware and automation system, thus allowing to cope with modifications affecting production characteristics in time, is a very interesting and complex topic within the factory of the future. This research field opens to the development of methodologies and tools for machinery and manufacturing systems’ reconfiguration, by introducing new strategies aiming at a reduction of energy impact and at an optimization of automation patterns for new mechatronic solutions. Moreover, the issue of technologies supporting factory reconfiguration is strongly connected to uncertainty: system reconfigurability is valueless in deterministic contexts, where system characteristics are known and do not modify. Within this context, it is important to develop methodologies supporting reconfiguration modeling and embodying uncertain information on the production context in which system solutions will have to operate.

2.2.6. Resource management/maintenance technologies
Performances by factories of the future will greatly depend on the efficaciousness with which production planning, scheduling and maintenance planning methods are able to face changes affecting the market (for instance demand) and the production environment (for instance configuration of production system, availability of resources). Most tools which are currently available do not take into account evolution and dynamism characterizing the context in which they operate, by showing the need to develop new techniques supporting the factory of the future which should be able to face the uncertainty and manage the change affecting production and maintenance plans. Promising techniques within this research area concern for instance planning techniques relative to reactive and sound production, predictive maintenance techniques, production planning and maintenance structured techniques, self-learning and self-organization algorithms for system self-repairing and Condition Based Maintenance (CBM) techniques.
2.2.7. Monitoring and quality-control technologies

Product customization and batch size reduction within the factory of the future leads to inevitable cost increases relative to set-up, process modification and adaptation of production resources. Therefore, innovative solutions increasing production efficiency, by affecting especially monitoring/quality control systems and pro-active improvement of processes, intelligent measuring systems guaranteeing production without defects, a development of a new generation of knowledge-based systems which should be able to self-learn, the development and design of hardware and software solutions allowing the in-line re-machining and repairing of flawed products within zero-defect manufacturing will be needed.

The issue of capture and processing of the data originating from the field is a very complex research area. On the one hand, complexity concerns the design of accurate low-cost sensors, which can simplify widespread dissemination in the manufacturing context. On the other hand, research has to deal with the creation of algorithms interpreting signs. One among innovative issues concerns the combination of research in metrology with research in the study of complex sensors; these aspects are currently founded on tools based on artificial intelligence techniques requiring long training periods and are devoted to specific applications. New algorithms and models for multi-resolution and multi-scale processing of data would allow to efficiently manage redundant sensor architectures and to improve the efficiency of quality-control tools based on product data together with process control and monitoring.

Finally, factory operability will also have to be assisted by structured methodologies relative to an analysis of system performances. The monitoring and the information originating from sensors and elaborated by these advanced models will allow to foresee process behaviour and carry out possible adaptive modifications, in order to ensure the achievement of target performances.

2.2.8. Man-machine interaction technologies

The idea of innovative and sustainable factory has to strive for social and economic growth, by aiming to a worthwhile interaction between human beings, machines and processes and to a development of new manufacturing models allowing to invest on product and process know-how in an innovative way. New generations of operational units will have to be able to operate autonomously and in a reliable and flexible way. Moreover, in terms of notions, supervision by operator will have to be replaced by cooperation between operator and autonomous machines. In the long term operational units will have to evolve towards application profiles, which will be more and more based on knowledge and characterized by “human” features. A very interesting issue is the coordination of operational units within dynamic environments requiring the ongoing and relatively detailed tuning of a whole range of operational criteria which are not always predictable.

Within factory automation it will be necessary to work at the development of more efficient and reactive man/machine interfaces, in order to increase interaction between robots and human beings in advanced manufacturing environments, supported by intelligent automation solutions which should guarantee employment, ergonomics and increase in human skills. Moreover, innovative industrial robots will have to be able to carry out their duty in a correct way within wide operational uncertainty intervals and meaningful knowledge gaps.

Advanced graphic interfaces will be necessary for allowing the use of tools characterized by higher and higher complexity. A particularly critical issue concerning interaction between real and virtual factory is the participation of human operators, whose behaviour cannot be completely represented through digital models. Scientific research activity on this issue is due to awareness of human crucial role in manufacturing contexts, in which multi-criteria decision-making skills and
experience in the management of complex problems cannot be replaced by algorithms and simulation software.

The “enabling technologies” described above embody new hardware, software and methodology solutions supporting the “Factory of the Future” model. Moreover, their impact refers to all five macro-objectives identified in Section 2.1. As a result, these “enabling technologies” are the basis for technology knowledge, which should be developed within the Flagship Project, in order to provide tangible and innovative feedbacks to the five great challenges identified.
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