Grace

inteGration of pRocess and quAlity Control using multi-agEnt technology

Work Package 1

Multi-Agent Architecture

Deliverable D1.1

Report with the Requirements of Multi-Agent Architecture for Line-production Systems and Production on Demand

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Rev.	**Content**	**Resp. Partner**	**Date**
0.1	Preliminary List of Requirements	IPB	15/09/2010
0.2	Integration of new requirements from all the partners	IPB	05/10/2010
0.3	New classification and integration of requirements	IPB	05/11/2010

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1. Introduction

This deliverable contains the outcome of Task 1.1, entitled "Analysis of characteristics and requirements of multi-agent architecture for line-production systems and production on-demand", which has two main objectives:

- Definition of the needs and requirements for the Distributed Manufacturing System (DMS) and the desirable features it will provide.
- Description of the production process for the washing machines that will be used in the specification of the multi-agent system architecture.

The document is divided into 4 chapters. After this brief introduction, chapter 2 will provide a contextualization of the problem addressed in this document and some definitions to clarify some important concepts used during the project. This guarantees an easy reading and understanding of the different contributions coming from the different partners and representing different domains.

Chapter 3 is dedicated to the specification of the requirements for DMS, with particular attention to the line-production systems. The requirements are numbered and specified by using a common approach, which facilitates its understanding and the posterior analysis. The discussion of these requirements will lead to their classification into different categories, according to their dependencies and similarities.

This document will be revised every six months and will be improved with the generated knowledge during the project execution.

2. Contextualization and Definitions

The main objective of the GRACE project is to conceive, study, develop, implement and validate a collaborative multi-agent system (MAS) which operates at all stages of a production line, integrating the process control with quality control at local and global levels. This approach is in line with the current trend to build modular, intelligent and distributed manufacturing control systems.

The next sections try to contextualize the focus of the GRACE production control system and to clarify some concepts used in this project, namely distributed manufacturing systems, manufacturing control and multi-agent systems.

2.1. Concept of Distributed Manufacturing Systems

Nowadays, manufacturing industry is characterized by dynamic enterprises operating in a global scale, each one being made up of a number of autonomous production units or facilities cooperating among themselves. A distributed manufacturing system (DMS) can be defined as a production system that is geographically distributed, dispersed within a widely area (the equipments, operators, products and information), acting in a cooperative way in order to work as a whole.

The several types of distributed manufacturing systems present structures and features that can be modelled and related through a layered approach, which exhibits a fractal structure (Leitão and Restivo, 1999), as illustrated in Figure 1. This model represents fractal layers with similar interaction models, but different actors and requirements. The lower the layer, the higher are the temporal restrictions and the complexity of integration with physical resources. On the other hand, the higher the level, the higher are the inter-operability problems.

The highest layer, the inter-enterprise layer, represents the interaction between distributed enterprises acting together in order to achieve a common objective. Supply chain is a well known example of distributed manufacturing, dealing with the management of materials, information and financial flows in a network comprising suppliers, manufacturers, distributors and customers. Worldwide market competition implies that manufacturing enterprises can no longer be seen as acting stand-alone or within rigid supply chains and forces them to reconsider how they are organized. The concept of Virtual Enterprise appears to represent a temporary alliance of enterprises that come together to share skills and resources in order to better respond to business opportunities and whose co-operation is supported by computer networks (Camarinha-Matos and Afsarmanesh, 1999). Nowadays, namely in automobile industry, other forms of enterprise organisation have emerged, such as the Extended Enterprise, e-Alliances or Smart Organisation (Leitão, 2004).

A similar scenario is found within each manufacturing enterprise. When zooming into an enterprise another distributed manufacturing layer can be seen, the enterprise layer, where it is possible to find the co-operation between geographically distributed entities, such as sales offices and production sites, in a multi-site environment.

By zooming down a production site it is possible to reach the factory layer, where the distributed manufacturing control within the site can be found. In this layer, the entities are distributed through shop floor areas, working together and in co-operation, in order to accomplish all the orders allocated to the production site. By zooming down a shop floor area it is possible to see the shop floor layer, where the co-operation between different cells, such as manufacturing, assembly and transport, all organized in a flexible manufacturing system, can be found. Finally, a similar environment is found in the cell layer, with the interaction between equipments and humans belonging to a cell.

