Production harmonizEd Reconfiguration of Flexible Robots and Machinery

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Deliverable 1.2

Requirements for Innovative Production System Functional requirement analysis and definition of strategic objectives and KPIs

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Abstract

One of the main purposes of PERFoRM project is to develop an innovative manufacturing system based on a new agile concept introducing the implementation and demonstration of methods, methodologies and strategies for transforming existing production systems into plug-and-produce production systems.

In these terms, the WP1 aims to become a successful guideline for this migration to flexible, reconfigurable and self-adaptive industrial environments. In fact, it will cover a comprehensive investigation on exiting integrated tools for the management of production systems, communication protocols and data representation standards (T1.1); it will provide technical requirements definition in order to identify the most appropriate technology components and tools to bridge the gap between current and future situation (T1.3) and it will identify strategic requirements in terms of social, environmental and economic aspect (T1.2).

This last point is the first step which allows the implementation of a next generation of agile manufacturing systems, based on Cyber-Physical Production Systems (CPPS) paradigm, not only within the shop floor but also at more strategical levels.

This document focuses on the presentation of T1.2 activities and results.

Thus, the overall goal is to identify and clarify the requirements and their relevant measurement metrics (KPIs). In order to realize that, four industrial Use Cases provided by Whirlpool, GKN, IFV-eD/POL-eD and Siemens have been analyzed. They represent four key European industrial sectors which are white goods, aerospace, automotive as well as power and gas respectively.

In this document, an iterative approach for requirements identification is applied, based on : Requirements Engineering (RE) and the methodology developed in MSEE project [1]. This methodology includes four steps (i.e. Elicitation, Analysis, Specification and Validation) which are repeated in two different moments. The main task of the Elicitation step is to verify, update and detail the end-user scenario. The Analysis aims at examining the current situation (AS-IS) and identifying weaknesses and opportunities for improvement (TO-BE situation). Four Use Cases have been identified within the project, each of them related to a specific Industrial Partner; after identifying the relevant requirements for each Use Case, an overall comparison among these requirements is carried out, to draw general conclusions. The Specification translates the identified gaps into an understandable form for each Use Case, taking into account their completeness, consistency and accuracy. The last phase (Validation), which is applied during the second iteration, has to validate the obtained requirements against the project objectives and the Industrial Partners' expectations.

Finally, in order to properly monitor and control the requirement trends proper KPIs have been identified and a suitable framework has been proposed to manage and visualize the relevant data.

1. Introduction

The main objective of PERFoRM project is to combine self-adjusting plug-and-produce devices with simulation, scheduling and optimization methods in order to achieve a flexible manufacturing environment based on rapid and seamless reconfiguration of machinery and robots as response to operational or business events.

This purpose implies that a new radical approach has to be developed compared with the traditional and currently available on many shop floors.

For this reason, the overall objectives of the WP1 *"Vision and objectives for demonstration of new innovative production systems based on flexible and reconfigurable production assets*" are to define a global view of potential integration and deployment of tools able to address self-adjustment, correction, control of individual machines and robots and their current integration with exiting production systems in order to show the flexibility and fast reaction of manufacturing environment to the rapid market changes.

In particular, this deliverable aims to provide a clear definition of general business and strategic requirements needed to transform the existing production systems (based on the traditional centralized, vertical and rigid paradigm) into a new system based on plug-and-produce paradigm.

Then, the second objective is to define the methodology to deploy these requirements. This means that an appropriate set of KPIs (technical and business) able to measure and benchmark them will be identified.

Therefore, this deliverable firstly presents the description of the Requirements Engineering (RE) methodology describing its objectives and pointing out its phases (elicitations, analysis, specification, validation), its characteristics and its constraints. Then, the practical application of RE is reported, considering the four industrial pilots detailed in WP7, WP8, WP9, WP10 as the main stakeholders.

The result of this part is a list of requirements and KPIs identifying the Use Case needs and related objectives to be achieved in order to ensure an agile manufacturing control system composed by true plug and-produce devices, robots and machines.

1.1. Objective of deliverable

The relevant objectives of D1.2 is concerned with the definition and deployment of general business and strategic requirements and the measurement and benchmark of KPIs (Key Performance Indicator), adapted on each Use Case proper reality. This is the first step needed to validate the introduction of new technologies enabling the robot and flexible machinery integration into distributed production environments. The overview about the main goals of this deliverable can be summarized as follows:

- Definition of strategic business requirements associated with the implementation of an Integrated modelling, simulation and information management systems including social, environmental and economic context;
- Definition of KPIs;
- Definition of an appropriate framework to deploy and evaluate KPIs.

1.2. Structure of deliverable

This deliverable is grouped into three blocks as shown in Figure 1

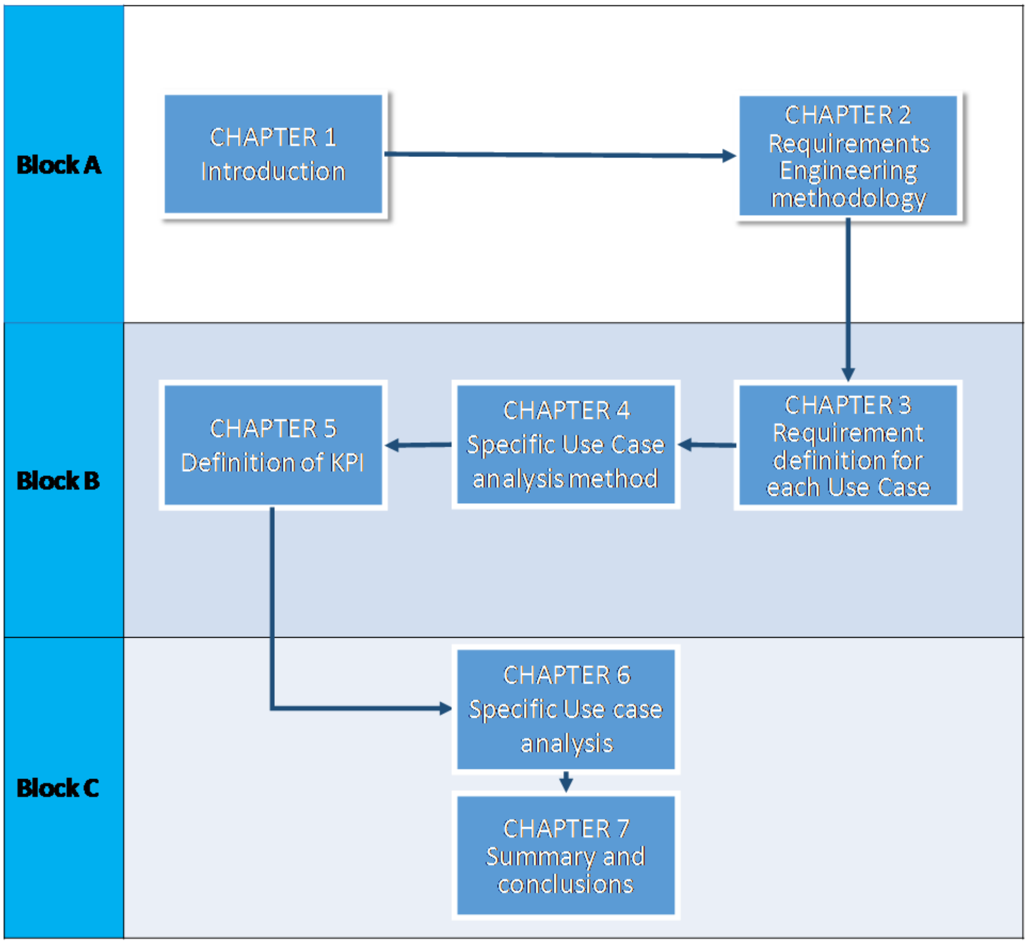

Figure 1 Structure of deliverable

Block A has the function to give a preface to the overall document. In particular, it includes chapter 1 where the document objectives are listed and the theoretical approach to reach them is reported in chapter 2 where the general process of Requirements Engineering (RE) is described.

Block B describes the practical approach applied to each Use Case. In particular, includes three main parts; the first ones are related to respectively to techniques used (chapter 3) and to specific phases conducted during Use case analysis (chapter 4) respectively. The last part concerns with the KPIs and firstly gives them a general definition, exploits the state of the art of the methodology utilized to identify them and then presents the final KPIs identified (chapter 5).

Block C contains each Use case specific results (chapter 6) and the conclusion of the deliverable including its general results (chapter 7).

2. Requirements Engineering methodology

The success of the requirement identification critically depends on the stakeholders and on the designers, who are responsible to gather the stakeholders' expectations and needs and to clearly translate them into both functional and technical requirements. This understanding precisely and unambiguously describes both requirements for the delivered system and any constraints on the development process. Any formal verification of the identified requirements is based on this process and so it is tied to the quality of the specification. The activity starting with requirement elicitation and formulation and ending with requirement specification and validation has been based on *Requirements Engineering (RE)* discipline [2].

This activity is related to the identification of the goal to be achieved by the envisioned system, the operationalization of such goals into services and constraints, and the assignment of responsibilities for the resulting requirements to agents such as humans, devices and software [3].

Before making a study of the RE, it is necessary to give a proper definition to requirements. In general, there are many different definitions and descriptions of a requirement in literature and for this deliverable it has been chosen to follow the IEEE (Institute of Electrical and Electronics Engineers) definition [4]. According to this, a requirement can be described as follows:

- A condition or capability needed by a user (person or system) to solve a problem or achieve a goal
- A condition or capability, which has to be provided by a system or part of a system, to fulfill a contract, a standard, a specification or any other formal documents
- A documented representation of a condition or capability, as in 1 or 2 referenced

Based on this definition, it can be concluded that a requirement is a need for a physical attribute or functionality of a solution [5]. It describes the capabilities or characteristics a product or service has to provide in order to deal with a specific problem [1].

Following the definition, requirements describe the conditions or capabilities of the solution only, but not the approach to be provided. Thus, the requirement and the form of the solution should be considered strictly separated.

In order to have a common understanding of a requirement, Table 1 provided by Ebert [6], can be used. Here, the main non-functional requirements and attributes are listed.

Table 1: Characteristics for good Requirements [6]

Characteristic	Meaning for the requirements
Unambiguity	The requirements cannot be interpreted in different ways. There is a clear understanding and open issues have been indicated.
Understandability	The requirements are understandably described for all stakeholders. Notations and models are adapted to the target group.
Completeness	The requirements describe the functionality completely.
Consistency	The requirements must be consistent according to the content, the degree of the abstraction and the description.

Verifiability	The requirements are weighted by their importance. The requirements are testable and can be measured unambiguously.
Traceability	The requirements are clearly identified and include information on status, author, version, etc. They are linked at least with one test case and if it is necessary, they are linked horizontally and vertically to other requirements of comparable abstractions.
Relevancy	The requirements are necessary to implement the properties, which has at least a concrete benefit for one target group.
Feasibility	The requirements can be implemented within the resources and the technology to be used. The complexity of the implementation is estimated and arranged.

2.1. Requirements typology

Most requirements are strongly linked to the business requirements and to the overall strategy of a company. Business requirements may be defined as a specific need that must be addressed in order to achieve an objective[7]. Business requirements relate to a business' objectives, vision and goals. They also provide the scope of a business need or problem that needs to be addressed through a specific activity or project. For example, if a trade association has an objective to promote the services offered by its members, the business requirements for a project might include creating a member directory that increases awareness of members.

Good business requirements must be clear and are typically defined at a very high level. They must also provide enough information and guidance to help ensure that the project fulfils the identified needs. In addition to understanding an organization's mandate, objectives or goals, a specific business need or problem that is being tackled should be clearly defined and understood before developing business requirements. The need or problem can related to the organization or business in general or focus on a stakeholder group, such as customers, clients, suppliers, employees or another group [7].

While bearing in mind that the scope of the project is limited to manufacturing environments and based on existing studies, depending on the specific viewpoints, requirements can be grouped into different categories [5], being prominent distinctions the following:

- Product requirements
- Process requirements
- Functional requirements
- Non-functional requirements
- Architectural requirements
- Constraints

Product requirements describe conditions or capabilities of the envisaged product, which can be of tangible or intangible nature. Therefore, they can refer e.g. to the functionalities of a physical product or the characteristics of a service. *Process requirements* on the other hand can be used to describe activities that have to be performed in order to fulfill a product requirement. These can be processed, which are usually executed when developing the product, like the NPD process or the V-model. Another class of process requirements is represented by the processes, which the solution itself has to support, i.e. the required flow of activities. Finally, also product-independent processes can be a source of requirements, e.g. administrative processes that have to be followed for quality assurance [1].

Functional requirements represent, as implied in the name, the functionalities which are expected from a solution. In the case of a software system, these can be capabilities like import or export of data formats, text formatting etc. In contrast, *non-functional requirements* describe characteristics of the system "hidden" to the user. Also called quality requirements, they contain aspects like usability, performance, reliability or safety. E.g. the time required to execute a functionality can be a non-functional requirement [1].

Architectural requirements describe the structure of a solution and how the different components will work together through their relationships. The term is referred essential functionalities of the system, e.g. communications with external systems, qualities for scalability, extendibility, etc. In the case of complex systems, this can be the interaction among products and services, or between software and hardware.

Constraints limit the alternatives, which can be envisaged to satisfy the other identified requirements. In this case the solution will have to comply with all the recognized constraints [1].

2.2. Process of requirements Engineering

The term *Requirements Engineering* describes the processes leading to the production and management of the requirement definition.

Creating the specification is far more than just analysis: it involves eliciting relevant knowledge, understanding the task and its social and organizational context, negotiating with the client over the scope, contents and language, resolving conflicting requirements and synthesizing appropriate structures for describing the result. Use of the term Requirements Engineering has been proposed to indicate the complexity of this process, and to convey the message that specifications need to be carefully constructed [2].

The requirement definition process adopted within this project can be described by the Figure 2 and can be summarized as follows:

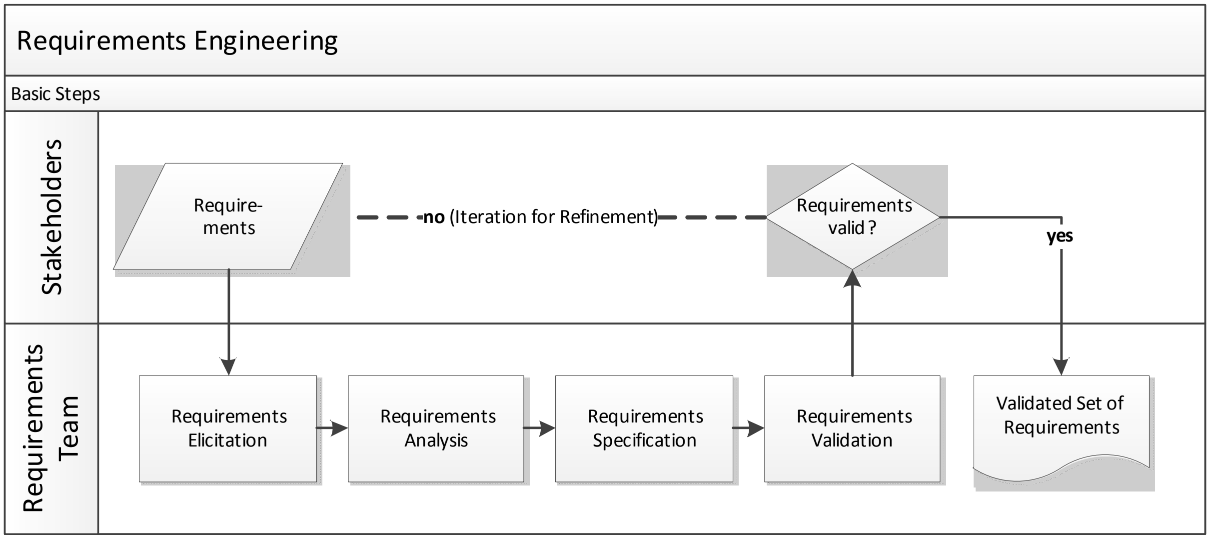

Figure 2 Basic Steps of Requirements Engineering[8]

Based on literature studies, the RE main phases are listed below:

1. Requirements elicitation (take-up of requirements for a solution to a problem)
2. Requirements analysis (checking requirements and stakeholder conflicts)
3. Requirements specification (documenting the requirements)
4. Requirements validation (does the proposed solution meet the requirements)

Requirements Elicitation

Requirements Elicitation of knowledge forms a major part of the process, whether or not it will eventually form a knowledge base. It involves the extraction and representation of information through some form of interaction with the experts, including various types of interviews, observing people in action (and subsequent debriefing), tutoring, and case analysis [2].

The central focus of this phase is the improvement of precision, accuracy and variety of requirements that are collected during the first iteration with the interested parts. For this reason, it has to be ensured that everyone who may be affected by the solution is consulted during requirements elicitation. In fact, the persons who might take benefit from the system or are governed by it have a large influence. First of all, it is needed to identify all *stakeholders* because the requirements might be very different or even opposite and contradictory [1]. In fact, according to Rupp, the stakeholders are the actual information providers for aims, requirements and boundary conditions, whose management is a factor of success for the satisfaction of the customer needs. Because of this, it is imperative to interview more than one stakeholder, to get a preferably harmonic and diversified picture of the customer needs [9]. The interested parts can be clustered in the different groups listed below:

- *Customers*: the term customer involves all individuals, person groups or companies, who have an interest in the usability or added value of the Extended Product. This includes also the future users of the product;

- *Internal Stakeholders*: employees, managers, owners;
- *External Stakeholders*: providers, government, creditor etc.

Requirements Analysis

The quality of the requirements captured during the previous step depends on their conformity towards the characteristics listed in Table 1.

In fact, there may be several discrepancies, such as lack of understanding, incomplete definition, low quality requirements, ambiguity or inconsistency. For this reason the goal of this phase is to evaluate if each requirement elicited describes something that is "necessary, verifiable and reachable" [6]. Regarding to this definition, a requirement will be "necessary" if the disappearance of this requirement changes the functionality of the solution. A requirement will be "verifiable" if it is clear how to test and approve it by reading the specification, and it will be "reachable" if it is reliable, not in contradictory with another requirement and compatible with all restrictions.

Requirements Specification

Specifications have a vital role to play in the requirements engineering process, as the only precise description of needs. The specification provides a way to verify the correctness of the eventual design and implementation. If the specification is inappropriate, verification will be pointless. Information omitted from the specification will not be taken into account in the design process. Ambiguities in the specification lead to uncertainty throughout the process. Misunderstandings and errors in the specification will lead to designs which do not properly satisfy the needs of the users [2].

In order to consolidate the information coming from the previous phases and to be aligned with stakeholder views, during the specification phase requirements are structured in a suitable way, providing a complete description of the solution that has to be developed, including the final the system architecture and eventual solution alternatives.

Requirements Validation

The specification must be validated with regard to the original needs of the client (stakeholders). This process is particularly difficult, as there is no definitive statement of those needs: the requirements specification is the first precise description of those needs [2].

Validation can only proceed if the participants can relate the specification to their needs, and is only successful if the specification is relevant to those needs. An important facility for validation is traceability [10]. If components of the specification can be traced back to the original statements that inspired them, then the participants can assess the relevance more readily. Also, if a statement has been misinterpreted, the parts of the specification which are based on it can be identified.

Validation is an important part of requirements engineering. As it requires the originators' participation, it is likely to be considerably smoother if those people have participated throughout the requirements process. Such an involvement means that the requirements can be validated as they evolve, rather than when they have been refined into a specification [2].

So the central focus is to prove that the solution proposed after Requirements Specification effectively meets the specified requirements. Therefore, the stakeholders have to be involved in a second review of the requirements in order to identify the faults in the previous steps, to correct and to validate them providing the final results.

2.3. Definition of functional requirements

The functional requirements describe the core functionality of one generic application. Basically, functional requirements describe the features, functioning, and usage of a product/system/software from the perspective of the product and its user. This means that they consist in the requirements that specifies a function that a system or system component must be able to perform.

