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D2.1.

Requirements Engineering Methodology and Tools 1

WP2 - Scenarios and Requirements for DIHs and Experiments

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Executive Summary:

D2.1 is part of MIDIH Project WP2 “Scenarios and Requirements for Digital Innovation Hubs and Experiments” and defines a method and suggests tools to guide scenarios definition and requirements definition, verification and validation by specification of a Requirement Engineering (RE) Framework. The analysis proposed in **Chapter 2** investigates the state-of-the-art of requirements engineering methodologies. To this end, the analysis of advantages and disadvantages in the existing methodologies shows that the RE methodologies of the ‘classic’ disciplines – systems and software engineering – are not fully applicable to MIDIH. Therefore, in **Chapter 3** we developed a customized MIDIH RE Framework where the intention was to create a recognizable MIDIH “modus operandi” starting from Chapter 2 findings that suggest the spiral RE approach as the one that better suits MIDIH features. This is due to the fact that the spiral approach allows the continuous check of all the steps undertaken to understand, plan, test and validate the solutions developed by minimizing risks and project resources (time and costs) utilization which is relevant in MIDIH project as it comes across a complex, trans-disciplinary and multi-stakeholder environment.

The MIDH RE Framework is composed of four main building blocks (phases) that follow a chronologic and logic sequencing. The first RE phase is the **“Scenarios analysis and business requirements elicitation”**, where tools for relevant Industry4.0-related business scenarios identification are suggested, together with guidelines and tools for the identification of business requirements and KPIs definition. The elicited requirements are then analysed in the second phase of RE Framework (**“Business requirements analysis”**) where suggestions on how to establish if the elicited requirements are necessary, verifiable and reachable are given together with recommendations on business requirements prioritization and categorization (grouping) to help resources and effort allocation along the project. The third phase **“Functional and Non-functional requirements specification”** shows guidelines and tools for a better understanding of the actions needed and how to carry out them to support the design/development/implementation/testing of the solutions that will allow the achievement of the desired scenario and objectives. Finally, the **“Requirements validation”** phase defining the process of verification and validation (V&V) of business requirements aims at confirming that the requirements specification is functional to absolve the objectives identified in the previous steps of the RE. According to the spiral approach, V&V can occur at any time a new requirement is deployed in order to guarantee a continuous monitoring and lessons learnt feedback from the implemented actions. Beside the Requirements Engineering methodology, **Requirements Management** guidelines have been proposed in order to ensure alignment between the requirements and the project plan and work results.

This RE Framework represents fixed steps to approach RE and has been customized according to the specific characterization and mission that are the differentiating elements for DIHs/CCs (**Chapter 4**), Industrial Experiments (**Chapter 5**) and the Open Digital Platform (**Chapter6**).

Because MIDIH project is structured in a double iteration cycle, the RE Framework is defined in this deliverable in its first iteration and will be reviewed in the second iteration cycle planned in D2.2 (M21).

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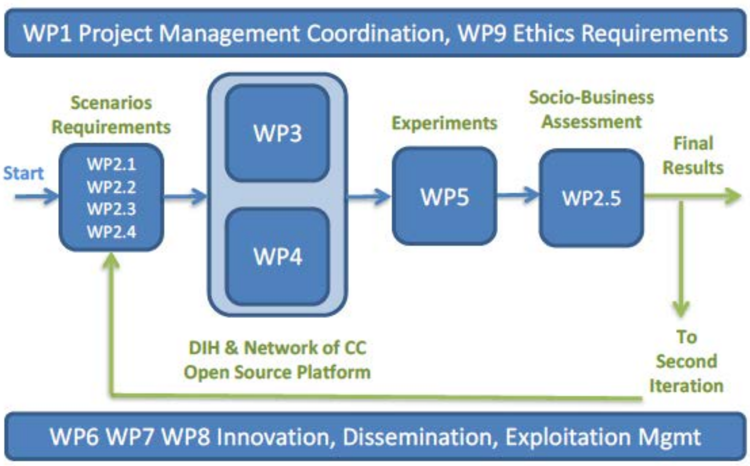
1 Introduction

1.1 Objective of the Deliverable

The main purpose of WP2 is the definition of scenarios, requirements identification and verification & validation (V&V) by use of a MIDIH Requirement Engineering (RE) Framework developed and specified in D2.1. The process of requirements definition and validation involves different entities for whom a specific MIDIH RE is designed: Digital Innovation Hubs (DIHs) and Competence Centres (CCs), Industrial Experiments, Digital Platforms. Thus, business scenarios will be specified and then instantiated in specific requirements for DIHs/CCs, Digital Platform and Industrial Experiments in the smart manufacturing environment related to the CPS/IoT domain.

According to WP2 overall objective, the purpose of this deliverable is to address the first iteration process of building the requirements engineering (RE) life cycle methodology for the definition of scenarios and requirements for Task 2.2 (requirements for CC / DIH), Task 2.3 (requirements for industrial experiments) and Task 2.4 (requirements for Digital Manufacturing Platforms). The overall RE methodology is structured in a two-iteration model with two main points of verification and validation (V&V), with the purpose to encompass appropriate methods and tools for conflict resolution and consensus building in the MIDIH complex multiple-actors environment. At the end of the first iteration the RE methodology designed for DIH/CC, Industrial Experiments and Digital Platforms will help WPs 3-4-5 managing their work content in addressing respectively DIH/CC, Industrial Experiments and Digital Platforms. The RE methodology will be analysed, reviewed and modifications will be applied to the RE. Thus, the modified RE will be implemented in the second iteration of the project.

1.2 Contribution to other WPs and Deliverables



1.3 Structure of the Deliverable

This deliverable is mainly structured in two main different parts. The first part includes **Chapter 2** – State of the art in Requirements Engineering (RE) and **Chapter 3** – MIDIH RE Framework. In Chapter two different RE methodologies are described and analysed. This step is ancillary to the identification of advantages and disadvantages linked to each of the presented RE methodologies. This chapter ends with the evaluation of the methodology that better suits MIDIH project features in order to propose a MIDIH RE Framework, which is content of Chapter 3. In the second part of the document, MIDIH RE Framework is then customized to specifically fit DIH/CC (**Chapter 4** – DIH and CC RE Framework: approaches and tools), Industrial Experiments (**Chapter 5** – Industrial Experiments RE Framework: approaches and tools) and Open Digital Platforms (**Chapter 6** – Digital Open Platform RE Framework: approaches and to). Each of the Chapters 4-5-6 propose guidelines and tools to allow the different entities involved in the project (refer to Chapter 1.1), to define business needs to address, business performances and objectives to fulfil (Scenario Analysis and Business requirements elicitation), the analysis and detail of the action to undertake towards the accomplishment of the set goals (Business requirement analysis and Requirement specification). At the end, the verification and validation process will serve to test whether the business objectives have been reached and validate the design, development and implementation of the initial requirements.

1.4 I4MS Phase III Projects and relation with Phase II Projects

It has to be understood that MIDIH project is an **Innovation Action (IA)** being one of the I4MS Phase III projects. Differently from the Research and Innovation Actions (RIA), which are expected to lead to the development of new knowledge or a new technology, an IA is focused on closer-to-the-market activities[1]. Thus, IAs will support fast adoption, and wide spread **technology transfer** of advanced ICT-based solutions for manufacturing[2]. As I4MS Phase III project, MIDIH addresses the adoption of the next generation of ICT advances in manufacturing and its focus is on emerging innovative technologies and processes. In that light, MIDIH’s focus is more on the adoption and integration of already available on the market IT artefacts for the development, testing and validation of customised IT systems/solutions. It is to specify that the development of new *ad hoc* (for MIDIH project purposes) IT components is not forbidden by the project, but it is less likely to happen.

MIDIH project is particularly related with BEinCPPS (Business Experiments in Cyber Physical Production Systems) project in the domain for CPS technologies and part of I4MS phase II projects (call FoF9-2015 for Innovation Actions)[3]. In fact, the main expected achievements of BEinCPPS project are intended to provide:

[1] http://www.ncpwallonie.be/en/projet-horizon2020-types-action
[2] http://i4ms.eu/
[3] http://www.beincpps.eu/

i) a set of five CPS-oriented Regional Manufacturing Digital Innovation Hubs (RM DIH) (located in five Vanguard regions specialized in Efficient and Sustainable Manufacturing ESM);

ii) a set of 25+ industrial experiments (five implemented by the five industrial champions of the consortium and 20 coming from open calls);

iii) an Open Platform integrating best of breed solutions from Smart Systems, Future Internet and IoT domains (more than 20 open source components integrated in innovative applications in eight domains such as zero-defect manufacturing, production optimization and predictive maintenance).

Therefore, MIDIH project is positioned as a “to be continued” of I4MS Phase II project and, in particular, of the BEinCPPS project. For this reason, this document present references to BEinCPPS project’s metrics, methods and tools. It is important to specify that the two projects partially overlap in terms of timeline, as MIDIH project has started in October 2017, while BEinCPPS will approach its end in 2018.

It is important to precise that, as BEinCPPS is an ongoing project, the approaches proposed and developed since now may not be at their final release. Furthermore, all the BEinCPPS approaches presented in this document are not necessarily intended to be adopted in MIDIH project without customization, but they can be a starting point for MIDIH methods and approaches and intended for further modifications and customization according to the project purposes.

2 State of the art in Requirements Engineering (RE)

Choosing the right methodology (also referred to as “approach” or “model”) for developing and managing a product or solution (depending to the case) is very important. Based on the methodology, the design, development, testing and validation processes are carried out.

There are various Requirements Engineering (RE) methodologies and they mainly come from the software development discipline. The most popular are listed below. For a detailed description of the following RE methodologies please refer to the ANNEX .

1. Waterfall model
2. V model
3. Incremental model
4. RAD model
5. Agile model
6. Spiral model

2.1 Comparison of RE methodologies

In order to find the right methodology to address MIDIH project, it is important to make an evaluation of the common available methodologies coming from the State of the Art (described in the previous paragraphs). The following Table 1 is intended to analyse the current RE methodologies in a critical perspective, allowing a quick and direct comparison among them, highlighting the main advantages and criticalities in their respective implementation, and try to describe the environment of application (depending on the features of the project they are took in consideration for) that is better suitable for each RE.