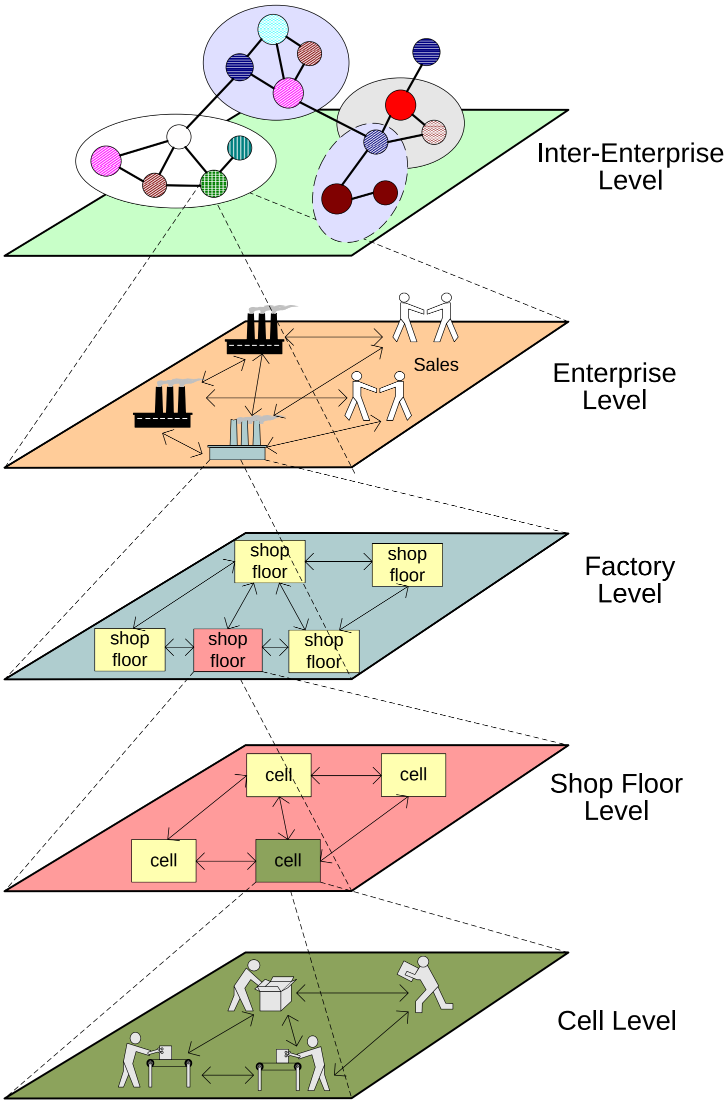

Figure 1 The layer approach to distributed manufacturing (Leitão and Restivo, 1999)

2.2. Concept of Manufacturing Control

Control is a key factor in automated production systems. It is required at two different stages: at low and at high level. At the low-level, the automation devices, such as industrial robots and numerical control machines, require control techniques that regulate their behaviour according to a specific objective. The control techniques may be simple or advanced, depending on the process to be controlled and the time scale, as illustrated in

Figure 2. Simple control functions are typically handled by standard controllers i.e. PID (proportional, integral and derivative) and are often delivered by the equipment suppliers. More advanced control functions are required in case of process disturbance, non-linear processes and robustness requirements.

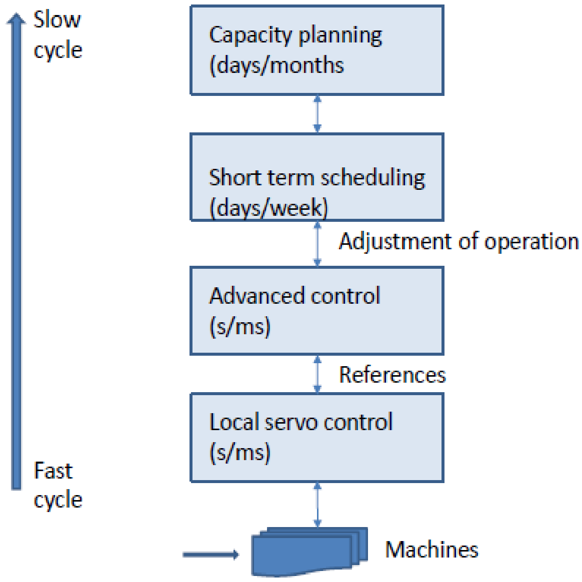

Figure 2 Time scales in the various automation levels

The high-level control is concerned to coordinate the manufacturing resources activities aiming to produce the desired products, such as in the case of flexible manufacturing control systems. Algorithms at this level are used to decide what to produce, how much to produce, when production is to be finished, how and when to use the resources or make them available, when to release jobs into the factory, which jobs to release, job routing, and job/operation sequencing (Baker, 1998).

The shop floor control, also referred as Manufacturing Execution Systems (MES), is concerned with the problem of monitoring and controlling the physical activities (processing, assembling, transportation and inspection) in the factory aiming to execute the manufacturing plans. It includes the scheduling (resource allocation), dispatching, monitoring and reaction to disturbances activities. The manufacturing control concept extends the shop floor control by considering also the short-term process plan activities. The production control encompasses manufacturing control of one or several plants, purchasing, material requirements planning, design, medium and long-term process planning, and other production activities. The production control is also referred as the production planning and control (PPC) systems.

