Manual work (MW) is a central and expensive component of manufacturing, assembly, testing and maintenance services in Europe. There are many industrial sectors that rely on the knowledge and skills of their manual workers, for example, satellite assembly, maintenance of nuclear reactors, operation of complex machinery, design and manufacturing of highly customized products. In these sectors, MW constitutes the core operations and it cannot be off-shored or automated. According to Eurostat (2008), there are about 19 million people involved in the high knowledge high value MW in Europe, mainly as plant and machine assemblers and operators. Considering the entire product lifecycle (LC) from design to recycling, the number of people related to MW is even larger.

The ManuVAR objective is to provide a systematic technological and methodological system to support high knowledge high value MW throughout the product LC. It combines the best potential of the lean and agile models with the knowledge and skill management in the product LC. The ultimate goal of ManuVAR is to go “beyond lean manufacturing” in order to

1. Increase productivity and quality and reduce cost of manual work in the whole LC (“lean”);
2. Facilitate adaptation to product customization and changes (“agile”);
3. Support efficient knowledge and skill management and bi-directional data and knowledge flows through the LC (“beyond”);

The ManuVAR approach is based on a product LC management (PLM) paradigm and virtual and augmented reality (VR/AR) technology combined with the ergonomics methods:

1. Bi-directional communication: modular architecture based on the Virtual Model as a shared object that enables bi-directional communication throughout the lifecycle;
2. Application tools: human factors methods implemented with ManuVAR technologies to support various types of MW across the LC;
3. VR/AR technology: user-oriented, intuitive and adaptable interfaces with the Virtual Model for all users involved in the LC;

The ManuVAR project workflow is structured into 12 work packages (WPs) corresponding to the general system workflow: input/reference → analysis → synthesis → testing → feedback → output. It includes the inductive phase (from requirements to the generalized solution: platform and methodology) and the deductive phase (from generalized solution to testing it in the companies). The project adopts a semi-agile approach with four of design-implementation-evaluation iterations, Figure 1:

- Inductive phase: requirements analysis and identification of the main gaps regarding manual work (WP1), definition and alignment of industrial cases (WP2), analysis of the requirements from the technological, human factors and PLM perspective (WP3), and general solution synthesis: the ManuVAR platform and methodology (WP4);
• Deductive phase: adaptation of the platform and methodology to the industrial needs (WP5), development of tools, industrial cases and demonstration prototypes (WP6), trials and assessment in the laboratory environment (WP7), training (WP8), and demonstration in the real factory environment (WP9).

The strong feature of ManuVAR is that it comprises five application clusters that cover a number of industry sectors. The clusters provide the factual basis for the requirement analysis and the real-life test-bed for evaluation and demonstration of the project results across several industries, Figure 2.

Figure 1. ManuVAR workflow

Figure 2. ManuVAR clusters: AR/VR for the terrestrial satellite assembly, low-cost VR systems for improving the assembly lines in small and medium enterprises, AR/VR-enhanced remote online maintenance support in the railway sector, VR for training on the nondestructive techniques in the industrial plant maintenance, and VR/AR in the heavy machinery productization and maintenance
During the first half of the project, WPs 1-3 have been completed and WPs 4-7 have been iterated twice. The following main results have been achieved:

- **Identification of the seven most prominent problem areas faced by European industries in the context of high knowledge high value MW.** These problem areas include: (1) hindered communication throughout the lifecycle; (2) poor interfaces; (3) inflexible design process; (4) inefficient knowledge management; (5) low productivity; (6) lack of supporting technology acceptance; (7) physical and cognitive stress.

- **Definition and harmonization of the 13 prioritized individual industrial cases for all five clusters including the preliminary business analysis and economic impact forecast.** The harmonization of the cases is performed (a) to highlight relevance to the gaps/requirements identified in WP1, (b) to balance various outcomes of the cases (scientific, business, policy, stages of the lifecycle), and (c) to find out the intersections and complementarities among the cluster cases. The following cases will be implemented during the first two iterations:
  - Cluster 1: Systems and procedures using VR & AR in aerospace assembly. Case: Off line application for integration and testing;
  - Cluster 2: Low cost VR system for improving assembly lines in SMEs. Case: Design and Testing of Existing or Virtual Production Processes;
  - Cluster 3: AR/VR enhanced maintenance support in the railway sector. Case: AR remote support and corrective maintenance;
  - Cluster 4: Metallographic Replica Technique in power plants. Case: Metallographic replica training;

- **Elaboration on the overall-project and cluster-specific performance criteria that will be used to evaluate the project results, for example productivity, quality, cost, communication throughout LC, efficient knowledge and skill management, physical and cognitive stresses, exploitation of supporting technology, flexible design process and adaptation to product changes, influence on EU policies.**

- **Review of existing VR and AR technologies and technical approaches for supporting MW.** Investigation of human factors, with particular regard to lean and agile processes using a combination of methods such as hierarchical task analysis, behavioral analysis and ethnography to analyze the behavioral, cognitive, physical, and environmental and systems ergonomics influences on the identified problem areas. Overview of the methods and tools for allowing the exchange of models and data throughout the LC and definition of a number of scenarios, which specifically emphasized PLM integration with VR/AR technologies, as a recommendation for supporting MW throughout the LC.

- **Definition of the Virtual Model (VM) based ManuVAR PLM model (Figure 3), ManuVAR industry application methodology, system architecture, ergonomics methods and software/hardware tools for integrating VR/AR Application Tools (AT) as an interface to the VM and ATs.** Formulation of the “main principle of the virtual modeling” that helps to manage change and complexity of the ManuVAR system. In ManuVAR, the following four ATs will be developed: (1) delivery of work instructions; (2) ergonomics evaluation; (3) task planning and analysis; and (4) training.

- **Design of the ATs and prioritized cluster cases for the use-case diagrams linked to functional and non-functional requirements, to the class and sequence diagrams and component interfaces including all technology elements and the virtual model.**

- **Implementation of the first two generations of AT prototypes and their systematic evaluation against the performance criteria, requirements, and human factors metrics in the laboratory environment within the defined prioritized cluster cases.**
Figure 3. ManuVAR PLM model. Future PM will be supported by the Virtual Model (VM).

The VM (a digital mockup or a virtual prototype) is a computer-based model that substitutes a real system. It is a systemic, semantic aggregation of all information, models, processes, and simulations that describe the system in evolution throughout its LC, specifically (1) the human actors, (2) the product, and (3) the human and product environment in the LC.

The VM facilitates continuous communication and collaboration between all users involved in the LC—from design and production, to maintenance and service, to disassembling and recycling. Each user will have a tailored intuitive VR/AR interface to access the VM and to participate in the LC.

During the second half of the project, there will be two more iterations of the design-implementation-evaluation cycle leading to the development and demonstration of semi-commercial prototypes on the factory floor within selected industrial cluster cases. Also, the business, social and policy impact of the ManuVAR system will be further evaluated resulting in the technology transfer plan, the business plan for a possible spin-off and the dissemination and policy strategies.

ManuVAR will demonstrate that high value, high knowledge MW presents an opportunity to improve the competitiveness of European industries. It will exploit the synergy between PLM, human factors methods, and VR/AR technologies. This will facilitate communication between all users and systems throughout the LC and across subsequent system generations. ManuVAR will engage with various people from designers to factory workers, operators, maintenance personnel, and end-users. As a result, it will enable the bi-directional flow of information and knowledge in the LC: its capture, accumulation, linkage, reuse and sharing.