Functional requirements break down the steps needed to meet the business requirement. Whereas a business requirement states the "*why*" for a project, a functional requirement outlines the "*what*". When developing functional requirements, a comprehensive list of steps that will be taken during the project is developed. Functional requirements are very detailed and provide information on how business needs and goals will be delivered through a specific project. The end objective is for each step to contribute towards achieving the business requirement [7].

So while both business and functional requirements are related to the same project, there are many major differences among them. In fact, although these sets of requirements contribute to a common goal, the functional requirements are much more specific and detailed. Moreover, while business requirements deal mainly with business goals and stakeholder expectations, functional requirements outline exactly how a project will support business requirements [7].

Therefore, a business requirement tells us what the future state of a project is and why the objective is worthwhile, while functional requirements tell us how we will get there. Functional requirements outline specific steps and outline how the project will be delivered. As a result, they help to ensure that a project is on track and are used for measuring performance.

This strong link existing between business and functional requirements is the reason why during the elicitation phase the Functional Questionnaire (see Chapter 3.2) has been used. In this document both business and functional aspects are collected in order to point out their differences, to identify their connections and to understand the boundaries, the constraints and the real context in which the solution will be applied.

2.4. Definition of technical requirements

Technical requirements refer to the group of non-functional requirements and are used to evaluate the operation of the system, rather than its specific functional characteristics. This subchapter aims at defining and describing the technical requirements of the system to be developed during the PERFoRM project and deals with the processes and procedures which occur during this analysis. This subchapter is strongly based on the technical results collected in T1.1 and is to serve as a profound base for the technology survey in T1.3. as well as in further development, integration and deployment tasks of all following WPs.

To reach the objectives of the requirements engineering and define technical requirements the steps to be considered are similar as for functional requirements, i.e.:

- feasibility study of existing decentralized distributed control approaches for flexible and reconfigurable production systems (includes T1.1 results), Use Cases and their technological background (includes T7.1, T8.1, T9.1 and T10.1 results)
- requirements elicitation and analysis
- requirements specification and validation

Based on the results from the previous projects collected in T1.1 a feasibility study for each Use Case was conducted in order to cover technical viability for each self-adaptive system to be developed in PERFoRM project. According to this, a research was done to verify whether the system which will be implemented is technically viable.

Based on this knowledge, the main technical weaknesses and strengths of the current and future systems were discussed with the Use Case providers and a large-scale research was done to record all provided recourses (plant, equipment, facility needs, material inputs, technology and skills) and elicit a set of technical requirements.

To determine whether the stated requirements closely correspond to the main demands of the work package task, i.e. clearness, consistence, completeness, etc., and in order to avoid apparent conflicts further analysis and specification of technical requirements was conducted. For this reason, two rounds of the Use Cases study were held.

As a result of the previous steps the following list of non-functional requirements could be collected specified and analyzed for the system to be implemented in PERFoRM project:

Table 2 Technical Requirements

Technical Requirement	Description
Accessibility	Design of devices, services, or systems for people or other systems.
Availability	Degree to which a system/module/cell/device is in an operable state of some task.
Composability	System design which allows inter-relationship of different components (highly composable systems can be assembled in various combinations to specify specific user/system needs).
Debugability	Supporting of the system debug operations to report on status and eventual system failures.
Disaster Recovery	Enabling of recovery or continuation of utilized infrastructure and system modules covered by natural or human-induced disasters.
Efficiency	Ability to avoid wasting materials, time, energy, efforts, money by producing/processing something.
Extensibility	System design principle to extend the system in such a way that a new functionality appears.

Failure Management	Ability to detect, handle and report system failures.
Feasibility	Ability of a system/system's software to be assessed regarding its practicality.
Flexibility	Flexibility of the product and process and adoption of a system design at external changes (e.g. process/machine/product/routing/program flexibility).
Integrity	Defines the security attributes of the system/modules/cells to protect the system and restrict the access rights or data exchange mechanisms.
Interoperability	Easy integration of systems/modules in other systems/modules by means of interfaces without any restricted implementations or access obstacles.
Maintainability	Ease, with which a product can be maintained, changed and evolved with minimal effort.
Operability	Enabling to keep a system/equipment/cell safe and in function for the planed operations and processes.
Performance	Measurable amount of useful/done work by software systems/cells/devices or computer network compared with planed time line and resource capacity.
Portability	Ability to build portable units/system modules which are easy to reuse for multiple cells (often by changing of their location).
Predictability	Degree to which a correct forecast of a system's/subsystem's state can be described using qualitative or quantitative parameters.
Productivity	Ability to change the rate at which the goods are produced or the work is completed.
Quality	Ability to measure the degree of whether the product was produced correctly.
Reconfigurability	Ability to change functionalities of cells/products/processes or systems to other types.
Reliability	Reliability properties with respect to a system's/subsystem's data delivery, process execution and work completeness.
Reproducibility	Ability of the system/module/cell to be duplicated/reproduced by any user.
Robustness	Ability to handle error conditions sufficiently, without failures, and to tolerate invalid data or unexpected software defects.
Safety	State of being "safe" or protected from harm or other non-desirable effects from outside (mainly used for Human-Machine Interaction).
Scalability	Ability to handle a large variety of system configuration sizes (system is able to scale up or increase capacity, time measurements, integration devices, etc.).
Security	Protected access to system/server/module or introducing of a certificate exchange mechanisms.
Simplicity	Ability to have a quality of being simple (complexity reduction).
Supportability/Serviceability	Ability of technical support to install, configure, monitor, debug failures and provide hard-/software support for solving a problem and restoring the product/process.
Sustainability	Ability or capacity of the system to endure and remain diverse and productive indefinitely.
Testability	Ability to observe practically if there are any faults in the system/software by means of testing.
Traceability	Traceability of the product and its quality.
Usability	Capacity of the system software to be easy understood, learned or used by an intended user.

3. Requirement definition for each Use Case

Within this chapter, the practical application of the RE methodology described in the previous paragraphs is shown. In particular, the approach utilized during the Elicitation phase and its output is described. It is composed of three complementary techniques:

- Swimlane
- Functional Questionnaire
- Technical Questionnaire

3.1. Process description (Swimlane)

A swimlane diagram documents the steps or activities of a process flow or workflow. More specifically, a swim lane diagram groups these activities into lanes which are horizontal or vertical columns that contain all of the activities, which fit into the category represented, by that lane. These lanes can represent many categories of information such as actors which perform the activities, the stage of the process in which the activity takes place, or whatever else the creator of the document feels should be emphasized and communicated by the swim lane diagram. Within PERFoRM project, the work interest is on the representation of the process flow and it focuses on the tools used in terms of production and logistics in order to identify which is the linkage between products, their manufacturing process and their IT systems. In the following paragraph, the swim lane of each industrial Use case is reported.

3.1.1. Siemens

Within the Siemens Use Case three main areas are involved, namely: Planning and Logistic, Production and Maintenance. The overall goal of the process is to identify disturbances in the production as early as possible and to deliver to all responsible partners as much information as possible. This all is done to ensure faster disturbance elimination. Basically three different outcomes can be differentiated:

- The machine can still operate (maybe with limited capabilities) and a future maintenance should be planned. The work does not need to be rescheduled
- The machine cannot operate, but repair can be done right away. The work does not need to be rescheduled
- The machine cannot operate and maintenance will need to be carried out by external staff (e.g. machine supplier). In this case, the work should be rescheduled to another machine.

The whole process is depicted in Figure 3.

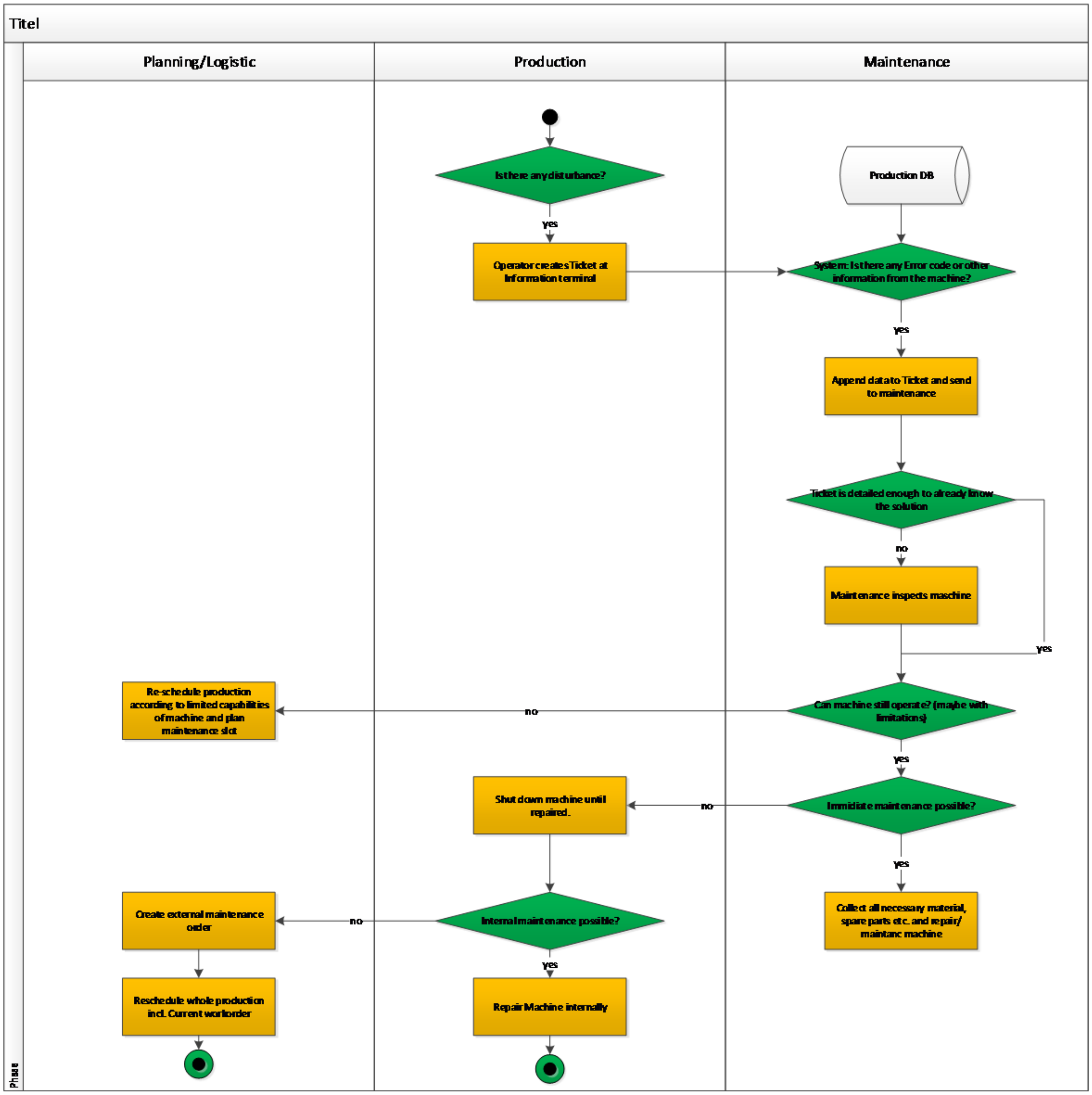

Figure 3 Siemens Swimlane

3.1.2. IFEVS

Within the E-District Use Case two main areas are involved, namely: Logistic and Production. The overall goal of the current process is to ensure a high quality of the products in spite of the throughput. Currently all the operations are manual and the main process is the welding. Within this project the line will be more automatized and will permit the necessary flexibility for the production of different type of vehicle configurations.

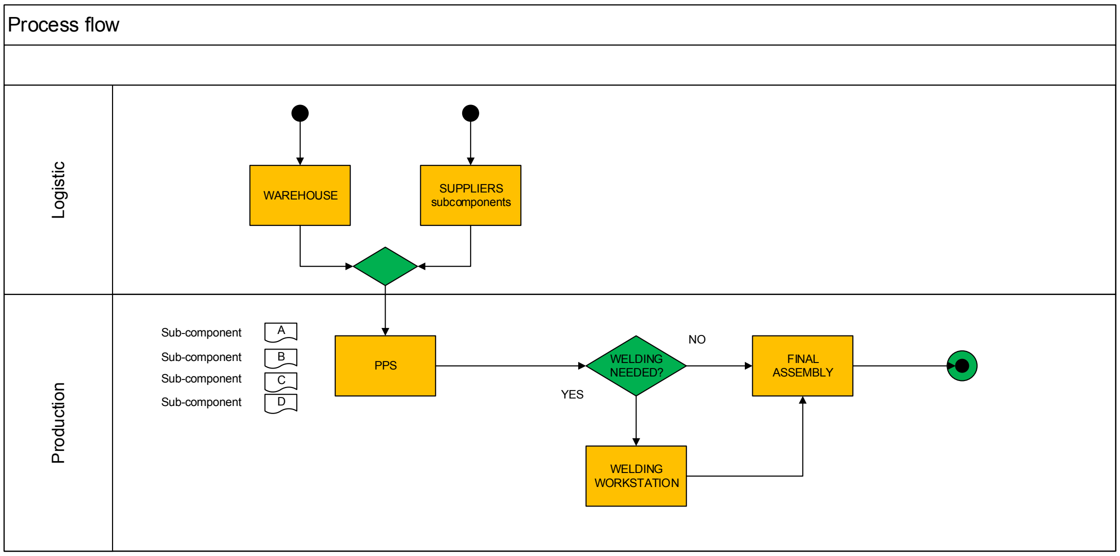

Figure 4 IFEVs Swim lane

3.1.3. Whirlpool

Within Whirlpool Use Case, it has been focused on microwave production. Final product orders are managed by Integrated Supply Chain department who is responsible of the overall planning of production and delivery of goods to trade partners. The main schedule is carried out through SAP APO application. A 5 days frozen plan is delivered daily to factory through Master Production Schedule (MPS). A MES tool named Pacemaker delivers production orders at the pacemaker station (door department) and determine plan to move materials from warehouse through shipping list. The actual production is monitored though a set of MES tools (MII, Andon, DCS, etc.) that supervise both the accounting of the real production and the variations from the plan in terms of inefficiency, quality etc. This final phase accomplishes both the completion of transaction of material consumption from the warehouse and the accountability of the SKU from production to logistic department. This information flow and its relationship with production steps and with product types are depicted in the figure below.

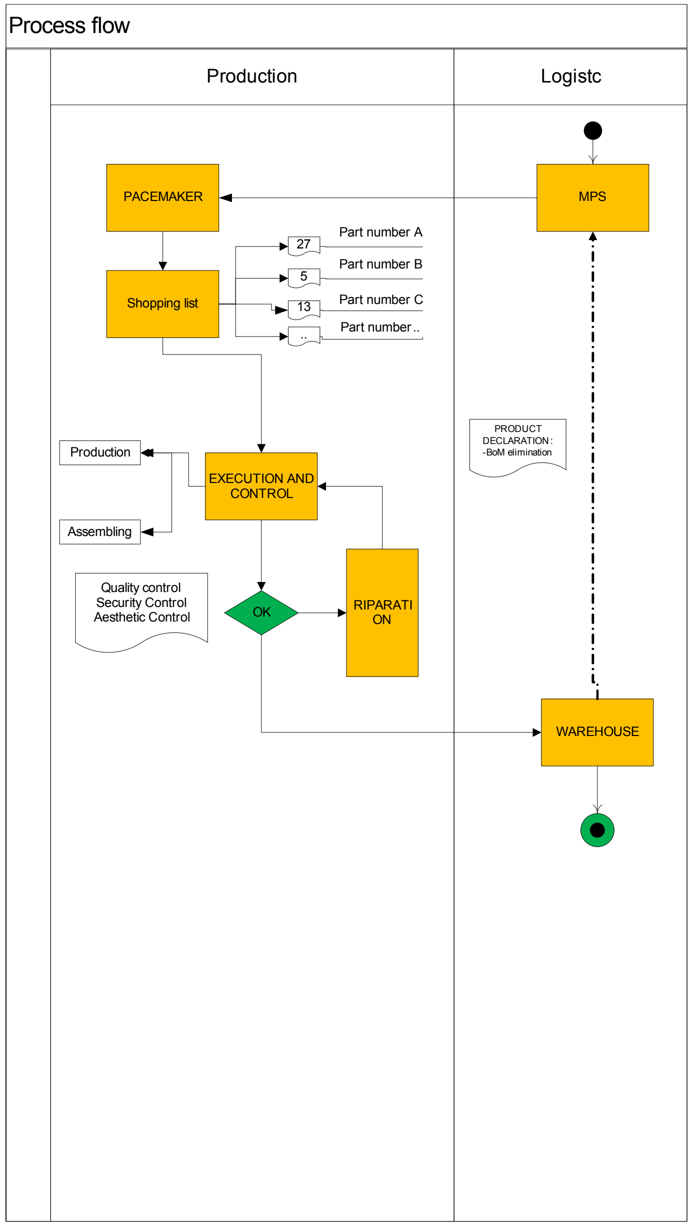

Figure 5 Whirlpool Swimlane

3.1.4. GKN

GKN manufactures complex, high value jet engine components with very stringent quality characteristics. The production system is like a large extent a functional workshop with standalone work centers and a mix of dedicated and common resources. The level of automation is usually rather low and more of separate process automation cells with low level of process flow integration. The production system has to cope with large variety of different components, low volumes and varying demands.

Usually, the typical production process with its information flow and its main production step is described in the figure below. It shows a straightly communication between different IT system which make available several kind of data such as order scheduling and customer demands.

In fact, all data (master data) is stored and managed through the ERP system (SAP). It exchanges data with production planning system, scheduling system and MRP and it collects also different kind of documentation from the processing and inspections in order to guarantee traceability. Some additional data and information is generated and made available in PDM system (Team Center Engineering and Manufacturing).

This data exchange comes first of production process that is initiated by the production plans while the production operations are controlled by the data provided from the ERP/PDM systems to execute the correct configurations of materials and process. The product is manufactured in a number of operation steps defined by a specific routing, and the procedure described above is repeated for each operation. At the end of the operations list, final inspection and packaging is done before shipping to the customer.