Figure 3 illustrates the pyramid related to the IT-enterprise for manufacturing.

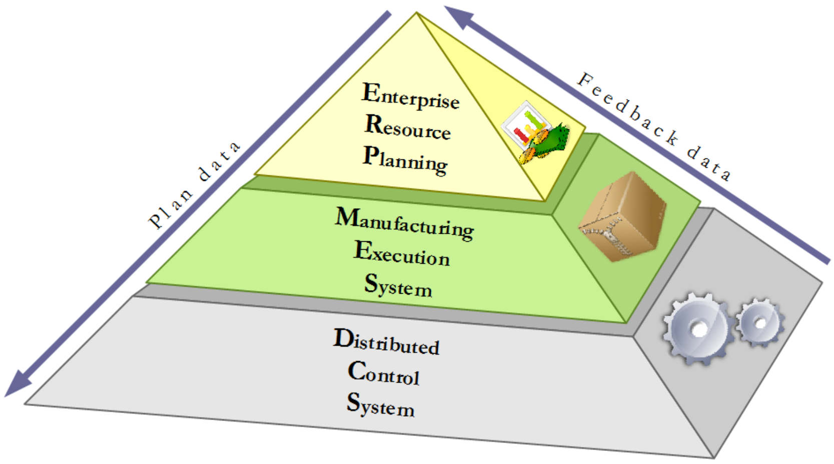

Figure 3 Modern IT-enterprise for manufacturing

The Enterprise Resource Planning (ERP) systems are integrated enterprise wide systems which automate core corporate activities such as manufacturing, human resources, finance and supply chain management. The ERP systems normally include all office planning, scheduling, sales, supportive logistics and services systems, interacting with the MES systems by providing the production plans. In the lower level of the pyramid is the distributed control system (DCS) which is related to control of the automation devices, e.g. by using a network of Programmable Logic Controllers (PLC).

The GRACE system will act at the MES level, so a deep analysis of this system is important at this stage. MES provides effective integration between production processes and enterprise business systems while allowing a detailed control of the actual production processes. According to the MES standard ANSI/ISA-95 the main functionalities provided are illustrated in Figure 4. This generic activity model is then applied to production, quality and maintenance domains. The following functionalities can directly and/or indirectly contribute to an optimization of the production management process and therefore special care must be paid. For a in depth study the referred standard should be consulted.

Figure 4 Generic activity model of manufacturing operations management (ANSI/ISA-95.00.03)

Taking into consideration the production management, the main functionalities are:

- *Detailed production scheduling*, that provides sequencing for the production based on a set of criteria, such as priorities, attributes, characteristics, production rules; it can be either very simple or very complex depending upon the process defined to level the production.
- *Production resource management*, that manages the resource utilization, occupation and correct utilization; coordination with maintenance resource and quality resource can also be taken into consideration.
- *Production tracking*, that provides reports on status of production executed and in execution, allowing forward and backward traceability;
- *Production dispatching*, that manages the flow of production in the form of orders, batches, lots and pitches by dispatching production information and/or signals to specific equipment and workstations; this may involve work orders to workstations

and/or to manual operations, and also information from quality operations that may affect the scheduled events.

- *Production definition management*, that manages the information required for the product manufacturing including the production rules; it contains the necessary information to instruct a manufacturing operation to produce a product.
- *Production execution management*, that is responsible for allocating the right resources to the right sequence of production, informing the other activities about timing, labour and materials used; a feedback may arise from the quality control to ensure the quality standards.
- *Product data collection*, that ensures all data due related to the manufactured product are collected and stored (it may involve, besides others, sensor reading, equipment states, operations actions and operator-entered data); all previous data collection is gathered with a time or event based form.
- *Production performance analysis*, that is responsible of calculating and analysing some performance parameters of the gathered data collection, such as equipment utilization, equipment performance and procedure efficiencies; these parameters can be used to optimize production and the resource utilization.

The above functionalities comprise the collection of information exchanged between them in order to obtain production optimization.

2.3. Concept of Multi-agent Systems

The traditional method used to deal with these large systems was to decompose the system into smaller, more manageable subsystems and machines, program the control for each one separately, and then write custom “glue” code to knit the smaller components into the complete system (Hall, 2007).

Traditional centralized, rigid approaches do not have the capabilities of responsiveness, flexibility, robustness and re-configurability. Multi-agent systems (MAS) are a suitable approach to support this challenge by providing an alternative way to design control systems, based on the decentralization and parallel execution of activities based on autonomous entities, the agents, which are able to respond promptly and correctly to change, due to their inherent capabilities to adapt to emergence without external intervention (Leitão, 2009). The most important properties of an agent are autonomy and cooperation. In this case, autonomy is defined as the ability to perform a process or a system adjustment through the system itself without human intervention during the process; autonomy enables systems to perform in dynamic environments. The level of autonomy can be assessed by defining the necessary degree of human intervention, i.e. semi-autonomous. Cooperation is the ability to interact with each other, acting together to achieve a global system goal, or shared goals. Additionally, agents can exhibit other characteristics, such as intelligence and adaptation.