Table 1 Comparison of RE methodologies

RE Methodology		Main Pros		Main Cons		When To Use
Waterfall model		• Simple and easy to understand and use • Phases are processed and completed one at a time and phases do not overlap		• Once an application is in the testing stage, it is very difficult to go back and change		- No ambiguous requirements - Ample resources (high skilled experts) - Small and short-time projects - No prototypes needed (low risk projects) - Verification at the end of the development
V model		•Time concern in comparison with the waterfall model is lower • Development of test plans early on during the life cycle		• Little flexibility, like the Waterfall Model • Systems/solutions are developed during the implementation phase, so no early prototypes of the system/solution are produced		- Small to medium sized projects - No ambiguous requirements - Ample resources (high skilled experts) - No prototypes needed (low risk projects) - Verification at the end of the development (uncertainty on customers' expectations)
Incremental model		• Generates working systems/solutions quickly and early during the system/solution life cycle • Flexible - less costly to change scope and requirements		• Need for a clear and complete definition of the whole system before it can be broken down and built incrementally • Total cost may be higher compared to other systems/solutions RE approaches		- Clearly defined and understood requirements of the complete system - Mandatory definition of major requirements; however, some details can evolve with time - Short-time project (need to get a product to the market early) - New technology use - No ample resources (experts with needed skill set are not available) - High risk project (critical features and goals)

RAD model		• Reduced development time • Integration from very beginning helps integration of the different developed parts of the system/solution		• Only system that can be modularized can be built using RAD • High cost of modelling and developing activities		- Short-time project (to be modularized in 2-3 months of time) - Ample resources (high skilled designers and high cost expenses for automatic coding)
Agile approach		• Regular adaptation to changing circumstances • Customers, developers and testers constantly interact with each other		• There is lack of emphasis on necessary designing and documentation (the project can go out of track • It can be difficult to assess the effort required to run a specific task		- New changes can be implemented at very little cost because of the frequency of new increments that are produced. - To implement a new feature the developers need to lose only the work of a few days, or even only hours, to roll back and implement it. - Very limited initial planning to start the project. - End users' needs are ever changing in a dynamic business and IT world. - Changes can be newly effected or removed based on feedback. - Developers and stakeholders have freedom of time and options (possibility to leave important decisions until more or better data or even entire hosting programs are available
Spiral model		• Development is fast • Customer feedback and the changes are implemented faster		• Risk analysis is important phase so requires expert people • It is costly for smaller projects • Spiral may go infinitely		- Costs and risk evaluation is important - Medium to high-risk projects - Long-term project commitment - Users are unsure of their needs - Requirements are complex - New product/solutions - Significant changes are expected (research and exploration)

In order to find the right RE approach, it has to combine MIDIH features with the opportunities offered by a specific RE methodology (or a combination of methodologies to create a "hybrid approach").

MIDIH is a long-term and wide project, has considerable resources particularly in terms of skills and experts (both form the consortium and from other stakeholders that will be involved in the project such as companies and organizations part of DIHs/CCs network, etc.).

MIDIH is characterized by high complexity in terms of number of interrelated objectives and needs to shape the manufacturing environment, which is the field of application of MIDIH project results and outcomes (i.e. the complexity of managing objectives of a DIH/CC that relates with a big number of stakeholders by offering an elevated number of different services). Furthermore, RE methodology is required to help different types of entities to pursue business objectives and goals. Further to DIHs and CCs, also Industrial Experiments have to be guided from the RE methodology in requirements elicitation, specification towards the digitalization of processes/systems/value chains, and an Open Digital Platform should be constituted to support technological awareness and transfer particularly to manufacturing SMEs and start-ups. This trans-disciplinarity, together with a multi-stakeholder environment (also in terms of spatial and organizational) detachment, increases the level of complexity of the MIDIH project. Moreover, it may be difficult to initially clearly define business objectives and requirement for each single entity. There is external heterogeneity among the different MIDIH entities: stakeholders related to DIHs/CCs, Industrial Experiments and Open Digital Platform will have different business objectives and thus requirements to fulfil. Also, internal heterogeneity is a further element of uncertainty, which means that for example two different DIHs can pursue different business objectives. It makes the process of requirements elicitation and definition of requirements difficult. Furthermore, changes of requirements in a dynamic environment, where people involved are numerous, make the management of the requirements understanding, design and implementation for the solution an uncertain process.

For all these reasons, according to the State of the Art of RE methodologies the RE methodology that better suits MIDIH features is the spiral approach. It allows the continuous check of all the steps undertaken to understand, plan and test the solutions developed to reach the desired business objectives.

3 MIDIH RE Framework

A common RE approach has been developed for MIDH as depicted in Figure 1. The RE Framework is constituted by sequential building blocks for requirements development activities and cross-sectional requirements management tasks to allow transparency, traceability and coherence of requirements development and analytic activities along the whole project. This RE Framework represents fixed steps to approach RE and will be customized according to the specific characterization and mission that are the differentiating elements for DIHs/CCs, Industrial Experiments and the Open Digital Platform.

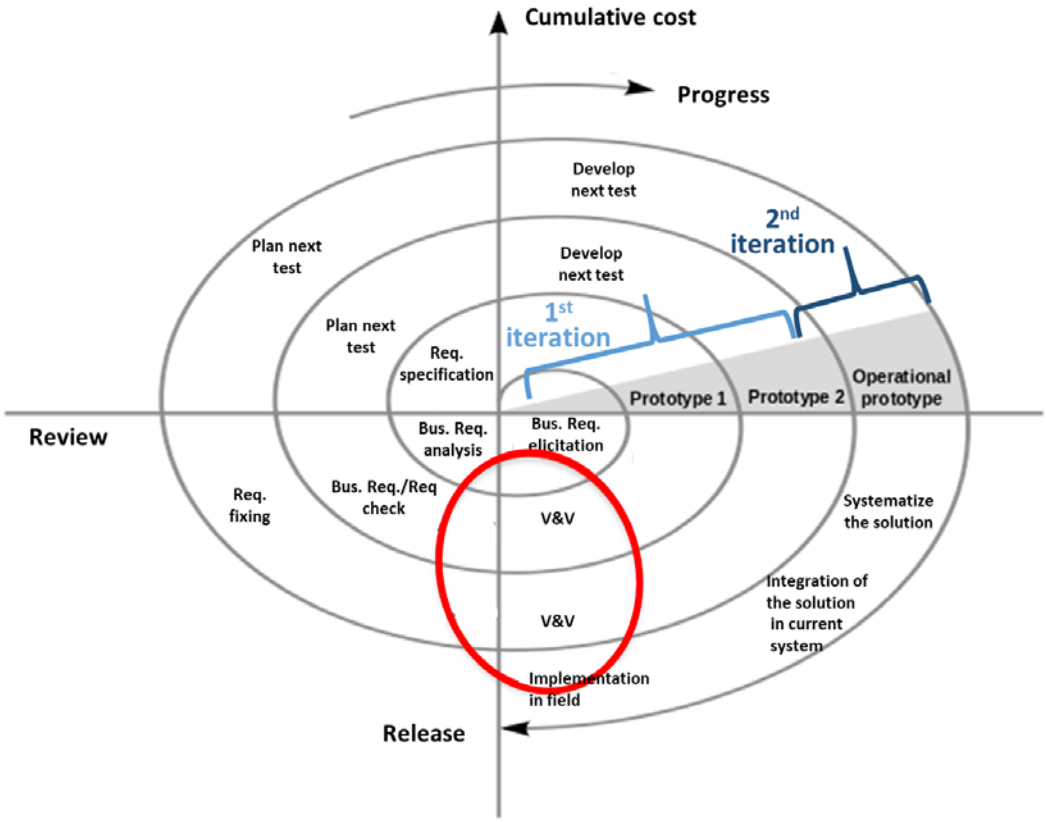


Figure 1 MIDIH RE Framework for DIH/CC and Industrial Experiments

The following sections will describe the activities involved in discovering, documenting and maintaining a set of requirements for the development of DIH/CC, Industrial Experiments and the Digital Platform in the RE Framework of MIDIH project. Scenarios and related requirements will be identified referring to the Industry 4.0 domain.

3.1 Requirements: definition

3.1.1 Business requirements

Business requirements relate to business objectives, vision and goals. In other words, the fulfilment of business requirements allows to satisfy the business needs. Whereas a business requirement states the **"why"** for a project, Business objectives have to respect MIDIH project vision. They also provide the scope of a business need or problem that needs to be addressed through a specific activity or project. 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 need.

3.1.2 Functional and non-functional requirements

Functional requirements

Functional requirements break down the steps needed to meet the business requirement or requirements. A functional requirement outlines the **"what"**. It essentially specifies something the system should do. Typically, functional requirements will specify a behaviour or function. When developing functional requirements, a comprehensive list of steps that will be taken during the project is developed. The end objective is for each step to contribute towards achieving the business requirement or requirements. It should also be clear who will be responsible for each step. Functional requirements outline specific steps and outline how the project will be delivered. As a result, they help to ensure a project is on track and are used for measuring performance.

Non-functional requirements (or Technical requirements)

Non-functional requirements specify **"how"** the system should perform a certain function (system's quality attributes or characteristics). In other words, a non-functional requirement will describe how a system should behave and what limits there are on its functionality. In fact, these types of requirements are often called quality of service (QoS) requirements or service-level requirements. Non-functional requirements cover all the remaining requirements, which are not covered by the functional requirements.

3.1.3 Comparison between the two sets of requirements

Both sets of requirements contribute to a common goal, although functional requirements are much more specific and detailed. While business requirements deal with mainly business goals and stakeholder expectations, functional requirements outline exactly how a project will support business requirements (and non-functional requirements the system's quality attributes or characteristics). A business requirement tells what the future state of a project is and why the objective is worthwhile, while functional requirements tell how to get there.

3.2 Requirements Development

3.2.1 Scenarios analysis and business requirements elicitation

The scenario analysis is the first step of RE processes, where relevant Industry 4.0 scenarios are identified, by building up the weakness and bottlenecks of the actual (**AS IS**) situation, clarifying the business objectives in terms of betterment of actual performances and attended impacts on business performances. It also provides a proposal for the **TO BE** scenario trying to identify technical areas of intervention, potential tangible and intangible benefits of its realization. The gaps identification between the AS IS and the TO BE scenario allows partners further defining the business requirements to be satisfied in order to facilitate the transition from the current to the desired situation, link them with objectives and related impacts.

Features that are commonly presented in a complex, trans-disciplinary and multi-stakeholder environment for requirements elicitation characterize the requirements elicitation process in MIDIH project:

- Complexity: Elicitation has to be able to handle a large number of interrelated requirements;
- Trans-disciplinarity: Elicitation and requirements exchange process has to be supported in order to create a common view of the targeted complex system;
- Multi-stakeholder environment: Elicitation has to be applicable for a large number of stakeholders that are detached spatially and organizationally.