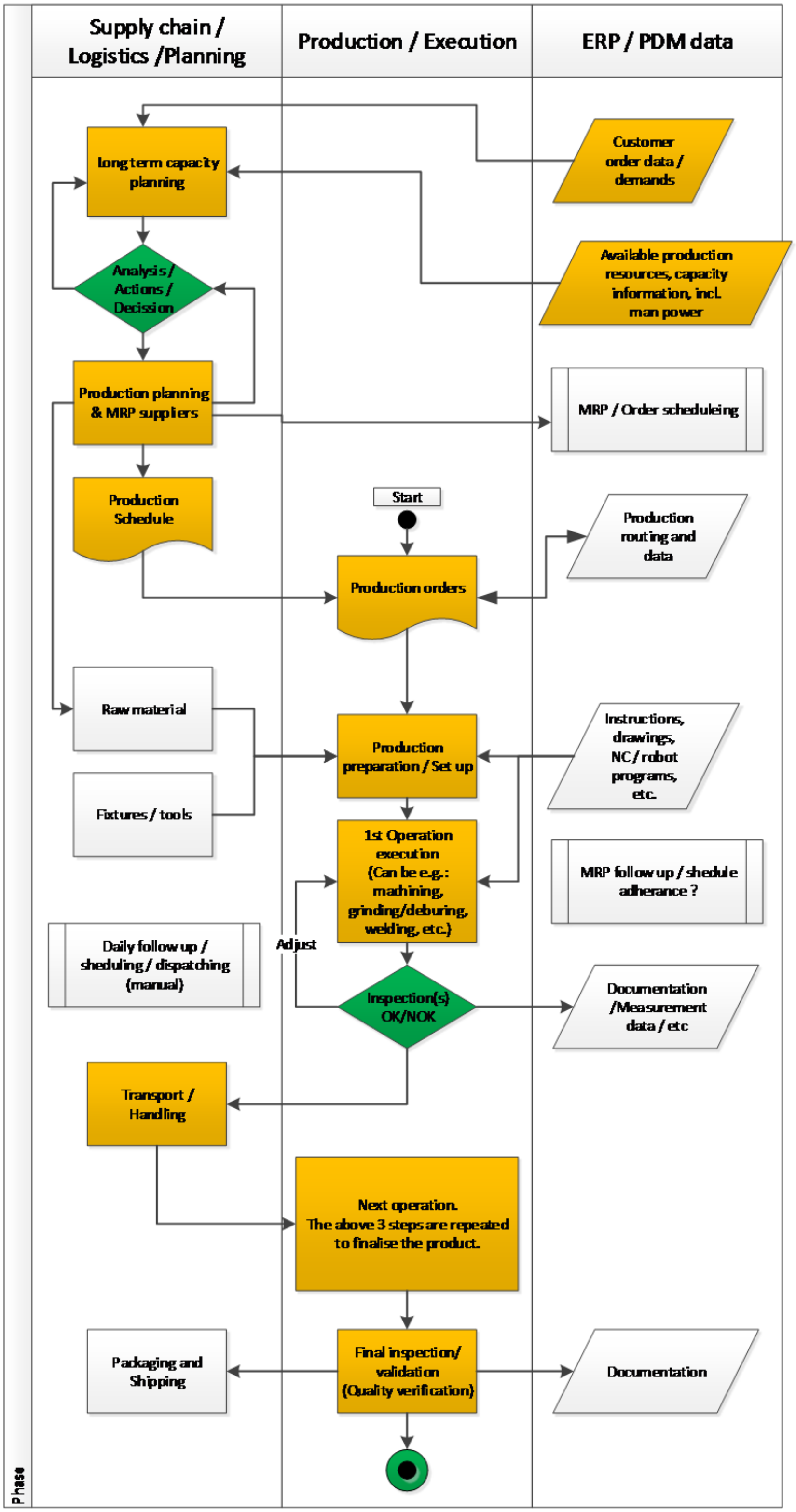

Figure 6 GKN swimlane

3.2. Business scenario (Functional Questionnaire)

The analysis of the business scenario has the double objective of both clearly map the current production constrains, phases, limitations and applications and to identify needs and expectations that have to be solved in order to transform the actual system into a more innovative one. In particular, within PERFoRM project, a structured questionnaire has been developed aiming to facilitate Use Case interviews. These activities are based on the systematic inquiry of a stakeholder's wishes and needs. they support eliciting requirements in different levels of detail, both in quantitative and qualitative terms. Each stakeholder interviewed has been personally invited to give feedback about his expectations towards the project, his needs and competences. This means that several steps have to be conducted in order to obtain enough details about the stakeholder needs and requirements. The most relevant ones are:

1. To prepare the Use Case the stakeholders were interviewed after sending them the questionnaire;
2. To explain each point of the questionnaire;
3. To conduct the interview;
4. To evaluate the output of the interview.

According to Chapter 2.3, the methodology utilized to identify and explain the functional requirements allows to depict the overall business scenario. As already said, in order to determine the first rough set of requirements, a structured questionnaire has been used. The questionnaire was split in two different areas: the former which concerns the AS-IS situation and the latter which deals with the TO-BE situation (see Table 3).

The AS-IS part is composed by the following points:

1. **Summary and Scope of the project**: it takes into account each Use Case requests which could be performed within the project scope;
2. **Business Scenario**: it describes the Use Case current situation. It includes answers to questions like "What are the main issues of your plant?", "What are your technical and business needs?"
3. **Technical aspects**: this part includes the description of the products (i.e. Bill of Material) and services supplied to the customers and the markets served;
4. **Main involved processes, main involved teams & roles**: this part wants to exploit the main involved processes, teams and roles that are actually working in the described scenario. It includes answers to questions like "Can you describe your current production process?", "Which are its criticalities?" The output of this section can create a link with the swim lane representation;
5. **Infrastructures: Shop Floor, Server, Network, Applications**: it lists the existing equipment and general assets (i.e. human robot, painting system, …), server, network and applications (i.e. alarm and scheduling systems, measurement devices, …) currently working in the production process;
6. **Social, organizational and economical issues**: it describes the existing constrains which depict the boundary conditions of the whole system;
7. **Environment:** it illustrates the working environment in terms of physical aspect (i.e. protections, barriers, picking areas, buffers, …), noise and emission aspects;
8. **Interested Parties and Internal/External Stakeholders**: this part lists the person or institutions that could have a potential interest such as suppliers, customers and local authorities;

9. **Internal and external issues**: it identifies the main internal and external constrains that limit the current scenario.

The TO-BE part is composed by the following points:

1. **Identify goals**: it lists the main objectives that would be achieved by each Use Case. The output of this section represents the first set of needs and wishes that would be reached;
2. **Identify relevant processes and tasks:** it focuses on the skills and on the process characteristics that need to be changed in order to obtain the real implementation of the new scenario;
3. **Stakeholders 'expectations:** it identifies which are the expectations of each stakeholder/ Interested Party listed within previous section 8;
4. **Constrains and possible obstacle/limitations:** it highlights the obstacles that could potentially limit the implementation of the new scenario.

In the following table, the questionnaire template is reported as example.

Table 3: Functional Requirements - questionnaire template

FUNCTIONAL REQUIREMENTS	
AS-IS	**Industrial Partner:**
Summary and scope of the project	
Business Scenarios	
Technical aspects (i.e. main products and services, markets)	
Main involved processes, main involved teams & roles	
Infrastuctures: Shop Floor, Server, Network, Applications …	
Social and organizational issues, (job enlargement, teamwork, involvement, etc..)	
Economical issues	
Environment	
Interested Parties and Internal/External Stakeholders	
Internal and external issues	
TO-BE	
Identify goals	
Identify relevant processes and tasks	
Stakeholders' expectations	
Constrains and possible obstacle/limitations	

3.3. Technical scenario (Technical Questionnaire)

The main goal of this chapter is to define the technical scenarios and their corresponding challenges in PERFoRM project based on collected knowledge from technical requirements (Chapter 2.4) for each Use Case. Each scenario will be described according to a specific structure presented in the next paragraphs and will help to complement, on one hand, to a business goal of each Use Case and, on the other hand, to the technology analysis and the technology gap identification in T1.3.

To specify the technical challenges of the system to be implemented and thus to outline the technical scope of each Use Case, a Technical Questionnaire (TQ) was worked out during the elicitation phase. Thus, the TQ aims at understanding the technical situation and the technical needs of the stakeholder and leads to elicitation of the technical requirements in the next steps. The methodology for the technical scenario includes the following main activities:

1. Preparing of the technical questionnaire;
2. Circulating the technical questionnaire among the stakeholders;
3. Explaining of the questionnaire items and required information;
4. Conducting of the personal interviews with each Use Case;
5. Analyzing and evaluating the results.

Table 4: Technical Requirements – questionnaire template

TECHNOLOGICAL REQUIREMENTS	
AS-IS	**Industrial Partner:**
Currently used technologies (collection of techniques, skills, methods and processes)	
Good/bad experiences with used technologies	
Currently integrated tools and interfaces	
Good/bad experiences with integrated tools and interfaces	
TO-BE	
Identify desired/required technology (if already known)	
Identify desired/required tools and interfaces (if already known)	

The TQ, together with the information collected in Chapter 23, comprises the overall questions which describe the technical AS-IS and TO-BE situations for each industrial partner and aims at collecting the first initial information with regard to:

- used infrastructure;
- hardware architecture;
- software platforms;
- applications;
- main products and services,
- markets;
- currently integrated and applied technologies and their tools;
- possible technical challenges;
- etc.

In order to describe the "state of the art" of the technological situation, for each Use Case a set of specific technological requirements was provided for the Use Case stakeholders.

The AS-IS part includes the following points:

1. **Currently used technologies:** this point requires a detailed information about the currently used technologies, which can be described as collected techniques, skills, methods and processes used or utilized by an industrial partner;
2. **Good/bad experience with used technologies:** this part includes the most important information about currently used technologies and gives a clue on which technical requirements can be applied to improve the current status;
3. **Currently integrated tools:** this point provides a list of all currently integrated tools in order to describe the current technical scenario for each Use Case in detail;
4. **Good/bad experience with integrated tools and interfaces:** this part includes essential information about the integration procedure of the used tools and gives an overview on which technical difficulties should be improved regarding each Use Case situation. On the top of this, this information can be used to describe the required recourses in a technical scenario.

The TO-BE part is composed of the following points:

1. **Identify desired/required technology:** this part lists the main desired or required technologies, if there is already a known tendency or necessity to apply these. This information is important for the description of the required infrastructure resources and integration platform specifications for the technical scenario and can be also used to support other project Tasks, as for example T1.3, T2.2, T2.3 and T2.4.;
2. **Identify desired/required tools and interfaces:** this part focuses on the desired/required tools and interfaces to supply the technical scenario with important information about the required recourses and, thus, address the right development partners.

4. Specific Use Case analysis method

For each Use Case, the requirement definition methodology has been carried out according to the following figure (as already mentioned in [1]).

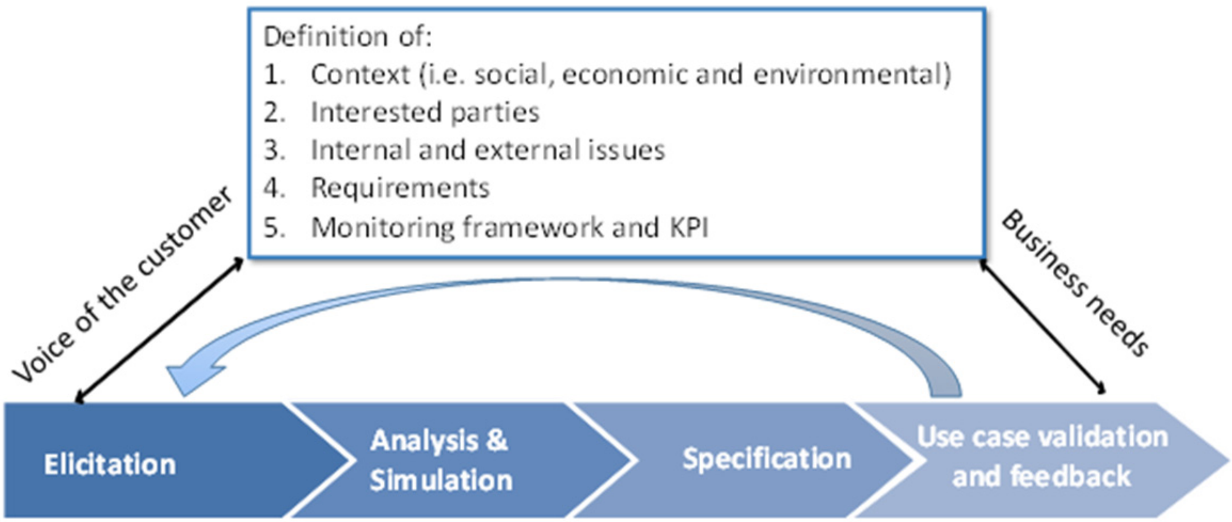

Figure 7 Requirements Engineering in PERFoRM [1]

The first step is the **elicitation phase** through which the description of the overall context is identified. It includes the end-user and other stakeholder description in terms of technical, physical, social and organizational environment. Based on this, first requirements are derived from all stakeholders' goals and tasks, their current processes and similar systems and products. Among the different techniques proposed by MSEE [1], during this step a suitable form is utilized to help in elicit useful requirements. It is prepared for each Use Case and its questions are arranged in groups dealing with a single topic or functionality. For each of these groups, a number of representative questions can be defined in order to capture qualitative as well as quantitative data.[9]. The main objectives of such question groups can be collected in the following points as shown in Table 3:

- Description of AS-IS and TO-BE end-user scenarios: The scenarios should describe the inputs, outputs, activities and entities of the current and the proposed ecosystem.
- Identification of stakeholders, technologies, legacy systems**:** The relevant stakeholders, technologies and legacy systems from the ecosystem scenarios have to be described to be considered in solution design.

The following phase consists in the **Requirements analysis**. During this phase, the user requirements, extracted from the scenarios and processes, have to be understood and discussed among all parties that are involved in each Use Case. It has to be documented what is technically and economically in scope with the project and different aspects have to be taken into account in order to provide a maximized set of requirements. In other words, this analysis has to consider the perspectives listed below:

- Stakeholder: The homogeneous *spatial distribution* of stakeholders, the enough *temporal availability* to conduct elicitation process and a good *collaboration among the different ecosystem members* can be considered as key success factor that can be enabled [1].
- Solutions: The *complexity of solution* (complex interaction of requirements), the potential need to make a *radical innovation* and *speed of Innovation* (the evaluation of timing necessary to reach the innovation required level) have to be taken into account to obtain a complete analysis [1].
- Requirements*:* The different types of requirements are analyzed taking into account the Table 1 and classified with the following cluster: *Functional and non-functional requirements*, *Rough and detailed requirements* [1].

Then, the **Requirements Specification** phase has to be run. During this phase, the main activities are the classification and documentation of relevant requirements in an understandable form for all the stakeholders. These activities were carried out following some of the main features of PERFoRM project, which deals with both flexibility and reconfigurability of a manufacturing environment within a CPS (i.e. Cyber Physical System). According to J. Lee, who has been deeply involved in studying CPS, the structure and the methodology to realize functionalities of the overall system for enhanced efficiency, reliability, product quality, and flexibility is represented by the 5C levels CPS structure, namely 5C architecture [11]. It basically consists in a step-by-step guideline for developing and deploying a CPS for manufacturing application. For this reason, the 5C architecture has been taken as reference model to properly locate both AS-IS and TO-BE situation with respect to their CPS attitude. Each industrial partner has been analyzed and positioned on the proper level according to its initial condition (AS-IS). In this way, starting from Industrial Partners' needs, during the specification phase it was possible to identify their main requirements and to select the final level (TO-BE) linked to those requirements.

According to J. Lee, the proposed 5C structure is composed by five levels that are listed below and are shown in the Figure 8.

- Smart Connection;
- Data-to-information conversion;
- Cyber;
- Cognition;
- Configuration.

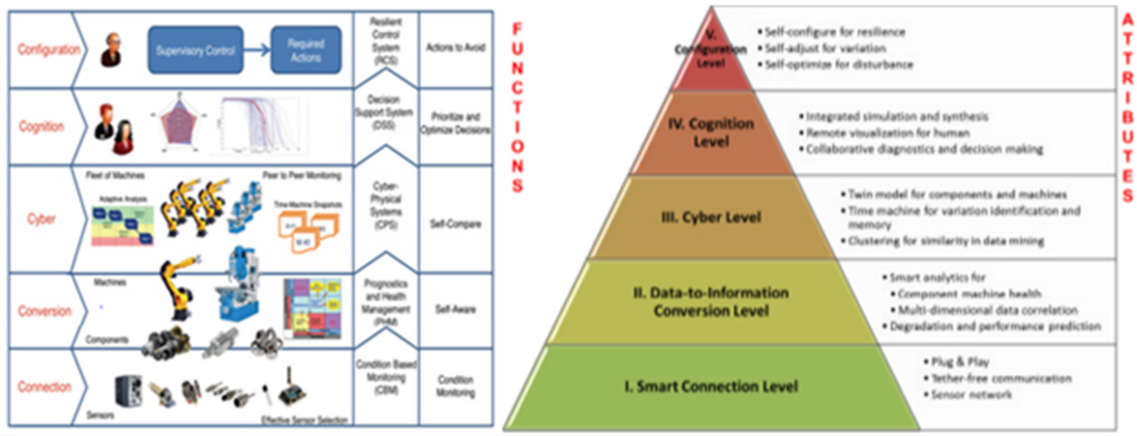

Figure 8 5C architecture for implementation of Cyber-Physical System [11]

<u>Smart connection</u>

This level consists of seamless and tether-free methods to manage data acquisition systems, streamline, and transfer the data to the central server. Selecting proper sensors, data sources and transferring protocols in this level can have a significant impact on the performance of CPS in the next levels and the quality and accuracy of the knowledge discovered through the system [12].

<u>Data-to-information conversion</u>

The core of such architecture is where the data is analyzed and transformed into valuable knowledge. Recently, there has been an extensive focus on developing intelligent algorithms and data mining techniques. Such algorithms can be applied to various data sources, from machinery and process data to business and enterprise management data [12]. By calculating health value, estimated remaining useful life and etc., the second level of CPS architecture brings self-awareness to machines[11].

<u>Cyber</u>

The cyber level acts as central information hub in this architecture. Information is being pushed to it from every source and compiled to establish a cyber space. Having massive information gathered, specific analytics have to be used to extract additional information that provides better insight over the status of individual machines among the fleet [12]. These analytics provide machines with self-comparison ability, where the performance of a single machine can be compared with and rated among the fleet. On the other hand, similarities between machine performance and previous assets (historical information) can be measured to predict the future behavior of the machinery [11].

<u>Cognition</u>

Implementing CPS upon this level generates a thorough knowledge of the monitored system. Proper presentation of the acquired knowledge to expert users supports the correct decision to be taken. Since comparative information as well as individual machine status is available, decision on priority of tasks to optimize the maintaining process can be made. For this level, proper info-graphics are necessary to completely transfer acquired knowledge to the users [11].

Configuration

The configuration level is the feedback from cyber space to physical space and acts as supervisory control to make machines self-configure and self-adaptive. This stage acts as resilience control system (RCS) to apply the corrective and preventive decisions, which has been made in cognition level, to the monitored system [12]

Finally, the last phase of the requirement definition process consists of the **Requirement Validation**. This task was essentially based on a second iteration, the main goal of which was to derive leading directions from the previous tasks, in order to properly define the context, and to identify functional and technical requirements, based on objectives, relevant processes and involved stakeholders.

This iteration is run through following table fulfillment according to the attached legend. Here, the relevant processes are investigated; the requirements are classified as technical or functional; priority should be defined as high (i.e. *must have* or within the scope of the project) and low (i.e. *nice to have* or beyond the scope of the project); KPIs are categorized into classes, types and relevant trends (i.e. monitored at different stages if the project, to verify effectiveness of the results).

Table 5 Second Iteration: validation phase

ID	Process (1)	Stakeholder	Requirement definition (2)	Type (3)	Priority (4)	KPI (5)

Legend

1. **Processes**: core processes (product/service realization) and support processes (risk assessment, planning, HR management, document control, sales, design and development, procurement, product/process monitoring, NC mgmt., continual improvement, etc.);
2. **Requirement definition**: technical aspects (materials, machines, methods), environment, social factors, economic issues, infrastructure;
3. **Type**: functional, technical, others;
4. **Priority**: high, low;
5. **KPI framework**, related to classes (e.g. cost, customer satisfaction, etc.), types (as-is, to-be, target), trends (2-3 iterations, to be consolidated later on).

This research task will lead to the identification of both general requirements, which are necessary for a successful implementation of reconfigurable system, regardless of the Use Case, and specific requirements which are use-case dependent.

5. Definition of KPI

In order to avoid the increase in number of general KPIs, a managing methodology has been adopted, essentially consisting in identifying the necessary performance indicators at each level of the organization, while assuring an overall consistency of the selected performance management system. Therefore, stakeholders have been involved and their different perspectives have been considered to limit the number of KPIs to the set which meets most interested parties' expectations and needs.

5.1. State of the Art of methodologies

As far as KPIs are concerned, several definitions are available in literature. A performance indicator may be defined as "a quantified data which measures the efficiency of decision variables (as a quantity that the decision-maker controls) in the achievement of objectives, defined at a considered decision level and in coherence with the defined business strategy [13].

Most methods identify relevant KPIs by sorting out performance indicators based on objectives, thus resulting in a significant number of parameters, not necessarily consistent at different levels of the organization. Should we assume, for instance, that KPIs are represented by revenues at top management level, then throughput at operational level and specific productivity at the line level should be considered accordingly. Therefore, the main interested parties should be involved by defining the associated decision variables, so that they all contribute in the same direction to meet the company targets at strategic, tactical and operational levels. This is the basic principle of MSEE approach [14], which has been originated from ECOGRAI[1] in combination with a performance indicators reference list derived from the Value Reference Model (VRM) [15]. In fact, ECOGRAI which is based on variables, i.e. drivers, and objectives, is organized according to the following steps (see also attached figure):

1. Identifying objectives assigned to the decision makers.
2. Determining the processes and the associated variables (called "Drivers") on which the decision makers can act to reach their objectives
3. Sorting out Key Performances Indicators which are related to the objectives and variables.