A multi-agent system is a society of agents that represent the objects of a system, capable of interacting, in order to achieve their individual goals, when they have not enough knowledge and/or skills to achieve their objectives individually. The global system behaviour is achieved through the complex interaction among the individual agents, each one having its own objectives and behaviours, and possessing its own perceptive and cognitive capabilities.

In the GRACE project, the focus will be in studying and designing distributed manufacturing control systems for production lines producing home appliances and particularly washing machines, using the multi-agent principles, which guarantee the achievement of flexibility, responsiveness and reconfigurability. A particular requirement to be considered is the integration of the production control with the quality control information. For this purpose, the manufacturing and assembly systems, and the quality control stations of a home appliance production line will be treated as intelligent agents, and the whole production process will be supervised and controlled through the networked collaboration of individual agents. In order to integrate process and quality control new feedback loops are needed and advanced control techniques as i.e. adaptive control loops may be designed.

3. Requirements and Characteristics for a Distributed Production Control System

This section intends to identify the needs and requirements for DMS in general and for washing machines process lines in particular, and the desirable features that the multi-agent system will provide.

Aiming at a clear understanding of the identified requirements, they will be represented using a descriptive form formatted according to the tuple **{id, title, description, scope, case study, date, author}**, where:

- The *id* parameter refers to a unique identifier of the requirement.
- The *title* parameter refers to a title that states clearly the requirement. A concise description of the requirement should be provided, containing a priority classification differentiating between:
  - MUST: which means that the definition is an absolute requirement of the specification.
  - SHOULD (or the adjective "RECOMMENDED"): which means that there may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood and carefully weighed before choosing a different course.
- The *description* parameter is concerned to a detailed description of the purpose and objective of the requirement.
- The *scope* parameter defines whether the requirement applies for particular scenarios or generic scenarios.
- The *case study* parameter indicates if the requirement is presented in the washing machine process case study.
- The *date* parameter provides the date when the requirement was issued.

– The *author* parameter indicates the name of the originator of the requirement.

The identified requirements will be presented in the following sections, grouped according to their similarities, e.g. considering the functional, non-functional and other more specific views. A catalogue of requirements is provided at the end of this chapter to provide an overview and an easy approach to find and understand these requirements.

3.1. Functional Requirements

Functional requirements are driven and traced from business and they define what a system is supposed to accomplish with. They generally describe what a "system should do" (system design), defining functions of a system or its components, while these functions can be described as a set of inputs, the visible behaviour and outputs.

Therefore functional requirements are supported by non-functional requirements which describe what a "system should be" (system architecture).

3.1.1. General Low-level Functional Requirements

Requirement ID:	**LLFR-1**				
Title:	**The system MUST execute and control well defined production processes**				
Description:					
A production control system must execute and control the production processes to produce (parts of) a product (in the case of this project for a washing machine).					
Scope:	Generic	**Author:**	SIEMENS	**Case study:**	Yes

Requirement ID:	**LLFR-2**
Title:	**The system MUST execute and control parallel production processes**
Description:	
A production control system must execute and control several production processes in parallel.	

Scope:	Generic	**Author:**	SIEMENS	**Case study:**	Yes

Requirement ID:	**LLFR -3**
Title:	**The system MUST execute and control the production related quality assurance processes**
Description:	
A production control system must execute and control the quality assurance processes for a product (or parts of it).	

Scope:	Generic	**Author:**	SIEMENS	**Case study:**	Yes

Requirement ID:	**LLFR -4**
Title:	**The system MUST facilitate product and process variation as far as required**
Description:	
A production control system must support a required variability and process redundancy in production of (parts of) a product (in the case of this project for a washing machine).	

Scope:	Generic	**Author:**	SIEMENS	**Case study:**	Yes

Requirement ID:	**LLFR -5**
Title:	**The system MUST execute and control production (semi-)automatically and manually**
Description:	
A production control system must facilitate the automatic, semi-automatic and manual execution and control of production processes for (parts of) a product (in the case of this project for a washing machine).	