In this environment, one of the main challenges in the requirements elicitation process is the definition of clear, correct and complete requirements.

Living lab approach comes useful at this stage, where key stakeholders are distributed into user panels and then asked about their specific challenges from both technical and non-technical perspectives. The major result of the elicitation process in MIDIH is a considerable pool of well-defined stakeholder profiles, each containing extensive numbers of unique participants. MIDIH shall enforce technology-specific and/or market-specific categories to properly manage further steps of RE.

3.2.2 Business requirements analysis

The business requirements analysis establishes if the elicited requirements are necessary, verifiable and reachable by examining their coherence with the defined objectives. The aspirational aim of this phase is limiting/removing requirements ambiguity, inconsistency or incompleteness, which should be avoided and thus removed. Moreover, hidden or latent interrelations between business requirements or missing assumptions during the process of elicitation should be managed and effort should be put on uncovering them to guarantee the quality of the elicited requirements and to avoid the uprising of obstacles to requirements satisfaction. Effort should be invested in achieving quality in terms of clarity in the description and explanation, and coherence in relation to the achievement of the TO BE scenario. It has to be considered that the spending of resources to be dedicated to this activity should be carefully reasoned and evaluated according to the existing trade-off between betterments and cost invested to achieve the improvements[4]. Furthermore, the relevance of the elicited business requirements should be evaluated by establishing a hierarchical structure for requirements' prioritization (i.e. Critical/Preferred/Optional). This allows the identification of the most relevant (must-have) requirements and a critical selection of the relevant requirements to be satisfied in order to reach the desired scenario. In MIDIH RE Framework, this can be supported by different approaches that have to be defined coherently with the approaches implemented during the elicitation process (for further details refer to paragraph 3.2.1) and accordingly to the specific characterization of requirements (Shen et al. 2004).

[4] http://www.hcode.com/seroi/documents/SE-ROI%20Thesis-distrib.pdf

By the end of this stage, MIDIH project can assess the innovation potential of stakeholders and end-users as well as indicate technological areas addressing challenges elicited. Furthermore, MIDIH project can prioritize stakeholders within each of key business-related and technological categories. One way to initially identify business-related challenges is by engaging a short self-assessment tool, incorporating a certain level of automation and detail, accordingly with the technological and market areas in question.

3.2.3 Functional and non-functional requirements specification

The requirements specification aims at describing in a more realistically completed way the functionality of the solution to be developed. Therefore, functional and also non-functional requirements and constraints are included.

In this RE phase, business requirements are translated into a detailed breakdown structure of what has to be done (functional requirements), including the expected quality of the achievements (non-functional requirements) in order to fulfil the desired objectives. Thus, in requirements specification it will refer to "requirements" as functional and non-functional requirements.

A hierarchical structure can provide sections and subsections for different levels of requirements, such as in the approach by (Hauksdóttir et al. 2013). All the information related to the requirements and necessary for the solution's development is detailed including information on the single steps undertaken (for business processes and models) or IT components/solutions (technical specification of IT architectures and artefacts). In order to represent the interactions between the different parts of the system to be deployed, information on the connections between the parts is relevant and serves as reference for requirements dependencies. This targets the involved disciplines and the individual stakeholders. Documentation has to establish the connection from the single requirement towards the whole system to be deployed, including information on the degree and moment of fulfilment.

As already stated in this document (for further details please refer to Paragraph 1.4), differently from the Research and Innovation Actions (RIA) characterizing I4MS Phase II projects which are expected to lead to the development of new knowledge or a new technology an IA is focused on closer-to-the-market activities[5]. Thus, IAs will support fast adoption, and wide spread **technology transfer** of advanced ICT-based solutions for manufacturing[6]. In that light, MIDIH's focus is more on the adoption and integration already available on the market IT artefacts for the development of customised IT systems/solutions.

3.2.4 Requirements validation

The process of verification and validation (V&V) of business requirements aims at confirming that the requirements specification is functional to absolve the objectives identified in the previous steps of the RE Framework by means of completeness and correctness of the

[5] http://www.ncpwallonie.be/en/projet-horizon2020-types-action
[6] http://i4ms.eu/

determined requirements (Hull et al. 2005). Thus, interesting from the validation point of view is the feedback mechanism within this process. V&V can occur at the end of the project or at any time a new requirement is deployed in order to guarantee a continuous monitoring and lessons learnt feedback from the implemented actions. The project outcomes are evaluated through a comparison with the requirements specification in order to guarantee the deployed solution to be in line with the desired objectives and expected business impacts. Therefore, the RE Framework involves the different stakeholders in the review of the requirements during validation. In general, Verification ensures that the project outcome satisfies and respects the requirements and the design specifications, while Validation investigates the ability of the reached project outcome to meet the stakeholders' needs and to fulfil its intended functions.

In order to carefully run the validation of requirements, V&V methods/measures need to be selected. This is pertinent as the adoption of metrics and tools allows to understand whether a requirement is satisfied or not. Important to avoid bias and bugs in the V&V is data triangulation that validates data and research outcome by cross verifying the same information. This triangulation of data strengthens the credibility and validity of data. The triangulation of data occurs when multiple theories, materials or methods are used. Among different common approaches to data triangulation, in MIDIH project the focus will be on the following:

- **Data source triangulation.** Use of evidence from different types of data sources (i.e. interviews, documents, public records, photographs and observations, etc.);
- **Methodology triangulation.** Combination of multiple methods to gather data (i.e. documents, interviews, observations, questionnaires, surveys, and also different times and in different places for information collection).

3.3 Requirements Management

Requirements engineering has a strong interdependency with requirements management to ensure alignment between the requirements and the project plan and work results. This includes the deployment of actions intended to requirements tracing during the different phases of the requirements life cycle, change management and qualification of the development process' results compared to the requirements' input.

3.3.1 Requirements traceability and change management standards

In order to understand how MIDIH stakeholders' requirements and the related solution's design are connected and transformed into each other, lower-level requirements have to be linked with the higher-level requirements they originate from, so that each requirement can be traced to its information source (Wynn et al. 2011). Requirements traceability enables both assessing the effect of changes of requirements to the solution's development along MIDIH project as well as to check if every solution's component is linked to a specific requirement. Thus, all requirements can be linked to lower layers and qualified, which is important to assure that they are met by the solution. This activity has a strong link with the requirements specification process in MIDIH RE Framework, where business requirements are translated into highly detailed requirements and linked among each other to guarantee coherence in the solution's design and then development. For complex systems as MIDIH, it is hard to avoid a change of requirements.

Changing environment or stakeholders may induce changes all along the life cycle and affect the development process (Lim & Finkelstein 2011). To ensure that such modified requirements are fed back into the solution development, a change management process has to be established (Huang et al. 2011). In RE Framework it is not referred to change management as an "organizational" process", but as structured actions to guide changes in the definition of needs and related requirements.

Changes to the requirements should be documented and controlled formally along MIDIH project. The Change management process ensures that changes are made systematically, similar information is collected for each proposed change (it would be better to have a pre-defined form for changes' information collection) and the information related to requirement is updated. The proposed changes have to be analysed in terms of impact of the change (how may components/parts of the system will be affected) and related impact. Furthermore, changes analysis is intended to avoid requirements' misunderstanding that may lead to unnecessary changes. One relevant aspect of change management is the evaluation of the trade-off between benefits and costs (in terms of money and time) ascribed to a potential change in the requirements (Sommerville & Sawyer 1999).

Change management activity is peculiar of the validation process of the RE Framework, where checks are undertaken to assure the correctness of the developed steps/components and overall solution, and relevant for collection and report of lessons learnt.

3.3.2 Requirements qualification testing

Finally, it has to be evaluated if the solutions developed along MIDIH project comply with the requirements specification or not (Project Management Institute 2013). The confirmation that a solution fully satisfies the documented requirements is conducted in requirements qualification. Deviations from requirements can be detected e.g. by requirement reviews, design inspections, component tests and trials, which has to start early in order to avoid late design changes and rebuilds (Hull et al. 2005). MIDIH RE Framework will qualify requirements by first testing the individual steps/components functions, then the final/integrated system and finally the fulfilment of stakeholder requirements. This activity is peculiar of the RE Framework process of V&V, where quality of the outcome has to be verified and guaranteed.

3.3.3 Requirements versus IPR

In case of ICT solutions, IPR management is of critical importance and right from the beginning of the process shall be approached as a priority building block in order to ensure sustainability and scale up of solutions, built on top of gathered requirements. Anytime NDAs need to be in place when engaging third parties, MIDIH platform must enable appropriate management of right and related economic and/or legal risks.

3.4 Data storage

The traceability and storage of the information collected along the project is a relevant issue. In order to preserve the relevant data coming from the different RE Framework phases and related activities, a database should be used for data storage, organization, tracing and updating. The information collected and then stored is intended to be useful for further processing and elaborations intended to meet and accomplish MIDIH project purposes. Therefore, in this document it will be referred to data storage in a database any time a relevant information for the project is collected.

Req	Business Requirement	Bus. Requirement Description
BR01	Acquisition of hystorical data on tests	During threshold definition quality manager can access hystorical data on test performed for the same or similar products
BR02	Support by mobile for single test run	Testing execution should be supported by application running on a mobile device
BR03	Execution of the test program on the portable testing unit	Test program should run the same as before on portable testing unit which includes controller and actuators connected to the appliance to be tested
BR04	Support by mobile to follow multiple testing units	Mobile application should allow quality operator to monitor in a single screen all testing units under her-his control and to switch on the single one
BR05	Test program change	Quality operator should be able to change the test program parameter if needed on the mobile interface
BR06	Sampling rate information	Qualiy operator should be able to access sampling rule- rate for the product under testing
BR07	Sampling rate change	Quality operator if needed should be able to change statistical control sampling rule-rate on the mobile
BR08	Support for test data analysis on the mobile device	Quality operator should be supported by the mobile application right after the completion of the test run by application that propose her-him if the test just run belongs to cluster of test data normal or anomaly-unknown
BR09	Support for test data confirmation on the mobile device	Quality operator should be able to complete the test by confirm test result -code (as per as is situation and furthermore to complete this by confirm the test just run belongs to normal or anomaly cluster
BR10	Additional data by user via mobile	Quality operator should be able to input additional data (such as comments and notes) to the test data
BR11	Support for multimedia data acquisition via mobile device	Quality operator should be able to acquire multimedia data (such as photo or sounds) with the mobile and store them in the test result data
BR12	Data analytics for test results	Quality manager should be able to perform analysis of data clustering on test data and results by validating the relationship between each cluster and its normal-anomaly flag

Figure 2 Example of business requirements collection data sheet retrieved from BEinCPPS

4 DIHs and CCs RE Framework: approaches and tools

This chapter depicts the adaption of the RE Framework presented in Chapter 3 to DIH/CC (including some reference also to the two RMDIHs involved in the project) in MIDIH focusing on Industry 4.0 vision for scenarios definition and requirements identification. As most implementations of RE Frameworks are in software products and services development, there is the need to accommodate it into the CC/DIH specific environment.