[1] ECOGRAI is a method to design and implement a PI measurement system for industrial organizations.[16]

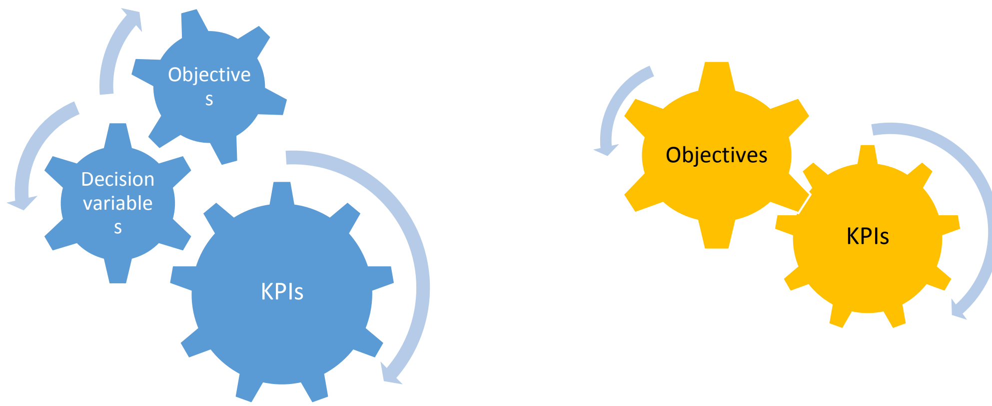

Figure 9 MSEE (ECOGRAI) KPI and Standard KPI methods

Therefore, MSEE method has been selected to properly identify effective performance indicators related to the different pillars. For each of them the relevant processes have been identified and interested parties have been highlighted by arrows, so to determine a consistent set of indicators, which are worthwhile for all Partners. Both external and internal input factors have been considered. Finally, a limited set of KPIs have been defined at strategic, tactical and operational level. Main results are herewith listed.in chapter 6

5.2. Definition and evaluation of relevant KPI

Gathering information from the Use Cases allowed us to collect a set of KPIs, currently used by Industrial Partners. These performance indicators, which have been herewith reported (see chapter 6), are associated with the as-is situation and with actual requirements related to the main processes and relevant objectives.

Different parameters were proposed by the different Industrial Partners and synergies seemed to be quite difficult and eventually unnecessary.

Therefore, new or modified KPIs will be determined after elicitation and validation of appropriate requirements related to selected processes, combining the objectives, the decision variables and the above mention method.

Such performance indicators will be managed by an appropriate framework to carry out the necessary evaluation and deployment on the Use Cases, thus providing feedback and opportunities for improvement at the implementation phase.

The framework will essentially consist in a classification of KPIs according to different categories:

- Productivity (e.g. throughput, MTBF, MTTR, etc.)
- OTD (e.g. On Time Delivery)
- Quality (e.g. scrap rate, FPY, etc.)
- Flexibility (e.g. set-up/change over time)
- Costs and administration (e.g. ROI, PBT, etc.)

KPIs will be monitored at different stages (e.g. as-is, to-be, target) of the project to verify both effectiveness and efficiency of the proposed solutions.

6. Specific Use Case analysis

The proposed approach has been applied to the four Use-Case as described in the next paragraphs.

6.1.1. Siemens

As far as the first iteration was concerned, both the scope and the main objectives of the project were determined. Rough machining of stator castings is supported by data logging and manufacturing data acquisition systems (proprietary applications) and manual adjustment of maintenance scheduling. The software applications for maintenance planning and failure reporting are neither synchronized nor integrated. A general lack of specific sensors results in the unfeasibility of data correlation and a general need for higher skilled operators.

Therefore, as depicted in the following figure, the main aims of the project are to implement a proper predictive maintenance system and to integrate it with the scheduling system, thus resulting in the below listed detailed objectives:

- To reduce delays mostly due to maintenance downtimes
- To improve reliability of machines
- To reduce production downtimes at machine level
- To move from reactive to proactive maintenance

As described on the functional and technical questionnaires (see Annex), the first iteration analysis has been extended to the stakeholders and to the relevant issues, thus showing the transition from the AS-IS to the TO-BE scenario.
An initial set of both functional and technical requirements has been elicited as listed on the following figure.

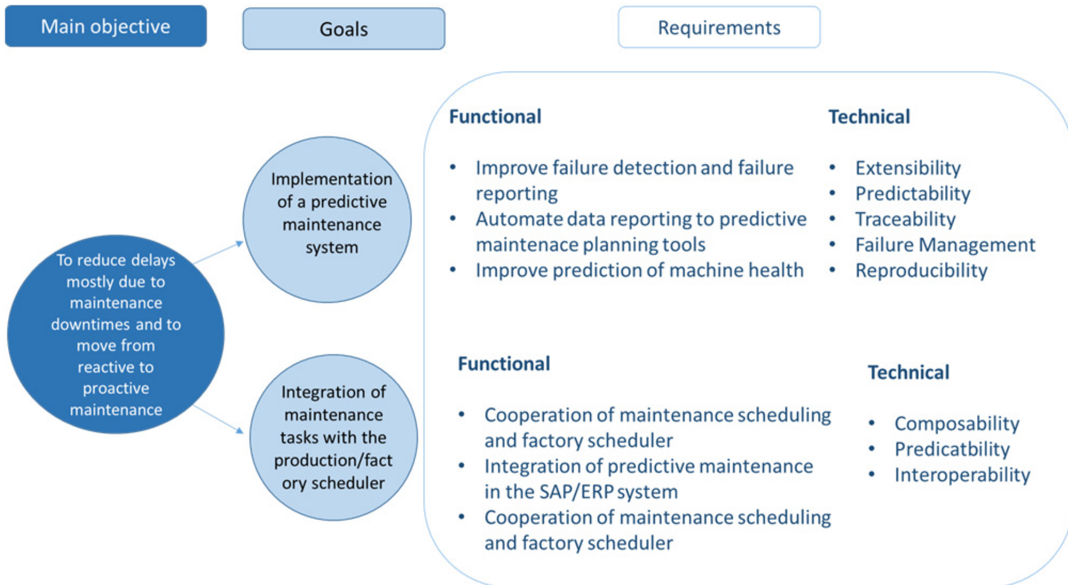

Figure 10 Siemens: First Iteration results

These requirements should finally lead to the integration of predictive maintenance and scheduling system, which represents the main outcome of the project.

As far as the second iteration was concerned, leading directions from the previous tasks, i.e. T1.1 were referred to the so called *PERFoRM framework picture*, where both maintenance and production processes (turning, machining, hardening, welding/soldering) were involved as well as IT assets (e.g. ERP, Data analytics and storage).

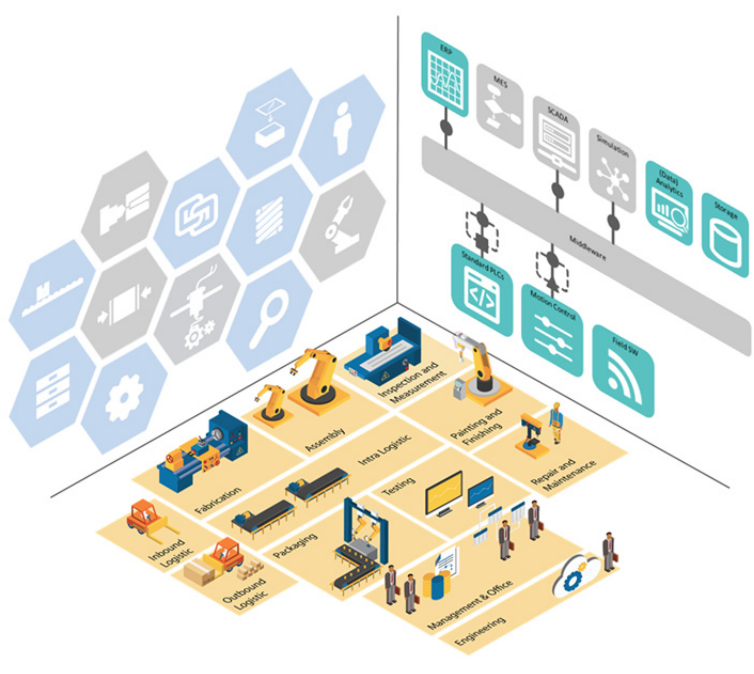

Figure 11 Siemens Use Case current status

While bearing in mind that the objective was to reduce machine downtimes and to integrate both proactive maintenance and production scheduling, a top-down approach was defined as shown in Figure 12:

1. to improve the ability to detect current machine status,
2. to improve detection/condition method,
3. to improve scheduling activities,

As far as detecting the status of the machine is concerned, the system should be able to predict potential failures and breakdowns, based on specific machine conditions, which should eventually generate a maintenance task.
The second step basically consists of defining the condition, observations and events, which should be automatically monitored to raise an alert, thus resulting in the machine conditions.
The third step highlights the integration of the maintenance tasks with the production scheduling.

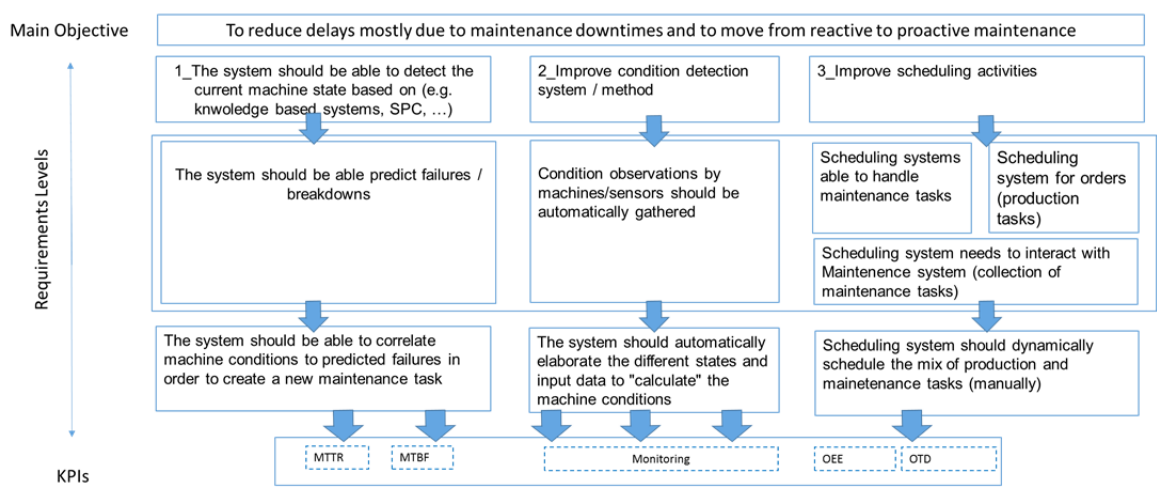

Figure 12 Siemens: framework for identifying requirements and KPIs

From a production perspective, the proposed approach essentially consists in:

- Detecting current machine conditions (process owner: Operations)
- Defining remaining up-time (process owner: Maintenance)
- Defining maintenance jobs (process owner: Maintenance)
- Integrating maintenance jobs with scheduling tasks (process owner: Scheduling)

Based on the above mentioned assumptions the Use Case requirements were defined and reported in the following table.

Table 6 Siemens Validation phase: Second Iteration results

ID	Process	Stakeholder	Requirement definition	Type	Priority	KPI
1 2 3 4 5	Turning station (CNC) Machining Hardening Welding/Soldering Assembly	Maintenance Production/Operation Scheduling	improved scheduling	Funct.	High	OTD, OEE
			scheduling system for orders (production tasks)	Funct.	High	OTD
			scheduling systems able to handle maintenance tasks	Funct.	High	OEE
			scheduling system needs to interact with ERP system	Funct.	Low	Not Relevant
			scheduling system needs to interact with Maintenance system (collection of maintenance tasks)	Funct.	High	OEE
			scheduling system should dynamically schedule the mix of production and maintenance tasks (manually)	Funct.	High	OTD, OEE
			scheduling system should dynamically schedule the mix of production and maintenance tasks (semi-automatically)	Funct.	Low	Not Relevant
			scheduling system should dynamically schedule the mix of production and maintenance tasks (fully automatically)	Funct.	Low	Not Relevant
			condition detection system / method	Funct.	High	Monitoring, MTTR
			conditions observations by humans should be included / given to the system	Funct.	Low	Not Relevant
			condition observations by machines/sensors should be automatically gathered	Funct.	High	Monitoring, MTTR
			the system should automatically elaborate the different states and input data to "calculate" the	Funct	High	MTBF

			machine conditions			
			The system should be able to detect the current machine state based on (e.g. knowledge based systems, SPC, …)	Funct.	High	MTBF
			the system should be able to create maintenance tasks based on the observed machine conditions	Funct.	Low	Not Relevant
			the system should handle maintenance information (e.g. time between scheduled maintenance)	Funct.	Low	Not Relevant
			the system should be able predict failures / breakdowns	Funct.	High	MTBF
			the system should correlate machine conditions to maintenance information in order to create a new maintenance tasks	Funct.	Low	Not Relevant
			the system should be able to correlate machine conditions to predicted failures in order to create a new maintenance task	Funct.	High	OEE
			the system should be able to decide if the maintenance task can be done internally or needs to be processed by an external supplier (e.g. machine supplier)	Funct.	Low	Not Relevant

As already stated in Chapter 4, the second iteration of each Use Case has been followed by the classification and documentation of the relevant requirements in an understandable form for all stakeholders. With this concern, the 5C architecture[12] has been chosen to clearly map the current Use Case situation (AS-IS) and the future scenario enabled by PERFoRM project activities. In particular, these two different scenarios have been analyzed and, after a deep study of Jay Lee assumptions, connected to the proper pyramid level.

Concerning Siemens Use Case, it is possible to state that its current situation sufficiently fits with the second level features of the pyramid. In fact, the difficulty in correlating data coming from the plant suggests that some more appropriate systems to transform data into information is needed (Level 2). To identify the level of Siemens objectives, its specific goals and requirements were analyzed. The ability to improve the fleet awareness and to get support in decisions taking, are the key aspects for the definition of the pyramid levels Siemens is tending do to implement (Level 3 and Level 4). This goal should be achieved through the integration of maintenance tasks and production and factory scheduling.

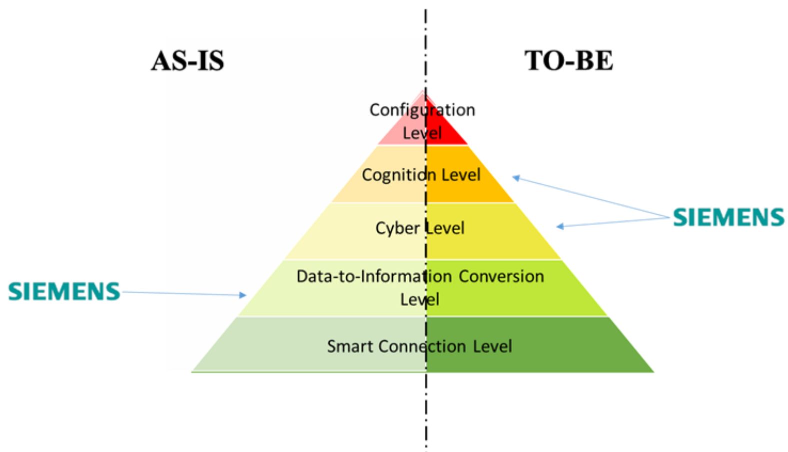

Figure 13 5C architecture: Siemens AS-IS and TO-BE classification

6.1.2. IFEVS

IFEVS Use Case is focused on the engineering of novel architectures of Micro electrical vehicles aiming at ready to manufacture turn-key solutions. IFEVS is a member and major driver of the cluster Torino e-district addressing the overall value chain of electro-mobility with a focus on Micro EVs. Its products have been realized thanks to the collaboration with Polimodel. It is a company specialized in concept car, construction of style and research models, industrial design and construction of master models for production, manufactures composed by resin, fiberglass, rtm, & sheet-steel and special fixture for C/N machines (contouring, drilling, profiling).

The main scope of the Use Case can be split into two main objectives:

- to realize available low cost automated turnkey flexible assembly line to rapidly start manufacturing of safe, ergonomic, clean and efficient vehicles adapted to local needs ("mini-factory" concept);
- to replicate and to spread "mini-factory" model all over Europe.

In the following picture the "mini-factory" production model is reported and the human and robot collaboration to be implemented by PERFoRM project in order to reach an agile, ergonomic and flexible assembly line is shown.

Figure 14 Mini-factory concept

The main challenge is to obtain a compact and repeatable assembly line, able to implement the following actions, listed in a sequential order:

- To improve adaptability of the production line from small lots to larger lots of passenger cars (Flexibility);
- To guarantee essentially the same investment whether the components are produced in a quantity of 2 or 50 a day (Cost efficiency);
- To follow the highest quality and security standards on manufacturing adopted in the automotive world in all over assembly steps (Quality);
- To associate each vehicle to a specific moment of manufacturing of all its components and sub-components (Traceability);
- To minimize human errors and manual actions as well as variability of manual operations;

- To implement predictive maintenance.

Going through a deeper analysis of IFEVS Use Case, the main product and process characteristics have been pointed out in the following chapter.

The core business of IFEVS Use Case is based on Micro Electric Vehicles that are planned and designed as a modular product. In fact, by simply changing the different sub-modules that are made up, it is possible to have different models which provide product flexibility and easily meet market needs (Figure 15)

Figure 15 Modular IFEVS product

The production process is planned to operate according to the following phases:

1. Incoming raw materials and semi-products are stored in the related warehouse;
2. Welding tasks are carried out on parallel/sequential stations for both the body and the power-train. It will be either manual or robotized or a combination of the two;
3. Assembling of components are the final stage, based on the previous modular subassemblies;
4. Quality controls are implemented to meet automotive standards;
5. Logistics are organized, so that stock level will be reduced (i.e. just in time);
6. Painting (i.e. cataphoresis process) are outsourced (i.e. Magnetto);

The production flow can be divided into two main parts:

1. R&D department;
2. Assembly process and final product realization areas.

Concerning the first part, it is possible to note that it is divided in three main divisions:

a) Lab 1: it is only related to body and structure. In this area, appropriate testing on prototypes are carried out, in order to validate both failure resilience and endurance analysis of parallelogram mono-block aluminum frame (Figure 16);

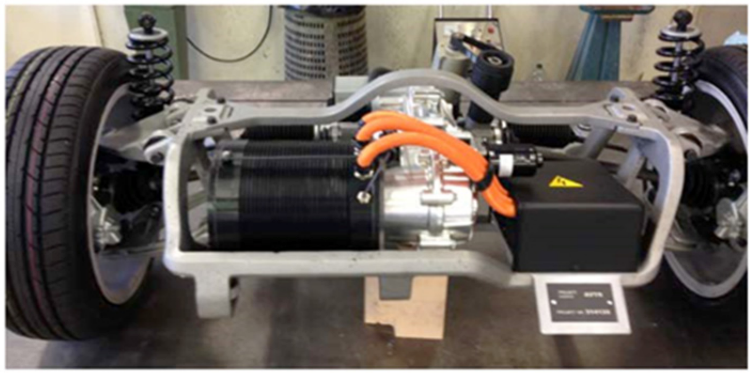

Figure 16 Lab1 Failure and endurance analysis

b) Lab 2: it is only related to the power-train systems. In this area the functionality of each component dedicated to the motion and transmission system (such as steering wheel, both axle systems with their parallelogram suspension, electric engine and suspension as shown in Figure 17) are checked.

c) Lab 3: it is devoted to carry out simulation test by qualified employees, in terms of acceleration and braking test, thanks to suitable software (Figure 17);

Figure 17 Lab 2&Lab3 - Functionality test and simulation test

The second part consists in of assembling and welding lines. Each modular sub-component reaches one or more of the 7 stations according to its BoM. The process takes place in parallel and therefore different sub-modules can be simultaneously processed in the welding stations and then assembled in a final step. The layout is designed to ensure cooperation among human operators and robots in the different phases of the process, i.e. sub component transportation from welding to assembling stations and from warehouse to the welding system.