Scope:	Generic	**Author:**	SIEMENS	**Case study:**	Yes

Requirement ID:	**LLFR -6**				
Title:	**The system MUST facilitate reproducibility of product and of product quality**				
Description:					
The production control system needs to facilitate the production of a product (parts) with a given process and quality, even after producing other parts or with another process.					
Scope:	Generic	**Author:**	SIEMENS	**Case study:**	Yes

Requirement ID:	**LLFR -7**				
Title:	**The system SHOULD document production**				
Description:					
A production control system should facilitate the technical and commercial documentation of the production of instances of (parts of) a product (in the case of this project for a washing machine).					
Scope:	Generic	**Author:**	SIEMENS	**Case study:**	Yes

3.1.1. General Functional Requirements

Requirement ID:	**FR- 1**				
Title:	**The system MUST implement time-constrained manufacturing functions**				
Description:					
The system must implement and supervise the required sequences of operations as well as detect and diagnose malfunctions within predetermined time windows. Control and quality functions must operate in the same time frame as the machine in order to guarantee the production flow. This is especially important when feedback loops (e.g. quality control) are introduced in the system and instability may occur due to sampling and control action delays. Furthermore this relates to the time-constraints related to communication algorithms and structure.					
Scope:	Generic	**Author:**	AEA and UNIVPM	**Case study:**	Yes

Requirement ID:	**FR- 2**
Title:	**The system MUST be able to take autonomous decisions to a specific (predefined) degree**

Description:

The system operation based on the coordination of individual entities happens with a certain level of predefined autonomy, i.e. without intervention from the outside or the assistance of an operator. The system should be acting autonomously, but different entities may show a different degree of autonomy. The objective of each entity is to fulfil the respective task, performing its behaviour and role.

Examples of process or production control functionality where autonomy can be present are:

i) the system can change production parameters in a predefined range, like configurations of single production steps and sequence of production or testing steps,

ii) the system can change resource (machine, etc.) utilization in a predefined range.

Scope:	Generic	**Author:**	IPB and AEA and UNIVPM	**Case study:**	Yes

Requirement ID:	**FR- 3**
Title:	**The system MUST be able to adjust with respect to the production needs**

Description:

Flexibility is intended as the ability of the system to manage different models of products (within a certain predefined range): the system must be able to perform its functionalities and to reconfigure itself depending on production needs (e.g. product fluctuation, change in the production equipments due to breakdowns). Complete customization can be seen as a limit case where all the products are different from each other.

Scope:	Generic	**Author:**	AEA	**Case study:**	Yes

Requirement ID:	**FR- 4**
Title:	**The system MUST handle association, change and removal of entities on the fly**

Description:

The addition, removal and modification of the system’s entities can be performed on the fly, i.e. without the need to stop, re-program and re-initialize the other entities (this also includes the substitution and

the insertion of new technologies and functionalities in order reply to new requirements following the technology development). Particularly, each part of the whole system should be upgradable and quickly replaceable (or their functions should be performed by another entity which can provide similar results).					
Scope:	Generic	**Author:**	IPB and UNIVPM and AEA	**Case study:**	Yes

Requirement ID:	**FR- 5**				
Title:	**The system MUST handle processes exceptions properly**				
Description:					
In industrial environment, robustness and fault tolerance are key issues. A production control system needs to automatically handle well defined production process exceptions arising during the production process. Particularly, the system has to decide whether to keep on running by using different entities or if the failures (e.g. physical devices or software entities malfunctioning) may require the system to run in a safe mode or to stop in a safety position.					
Scope:	Generic	**Author:**	IPB and AEA and UNIVPM	**Case study:**	Yes

Requirement ID:	**FR- 6**				
Title:	**The system MUST interact with legacy systems and physical devices**				
Description:					
Industrial systems comprise physical devices and running applications that must be integrated with the developed applications. For this purpose, the success of the integration of a new application requires the interface with legacy systems (e.g. existing hardware, software and computer infrastructure) and physical devices (e.g. production automation equipment and testing equipments). Note that this also includes the information provided/received to different users (e.g. operators, manufacturing engineers and managers) during the execution of their tasks.					
Scope:	Generic	**Author:**	IPB and AEA	**Case study:**	Yes

Requirement ID:	**FR- 7**				
Title:	**The system SHOULD provide concise but meaningful output**				
Description:					
The output of the system should be concise, providing few data with high "density" of useful information. The system should provide the most relevant information to the other entities, and the remaining should be stored in a database for future use.					
Scope:	Generic	**Author:**	UNIVPM	**Case study:**	Yes

Requirement ID:	**FR- 8**				
Title:	**The system SHOULD aggregate information**				
Description:					
Information and data from different entities should be aggregated in order to be easily understandable for a human operator and more valuable for other entities of the system.					
Scope:	Generic	**Author:**	AEA	**Case study:**	Yes

Requirement ID:	**FR- 9**				
Title:	**Information SHOULD provide an access right system**				
Description:					
The system should ensure the availability of the data, resources and services required by authorized entities. However, the system information can only be read by a legitimate entity and also modified in an authorized manner.					
Scope:	Generic	**Author:**	AEA	**Case study:**	Yes

Requirement ID:	**FR- 10**				
Title:	**The system SHOULD permit to validate critical functions**				
Description:					
Human operator should be able to validate or modify critical functions in order to influence the overall behaviour of the system and prevent from anomalous operating conditions.					
Scope:	Generic	**Author:**	AEA	**Case study:**	Yes