DIHs/CCs business mission is mainly focused on interacting and collaborating within a network of stakeholders to provide the required services and products to its customers.

Therefore, requirements engineering helps DIH/CC to understand their stakeholders' needs (i.e. customers) running a multi-perspective analysis. Building some elegant business objectives that ignore the stakeholders' needs (i.e. customers' needs) helps no one. Main task is to specify proper scenarios according to the current (AS IS) situation and the elicited business objectives and requirements to be satisfied. In order to minimize risks in interpretation, it is important that stakeholders are exact in specifications, eliminate conflicting needs and factors which may influence the requirement specification, design and implementation of business processes, choices and solutions. The DIH/CC needs to undertake problem specification, negotiation, implementation and review or validation of the specifications required by customers.

The aim of this chapter is to provide a more detailed description of the process of business objectives and requirements definition, together with requirements specification, design and implementation intended to satisfy stakeholders' needs.

4.1 Scenario analysis and requirements elicitation

The scenario/s definition activity for DIHs and CCs in MIDIH aims at fixing objectives to actuate a one-stop-shop marketplace, including services for manufacturing start-ups, SMEs and ICT Innovators. The scenario/s' related requirements for a one-stop-shop marketplace need to be carefully mediated and harmonised in order to not dissatisfy any of the involved communities, by modelling and instantiating "Access to" and "Collaborate with" services as reference workflows to be implemented in the MIDIH Collaboration Platform involving the different stakeholders of the MIDIH ecosystem. In order to support the project objectives, scenarios must be collected, shared and endorsed among the DIHs and CCs involved in the project. Each scenario represents the desired betterment that might involve one or more aspects of the DIH/CC business and performances to support the digitalization and smart specialization of the European manufacturing industry.

Furthermore, the scenario/s definition process must include actions for nurturing and supporting the evolution of the two selected Regional Manufacturing DIH from Phase II, by verifying and deploying the "Access to" services business plan and model already instantiated in the phase II project BEinCPPS.

4.1.1 DIH/CC and Didactic Factory (DF) description

At the core of the MIDIH ecosystem we have three types of entities: DIHs, CCs and DFs (referred as “Teaching Factories” in the DoA). These elements all play a clear and valuable role in the "Digitising European Industry" (DEI), the strategy designed by the European Commission to reinforce the EU's competitiveness in digital technologies and ensure that any industry in Europe can fully benefit from digital innovations.

DIHs are one-stop-shops where companies – especially SMEs, start-ups and mid-caps – can get help to improve their business, production processes, products and services by means of digital technology, while CCs provide access to technological based services and testing.

DF are a new complementary concept introduced by MIDIH, they refer to infrastructure where knowledge, facilities for hands-on experiment and specific training are available for SMEs. In the picture below, the different services are mapped to the entity of reference, although this distribution is flexible and certain services can be related to more than one type of entity.

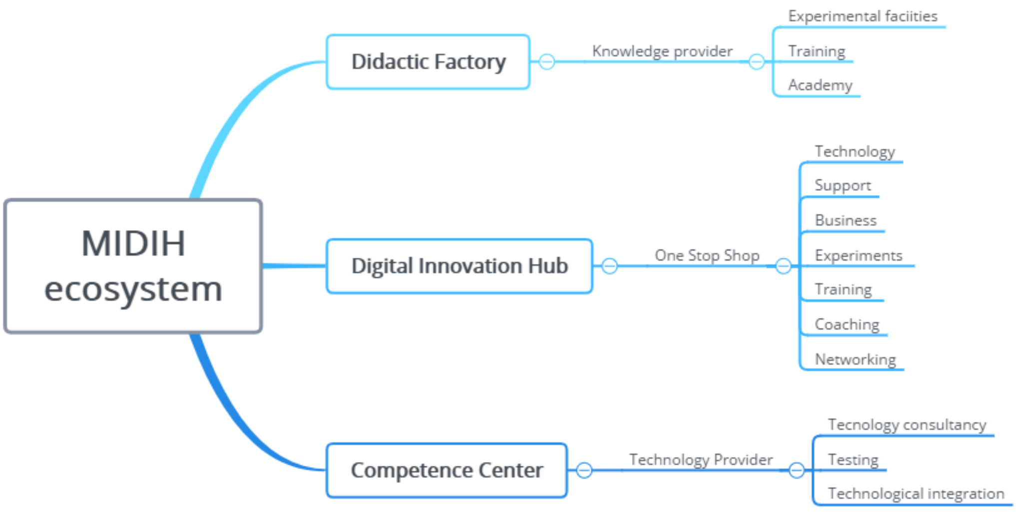


Figure 3 MIDIH ecosystem

4.1.2 Scope and vision of DIH/CC

According to the final report of DEI Working Group 1, a DIH is “a support facility that helps companies to become more competitive by improving their business/production processes as well as products and services by means of digital technology. DIHs act as a one-stop-shop, serving companies within their local region and beyond to digitalise their business. […]. As an innovation ecosystem that provides access to the services, facilities and expertise of a wide range of partners, Digital Innovation Hubs ensure that individual customers get the services they need; that the target market segments receive innovative, scalable solutions; and that DIHs co-operate effectively with each other” (Sharpe 2017). Furthermore, CCs are part of DIHs network.

Thus, according to the definition above, the scope of DIH/CC must consider the relevance of

European SMEs' digital transformation. In this light, the DIH/CC embraces the vision of work together in an open innovation ecosystem with a clear digital innovation focus via the development of multi-level European investments and cluster initiatives for emerging and transforming industries (note that in Figure 4 XXX stands as placeholder).

> DIH vision is to boost XXX and facilitating start-ups and SMEs access to EU-wide markets in order to increase employment and competitiveness of European manufacturing industry.

Figure 4 Example of vision declaration example retrieved from BEinCPPS

In order to further communicate the expectations and impacts from the project, the DIH/CC can use free text to further detail their vision (in terms of actions).

> In order to foster connections between all key relevant regional stakeholders (competence centers, companies, users and suppliers, technology experts and investors) and to boost Industry 4.0 revolution and smart specialization of European manufacturing start-ups/SMEs, the main foreseen actions a DIHs should undertake are:
> - Increasing companies' awareness on existing opportunities on Industry 4.0
> - Supporting companies in innovative investments planning activities
> - Supporting companies in identifying Competence Centers having specific competences on Industry 4.0
> - Support in accessing private and public available funds
> - Companies mentoring services
> - Interaction with other European Regional Manufacturing DIHs

Figure 5 Example of further declination of the DIH/CC vision

4.1.3 AS IS scenario

This section provides methods and advices for the identification and description of the actual (AS IS) scenario defined as the current DIH/CC features and business performances that are expected to improve towards the achievement of the desired (TO BE) scenario. Tools and guidelines for the information that should be collected for further processing intended to satisfy MIDIH project purposes are also proposed.

4.1.3.1 *Introduction*

Brief introduction on the core business structure and processes (workflow) of the DIH/CC by use of free text and images.

4.1.3.2 *Network of stakeholders*

4.1.3.2.1. Stakeholders identification

In order to describe the DIH/CC ecosystem, it is necessary to describe the industrial environment of the region where the DIH/CC is located, the key sectors and the policies established and implemented by regional government to support manufacturing industry and innovation and identify the different involved stakeholders at public and private level. Below a list of potential stakeholders that might be part of a DIH/CC network.

- Industrial Champions (LE)
- Manufacturing SMEs Ecosystem
- CPS Solution providers
- IT Innovation Ecosystem
- Regional/National Authorities
- Banks, Access to Finance Venture capital Ecosystem
- Chambers and Trade Ecosystem
- Spinoff, Spinouts Ecosystems
- Students & Social Communities
- Experimental facilities
- Marketing, Press & Brand Management
- Others

Information regarding name and description of the stakeholders must be collected through questionnaires, webinars or meetings and stored in a database.

4.1.3.2.2. Stakeholders analysis

After having identified the relevant stakeholders, a step further is related to their analysis. In particular, the analysis of the stakeholders has to be performed according to the level of interest and influence each stakeholder has on the DIH/CC ecosystem and business.

The interest concerns with the amount of effort and the level of involvement of a stakeholder, while the influence is related to its ability in facilitating, supporting or, on the contrary, in preventing the development and the functioning of the DIH/CC.

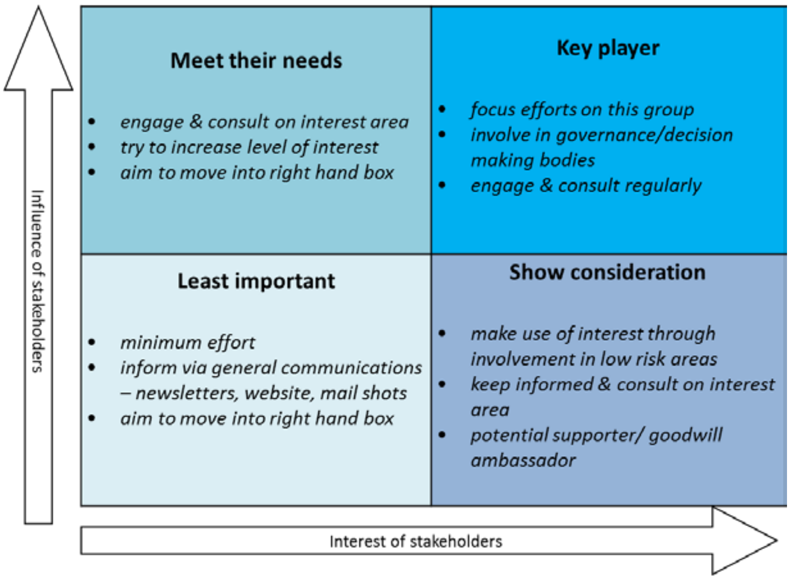


Figure 6 Example of Stakeholders' analysis matrix retrieved from BEinCPPS

In order to evaluate the stakeholders' level of influence and interest, a three-level qualitative evaluation scale can be adopted:

Table 2 Stakeholders level of interest and influence assessment scale

Level	Description
H	High
M	Medium
L	Low

The next step towards stakeholders' analysis is the understanding of the stakeholders' needs ("What is important for them?"), their ability to facilitate or challenge DIH/CC activities ("How can the stakeholder contribute/block the activities?") and how to keep them engaged ("How to engage stakeholders"?).