Nevertheless, the typical electric automotive sector presents different kind of limits. First, the high complexity of both product and process do not allow producers to obtain the level of flexibility required by customers. Therefore, the main aspects which should be improved can be summarized as follows:

- High complexity level;
- Lack of flexibility;
- Traditional technology;
- High up-front investments;
- High support costs;
- Poor asset utilization;
- Multitude of point to point integrations;
- Various operating systems & languages;
- Many device connections.

As far as the first iteration was concerned, both the scope and the main objectives of the project were determined. As described on the functional and technical questionnaires (see Annex), the analysis has been extended to the stakeholders and to the relevant issues, thus showing the transition from the AS-IS to the TO-BE scenario.
An initial set of both functional and technical requirements has been elicited as listed on the following figure.

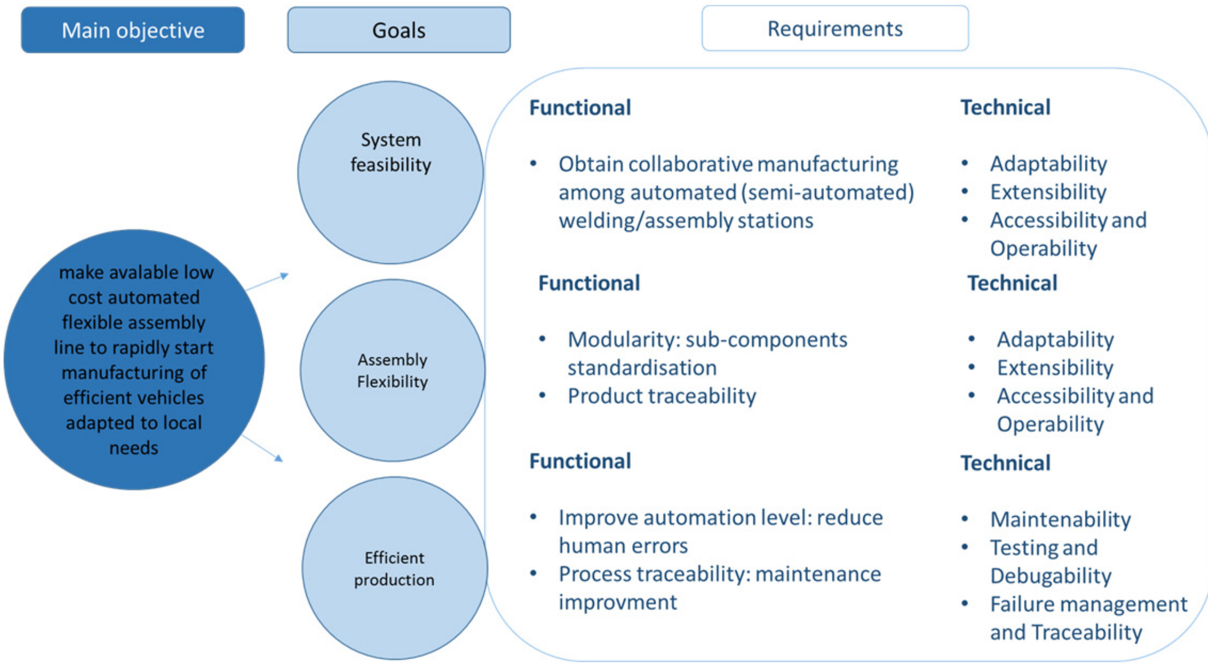

Figure 18 IFEVs :first Iteration results

As far as the second iteration was concerned, leading directions from the previous tasks, i.e. T1.1 were referred to the so called *PERFoRM framework picture*, where both chassis and motorized axles production processes (welding) were involved.

Figure 19 IFEVs Use Case current status

While bearing in mind that the objective was to provide an easily reconfigurable production line with a high degree of traceability, a top-down approach was defined as shown in Figure 20:

1. to implement system feasibility,
2. to improve assembling/welding flexibility,
3. to improve production efficiency

System feasibility is essentially focused on both implementing an effective feedback strategy from production to design and defining a simulation mode on prototypes based on a CPS environment.
With regard to flexibility, production may be affected by frequent material or process changes, which should result in an agile process, based on a quick adaptability policy. Cooperation between welder and robot should be pursued, in order to guarantee the highest quality level through standardization and fine tuning rework. Reconfigurability is a key success factor and relevant costs should be monitored accordingly.

Improving production efficiency represents an opportunity to manage both the interactions among different processes and the process iteration, namely reducing variation and increasing capability/reliability of the production control (i.e. ramp up phase), including maintenance efficiency.

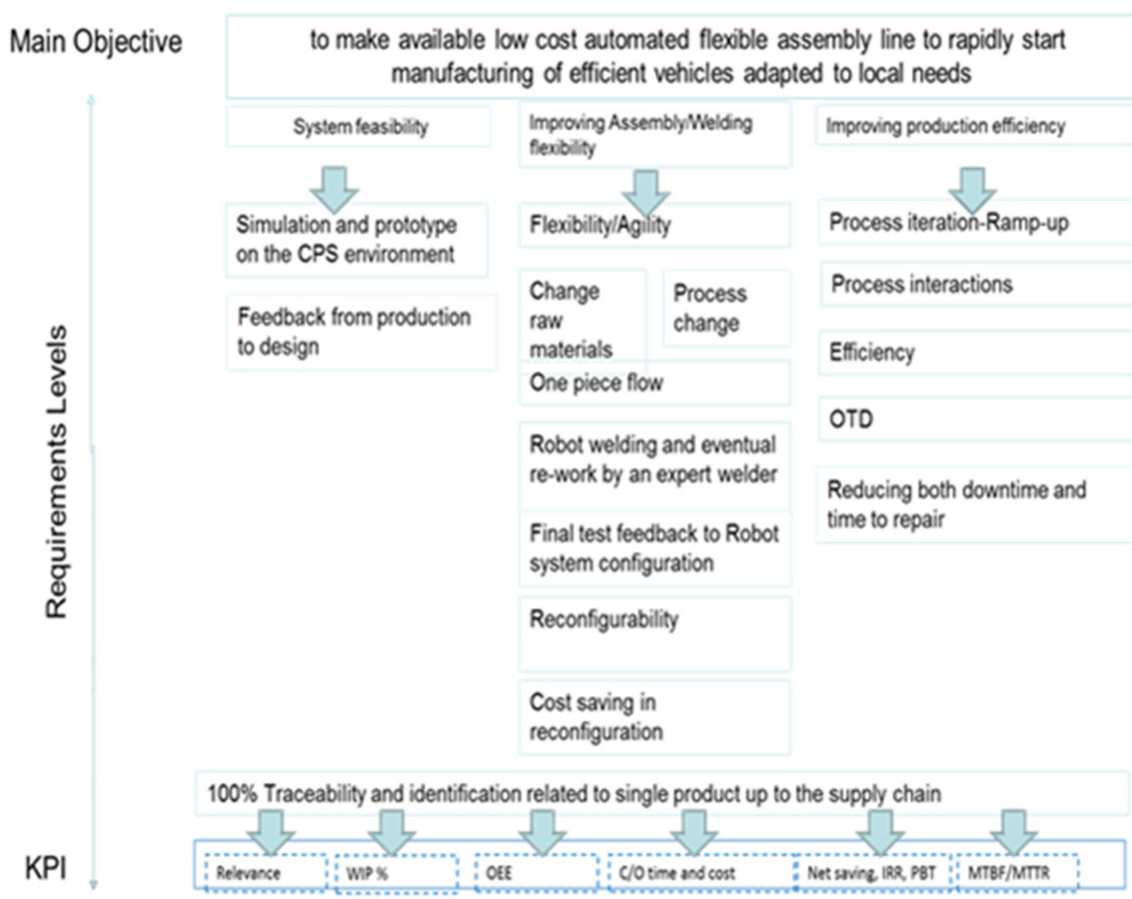

Figure 20 IFEVs: framework for identifying requirements and KPIs

Based on the above mentioned assumptions, the Use Case requirements were defined and reported in the following table.

Table 7 IFEVs Validation phase: second iteration

ID	Process (1)	Stakeholder	Process owner	Requirement definition (2)	Type (3)	Priority (4)	KPI (5)
1	Chassis fabrication	People in the production Environment	Production	Process iteration	Funct	High	OEE
				Change raw materials	Funct	High	OEE
				Process change	Funct	High	C/O time
				Feedback from production to design	Funct	High	Not relevant
				No modification of fixture and tools	Tech	Low	C/O time and costs
				Robot welding and eventual re-work by an expert welder	Tech	High	OEE
				Final test feedback to Robot system configuration	Func.	High	OEE
				100% Traceability and identification related to single product up to the supply chain	Func.	High	Number of correctly identified and traceabl

							e products vs total products
				Simulation and prototype on the CPS environment	Funct	High (top)	Net saving,
2	Motorized Axle production	Quality department Maintenance department Engineering department Logistics	Quality	Process interactions	Funct	High	Lead Time
				Reducing both downtime and time to repair	Funct	High	MTBF, MTTR
				Predictive maintenance	Funct	Low	Not Relevan t
				Reconfigurability	Func.	High	C/O time and costs
				Cost saving in reconfiguration	Funct	High	Net saving, IRR, PBT
				Efficiency	Funct	High	OEE
				Flexibility/Agility	Funct	High	C/O time and costs
				One piece flow	Funct	High	WIP %
				OTD	Funct	High	Hours

As already stated in chapter 4, the second iteration of each Use Case has been followed by the classification and documentation of the relevant requirements in an understandable form for all stakeholders. With this concern, the 5C architecture [12] has been chosen to clearly map the current Use Case situation (AS-IS) and the future scenario enabled by PERFoRM project activities. In particular, these two different scenarios have been analyzed and, after a deep study of Jay Lee assumptions, connected to the proper pyramid level.

In particular, two main characteristics of IFEVs Use Case guide to the selection of the first level of the pyramid to map its current situation (AS-IS): the presence of multitude point-to-point integrations and of traditional technologies do not facilitate an easy and coherent data collection. In the same way, it is possible to figurate the TO-BE scenario with the cyber level (3 level) of the pyramid as IFEVs main objective is to be clearly aware of fleet machines, system and business context in order to rapidly change production rates according to local needs.

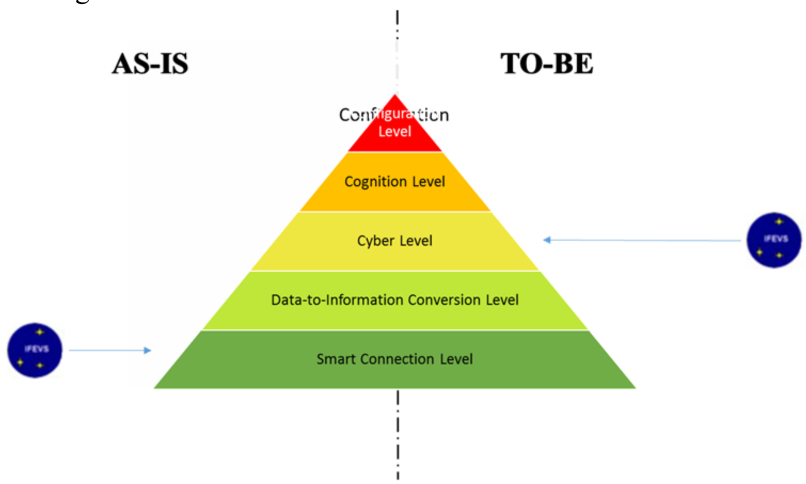

Figure 21 5C architecture: IFEVs AS-IS and TO-BE classification

6.1.3. Whirlpool

Whirlpool is a world leader in large domestic appliances with a strongly present in Europe with 11 factories and development centers located in six countries. Whirlpool Europe is a wholly owned subsidiary of Whirlpool Corporation, world leader in large domestic appliances. Its main sector is the White Goods one and for this reason it was chosen to focus on one of them.

The main objective of the Whirlpool Use Case within PERFoRM project can be summarized as the desire to realize a real time monitoring system able to correlate dynamic behavior of the factory to its Key Performance Indicators (KPIs) implementation and to static indicators such as Key Business Factors (KBF).
It is represented in the picture below where it is shown the model to be implemented within PERFoRM project.

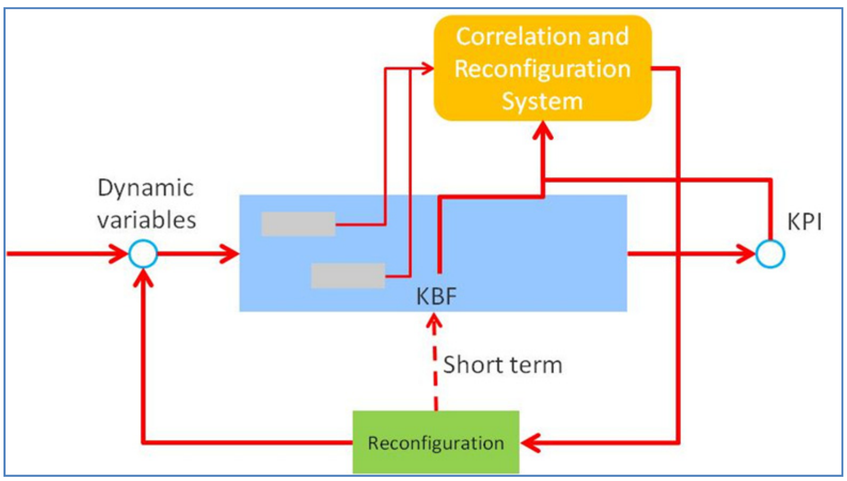

Figure 22 Reconfiguration system model

The model objectives should essentially consist in a particular and dynamic system which is able to manage the following actions:

- to recognize the input: the variable external issues (e.g. market demand);
- to identify the KBF;
- to define a relevant model;
- to evaluate the output, i.e. the KPI value;
- to compare inputs, KBFs and KPIs in order to choose the actions needed to obtain the system reconfiguration and to improve the output.
- to apply a sensitivity analysis, aiming at defining the relationships (i.e. sensitivity factors) among KBFs and KPIs.
- to validate the model consistency

With the aim to present a deeper analysis of Whirlpool Use Case, the main product and process characteristics have been pointed out in the following chapter.

The Whirlpool core business is based on White Good manufacturing. As far as the project is concerned, the focus of the analysis was centered only on Microwave oven line, which is composed by:

- Metallic frame (i.e. cavity);
- Microwave door (glass);
- Turn-table (plastic).

The brief description of the process is shown as follows:

The Whirlpool Microwave factory at Biandronno site produces up to 450.000 built-in microwave ovens in one year. The production process is composed of 8 major steps:

1. Material Incoming: raw material (steel and stainless steel coils) and mechanical, electrical and electronic component are delivered at any hour of the day every day. They are checked and stored in a warehouse
2. Cavity line Fabrication: the process aims to produce the internal cavity of the oven starting from carbon steel then painted or stainless steel in three major steps:
    a. Cavity parts stamping: cavity parts (top and wrappers) are stamped in hydraulic presses
    b. Cavity Assembly: cavity parts are welded to form an open box
    c. Painting: cavities made in carbon steel are washed and then painted.
3. Door fabrication and assembly: door is made of a combination of steel frame, a shield, a glass and a handle. The most critical step in this process is the gluing of glass to the steel frame
4. Part Fabrication and Silk Screening: other metal parts are stamped from steel coils. Aesthetical parts as front panel are marked using a silk screening technology.
5. Final Assembly: Cavity, door and all other components are assembled in sequence in a continuous flow conveyor.
6. Testing: ovens are tested from safety and functional point of view.
7. Repairing Bay: products not passing the test are examined and repaired in a separated bay.
8. Packaging: ovens are finally packaged and sent to finished good warehouse.

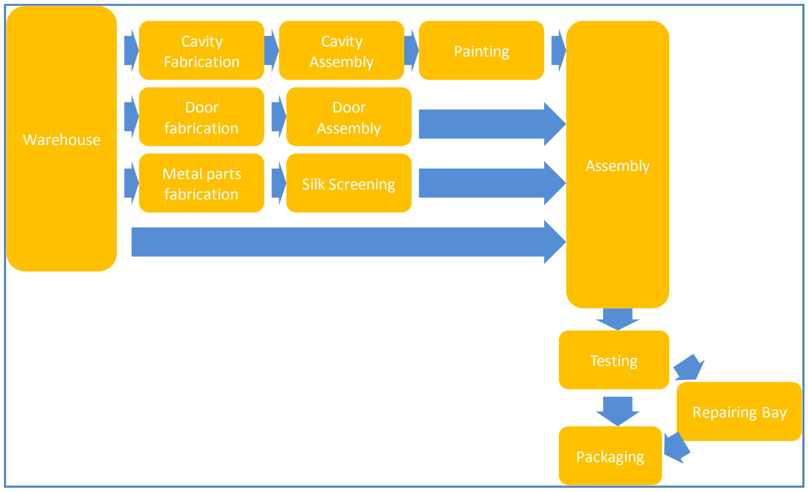

Figure 23 materials and techniques used

The factory is usually organized in a hierarchical and functional way, with the double aim of controlling and drive operations and to account costs and expenses.

The KPI identification system utilized in the factory is able to collect only equipment information regarding their batch size, production activity, resource consumption, quality data and operative status. Thanks to this data, the system can point out both dynamic KPI (e.g. daily production, absenteeism, quality) and KBF (e.g. installed capacity unit, worked hours/ years, cost) separately.

The current IT standard architecture, which helps in collecting this KPI information, is composed by four IT system types:

- Production Management system
- Equipment Management system
- Assembling Management system
- Quality Management system

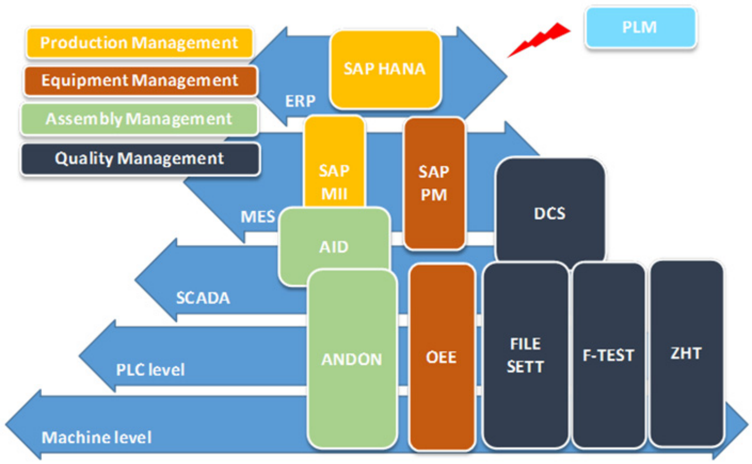

Figure 24 Current IT standard architecture

- MRP II
- Master Production Schedule / Declaration
- Warehouse management

- Spare part management
- Work order management

- Pacemaker
- Part production planning
- Shopping list

- Equipment Efficiency Monitor

- Automatic assembly line Monitor and Control
- Help Chain Activation

- Work instructions
- Serial Number
- Kitting

- Manufacturing Defects collection and management

ZHT
- Statistical Product Quality control system

F-TEST
- Automatic product testing system (safety and functional)

Therefore, starting from the current status analysis, the main disadvantages of this model, that should be improved, are listed below:

- The global view of the entire factory is not completely supported;
- The correlation between KPI and KBF needs to be finalized;
- The simulation and the structured analysis of the whole factory behavior has to be improved;
- KPI are evaluated off-line on a monthly base;
- Only some of the dynamic factors are monitored on real-time.

As far as the first iteration was concerned, both the scope and the main objectives of the project were determined. As described on the functional and technical questionnaires (see Annex), the analysis has been extended to the stakeholders and to the relevant issues, thus showing the transition from the AS-IS to the TO-BE scenario.
An initial set of both functional and technical requirements has been elicited and listed on the following figure.