Requirement ID:	**FR- 11**				
Title:	**The system SHOULD warn abnormal situations**				
Description:					
Because it is not possible in distributed environment to follow each single problem and at the same time have an overview of the effects of any deviation etc. on other groups/units or tasks, a warning system should point to abnormal situations before they create big problems. Therefore, in case of failures, schedule deviations or other events that endanger the delivery date the system must warn automatically the user. Warning messages have to be displayed when a user logs on in the system as well as when the event occurs. The warning system should provide different warning levels, assigned to different users (for decentralised units). It must be possible to print lists of warning messages. The system must provide the notification of service and/or device downtime or failure.					
Scope:	Generic	**Author:**	IPB	**Case study:**	Yes

Requirement ID:	**FR- 12**				
Title:	**The system SHOULD provide an interaction with other DMSs**				
Description:					
The inter-DMS communication permits the interaction with other DMSs (e.g. suppliers, customers and partners DMSs).					
Scope:	Generic	**Author:**	AEA	**Case study:**	No

Requirement ID:	**FR- 13**				
Title:	**The system SHOULD leverage standards as much as possible**				
Description:					
The use of standards is a contribution to support the integration of legacy systems and heterogeneous devices/systems.					
Scope:	Generic	**Author:**	IPB	**Case study:**	No

Requirement ID:	**FR- 14**				
Title:	**The system MUST provide virtual commissioning**				
Description:					
A production control system needs to provide facilities to test the production processes with and without production equipment.					
Scope:	Generic	**Author:**	SIEMENS	**Case study:**	No

3.1.1. Functional Requirements on Quality Control Processes

Requirement ID:	**QCR-1**				
Title:	**The quality control system SHOULD manage measurement results**				
Description:					
The quality assurance part of a production control system is expected to measure the production process quality, to manage production the process quality, to manage the production result quality and to manage the production history.					
Scope:	Particular	**Author:**	SIEMENS	**Case study:**	Yes

Requirement ID:	**QCR-2**				
Title:	**The system SHOULD not require action to be performed on the product**				
Description:					
The measuring system should avoid actions performed on the product, requiring the installation of some kind of sensor on the product, in preference using non-contact techniques.					
Scope:	Particular	**Author:**	UNIVPM	**Case study:**	Yes

Requirement ID:	**QCR-3**				
Title:	**The measurement systems SHOULD be accurate**				
Description:					
The measurement systems should provide accurate results, matching the desired level of uncertainty (low uncertainty)					
Scope:	Particular	**Author:**	UNIVPM	**Case study:**	Yes

Requirement ID:	**QCR-4**				
Title:	**The measurement system SHOULD be stable**				
Description:					
The measurement instrumentation should provide stable signals in order to have meaningful results. The signals must remain of high quality when the conditions of the environment or of the measured part change, i.e. robust measurements.					
Scope:	Particular	**Author:**	UNIVPM	**Case study:**	Yes

Requirement ID:	**QCR-5**
Title:	**The data collected by the measurement system MUST be traceable**
Description:	
The data collected by the measurement system must be related to standard references through an unbroken chain of comparisons.	

Scope:	Particular	**Author:**	UNIVPM	**Case study:**	Yes

Requirement ID:	**QCR-6**				
Title:	**The system SHOULD execute manual/automatic quality analysis and reporting**				
Description:					
The systems should execute interactive/manual and/or automatic production quality analysis and reporting.					
Scope:	Particular	**Author:**	SIEMENS	**Case study:**	Yes

3.2. Non-Functional Requirements

Non-functional requirements are driven from functional requirements, but are related to mode internal behaviour (e.g., performance or quality) or constraints of the service provided (e.g., standard compliance).

3.2.1. General Non-Functional Requirements

Requirement ID:	**NFR- 1**				
Title:	**The system MUST be based on a set of distributed entities**				
Description:					
Traditional control systems often operate in a centralized manner, upon rigid control and communication structures. In opposition to the traditional centralized structures, the new approach must be based on a decentralized control structure built upon a set of distributed entities, each one is independent and autonomous, with proper objectives, knowledge and skills. An entity could be a production machine, a quality control station, the product itself or part of the information system. This means that the high level functionalities (e.g. control, scheduling and monitoring) are distributed.					
Scope:	Generic	**Author:**	IPB	**Case study:**	Yes

Requirement ID:	**NFR- 2**				
Title:	**Entities of the system MUST interact/cooperate with each other**				
Description:					
In distributed systems based on a community of individuals, entities must share their knowledge and skills/functions throughout cooperation, in order to accomplish their own functions (when they cannot perform them alone due to insufficient knowledge or skills). Therefore an interaction between the individuals is needed, so that every entity can send /receive which functions it is able to offer and which are needed.					
Scope:	Generic	**Author:**	IPB and AEA and UNIVPM	**Case study:**	Yes