This AS IS scenario information can be collected by use of questionnaires, interviews, etc. and then stored in a database for further processing and analysis required along the MIDIH project.

Table 3 Example of AS IS scenario dataset

Stakeholder name	Interest (L-M-H)	Influence (L-M-H)	What is important to the stakeholder?	How can the stakeholder contribute/block the DIH/CC actions?	How to engage the stakeholder?
X	L	H	Raise awareness. Use digital tech. for increasing competitiveness, econimic developments	Contribution providing experiments/use cases	Through workshops Experiments opportunity within their processes
Y	H	H			
Z	H	H			
	M	H			
	H	M			
	H	M			

4.1.3.3 *Portfolio of services*

The current scenario must be described focusing on the current services the DIH/CC is able to provide to manufacturing enterprises. The AS IS scenario must be defined including the "Access to" services currently deployed. In order to specify and list the actual services' offer, the following table provides an example of categorization for different "Access to" services defined in BEinCPPS project on which MIDIH project is building on (for further details refer to paragraph 1.4). The "Access to" services categories can be further expanded and/or modified along the project.

It is relevant to consider that in the AS-IS scenario it has to be seen how much the actual DIH/CC services fit into the requirements categorization, considering that not for all there are the same requirements (i.e. for CC that Access to Market/Finance is not applicable and will also not be applicable in the TO BE scenario for those CC that do not aim at becoming a DIH).

Table 4 "Access to" services categorization for defined in BEinCPPS

Requirements categorization	Description
Access to Technology	To provide smart manufacturing technological solutions for start-ups/SMEs by means of Open Source components for the most generic and commoditised functions
Access to Competencies	To provide industrial capabilities and human Skills to support start-ups/SMEs in the implementation of Industry 4.0 projects
Access to Experiments	To provide the best practices and test exploitation open datasets for Start-ups/SMEs through pilot plants/teaching didactic factories
Access to Knowledge	To provide services related to the migration of Manufacturing start-ups/SMEs towards the new Industry 4.0 technologies
Access to Market/Finance	To offer services related to design/deploy a growth plan towards market and investors (for CPS/IOT solution providers (mostly start-ups and web entrepreneurs). To offer services of access to public/private capital sources to start-ups/SMEs in order to implement their Industry 4.0 projects.

It has to be specified that DIHs' focus is to provide access to all the 5 categories of services, while CCs do not provide services related to market/finance (which can constitute the basis for a potential TO BE scenario).

4.1.4 TO BE scenario

The desired (TO BE) scenario will be elaborated analysing the changes in the services the DIH/CC will be able to provide. This will be allowed by a change in the business and process settings, network of stakeholders, in the way the DIH/CC is able to improve the engagement of the current stakeholders and the engagement of new ones. The TO BE scenario will be depicted by highlighting the changes in the "Access to" services and network of stakeholders.

According to what specified in this document, the AS IS scenario is described according to the current DIH/CC business model and processes together with the current portfolio of services provided by the DIH/CC and the actual network of stakeholders, and the TO BE scenario deducted. The specification and then the achievement of the TO BE scenario follows the gap analysis between the actual (AS IS) and the desired (TO BE) situation. Gap analysis will constitute the basis for requirements elicitation and is intended to multiple purposes such as start envisioning the actual value proposition (in terms of services provided), business structure and implementation and evaluating which improvements are expected to be reached (in order to evaluate where to direct effort and resources), which aspects of the business features should be modified/added to reach the desired scenario. Another relevant purpose of the gap analysis is the identification of potential barriers and drawbacks that may currently limiting the actual business exploitation and betterment. In this case, risks are known as they characterize the actual environment for the current system and the role of MIDIH project is to help mitigate them in order to allow the achievement of the desired business objectives.

It may be helpful to list and specify the identified barriers by naming (one/few words) and describing them by use of free text (few sentences).

4.1.5 Business Objectives, Impacts and Indicators

4.1.5.1 *Business objectives and impacts*

In this RE process, the desired TO BE scenario is translated into business objectives referring to the expected configuration in the portfolio of services to be deployed and network of stakeholders. The new configuration is expected to impact on the business performances the DIH/CC desires to improve. Business objectives have to be listed, named (one/few words) and described (few lines). As well as business objectives, the desired impacts on specific DIH/CC performances have to be defined and collected. The business objectives fulfilment is expected to have a direct impact on the DIH/CC business performances and indirect impacts on the business performances of the stakeholders constituting the DIH/CC network.

4.1.5.1.1. For the DIH/CC

This section must include objectives and related impacts the DIH/CC expect to achieve through the collaboration within MIDIH project. Information has to be collected by use of questionnaires, interviews, physical meetings, etc. The information should be stored in a database for further processing and analysis along the project. Some examples are listed below:

- To search for relevant technical components, services, partners (both organizational and individual);
- To access country-specific legal and financial information (personal data, IPR, VAT, invoicing…);
- To assess the quality of relevant technical components, consultancy services, partners. To expose the offer of DIH and each of its separate partners inside the DIH;
- To log in and create DIH profile;
- To manage profiles of stakeholders within my DIH/network;
- To expose individual experts within DIH;
- To list R&D challenges among DIHs and search for scientific experts;
- To barter services/experts among DIHs;
- To calculate services and invoice other DIHs;
- Etc.

4.1.5.1.2. For the network of stakeholders

This section must include objectives and related impacts the DIH/CC expect to generate for the stakeholders that are part of its community (refer to 4.1.3.2.1). The information should be stored in a database for further processing and analysis along the project.

4.1.5.2 *Indicators*

The achievements and satisfaction of the defined objectives is related to the expected impacts generation both on the DIH/CC and the stakeholders’ business.

4.1.5.2.1. For the DIH/CC

Each service provided in the AS IS scenario and expected to change into the TO BE scenario must be associated to a KPI that will be able to measure the impact of the project on the performance indicators of relevant services provided by the DIH/CC. The KPI can be both qualitative and quantitative and belong to the socio-economic sphere. They must be defined and described. The AS IS value for the indicators must be declared and the expected TO BE value assumed. This information must be collected by use of questionnaires or interviews and stored in a database (i.e. spreadsheet) as the information can be further processes and analysed along the project.

4.1.5.2.2. For the network of stakeholders

Business indicators will be related to I4.0 Impact Dimensions that MIDIH project is expected to have an impact on. The project impact will be constituted by the actions undertaken from companies/organizations involved in the project, that are required to identify (for each I4.0 Impact Dimension) a business indicator to be monitored along the project and which will give the measure of the magnitude of each single stakeholder’s impact on the defined dimensions.

This is a relevant point to link MIDIH outcomes to the European manufacturing impact dimensions priority. BEinCPPS project has defined six I4.0 Impact Dimensions (Cost, Efficiency, Flexibility, Sustainability, Quality, and Innovation), from which the table below was retrieved reporting the Industry 4.0 Impact Dimensions suggested for MIDIH project.

Table 5 Business indicators for stakeholders’ I4.0 impact evaluation

Industry 4.0 Impact Dimensions	**Short Description**
Scalability – The extent to which the new/modified process/product can grow and/or win new markets	Stakeholder Business Indicator
Cost - The costs associated with operating the organization's supply chain processes	Stakeholder Business Indicator

Efficiency - The extent to which the organization's resources (e.g. time, use of facilities) are exploited	Stakeholder Business Indicator
Flexibility - The extent to which an organization's supply chain supports changes in product or service offerings (e.g., features, volume, and speed) in response to marketplace changes (e.g., competitors, legislation, technological innovation etc.	Stakeholder Business Indicator
Feasibility – The extent to which the new process/product is financially and technically feasible	Stakeholder Business Indicator
Sustainability - The extent of usage of an environmental resource, so that the resource is not depleted or permanently damaged	Stakeholder Business Indicator
Quality - The degree to which the outcome of the process fulfils customer's needs and requirements	Stakeholder Business Indicator
Innovation - The extent to which the organization introduces new processes, products, or services	Stakeholder Business Indicator

The stakeholder is required to associate a weight to each I4.0 Impact Dimension by use of a 5-point Likert-Scale evaluation metric where:

- 5: Strong impact
- 4: Impact
- 3: Discrete impact
- 2: Low impact
- 1: No impact

The stakeholder must provide a brief description of the expected impact it will provide for each impact dimension where the relevance of the impact is at least equal to 2.

4.1.6 Benefits

The transition from the AS IS to the TO BE scenario has to be translated into expected benefits for the DIH/CC itself and for the network of stakeholders, part of the DIH/CC community.

4.1.6.1 *For the DIH/CC*

According to the objectives and related indicators defined in the sections above, the benefits the DIH/CC expects to achieve at the end of the project must be listed, named and briefly described.

4.1.6.2 *For the network of stakeholders*

According to the objectives and related indicators defined in the sections above, the benefits the stakeholder expects to achieve at the end of the project must be listed, named and briefly described.

4.1.7 Business requirements elicitation

Each scenario is associated to a list of business requirements that correspond to the breakdown structure ancillary to a successful achievement of the desired scenario. Each of the elicited requirements should be coded, named and described.

In order to capture business requirements, different approaches can be used. One popular approach used during the business requirements elicitation process is the story telling approach because it allows risk reduction of catching misleading/false requirements (Ribeiro et al. 2014) (Vink 2015). Another method able to ease the requirements elicitation process in a complex environment is represented by gamified approaches, characterized by the use of game-based constructs and mechanisms in a non-game environment (Johnston et al. 2015). The motivating aspect is one of the most relevant benefits of this technique compared to more traditional approaches (Wiesner et al. 2016). The best approach for business requirements elicitation will be selected along the project.

The elicited requirements have to be collected and stored in a database for further analysis and processing related to MIDIH purposes.

Table 6 Business requirement collection template example

Req	**Business requirement**	**Business Requirement Description**
BR0X		

In order to guarantee a common understanding of requirements for DIH/CC and comparable information for the further steps of requirements analysis, specification, verification and validation, requirements should be elicited suggesting an a-priori categorization structure and then grouped according to common principles. An example of categorization is proposed in Table 4 (Chapter 4.1.3.3), which can be a starting point for further expansions and/or modifications. Furthermore, in order to maintain the requirements elicitation process simple and coherent among the involved parties, each requirement's category is further detailed in specific groups of requirements. Table 8 proposes an example for possible grouping rationales. The elicited requirements must be organized in a repository (database) for further processing.