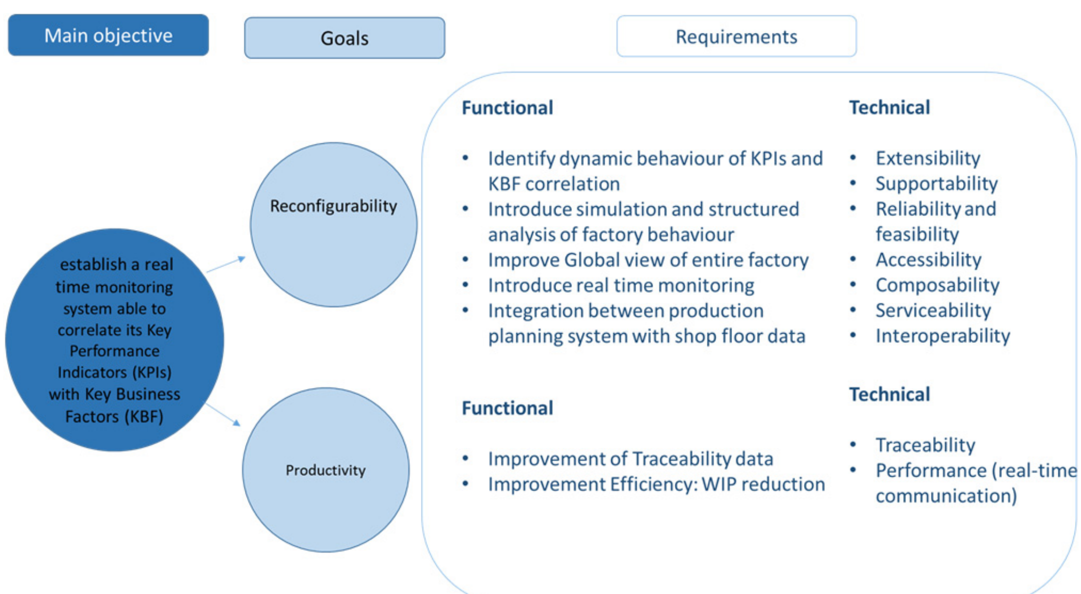

Figure 25 Whirlpool: First Iteration results

As far as the second iteration was concerned, leading directions from the previous tasks, i.e. T1.1 were referred to the so called *PERFoRM framework picture*, where microwave oven production processes (incoming material, cavity fabrication, stamping, industrial foaming, industrial bonding, painting and testing) were involved as well as IT assets (e.g. ERP, MRP, Master Production Scheduling/Declaration, Part Production planning,).

Figure 26 Whirlpool Use Case current status

Following the methodology explained in previous chapters, it is possible to point out the linkage among the Use Case main objectives and the three identified levels of requiremnts that describe the gap between the AS-IS and TO-BE scenarios. This picture also illustrates the specific KPIs that will be used to monitor the requirements behaviour during PERFoRM project development.
In partucular the ability to simulate and model the entire factory status is the key aspect to inspire the real time monitoring system implementation, improving both production optimization and reconfigurability and their related aspects such as WIP, production efficiency, costs and set-up.

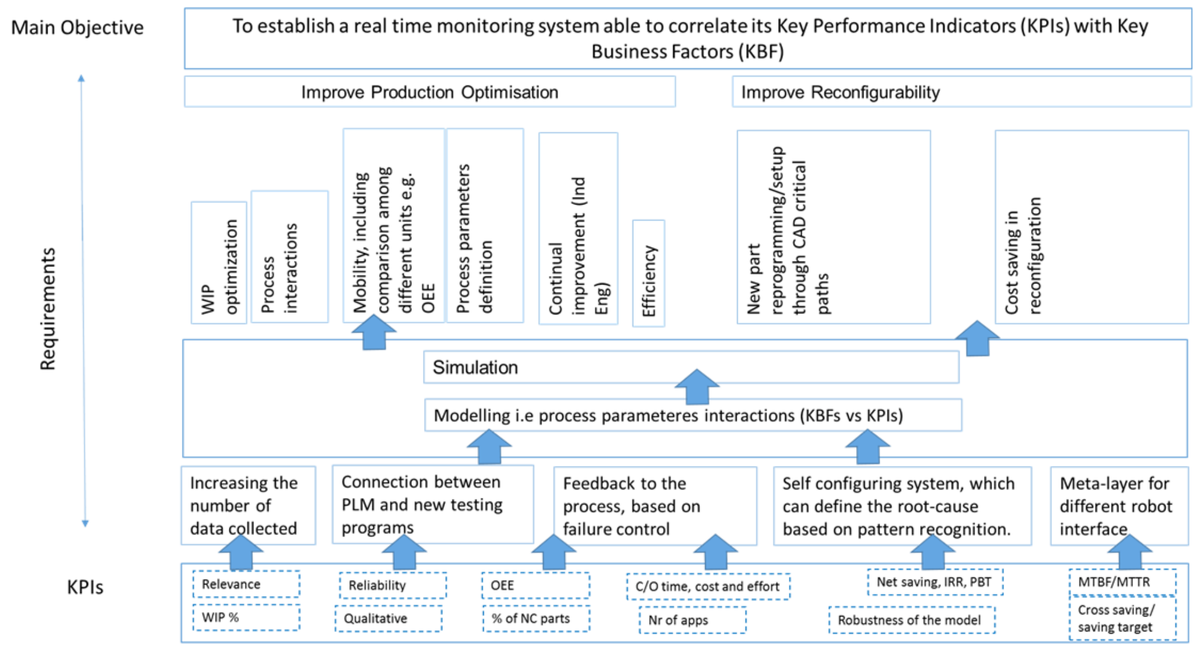

Figure 27 Whirlpool: framework for identifying requirements and KPIs

Based on the above mentioned assumptions, the Use Case requirements were defined and reported in the following table.

Table 8 Whirlpool Validation phase: second iteration

ID	Process (1)	Stakeholder	Process owner	Requirement definition (2)	Type (3)	Priority (4)	KPI (5)
1	Incoming material	OTD Deptm (Supply Chain) Quality ICT HR Logistics Suppliers	OTD Factory Quality	Data Availability	Funct.	High	Time to access data
				Relevant data availability	Funct.	High	Time to access data
2	Cavity fabrication (stampling, welding, painting, etc.)	Production Quality Maintenance Industrial Engineering HR	Production Quality	Simulation	Funct.	High	Sensitivity analysis
				Process interactions	Funct.	High	Sensitivity analysis

4	- MIDI Value Stream	ICT		Model, i.e. process parameters interaction	Funct.	High	Sensitivity analysis
				Process parameters definition	Funct.	High	Sensitivity analysis
				Reconfigurability	Funct.	High	C/O time and costs
				Cost saving in reconfiguration	Funct.	High	Net saving, IRR, PBT
				Cost monitoring	Funct.	Low	Not Relevant
				Efficiency	Funct.	High	OEE
				Identification and traceability (e.g. products and components)	Funct./ Techn	Low	Not Relevant
				Reducing both downtime and time to repair	Funct.	Low	MTBF, MTTR
				Continual improvement (Ind Eng)	Funct.	High	Cross saving/saving targets
				User friendly model	Techn.	High	Qualitative
				WIP optimization	Funct.	High	WIP %
				OTD	Funct.	Low	Hours
				Increasing the number of data collected	Funct.	High	Sensitivity analysis

				Mobility, including comparison among different units e.g. OEE	Funct.	High	Nr of apps
3	EMF Leak test robot station	Production Quality Maintenance Industrial Engineering HR ICT	Production Quality etc	New part reprogramming/set up through CAD critical paths	Funct./Techn	High	C/O time and efforts
				Connection between PLM and new testing programs	Funct.	High	C/O time and efforts
				Self-configuring system, which can define the root-cause based on pattern recognition.	Funct.	High	Sensitivity analysis
				Meta-layer for different robot interface	Techn	High	Sensitivity analysis
				Cost saving in reconfiguration	Funct.	High	Net saving, IRR, PBT
				Feedback to the process, based on failure control	Funct.	High	% of NC parts
				Efficiency	Funct.	High	OEE
				Reducing both downtime and time to repair	Funct.	Low	MTBF, MTTR
				Mobility, including comparison among different units e.g. OEE	Funct.	High	Nr of apps

As already stated in chapter 4, the second iteration of each Use Case has been followed by the classification and documentation of the relevant requirements in an understandable form for all the stakeholders. With this concern, the 5C architecture [12] has been chosen to clearly map the current Use Case situation (AS-IS) and the future scenario enabled by PERFoRM project activities. In particular, these two different scenarios have been analyzed and, after a deep study of Jay Lee assumptions, connected to the proper pyramid level.

Identifying with Whirlpool Use Case, it is possible to state that its current situation sufficiently fits with the second level features of the pyramid. In fact, this Use Case is able to collect data and transform it into profitable information through the definition of KPIs and KBF but only delineating it at a single workstation level and in a separate way. To identify the level of Whirlpool objectives, its specific goals and requirements were analyzed. As this Use Case main objective is to implement a real time monitoring system, which implies the ability to have a factory overview and to be able to implement corrective actions, it can be state that its TO-BE scenario is pretty well linked to Levels 3 and 5 of the pyramid.

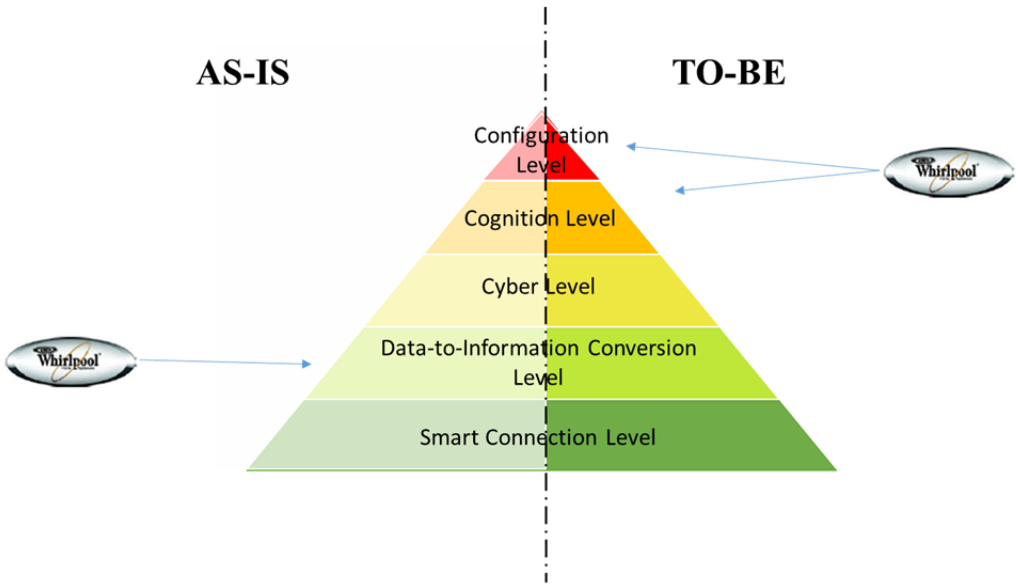

Figure 28 5C architecture: Whirlpool AS-IS and TO-BE classification

6.1.4. GKN

GKN plc (public limited company) is registered in England and is a global corporation that operates in four divisions: GKN Aerospace, GKN Driveline, GKN Powder Metallurgy and GKN Land Systems. GKN Aerospace is a global first tier supplier of airframe and engine structures, components, assemblies and transparencies to a wide range of aircraft and engine prime contractors and other first tier suppliers. It operates in three main product areas: aero-structures, engine structures and systems, and special products. GKN Aerospace Sweden, which is the partner in this consortium, is designing and manufacturing engine components

The Use Case main objective is to implement a new industrial structure in the current production plant based on a Micro-Production Flow Cell (Figure 29) that is able to reduce change over time and to realize different product and, therefore, also to able to give a flexible and reconfigurable aspect to the whole industrial plant.

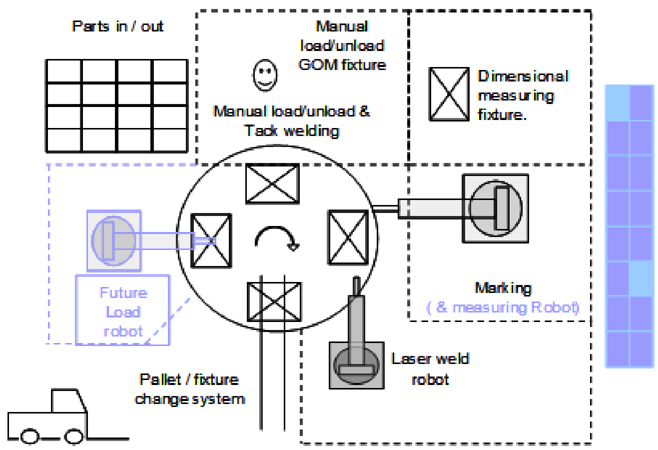

Figure 29 Principle view of an extended Micro-flow - production flow cell (visionary).

The figure 29 represents visionary objective that could be implemented in the future. Thus, the first step to be taken is to realize modular and Integrated Flexible Cells (Figure 30) that are able to integrate the sequence of operation steps needed to obtain finished products. The idea, that consists also on current GKN vision and goal, is to create a unique production environment made by several micro-cells aiming to relocate machines in a short time, maximizing use of low cost robots.

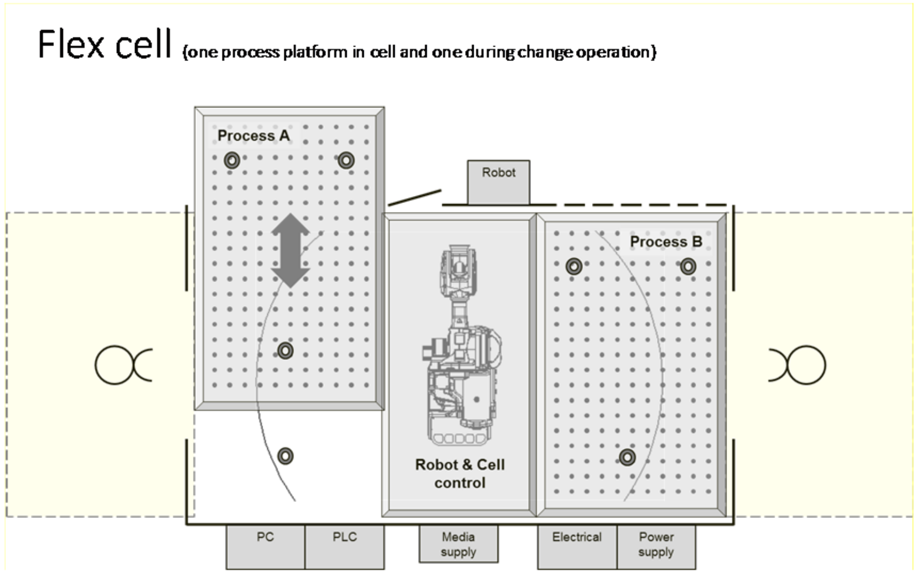

Figure 30 Principle view of the micro-flow flexible and reconfigurable cell in the GKN Use Case.

This Integrated Flexible Cell is composed of the same main functions which are listed below

- Manual load/unload into fixture or rack
- Robot load/unload into fixture
- Operation automated (brushing, marking, surface measurement and dimensional inspection.);
- Pallet/fixture change system on process module for different product variants
- Process module change system for different kind of processes;

The strategic main challenges for industrial development and potential high productivity solutions can be divided into two different groups:

Competiveness by production flexibility:

- Flexible product design
- Flexible product volumes
- Flexible product life cycle
- Fast start up of low volume production

Competiveness by production efficiency:

- High efficient industrial system
- High delivery precision
- Usage automation manufacturing technology

The core business of GKN Engine Systems is constituted by a range of components needed for commercial aircraft engine. The main components in the current product portfolio are the following:

- Fan and rotative parts;
- Fan and static parts;

- Engine carcass part;
- Diffuser parts;
- Turbine static parts.

Due to the high product variety and to the different operations needed, the production process is planned to operate according to job shop logic and mainly a functional layout. Each part of the plant is specialized in a proper operation and, therefore, products need to be moved several times to the different workstations, creating a complex and not very visual and controllable product flow. The overall production efficiency is therefore affected. Moreover, the current industrial and business/market conditions have a relatively large variety of products, variations in demand as well as the supply of raw material is sometimes disturbed by quality issues and delivery precision. Thus the variability in the supply chain is fairly high.

For this reason, it is recommended to set up a flexible reconfigurable system to be able to adapt layout and the available resources, capacity etc. to improve production flow and to reduce both the idle time and the lead time.

The current layout can be described as a series of workstations that do not always have a proper order according to the operation sequence. Each product and its subcomponent have to cross these operations which makes the lead time relatively long.

Concerning to the process the raw material for the components are either large castings or forgings in size of the final parts, alternatively smaller parts are used and fabricated into larger subassemblies and finally the complete assembly of the engine components. The most common process is machining (e.g. turning, milling, drilling etc.) to give the parts their final dimensions. Also deburring and polishing among other methods are used to give the parts correct surface properties. Welding and additive manufacturing is also used for the components that are fabricated. Various kinds of inspection and non-destructive testing is used to verify the material integrity and quality of the components.

A list of the workstations which constitute the Use Case plant and possible future application areas are described below (Figure 31):

Figure 31 Examples of GKN Workstations

Multi Task Cell (machining): in this workstation, several kind of operations are made (i.e. milling, turning and drilling processes). Here both humans and robots work on different tasks. Robots are used for handing tools to/from the NC machines, and deburring. Tool changes and part / fixture set-up is manual

X-ray (conv & digital): it is a semi-automated process. Preparing films and parts is a manual operation workstation, and the automatic part is to position and expose the film.

Deburring: manual deburring is applied to either small volume or big part components. Automatic deburring stations can be developed for specific components in order to reduce ergonomic issues. Nonetheless, when automatic deburring is applied, fine tuning is still manual and required to some extent,

Welding: Different automated systems are used, such as laser/TIG/plasma welding systems.

Fluorescent Penetrant Inspection - FPI (NDT): preparation of the specimen is automatic, while testing is carried out by an Operator

Even though several manufacturing tasks have been considered, such as multi-task Cells, deburring stations (i.e. manual or robotized), welding stations (i.e. manual or robotized), quality control checks (e.g. NDT; FPI, Ultra Sonic, X-ray) and others, the scope of the project has been limited to deburring operations only, while bearing in mind that results may be extended to the other processes in future.

The current IT systems is characterized by a lack of communication between PLM and ERP and between old machine and standard PLC. The Micro-Flow cell will use automation solutions and be flexible and reconfigurable and therefore it will require a well designed architecture and communication solutions to allow plug-and-produce. In Figure 32 the principles and examples of components in the cell is illustrated as a starting point for further development. In this case, it is needed to retrofit the older machines in order to obtain the upgrade in terms of mechanical, electronical and communication (middleware connection).

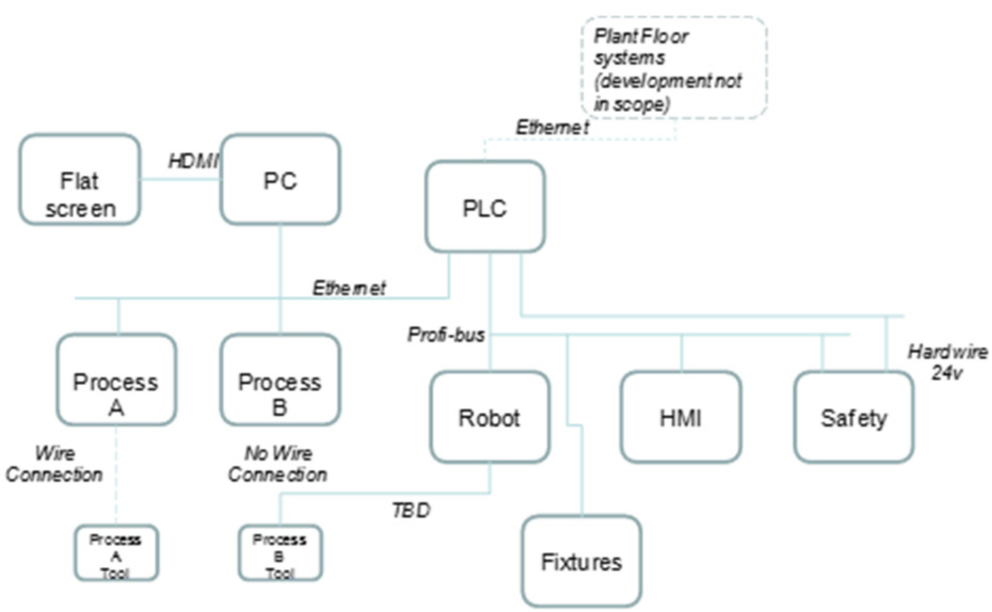

Figure 32 Principle view and examples of components and communication in the micro-flow cell

Based the position on the market and the kind of products/technologies GKN is working with, the flexibility approach has several advantages. The main disadvantages of the current system and solutions, which could be improved implementing the Micro-Integrated –Flexible Cell, are listed below:

- Human and robot collaboration is not fully supported by an ergonomic and safe workstation.
- Each working process is not completely automated;
- Processes able to realize a finished part have to be integrated: the current standalone cells / islands in production system are able to realize only one specific operation;
- Advanced or flexible cells architecture have to be implemented: the current system limits flexibility potential: using robot as cell controller (no PLC);
- Bidirectional communication between PLM and ERP and integration between MES system, and PLM / ERP have to be improved.