Requirement ID:	**NFR- 3**				
Title:	**Interoperability MUST be supported between heterogeneous control entities**				
Description:					
Today's industrial applications are composed of several heterogeneous components, i.e. different devices, pallets and products. Interoperability is a property of a system, whose interfaces are completely understood, to work with other systems, present or future, without any restricted access or implementation. For this purpose, a special attention to attain the interoperability issues is needed when designing interaction mechanisms to achieve cooperation					
Scope:	Generic	**Author:**	IPB and UNIVPM	**Case study:**	Yes

Requirement ID:	**NFR- 4**				
Title:	**The system SHOULD be scalable to allow large scale networks without significant performance loss**				
Description:					
The scalability of the system should be possible without the loss of performance.					
Scope:	Generic	**Author:**	IPB	**Case study:**	No

Requirement ID:	**NFR- 5**				
Title:	**The system SHOULD have an user-friendly interface**				
Description:					
The system provides information to the users (e.g. operators, manufacturing engineers and managers) throughout user-friendly interfaces. Particularly, the system should provide facilities to visually monitor the production processes and/or use external monitoring using software such as SCADA.					
Scope:	Generic	**Author:**	AEA and SIEMENS	**Case study:**	Yes

Requirement ID:	**NFR- 6**				
Title:	**The system MUST support production performance monitoring**				
Description:					
The system must support monitoring of production using performance indicators such as energy consumption, costs, efficiency and productivity.					
Scope:	Generic	**Author:**	AEA	**Case study:**	Yes

Requirement ID:	**NFR- 7**				
Title:	**The system SHOULD work correctly/not be influenced by changing condition over time.**				
Description:					
The performance of the system should not be degraded over time. The system should maintain its full capabilities in different condition (i.e. a machine vision measuring entity should operate in the same way during the day and the night).					
Scope:	Generic	**Author:**	UNIVPM	**Case study:**	Yes

Requirement ID:	**NFR- 8**				
Title:	**The system SHOULD provide the self-organizing functionality**				
Description:					
In order to support flexibility and re-configurability, the system should provide the capacity to self-organize according to the current environmental conditions.					
Scope:	Generic	**Author:**	IPB	**Case study:**	No

Requirement ID:	**NFR- 9**				
Title:	**The system SHOULD provide the self-optimization functionality**				
Description:					
The system should exhibit self-optimization in order to improve its performance, performing self-diagnosis and self-tuning its control parameters.					
Scope:	Generic	**Author:**	IPB and UNIVPM	**Case study:**	Yes

Requirement ID:	**NFR- 10**				
Title:	**The system MUST provide the self-adaptation functionality**				
Description:					
The system should dynamically adapt its behaviour to a given physical production process state or in response to disturbances from both internal and external manufacturing environments. This functionality is related to the hardware and software reconfiguration.					
Scope:	Generic	**Author:**	AEA	**Case study:**	Yes

Requirement ID:	**NFR- 11**
Title:	**The system entities SHOULD provide the learning functionality**
Description:	
Aiming to improve the performance of the system (e.g. productivity, products optimization), the	

system's entities should be able to learn from past experience.					
Scope:	Generic	**Author:**	AEA	**Case study:**	No

Requirement ID:	**NFR- 12**
Title:	**The system functionalities SHOULD be reusable**
Description:	
The implementation of the same functionality should not be duplicated; different instances of the same functionalities should be used if needed. Reusable modules and classes reduce implementation time, reduce the possibility of bugs because they have been already tested, and facilitate code modifications. Reusability implies some explicit management of building, packaging, distribution, installation, configuration, deployment, maintenance and upgrade issues.	

Scope:	Generic	**Author:**	AEA	**Case study:**	Yes

Requirement ID:	**NFR- 13**
Title:	**The system SHOULD support traceability**
Description:	
The system should support the traceability of the production process, i.e. the completeness of the information about every step in the production process sequence (production history from components to final products).	

Scope:	Generic	**Author:**	AEA and IPB	**Case study:**	Yes

Requirement ID:	**NFR- 14**
Title:	**The system MUST operate at planned production capacity and speed**
Description:	
The computational resources of a production control system must support maximum planned production capacity and execution and control requirements of the fastest processing.	