Table 7 Business requirements grouping rationales from BEinCPPS project

Access to Technology	**Access to Competencies**	**Access to Experiments**	**Access to Knowledge**	**Access to Market/Finance**
OSS Catalogue	Assets management	Lighthouse Experiments	Maturity Model	Ideas Incubator
Reference Architecture	Team Building	X-border	6P Migration Model	Business Acceleration
Applications Marketplace	Partner Search	KPIs lesson learned	Training & Formation	Capital & Funding

4.2 Business requirements analysis

The main purpose of this RE process is to verify the coherence between the elicited business requirements and the identified expected scenario/s. The most suitable approaches for the requirements analysis can be conference calls, interviews, workshops and collective sharing and analysis of the elicited requirements.

MIDIH project aims at creating a network of DIHs/CCs to facilitate particularly entrepreneurs and SMEs access to smart specialization. For this reason, in order to facilitate requirements elicitation and capturing, "Access to" services categorization structure has been proposed *a-priori*. Requirements analysis will concentrate on the identification of eventual further "Access to" categories that may arise from the elicitation phase and that do not suit into the a-priori categorization schema provided. This action will allow enriching and extending the current identified services that DIHs and CCs should provide in order to create a Collaborative Platform able to serve start-ups and SMEs in their smart specialization towards I4.0 manufacturing.

Moreover, in order to maintain the requirements elicitation process simple and coherent among the involved parties, each "Access to" could be further detailed along the project if needed. These proposed sub-grouping can be further enriched during the requirements analysis process.

Categorization and grouping of the elicited requirements is core to identify the coherence of requirements within each "Access to" service category and to avoid misalignment among requirements captured.

Furthermore, in order to enable the next processes towards the desired scenarios deployment, requirements must be organized in a priority-ordering framework. Thus, each requirement must be associated with a specific level of priority according to its relevance for the accomplishment of the final scenario.

4.3 Requirements specification

In this part of the RE Framework methodology, the business requirements identified in previous sections must be declined in operational requirements (plans and actions). Thus, the value proposition, the service offer delivery and all the actions needed to fulfil the defined objectives linked to the scenario must be specified. In order to structure and deploy a plan for the fulfilment of the elicited requirements and related objectives, the business processes have to be structured in business workflows, the value proposition, the resources needed and all the other elements characterizing the business planning and modelling must be specified.

Furthermore, in MIDIH, the two RMDIH selected from BEinCPPS Phase II project must highlight the way in which they would deploy the business plan and business model already defined in BEinCPPS project. The business deployment may require changes or adaptions according to changes in the AS IS scenario that have affected also the expected objectives and requirements.

4.4 Requirements validation

The V&V process allows understanding whether the objectives defined in the first RE Framework iteration step have been fulfilled. Thus, the coherence between the expected impacts and the requirements' fulfilment is matched. In this light, the suitability of the actions undertaken by the DIH/CC in the first iteration of the project, the planned operative steps and business processes and business modelling are critically analysed, criticalities are sought and must be solved.

4.4.1. Portfolio of services

It has to be verified if the portfolio of services characterizing the desired scenario has been actually deployed. Any reason for the impossibility to the deployment must be reported.

4.4.2. Impact

The impact of services deployment will be evaluated in two steps.

4.4.2.1. For DIH/CC

The defined target KPI indicators associated to each service offered by the DIH/CC will be compared with the actual one.

4.4.2.2. For the network of stakeholders

The business indicators related to the TO BE scenario expected impacts on the stakeholders' business performances have to be verified by data collection for the business indicators actual value then compared with the target value.

4.4.3. Lesson learnt

In this section, the DIH/CC must verify the changes (if any) to implement in the second iteration for the RE methodology. This section is important to identify the reasons behind any misalignment between the expected and actual results obtained after the deployment of the operational planning of business activities defined in the requirements specification phase. The reasons for misalignment to occur may be different. The correctness of the objectives' and related impacts identification has to be verified, as well as the correctness of impacts' magnitude estimations (check for under/over estimations). Furthermore, once the eligibility of the requirements elicitation process (objectives and impacts estimation) is verified, the reasons for failures in the deployment of the TO BE scenario have to be sought in the operational and business planning developed in the requirements specification phase of the RE. Finally, external events may affect the results of the implemented strategy such as changes in the stakeholders' community setting or the modification of stakeholders' needs. These evidences will constitute the starting point for the RE Framework iteration by modification of the actual new AS IS scenario.

5 Industrial Experiments RE Framework: approaches and tools

This chapter depicts the adaption of the RE Framework presented in Chapter 3 to Industrial Experiments. Differently from what concerns the RE Framework methodology proposed in Chapter 4 for DIH/CC, Industrial Experiments focus more on the technological side of digitalization of processes/systems/value chains of the manufacturing partners involved in MIDIH project. The final aim is the business performances' improvement of Use Cases partners and of the organizations/companies belonging to their network. This is achieved through the digitalization process of manufacturing and thus, in a broader meaning, the expectation is to create expertise and lessons learnt to contribute improving the competitiveness of European manufacturing industry at large.

In MIDIH project (and in real life) DIHs/CCs are expected to play a relevant role in the manufacturing digitalization process and thus they are involved in the deployment of Industrial Experiments along the project. In that light, the main contribution of DIHs/CCs lies in the provision of the resources needed from the Use Cases to fulfil and satisfy the requirements coming from business needs (refer to the following paragraph 5.1) for a clear understanding of the difference among Industrial Experiments and Use Cases).

5.1 Industrial Experiment VS Use Case: definitions

In MIDIH project (and as well in this document) it is referred to "Industrial Experiment" and "Use Case" not as synonymous, as they are not intended to have the same meaning. For this reason, a brief explanation of the sense given respectively to Industrial Experiments and Use Cases is priority to introduce Chapter 5.

5.1.1 Use Case (UC) Definition

The first clarifying difference between IE and UC is that a single UC is characterized by at least one IE, which means that the relation between the two it is explained by the ratio 1: (≥1). A UC cannot exist without an IE, but different experiments can refer to the same UC. The reason for that lies on the different nature of the two.

The UC can be described as a series of interactions (that can be represented by a list of actions or event steps) between actors (i.e. a user of the system) and the system under consideration to achieve a goal (Cockburn 2001). Actors are not necessarily humans, as they can be persons, organizations, companies, hardware and/or software, etc. It has to be noticed that actors are always system's stakeholders, but not all the stakeholders are actors as they do not directly interact with the system and cannot make decisions over the system (Cockburn 2001).

In systems engineering use cases often represent missions or stakeholders goals and are often used to capture the requirements of a system that specify the intended behavior of the system (Ferreras et al. 2014). Use cases and initial requirements coming from stakeholders' needs are going to be used for the requirements specification activity. Furthermore, the use case development has the central goal of describing the main functionalities of the system (then transformed in specific actions) that constitutes the primary input for the desired system design, development and deployment (Jacobson et al. 2011).

There are the three basic elements that make up a use case (3):

- Actors: Actors are the type of users that interact with the system.
- System: Use cases capture functional requirements that specify the intended behaviour of the system.
- Description/goals: Use cases are typically initiated by a user to fulfil goals describing the activities and variants involved in attaining the goal.

These basic elements can be extended to offer a better description of the use case, to help in the development of functions and requirements and the information can be stored in specific Use Case templates (i.e. Use Case Template).

In MIDIH project (and as well in this document) the Use Case represents the rationale behind the industrial experiment/s to occur.

5.1.2 Industrial Experiments (IE) Definition

According to the scientific world, the experiment is an empirical procedure to compare competing models or hypotheses and also to test existing theories or new hypotheses to support or disprove them (Griffith & Brosing 2001). Hypotheses are the expectation about how a particular entity (process, system or phenomenon) works. However, experiments can be conducted with the final aim to answer a "What-if" question, without a specific expectation about the experiment outcome. Experiments provide insight into cause - effect relations among different part or variables describing the entity under study by demonstrating what outcome occurs when a particular factor is manipulated. Experiments deliver demonstrators and need to show a substantial measurable strategic and/or economic impact.

More specifically, in engineering disciplines experiments are the primary component of the scientific method. They are used to test how physical processes or systems work under particular conditions. IEs' focus on processes is one of their main characterizing elements. Experimentations are generally performed to increase knowledge of a particular machine/process/system and to adjust the settings/components of a machine/process/system in a *systematic* manner and to learn which factors have the greatest impact on the resultant outcome, which modifications are needed and how the modification work in a field/laboratory/virtual environment (Antony 1999). Specifically, the goal of IE is to identify the optimum settings for the different factors that affect the machine/process/system.

In that light, in MIDIH project (and as well in this document) it is referred to IE as the deployment of the developed system/solution intended to the digitalization of specific manufacturing processes/activities/value chains in a field/laboratory/virtual environment to arise business performances of the involved manufacturing enterprises and, in a broader meaning, of manufacturing industry.

5.2 Scenario analysis and requirements elicitation

5.2.1 Use Case description

An overall picture of the Use Case must be provided in this section where the use case must be named and described.

The Use Case partner's (the company that wants to go through a process of digitalization of its processes/system/value chain) **name** must be recorded as the name of the manufacturing company (SME/start-up) involved and further information that will be considered important for further analysis.

Descriptive information related to the Use Case partner must be stored in a database (i.e. spreadsheet) for further use along the project: Name, Sector, Size, Country, and Domain.

Sector. The Use Case partner must operate in one of the Industrial Sectors defined as the most promising for the digitalization of the European Manufacturing listed below[7]. Whether the Use Case partner does not fit the reference sectors, it belongs to the option "OTHER", which must be specified. If the Use Case partner operates in more than one sector, it has to refer to the sector of application of the Use Case in analysis.

- AUTOMOTIVE
- AEROSPACE
- MACHINERY
- METAL PRODUCTS
- TEXTILE
- ELECTRICAL EQUIPMENT
- OTHER

Domain. Some examples of domains are listed below:

- IOT (INTERNET OF THINGS)
- DIGITAL TWINS SIMULATION MODELS
- ADVANCED ROBOTICS
- BIG DATA ANALYTICS
- VIRTUAL/AUGMENTED REALITY
- CYBER SECURITY
- 5G
- M2M COMMUNICATION
- ETC.

[7] https://www.strategyand.pwc.com//digitization/sector

5.2.2 Scope of the Use Case

The scope of the Use Case refers to the explication of the Use Case final goal which can be reassume to the **vision**. This information must be enclosed in a sentence.