As far as the first iteration was concerned, both the scope and the main objectives of the project were determined. As described on the functional and technical questionnaires (see Annex), the analysis has been extended to the stakeholders and to the relevant issues, thus showing the transition AS-IS to the TO-BE scenario.
An initial set of both functional and technical requirements has been elicited as listed on the following figure.

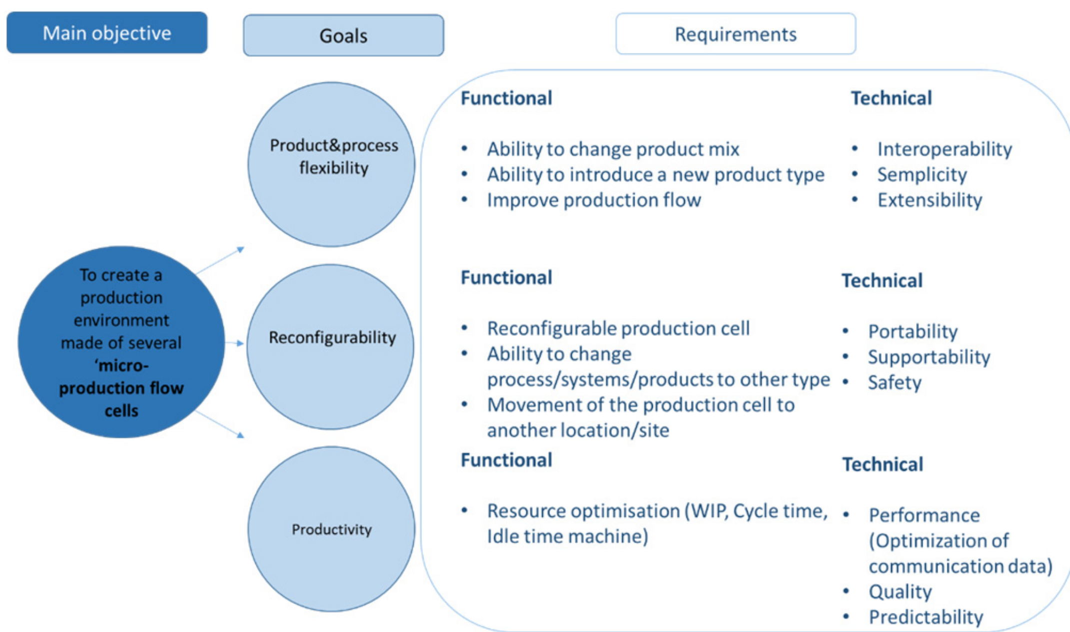

Figure 33 GKN_First Iteration results

As far as the second iteration was concerned, leading directions from the previous tasks, i.e. T1.1 were referred to the so called *PERFoRM framework picture*, where four processes (brushing, marking, surface inspection, dimensional inspection) was involved as well as IT assets. The IT infrastructure is principally based on ERP and MRP for the long term scheduling and on PPs (Production planning system) and standard PLC for the short time. The scheduling process is based on SAP, even though manual scheduling is applied on the shop floor according to SOPs.

Figure 34 GKN Use Case current status

Following the methodology explained in previous chapters, it is possible to point out the linkage among the use case main objectives and the three identified levels of requirements that describe the gap between the AS-IS and TO-BE scenarios. This picture also illustrates the specific KPIs that will be used to monitor the requirements behaviour during PERFoRM project development. In particular, the ability to simulate and model the entire factory status is the key aspect to inspire the real time monitoring system implementation, improving both production optimization and reconfigurability and their related to aspects such as WIP, production efficiency, costs and set-up.

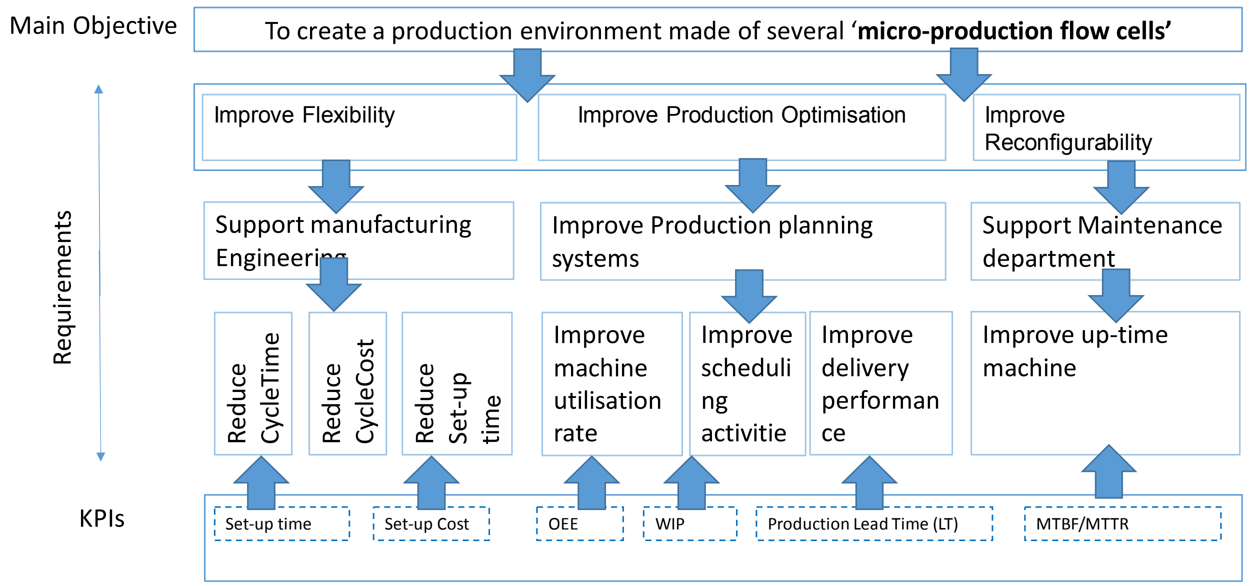

Figure 35 GKN: framework for identifying requirements and KPIs

With reference to the Figure 35 the first level of requirements is related to Flexibility, Production optimization and reconfigurability improvement. In particular, GKN would ensure the ability to quickly change the product type according to customer and market needs (flexibility), to be able to replace the micro-cell in any part of the plant or in another factory (reconfigurability) and finally, to ensure high productivity performance (production optimization). The second level represents those areas where GKN has focused its attention to accomplish these objectives. Finally, last level shows the specific requirements collected for each of the previously identified areas. This relationship is shown below:

Based on the above mentioned assumptions the use case requirements were defined and reported in the following table.

Table 9 GKN_Validation phase: Second Iteration results

ID	Process (1)	Stakeholder	Requirement definition (2)	Type (3)	Priority (4)	KPI (5)
1	Brushing	Operator, Method Technician, Manufacturing Engineering, Maintenance, Robot technician,	Op – Productivity,	Funct.	Low	Not Relevant
			Op-Environment (ergonomics/S&H).	Funct.	Low	Not Relevant
			MT – Quality spec	Funct.	Low	Not Relevant

		Supervisor, Production Planner, Purchasing, Customer	ME – Cycle time, cost, Set-up time.	Funct.	High	Set-up time, Set-up cost, OEE
			Maint – Up-time	Funct.	High	MTBF/MTTR
			RT- N/A	Funct	Low	Not Relevant
			Superv. – Productivity / cost,	Funct.	Low	Not Relevant
			Superv-Environment (ergonomics/S&H).	Funct.	Low	Not Relevant
			PP – Scheduling & utilisation,	Funct.	High	WIP, Prod. Lead Time,
			PP-Delivery performace	Funct.	Low	Not Relevant
			Purch – Cost	Funct.	Low	Not Relevant
			Customer – Cost, Del.	Funct.	Low	Not Relevant
			Customer-Performance, quality	Funct.	Low	Not Relevant
2 3 4	Marking Surface inspection Dimensional Inspection	Operator, Method Technician, Manufacturing Engineering, Maintenance, Robot technician Supervisor, Production Planner, Purchasing, Customer Quality	Op – Productivity, environment (ergonomics/S&H).	Funct.	Low	Not Relevant
			MT – Quality spec	Funct.	Low	Not Relevant
			ME – Cycle time, cost, Set-up time.	Funct.	Low	Not Relevant
			RT- N/A	Funct	Low	Not Relevant
			Superv. – Productivity / cost, environment (ergonomics/S&H).	Funct.	Low	Not Relevant
			PP – Scheduling & utilisation, delivery performace	Funct.	High	WIP, Prod. LT
			Purch – Cost	Funct.	Low	Not Relevant
			Customer – Cost, Del. Performance, quality.	Funct.	Low	Not Relevant

			Q – quality of the marking / fulfills spec. + traceability	Funct.	Low	Not Relevant
			Maint – Up-time	Funct.	High	Set-up time & cost, OEE, MTBF/MTTR

As already stated in chapter 4, the second iteration of each use case has been followed by the classification and documentation of the relevant requirements in an understandable form for all the stakeholders. With this concern, the 5C architecture [12] has been chosen to clearly map the current use case situation (AS-IS) and the future scenario enabled by PERFoRM project activities. In particular, these two different scenarios have been analyzed and, after a deep study of Jay Lee assumptions, connected to the proper pyramid level.

Concerning with GKN use case, it is possible to state that its current situation sufficiently fits with the third level features of the pyramid. In fact, this use case is already aware of the fleet machine in terms of status, consumptions, utilization, etc. but within PERFoRM project it would also have the ability to reconfigure process and production mix based on market needs. This is where the will to implement a flexible micro-flow cell arises. According to 5C architecture, this objective can be mapped with the configuration level (Level 5).

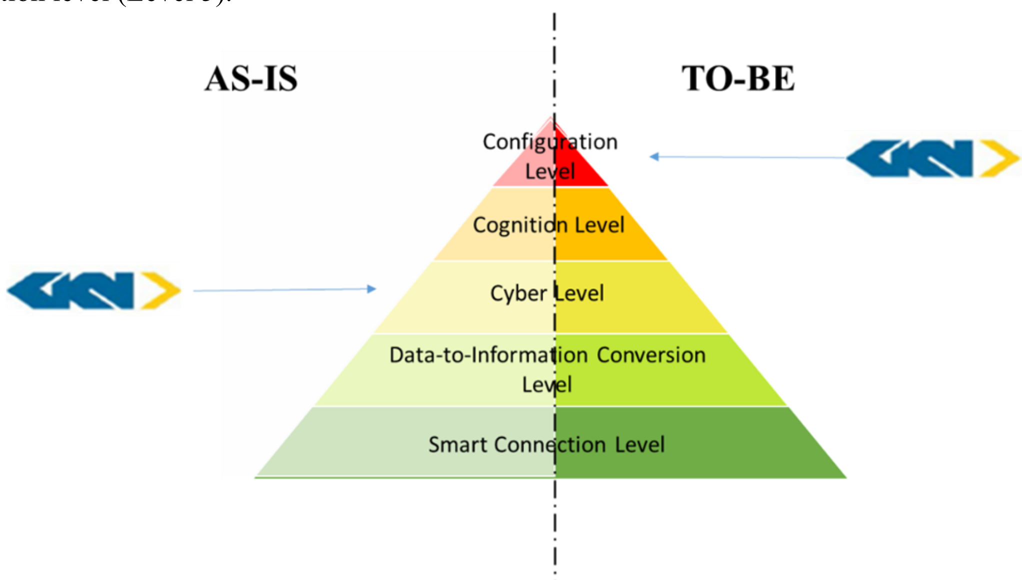

Figure 36 5C architecture: GKN:AS-IS and TO-BE classification

7. Summary and conclusions

PERFoRM project aims at developing an innovative manufacturing system based on new agile concept based on plug-and-produce production systems.

The relevant objectives of D1.2 are concerned with the definition and deployment of general business and strategic requirements and the measurement and benchmark of KPIs (Key Performance Indicator), adapted on each Use Case proper reality.

For this reason, this document was focused on selecting the proper methods to define the requirements and relevant KPIs, which are necessary to develop such plug and production systems. The proposed methodology, which was derived from RE essentially consists in four main steps (i.e. Elicitation, Analysis, Specification and Validation) and has been carried out through a double iteration exercise in order to first identify the requirements and then to validate them. In particular, the proposed methodology has been adopted for all the Use Cases, in order to realize which requirements and KPIs are essentially to be implemented and benchmarked in a flexible and reconfigurable production system and to evaluate their consistency with the CPS framework.

According to this framework, the 5C architecture was utilized to map the current Use Case level (AS-IS) and the future situation (TO-BE) enabled by PERFoRM project activities, as summarized in the following picture.

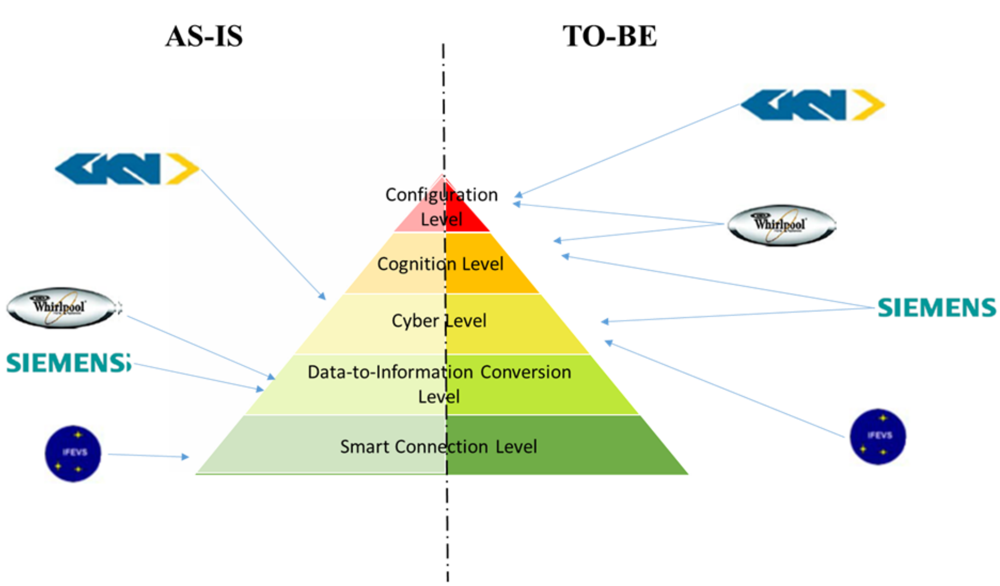

Figure 37 5C architecture: Use Case overview

In a later step, it was carried out a classification among the specified requirements and other requirements; the former represent the general requirements which directly allow a flexible and reconfigurable industrial environment implementation, while the latter are support the previous mentioned requirements. In particular, the table below represents these results: flexibility can be granted by developing the ability to quickly change raw materials, processes, and cycles, while reducing change over time; reconfigurability can be obtained through the ability to manage feedback and data from process and production departments.

Table 10 General requirements: flexibility and reconfigurability overview

<table>
<tr><th colspan="2">General Requirements</th><th>Others Requirements</th></tr>
<tr><th>Flexibility</th><th>Reconfigurability</th><th>Necessary to flexibility and reconfigurability</th></tr>
<tr><td rowspan="5">• Ability to Change Raw material
• Ability to Change Processes
• Ability to obtain Process interactions
• Agility production
• To facilitate Mobility, including comparison among different units e.g. OEE, micro-flow-cells)
• Cycle time reduction
• Cycle , cost reduction</td><td rowspan="5">• To obtain feedback from production to design
• To obtain Final test feedback to Robot system configuration
• To obtain feedback to the process, based on failure control
• Cost saving in reconfiguration
• To obtain new part reprogramming/setup through CAD critical paths
• Self-configuring system, which can define the root-cause based on pattern recognition.
• Set-up time reduction</td><td>100% Traceability and identification of single products up to the supply chain</td></tr>
<tr><td>Ability to enable Simulation, Model and prototype in the CPS environment

(i.e. process parameters interaction, global factory behaviour, predictive failure)</td></tr>
<tr><td>Increase the amount of data collected and data availability</td></tr>
<tr><td>Automatic (semi-automatic) data gathering of machine condition</td></tr>
<tr><td>Full integration and quick communication among different departments and functions (i.e. scheduling system and maintenance system integration, machine condition and maintenance tasks, production and process planning, etc.)</td></tr>
</table>

As far as KPIs are concerned, related to values will be gathered during the implementation phase and they will be compared with targets and actual values at different stages of the project, in order to show a significant trend and to prove the effectiveness of the proposed reconfigurability solutions.

This document will be updated at M18 to review the requirements in parallel with the main outcomes of WP2, WP3 and WP4, i.e. referred to the definition of middleware architecture, technology adaptors for plug-&-production and simulation methods.

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Annexes

In this section, for each Use Case, the results from functional and technical requirement identification are reported.

Siemens

1st iteration requirements

As already explained in chapter 3.2 and 3.3, the tables reported below show the AS-IS and TO-BE scenarios of Siemens Use Case. In particular, Functional and Technical Requirements are explicated.

FUNCTIONAL REQUIREMENTS		
	AS-IS	**Industrial Partner: Siemens**
A1	•Summary and scope of the project, Business Scenarios	Improve Machine Maintenance by predicting Machine Maintenance using existing manufacturing data and additional newly implemented sensing technology for data acquisition
A2	•Product Technical aspects (i.e. main products and services, markets)	Industrial compressors production, application targeting on rough machining of stator castings

A3	•Main involved processes (2) (3), Main involved teams & roles	Manufacturing (Machining: Turning, Milling); Maintenance Department; Production Planning / Scheduling 
A4	•Infrastructures: Shop Floor, Server, Network, Applications … (4)	Turning machines equipped with machine data logging and manufacturing data acquisition systems (proprietary applications), SAP for ERP/MES levels, manual adjustment of maintenance scheduling in place (using factory task planning application with underlying database)
A5	•Social and organizational issues, (job enlargement, teamwork, involvement, Training, Motivation, etc..)	maintenance often in firefighting mode, maintenance duration / efforts hard to predict, only weak failure descriptions available, high set up efforts
A6	•Financial issues	high setup efforts for parts to be machined (e.g. stator) makes switching machinery very expensive; after starting machining started an equipment change implies quality impacts; maintenance tasks often postponed due to high machine utilization and unplanned/short term scheduling adaptations
A7	•Environmental issues	significant energy required for craning and machine stand by in case of machine failure (large machinery, huge cranes)
A8	•Interested Parties and Internal/External Stakeholders	Maintenance department, Planning department, Factory management; machine and tool providers
A9	• ….. Other relevant ….	customers might receive products later if predictive maintenance is not applied
	TO-BE	

T1	•Evaluation Criteria (1) (5)	maintenance and downtime costs reduction, machine availability increase
T2	•Identified goals/objectives (2)	improve prediction of machine health; derive maintenance tasks; reproducible and learned maintenance objectives and executions (knowing tasks when coming to machine); schedule tasks within production schedule for avoidance of breakdown / unplanned downtime
T3	•Identify relevant processes and tasks changes (2) (3)	Machine maintenance, failure detection and reporting, C-Check better plannable according to production load, dynamic maintenance schedules and processes
T4	•Stakeholders‘ expectations	increased productivity (available machine hours), reduced maintenance costs (Euro); maintenance planning and reality better aligned (execution time, costs, spare part procurement and availability)
T5	•Constrains and possible obstacle/limitations	required physical data can not be acquired in an adequate manner (e.g. no Sensors available, no data correlations possible to draw planning decisions), no transformability from machine to machine / single purpose solution), higher skilled workers necessary
T6	•….. Other relevant ….	n/a

Table 11 Siemens functional questionnaire

TECHNOLOGICAL REQUIREMENTS	
AS-IS	**Industrial Partner: Siemens**
Currently used technologies	in-house windows software for machine and manufacturing data acquisition as well as maintenance planning and failure reporting, both tools not synchronized nor integrated; further standard SAP systems in place; no dedicated sensors implemented in machines

Good/bad experiences with used technologies	easy to use, but not integrated, double, sometimes triple work necessary, failure information detail dependent on reporting worker, failure analysis thus mostly executed at machine site
Currently integrated tools and interfaces	special in-house tools, no standards, light SAP connection partially implemented
Good/bad experiences with integrated tools and interfaces	departments are used to it, know about tool weaknesses and compensate them by personal engagement
TO-BE	
Identify desired/required technology (if already known)	complete integration of maintenance system in ERP/MES (SAP); sensor technology integrated with machine control; automated data analysis; automated data reporting in maintenance planning tools, (semi-) automated maintenance task definition
Identify desired/required tools and interfaces (if already known)	Sensors to acquire machine health data, software to analyze health data automatically, software to plan maintenance tasks and synchronize them with overall planning tools (SAP)

Table 12 Siemens technological questionnaire

IFEVS

1st iteration requirements

The table reported below shows, as further explained in chapter 3.2 and 3.3, the AS-IS and TO-BE scenarios of IFEVs Use Case. In particular, Functional and Technical Requirements are explicated.