Scope:	Generic	**Author:**	SIEMENS	**Case study:**	Yes

3.2.2. Non-Functional Requirements on Integration of Production and Quality Control

Requirement ID:	**IPQR- 1**				
Title:	**The system MUST support the integration of production and quality control**				
Description:					
Quality control data and functionalities (acquisition, processing, classification, visualization and collection) must be considered in the production control system by introducing feed-forward production actions and the generation of new feedback loops (provide/receive quality measurements in the production context and change the production process automatically based on quality measurements).					
Scope:	Generic	**Author:**	IPB and AEA	**Case study:**	Yes

Requirement ID:	**IPQR- 2**				
Title:	**The system SHOULD be able to customize the measurements of quality control stations**				
Description:					
Quality control should be customized for each product basing on data coming from previous stages in the production line and information from the environment and the production process.					
Scope:	Particular	**Author:**	WHI	**Case study:**	Yes

Requirement ID:	**IPQR- 3**				
Title:	**The system SHOULD be able to optimize the operations of production machines**				
Description:					
Production machines operations should be optimized basing on data coming from quality control stations and information from the environment and the production process.					
Scope:	Particular	**Author:**	WHI	**Case study:**	Yes

Requirement ID:	IPQR- 4				
Title:	The system SHOULD manage the statistical quality test areas				
Description:					
The percentage and the type of products chosen for the statistical test should be managed by the system depending on the information collected during the production process.					
Scope:	Particular	Author:	WHI	Case study:	Yes

Requirement ID:	IPQR- 5				
Title:	The system SHOULD be able to customize the product				
Description:					
The product should be customized, i.e. the setting of EEPROM parameters of the appliance control board, basing on data and information coming from the production process and market surveys in order to satisfy quality standard requirements and market needs.					
Scope:	Particular	Author:	WHI	Case study:	Yes

3.2.3. Non-Functional Requirements on Design, Configuration and Maintenance

Requirement ID:	DCMR- 1				
Title:	The system SHOULD enable the adaptability of the implementation				
Description:					
Enable the adaptability of the implementation, in terms of controlled production processes and used production resources, to different use cases or different types of production processes.					
Scope:	Generic	Author:	SIEMENS	Case study:	Yes

Requirement ID:	**DCMR- 2**				
Title:	**The system SHOULD provide interfaces to interact with**				
Description:					
The production control system needs to provide facilities to interact with (e.g. receive input from) a process planning and validation environment for line production systems, and in particular for washing machine production (Basic Process, Assembly Process and Testing Process).					
Scope:	Generic	**Author:**	SIEMENS	**Case study:**	Yes

Requirement ID:	**DCMR- 3**				
Title:	**The system SHOULD be configurable by input information**				
Description:					
The production control system needs to be configurable by input of the following information: • Specifications of the production process flow, consisting of process segments and single steps (like basic step, assembly step, transport step, testing step) and their physical and logical order (according to the Whirlpool concepts of “Process Product Structure” and “Functional Product Structure”); • Specifications of variants and dependencies of production process, process segments, single steps and their operational parameters (e.g. sequence, parallelism, parameters, optional steps); • Specifications of production related activities that are needed in the production process (e.g. material supply steps, tooling exchange steps); • Definitions of production parameter ranges and other process specific production rules restricting operational flexibility; • Specifications of dependencies of parameters of production and those of testing steps (e.g. cause-effect relations of parameters, parameter sets or parameter ranges); • Specifications of functionalities (and behaviours) of resources (machines, equipment etc.) in the plant for the performance of a production step; • Definitions of equipment parameter ranges and other equipment specific production rules restricting operational flexibility; • Detailed static production scheduling information.					
Scope:	Generic	**Author:**	SIEMENS	**Case study:**	Yes

Requirement ID:	**DCMR- 4**				
Title:	**The system SHOULD be maintainable**				
Description:					
The system should be easily maintainable by someone who does not know the implementation details in order to correct defects, meet new requirements, make future maintenance easier, or cope with a changed environment.					
Scope:	Generic	**Author:**	AEA	**Case study:**	Yes

Requirement ID:	**DCMR- 5**				
Title:	**The design and implementation SHOULD be cost effective**				
Description:					
The design of the production control system should be maintained at a minimum cost without compromising performance.					
Scope:	Generic	**Author:**	UNIVPM	**Case study:**	Yes

3.2.4. Non-Functional Requirements on IT environment

Requirement ID:	**ITR- 1**				
Title:	**The system software MUST run on standard computational equipments**				
Description:					
The software production control system must run on standard computational equipment using different operating systems and connected by a network using a standard communication protocol.					
Scope:	Generic	**Author:**	IPB	**Case study:**	Yes

Requirement ID:	**ITR- 2**				
Title:	**The system MUST have the ability to work in a network based environment**				
Description:					
The system must have the ability to work in a network-based environment and to communicate with each part of the system itself and with other (external) systems that are present in the same network (e.g. LAN, VPN, Internet and Profibus).					
Scope:	Generic	**Author:**	UNIVPM	**Case study:**	Yes

Requirement ID:	**ITR- 3**				
Title:	**The system MUST use secure cross enterprise and/or location processing**				
Description:					
The cross enterprise process interfaces of a production control system have to be secured, and the shared information has to be IP (Intellectual Property) protected on each side.					
Scope:	Generic	**Author:**	SIEMENS	**Case study:**	No

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