The use case X aims at introducing innovation to enhance quality control procedures, evolving from reactive statistical control to proactive real time quality control.

Figure 7 Example of Use Case vision declaration

In order to further communicate the expectations and impacts from MIDIH project, the Use Case must use free text to describe how the digitalization strategy is expected to change the actual processes and impact on overall performances.

> The CPS-ization of the current ZHQ (Zero Hours Quality) system will allow usage of mobile testing stations (strategy CPS1), enhanced operator interaction (strategy CPS 2) and auto-reconfiguration of the testing stations (strategy CPS 3), thus improving throughput and effectiveness of the system (the latter by the possibility for the operator to interact through mobile device and modify the testing programs on the fly).
>
> Furthermore, while, in the current situation, quality testing is based on threshold rules, focused on the identification of the most critical situations (such as pump does not provide target pressure), with the CPS-ization will make possible to highlight more in detail and in real time, a wider set of potential problems (CPS 4), for instance by comparing the dynamic behavior of each component to the expected one (such as pump pressure is constantly oscillating +- (X) % around the target pressure).
>
> The innovation will also improve the company knowledge related to production, as possible malfunctions might be directly related to the production process feeding the system, therefore enabling immediate correction in the upstream production lines or in the purchasing and logistic channels.

Figure 8 Example of digitalization strategy description and implications retrieved from BEinCPPS

5.2.3 AS IS Scenario

The actual (AS IS) scenario is defined as the current system characterized by specific features and related performances that are expected to improve through the digitalization of the current system itself. The AS IS scenario must be described by use of free text to provide an overall picture of the areas of interest and current functionalities to guide future interventions, information on the architecture and operations.

5.2.3.1 Introduction

A general introduction is required to highlight which activities and processes have to be approached in order to understand the areas of interest for further interventions to be undertaken. Furthermore, the main objectives of the current system must be clearly stated.

The department/s and operators involved in the current operations management are also relevant for the understanding of the actual system structure and performances. Therefore, it is recommended to refer to the people involved in the daily system management and running when describing and analysing the current system.

5.2.3.2 *Basic Functionalities*

The main functionalities of the current system have to be clearly listed following an ordination numbering. Each functionality must be named (one/two words) and described (one/two sentences) by use of free text. Any further data source (i.e. images) that would provide a better understanding of the actual system's functionalities can be added as clarifying element.

CPS at ZHQ provide four basic functions:

1) Guided operations: operators are instructed in real time to perform sequence of tasks to check and measure products (Rule Editor)
2) Programmability: sequence of tests can be programmed by Quality managers using a programming tool (Rule Editor)
3) Automatic I/O: the product under test is interfaced both in input (actuators) and output (sensors) to automatically change state of product and gather data (Box Handler)
4) Data management: data are stored and available for immediate or historical analysis (Display Result)

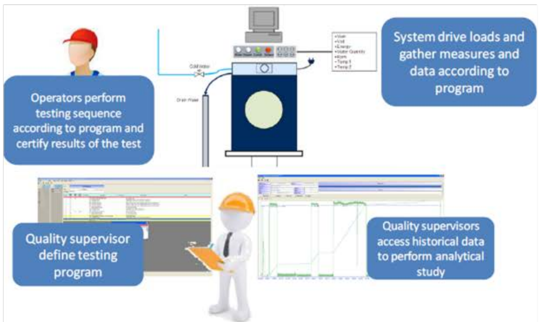


Figure 9 Example of AS IS system functionalities retrieved from BEinCPPS

5.2.3.3 *Architecture*

The description of the current architecture must be provided by use of free text (max half page), with the description of the hardware and software components. Hardware components must be specified with their type, functionality (their role in the system process, the measures they capture, etc.), and whether the functionalities provided are basic or advanced. The description of software components focuses on the identification of the type of component, the activities/actions they allow (i.e. program, control, etc.) including virtual integration of the hardware components of the system. The need for operators to manage hardware or software components must be specified.

The CPS involved is composed by subordinated control stations able to connect to the product to sense and measure values such as power consumption, tension applied, water flow, drum speed, temperatures etc. Stations are divided, according to their functionality, in Basic and Advanced. The whole CPS is made of 20 basic station and 4 advanced stations controlled by 6 Window XP PCs running SQL 2000 as database. At each station a programmable sequence of tests can be started and managed by the operator according to the product under test. Stations I/O are controlled by a group of 6 Beckhoff PLC BC9000. Each PC is also equipped with a laser scanner used to read product barcodes and identify both the product model code and the serial number.

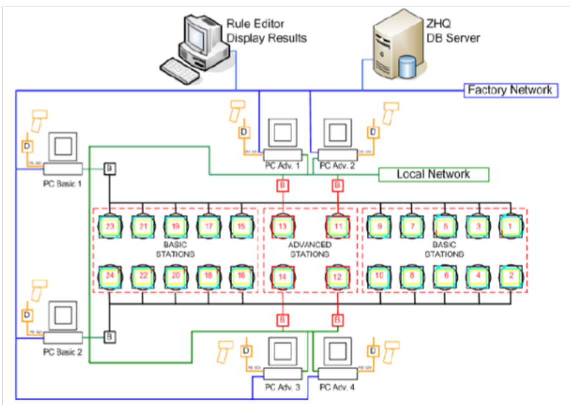


Figure 10 Example of AS IS system architecture retrieved from BEinCPPS

5.2.3.4 *Operational details*

This section provides a general understanding of the typical cycles of the running process. The description must follow the sequential logic of the process, specifying the required inputs necessary to obtain a certain output, involved components and operators. The description must be provided by use of free text (max half page) and flow charts that would describe the communication between components of the scenario.

5.2.4 TO BE Scenario

5.2.4.1 *Approaches and tools to define future scenarios*

In order to facilitate the definition of digitalization scenarios, different approaches can be adopted further the perception and experience of the use case partner. Two different approaches are presented and describe below. Even if they have not been specifically developed for MIDIH project, they are scientifically consolidated and accepted approaches that can serve as example or good accelerators for the TO BE scenario definition process.

5.2.4.1.1. Black box modelling

The Black Box Modelling approach applied to system engineering is an abstraction aiming at representing the functioning of an system by viewing it solely in terms of its *stimuli input* and *output reactions* (Beizer 1995). The Black Box Modelling can be currently considered a useful approach to scenario definition also in the IOT domain.

This approach allows the Use Case partner focusing on the input-output logic of the system without being influenced from the current features, functionalities and implementation to avoid bias. This approach eases the definition of the desired (TO BE) scenario starting from the model of the AS IS architecture. This modelling approach uses black boxes that receive specific flows of information as inputs and are expected to generate as outputs flows of information correlated with the defined inputs.

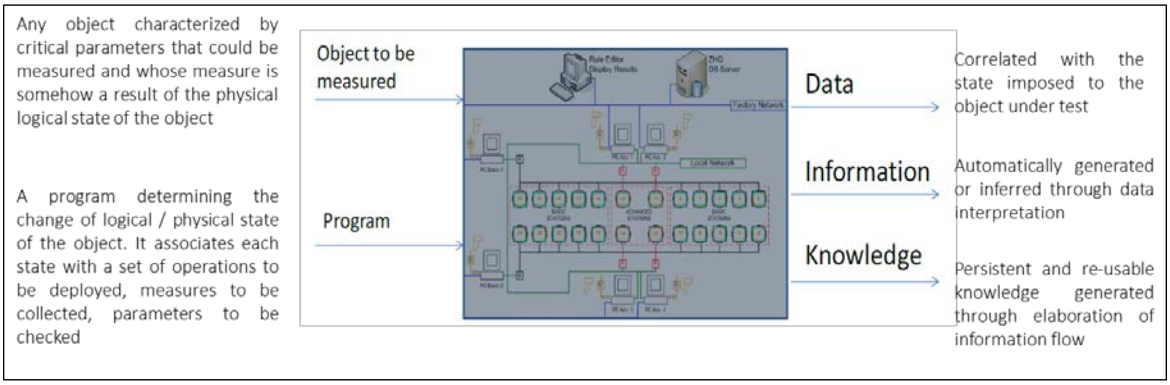


Figure 11 Black box modelling template and specification retrieved from (Beizer 1995)

5.2.4.1.2. 5C Architecture

Due to the fact that one of the most recent focus of digitalization refers to Cyber Physical Systems (CPS), it may expect that future scenarios can be developed under the concept of CPS-ization, a neologism that encompass all the actions needed to transform a system into a CPS or to improve the degree of development of both cyber part or its integration with the physical part. The 5C Architecture approach proposed by Lee et al. (2015) allows the Use Case partner addressing all the functional (and not necessarily technical) aspects of the CPS-ization. The figure below reports the C architecture for Industry 4.0-based manufacturing systems and an example of how functions and parts of equipment could be mapped to the 5C architecture.

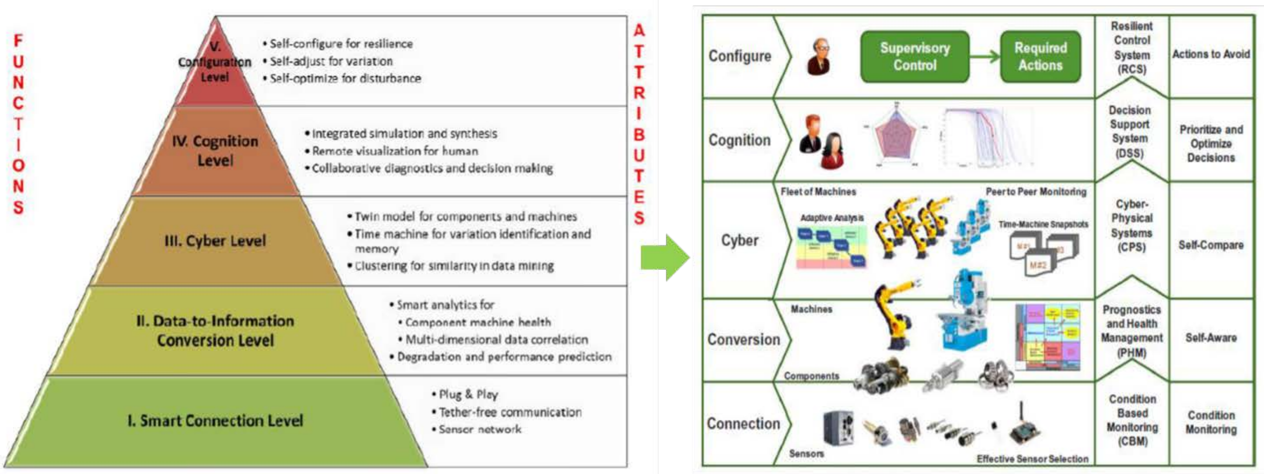


Figure 12 5C architecture and example of components mapping retrieved from (Lee et al. 2015)

5.2.4.2 *Digitalization scenario definition*

This section is dedicated to the identification of the TO BE scenario. Each Use Case must be related to one TO BE scenario, which represents a modification and evolution of the actual physical and logical characteristics and functionalities of the system. The scenario must be named and described in terms of provided functionalities that are not available in the actual system. The system components that are involved in the expected changes must be reported. The name of the digitalization scenario (one/few words) identified must be self-explaining of the desired new functionality of the expected system. The scenario description must be provided by use of free text (max half page) and figures to facilitate the understanding of the expected system. The TO BE scenario description can be also facilitated by compiling the Black Box modelling template.