FUNCTIONAL REQUIREMENTS	
AS-IS	**Industrial Partner: I-FEVS**
Summary and scope of the project	The Use Case aims at making available low cost automated turnkey flexible assembly lines to rapidly start manufacturing of safe, ergonomic clean and efficient vehicles adapted to local needs
Business Scenarios	IFEVS will lead the case study on Micro Electric Vehicles. Even though the production line has not been set up yet (draft design within 3 months, final issue after 6 months), the following aspects have been identified: - High complexity level - Lack of flexibility - Traditional technology - High up-front investments - High support costs - Poor asset utilization - Multitude of point to point integrations - Various operating systems & languages - Many device connections - World class manufacturing (e.g. quality, reliability, etc.)

Technical aspects (i.e. main products and services, markets)	Micro 4 wheel IFEVs composed by: - Two identical axle systems using a parallelogram suspension system - Two motor-power train with two identical motors and transmission systems in 4WD configuration - Tubular chassis and rotomodular bumper coupled with two identical axle system Market: focus on City e-Car (700-1000kg) that constitute a good trade-off between safety, quality, size, performance and cost
Main involved processes, main involved teams & roles	Products: Micro Electric Vehicles (e.g. taxi, pass-car and pick up), powered by Ion-Lithium batteries and photovoltaic cells. Processes: R&D (e.g. testing labs), manufacturing (welding), assembling, painting (outsourced). Production model: - incoming raw materials and semi-products will be stored in the related to warehouse - welding tasks will be carried out on 7 stations (parallel) for both the body and the powertrain. It will be either manual or robotized or a combination of the two (TBD) - painting (i.e. cataphoresis process) will be outsourced (i.e. Magnetto) - assembling of components will be the final stage, based on modular subassemblies - quality control will be implemented to meet to automotive standards - logistics will be organized, so to reduce the stock (i.e. just in time) - throughput will be between 2-50 cars/day (at least two different PNs), but investments will be planned for the highest capacity Supply chain should be as close as possible. See also COMAU's production flow (in progress) Skills: Welding Operators, Process Engineers, Production Manager, Quality Manager, Logistic Mgr. Maintenance has been assigned to COMAU
Infrastructures: Shop Floor, Server, Network, Applications …	Air extraction systems, testing labs, general purpose welding templates, weight lifting devices, robots/gantry (TBD)
Social and organizational issues, (job enlargement, teamwork, involvement, etc..)	TBD

Economical issues	Significant investments in infrastructures, even though lower than an OEM automotive manufacturer.
Environment	Welding protections
Interested Parties and Internal/External Stakeholders	Suppliers, Customers, Employees, Magnetto (key supplier), Comau (system integrator), Cidaut (testing), Loccioni, Certification and Inspection Bodies
Internal and external issues	Supply chain and need for collaborative manufacturing networks (sustainability)
TO-BE	
Identify goals	System feasibility Traceability Flexibility Improving adaptability of the production line from small lots to larger lots of passenger cars Minimizing human errors and manual actions Minimizing the variability of manual operations CPS to support maintenance Thermal gradient factor: monitoring and feedback system
Identify relevant processes and tasks	Processes: R&D, manufacturing (welding), assembling, painting (outsourced). Supply chain should be as close as possible. See also production flow (in progress) Skills: Welding Operators, Process Engineers, Production Manager, Quality Manager, Logistic Mgr. Maintenance has been assigned to COMAU
Stakeholders‘ expectations	Examples Comau: standardization and replication opportunities, i.e. adaptability of components/systems Magnetto new business opportunities Certification and inspection Bodies: Compliance with regulations Loccioni: On-line controls (technology adaptors and measurement systems- WP3) Employees: job enlargement, competence upgrading

Constrains and possible obstacle/limitations	Fund raising
How we can measure results?	Productivity (i.e. number of products per day), compliance to ISO 9001 standard, meeting product certification requirements, Lead Time, set up time, 100% product traceability, manual operation failures, skill evaluation, MTBF
•….. Other relevant ….	

Table 13 IFEVS: functional questionnaire

TECHNOLOGICAL REQUIREMENTS	
AS-IS	**Industrial Partner: I-FEVS**
Currently used technologies (collection of techniques, skills, methods and processes)	TBD How can the Use Case objective be addressed with currently available/installed solution workaround look like? – The intention is to get an overview on relevant information • e.g. functionality chain (activity diagram?) throughout current production IT actors, machines) • …
Good/bad experiences with used technologies	NA Weak points of current processes (e.g. number of failures during manual data transfer)
Currently integrated tools and interfaces	CAD /PLM (Catia, Alias), milling CAM (TBD), ERP (TBD), • e.g. ERP (SAP R3, potentially also modules), Interfaces / information exchanged: e.g. orders and product configurations forwarded to MES (e.g. by means of B2MML); • PLC: Siemens, interfaces to above levels using OPC-UA;

	MES (Supplier XYZ), modules/functionalities ABC in focus/used, interfaces …
Good/bad experiences with integrated tools and interfaces	• Lack of extendibility (e.g. high efforts spent for last system extension/integration of functionality)
TO-BE	
Identify desired/required technology (if already known)	
Identify desired/required tools and interfaces (if already known)	

Table 14 IFEVS: technological questionnaire

Whirlpool

1st iteration requirements

The table reported below shows, as further explained in chapter 3.2 and 3.3, the AS-IS and TO-BE scenarios of Whirlpool Use Case. In particular, Functional and Technical Requirements are explicated.

FUNCTIONAL REQUIREMENTS	
AS-IS	**Industrial Partner: WHIRLPOOL**
Summary and scope of the project	The Use Case will be based on a real factory in order to establish a real time monitoring system able to correlate dynamic behavior of the factory (Key Business Factors) to its Key Performance Indicators Implementation
Business Scenarios	WHP will lead the case study based on r Microwave oven value stream. Typical WHR factory: a mix of automatic, robotic and human operations with a production capacity of 500K to 1M pcs/year Currently WHP Is able to collect the equipment status information in terms of: - Batch information -Operative status -Production information (pcs, etc.) -Quality data -Resource consumption (Energy, air, water, etc.) <u>Open Issues:</u> -Lack of a global view of the entire factory -Lack of correlation between KPI and KBF --Lack of simulation and structured analysis factory behavior -Lack of Traceability

Technical aspects (i.e. main products and services, markets)	Four typologies of Microwave composed by (see BOM): - Metallic frame - Microwave door -Turn-table -EMF source -Market: European market with 500k pos/year
Main involved processes, main involved teams & roles	Products: Build-in Microwave oven, (4 products type) Processes: R&D (e.g. testing labs), manufacturing, industrial foaming, assembling, painting, industrial bonding, quality control. Production model: - Incoming semi-products that are stored in dedicated warehouse - Pre-assembling of modular sub-components is carried out in the first part of the layout and its target is established by scheduling process Following phases are replayed on each dedicated line: - Assembling of macro-components (automated) - Bonding (automated) - Assembling of final components (screws, electric cables, etc. etc.) (manual and continuous flow with KANBAN/peach policy) - First Quality control realized by statistics methodology (operator with specific automatic system) -Security control applied for the whole production (Automated) Sub-assembling are transferred on the process by conveyors, properly identified by microchips with most relevant information
Infrastructures: Shop Floor, Server, Network, Applications …	Production lines, human robots , painting systems, measurement devices, scheduling systems, real time production data monitoring , alarm systems

Social and organizational issues, (job enlargement, teamwork, involvement, etc..)	Repetitive work, not extensive breaks, low work qualification, Production flow is based on both manual and robotized assembling tasks. -Working hour: 8h including breaks and team change-over -In case of absenteeism operators can be moved from similar lines - Working instructions are available for the operators at the point of use including pictures taken on the shop floor (no PLM) - Ergonomic fixture available - In case of absenteeism operators can be moved from similar lines - Visual management display monitors both production throughput and quality indicators
Economical issues	Not relevant
Environment	Protective barriers due to robot presence, -Equipment for assembly components (assembly kit) -Picking areas dedicated to forklist, pallet, and industrial trucks -Noise level has been checked and it is complying with existing regulations - Area emission are limited to painting plant and to heating systems - Interoperational buffers for the final dispatching
Interested Parties and Internal/External Stakeholders	Suppliers, Customers, Employees, Logistic Company within the group, Local authority, Trade Unions, Indesit
Internal and external issues	Static: KBF (Key Business Factors, see slides presentation): -Installed capacity Units -Worked hours / years -Labour Cost -etc. etc.
TO-BE	

Identify goals	The main goal is to relate KPIs to KBF Therefore : -Productivity -Traceability -Efficiency -Flexibility -Reconfigurability -Real time control
Identify relevant processes and tasks	Processes: R&D, industrial bonding, assembling, painting. quality control, The whole production process should be as coordinated as possible. (synchronization between manual assembly, automated bonding and product quality control) Skills: Assembling Operators, Process Engineers, Quality Manager,
Stakeholders' expectations	Quick Reconfigurability Time Indesit: integration production model Customer: on time delivery and high quality and traceability Logistic companies: high flexibility in order to reduce WIP Local authority: meeting regulation and laws (e.g. Muscle skeleton disorders) Trade unions: reduced workload Employees: job enlargement, competence upgrading, job rotation
Constrains and possible obstacle/limitations	Little integration between PLM and SOPs IT systems within the group Customer: on time delivery and high quality and traceability Logistic company: high flexibility in order to reduce WIP
How we can measure results ?	See KPI definition and see slides presentation

Table 15 Whirlpool: functional questionnaire

TECHNOLOGICAL REQUIREMENTS	
AS-IS	**Industrial Partner: WHIRLPOOL**
Currently used technologies (collection of techniques, skills, methods and processes)	-Statistical Process Control: visual measurement system for the correct components alignment - PLC , Robot Alarm system: sound system to warn the line block -Assembly kit: part number collected in suitable kit in line with the logic Kanban -Production Control: display panel which is updated Production status
Good/bad experiences with used technologies	NA Weak points of current processes (e.g. number of failures during manual data transfer)
Currently integrated tools and interfaces	Production manager-ERP : SAP HANA, SAP MII Equipment management-SCADA-MES: SAP PM, OEE Assembly management-PLC level: AID, ANDON Quality management-MCHINE level: DCS, f-test, ZHT
Good/bad experiences with integrated tools and interfaces	<u>Good experiences:</u> ERP - PACESMAKER: excellent management of production planning with which it is possible combine market orders with BOM and materials available to the warehouse. It generates the shopping list where, keeping the Kanban logic, indicates that material and what materials to bring to those who take it. - PROD. DECLARATION: counting of products moving from the manufacturing to that of logistics. Simultaneously with this automatically, SAP deletes the product produced BOM SAP PM: - Breakdown analysis: breakdown routes analysis ->Breakdown loss reduction, component lifecycle optimization, - INVENTORY MANAGEMENT: spare parts inventory control-> spare part inventory optimization ANDON

	- Various operating systems & languages - Many device connections ZHT - Analysis quality historical data -test sequence according to program and result certification - loading measure and data in the system <u>Bad experiences</u> PLM - PTC and Pro/Engineering: little symbiosis between SAP and PLM software because the first is related to the regional industrial area while the second is inclined to consider the industry globally. The contact between SAP and PLM software occurs at the BOM level but the transition from design to production still takes place manually
TO-BE	
Identify desired/required technology (if already known)	
Identify desired/required tools and interfaces (if already known)	-PLM software that are able to communicate with entire production systems (ERP, MES ATC) -Implementation of MOS system

Table 16 Whirlpool: Technological questionnaire

GKN

1st iteration requirements

The table reported below shows, as further explained in chapter 3.2 and 3.3, the AS-IS and TO-BE scenarios of GKN Use Case. In particular, Functional and Technical Requirements are explicated.

FUNCTIONAL REQUIREMENTS		
	AS-IS	**Industrial Partner: GKN**
A1	•Summary and scope of the project, Business Scenarios	The Use Case will be based on the plan to build and demonstrate a flexible and reconfigurable production cell architecture. The planned base line solution is a "micro-flow cell with robot automated processes for surface treatment, marking (or other processes in the scope for robot automation) integrated with required quality inspection / measuring methods to get a finished and approved part from the cell. GKN will lead the case study based on this cell concept for automated and integrated operation sequences as part of different value streams for jet engine components manufacturing. The business scenario in to improve the business case for automation with robots and similar solutions by improving production efficiency and utilization to motivate investments (improved business case). The key business factor is to adapt to current production demands through flexibility and reconfigurability and a chive higher asset utilization. The key performance indicator is lead time for changeovers.

A2	•Product Technical aspects (i.e. main products and services, markets)	A range of different families of jet engine components (see also product key) will make use of this solution over time. The primary application will be on: turbine rear cases and intermediate cases Future product application areas are: - Spools, disks and blisk - Blades and vanes - Fan cases - Low pressure turbine casings
A3	•Main involved processes (2) (3), Main involved teams & roles	Involved operative work processes are: - Manufacturing - Material handling - Production planning and scheduling - Manufacturing Engineering - Maintenance Involved teams and roles are: - Machine operator - Material Planners - Industrial engineers - Maintenance operators Involved manufacturing processes in the Use Case are: - Brushing - Marking - Surface roughness inspection -Dimensional inspection (Other processes can be implemented in the future).

A4	•Infrastructures: Shop Floor, Server, Network, Applications … (4)	Typical GKN workshop and value streams are a mix of functional workshops, (short) product flows and shared resources. In general, it is built with standalone work centers or stations. Material handling and transportation is manual or with fork lift trucks. There is a mix of automatic CNC machining, semi-automatic processes, e.g. for welding, robotic cells for deburring and human operations, especially for inspections and assembly. CMM and Non Destructive Testing is used frequently on all products. The shared resources are used for many value streams and sometimes closed / remote areas (there are different reasons for that). ERP/SAP is the master data system and all information is or stored there to fulfill the requirements for tractability, regardless of where it was created. Different systems are used for different purposes. The most important parts/functions used are: - SAP; Capacity planning and MRP and to some extent/level production scheduling and control (but also much shop floor planning in real time by humans). - SAP; Production order data, handling of non conformances documentation etc. .... - SAP; Operator instructions etc. for production as well as maintenance - Siemens; NX, Process Simulate and Team Center PLM for process planning (CNC, Robot, etc.) - DNC network communication - QSYS (from 2016); Quality inspection planning, data management and SPC - AXOS (from 2016) for stop time analysis (OEE measurements)

A5	•Social and organizational issues, (job enlargement, teamwork, involvement, Training, Motivation, etc..)	Long cycle times and highly skilled operators trained for complex machining, welding, etc. Operators are trained to do the inspection and approve the result of the operation they finish. (Many of the operators are more of a technician/engineer than a typical blue collar worker). Usually the work is performed by individuals in their respective work centers. Some work sharing/supporting each other and/rotation. Production flow is based on both manual and automated or robotized tasks and processes. - Std Shift pattern is a variant of 2 shift -In case of absenteeism operators have some degree of flexibility and skills/ competences to move between jobs/work centers. - Working instructions, drawings, specifications etc. are available for the operators at the point of use from computer terminal - SAP system, or in paper format. - Besides the manufacturing tasks, the operator may have other role/task to train new employees or production support/services. - All personal is expected to be involved in problem solving/continuous improvements, 5S and TPM activities.
A6	•Financial issues	Business model / Investment calculation model
A7	•Environmental issues	- Shop floor production flow and processing is not very visual - In general good working environment and large focus on safety and health - Material handling and transport mainly with trolleys and fork lift trucks
A8	•Interested Parties and Internal/External Stakeholders	Research & Technology, Manufacturing Engineering, Finance, Operations/Production, Logistics/Production planning, Maintenance, IS/IT
A9	• ….. Other relevant ….	Robustness and reliability of the flexible / reconfigurable systems - Experiences / Maturity / Mindset about automation, etc.
	TO-BE	

T1	•Evaluation Criteria (1) (5)	The main goals for the Use Case is to demonstrate: - Automation with a few process steps integrated in the cell (Micro-flow cell concept) - Flexibility - Reconfigurability - Movable
T2	•Identified goals/objectives (2)	The main KPIs to relate to KBF for the specific purpose and goals Use Case are ((In priority order): - Lead time for change over - OEE / Resource utilization -Efficiency/productivity (- ROI)
T3	•Identify relevant processes and tasks changes (2) (3)	Involved manufacturing processes in the Use Case are: - Brushing - Marking - Surface roughness inspection - Dimensional inspection - Production planning / scheduling will be affected directly for the local scheduling in the cell and/or indirectly for long term production planning (but this is not the primary focus to solve in the current Use Case). The goal is to contribute to improve total production flow through less functional layout and complex logistics. Skills/Roles: In value stream: Operators, Supervisors, Product and Process Engineers, Quality Engineers In central/support functions: Maintenance, Industrial / Manufacturing Engineering (CAM/NC/Robot/...), Logistics and planning.
T4	•Stakeholders' expectations	Quick Reconfigurability Time Customer: on time delivery Logistic companies: "micro flow processes" in order to reduce WIP Increased Automation utilization Employees: job enlargement, competence upgrading, job rotation

T5	•Constrains and possible obstacle/limitations	Business model / Investment calculation model need to include the value of flexibility Issues to integrate manufacturing processes in cell architecture Unclear demand from manufacturing
T6	•….. Other relevant ….	

Table 17 GKN functional questionnaire

TECHNOLOGICAL REQUIREMENTS	
AS-IS	**Industrial Partner: I-FEVS**
Currently used technologies	Operations are orientated in a functional shop layout approach. Long lead-time affects production negative. Utilization of Automation is limited to manly ergonomic reasons due to large number of product variants and traditionally reasons in aero engine business.
Good/bad experiences with used technologies	Deburring and marking cell designs show good potential. Investment in automation is low utilized due to changing demand in what process is needed.
Currently integrated tools and interfaces	Robot - PLC Robot - Process Process - PLC RS 232, Profinet, RS422, USB, Ethernet …
Good/bad experiences with integrated tools and interfaces	Good experiences: All processes with profit communication is duable to integrate in cell system Bad experiences Other communication concepts like RS 232, RS422, USB, Ethernet … is more complicated to integrate. Tool changer is difficult or impossible to use for many processes (tool changer is requested due to high flex demands).
TO-BE	

Identify desired/required technology (if already known)	Hi flexibility and functionality to host several processes in one low cost single robot cell is required.
Identify desired/required tools and interfaces (if already known)	Not yet decided

Table 18 GKN Technological questionnaire