According to what specified in paragraph 4.1.4, the AS IS scenario is described according to the current running processes and the TO BE scenario is deducted through the gap analysis. The identification of the most relevant areas of intervention to pursue the final business objectives and risks mitigation is a relevant issue to be considered (for further details refer to Chapter 4.1.4).

It can be helpful to list and specify current drawbacks (barriers) by reporting the name (one/few word) of the identified barrier and a description by use of free text (few sentences).

ZHQ presents some drawbacks that are currently limiting its full adoption in the use case's factories:

1) **Mobility**. Operators are required to frequently interact with the appliance under test and a full help from system is available only at advanced stations, where a 1:1 relation between appliance and PC is available. On Basic stations the distance between supervisor computer and appliance is of several meters and thus this help is unavailable. Moreover, operators need often to operate at the same time on the computer and on the appliance (e.g. reading barcode, or gather images, open door, touch buttons, etc.). As a result not all the functions of Rule Editor (i.e. complex and customized programming sequences) have been implemented yet.

2) **Scalability**. A full implementation of ZHQ requires important investments in hardware and software and is not easily scalable down and up. As a result only factories with complex products and incidentally availability of capital installed it, while other still rely on semi-manual implementation of statistical check.

3) **Data Interoperability**. Despite a standard system, ZHQ still lack a full integration with other company systems (ERP, MES, BI, etc.). As a result, a great amount of relevant data is not currently being shared and used by other functions.

Figure 13 Example of current drawbacks description retrieved from BEinCPPS

Drawbacks may also arise along the transition from the AS IS towards the TO BE scenario and then need to be mitigated. In this situation, risks are not identifiable *a priori* as they may arise along MIDIH project. Therefore, the skills and the ability of entities involved in MIDIH project (refer to 1.1) will serve to mitigate the risks and try to overtake the upcoming drawbacks.

5.2.5 Business Objectives, Impacts and Indicators

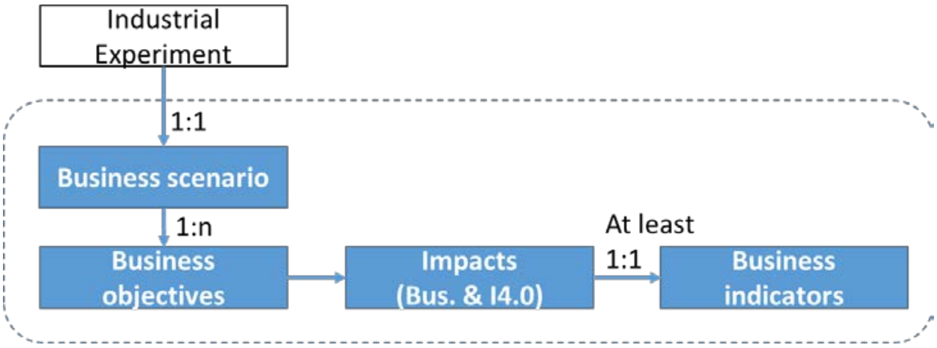


Figure 14 Framework structure to business indicators definition

5.2.5.1 *Business objectives*

After the Use Case partner defines the TO BE scenario, the desired scenario is translated into business objectives. Business objectives can exceed a 1:1 relation with the business scenario, as changes in the structure and functionalities of the current systems can generate benefits for different performances in the business of the Use Case partner. The objectives refer to the expected functionalities the new system's configuration will allow and that are expected to impact on business performances the use case desires to improve. Business objectives have to be listed, named (one/few words) and described (few lines).

5.2.5.2 *Business processes*

The take-up of the AS IS scenario (analysing the current running processes) and deduction of the TO BE scenario allow the identification of gaps that highlight the weaknesses and bottlenecks for the transition from the AS IS towards the TO BE scenario.

According to the RE Framework, in order to maintain alignment between the defined TO BE scenario and objectives, the identification and definition of the business processes (BP) is necessary. The analysis and description of the BP that support the link between the scenario and the requirements can be eased by the use of state of the art methods (use case models, BPMN, extended actigrams, UML, etc.). The definition of the BP helps to identify precisely how the system/solution to be deployed will support the transformation of the AS IS processes to the new TO BE situation. BP must be defined, named and collected.

5.2.5.3 *Business impacts and indicators*

5.2.5.3.1. Expected results and indicators

According to each BP identified in the previous section, a business process indicator (BPI) must be defined. The definition of a BPI is ancillary to guarantee the understanding of the expected results. Thus, the use case must declare the expecting positive results on specific impacts areas.

KPI	***IMPACT AREA*** *(technical, process, business, IH, region, sector…)*
TCQ, Total Cost Quality (€/unit)	*Quality*
ZHQ productivity, (# test/shift/person)	*Process Cost, Quality Cost*
12M SIR, (calls/units sold)	*Consumer Quality*
1M SIR (calls/unit sold)	*Consumer Quality*
FOR (# defects/units produced)	*Production Process Quality*

Figure 15 Example of Business KPIs definition and relation with impact areas retrieved from BEinCPPS

5.2.5.3.2. Industry 4.0 impacts

The achievements and satisfaction of the defined objectives is related to the expectation of impacts' generation on the Use Case partner business. Similar to the impacts evaluation proposal for DIHs/CCs (refer to paragraph 4.1.5.2.2.), BPI will be related to six defined I4.0 areas the project is expected to impact (Cost, Efficiency, Flexibility, Sustainability, Quality, Innovation). The Use Case partner have to evaluate the relevance of each area of impact on its TO BE scenario by use of a 5 point Likert-Scale evaluation metric (refer to Chapter 4.1.5.2.2).

The Use Case must provide a brief description of the expected impact he will provide for each area where the relevance of the impact is at least equal to 2.

Industry 4.0 improvement areas	Relevance (1 – 5)	Business Impact description
Cost - The costs associated with operating the organization's modification processes		Use Case-specific
Efficiency - The extent to which the organization's resources (e.g. time, use of facilities) are exploited		Use case-specific
Flexibility - The extent to which a organization's supports changes in product or service offerings (e.g., features, volume, and speed) in response to marketplace changes (e.g., competitors, legislation, technological innovation etc.		Use Case-specific
Sustainability - The extent of usage of an environmental resource, so that the resource is not depleted or permanently damaged		Use Case-specific
Quality - The degree to which the outcome of the process fulfils customer's needs and requirements		Use Case-specific
Innovation - The extent to which the organization introduces new processes, products, or services		Use Case-specific

Figure 16 Industry 4.0 improvement areas and business impacts from BEinCPPS

Industry 4.0 improvement areas	Relevance (1 – 5)	Business Impact description
Cost - The costs associated with operating the organization's modification processes	4	**Total Cost of Quality (TCQ):** Statistical quality check implies both capital investment and human labour force

Figure 17 Example of business indicators summary retrieved from BEinCPPS

5.2.5.4 *Benefits*

Each business KPI identified in the previous section have to be defined according to the expected benefits. Thus, there must be a univocal relation between the BPI and the benefits expected from the implementation of digitalization solutions. Benefits must be listed, named (the name must be short and explicative for the KPI/area of impact it refers to) and described by use of free text. All the information collected during the business objectives and impacts analysis must be collected and stored in a database (i.e. spreadsheet) with the following characteristics:

Business Process	Business Objective	Business Impact	I4.0 Impact	Bus. Process Indicator	Benefits Description	Facts and Figures
Create test rule	To minimize time for new rule generation	Optimize ZHQ flow time	Efficiency	Time for new rule generation (minutes)	Now the use case quality managers sets up test instructions and program on the basis of test information of similar products, by relying on personal knowledge	The use case estimates that test programming and preparation might be reduced, on average, by X minutes in Y minutes

Figure 18 Example of business objectives, impacts and indicators dataset retrieved from BEinCPPS

5.2.6 Business requirements elicitation

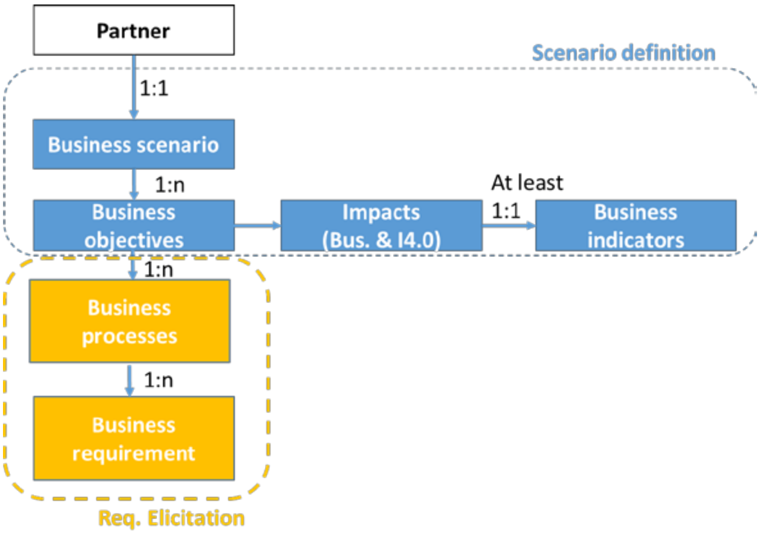


Figure 19 Requirement elicitation structure and relation with scenario definition

In line with the approaches proposed in the RE Framework, the elicitation process derives from the take-up of the AS IS scenario (analysing the current running processes) and deduction of the TO BE scenario. The gap analysis highlighting the weaknesses and bottlenecks for the transition from the AS IS towards the TO BE has created the basis for the requirements elicitation.

The definition of the BPs helps to identify how the system/solution to be deployed will support the transformation of the AS IS processes to the new TO BE situation and guarantees the coherence of the elicited requirements, that are ancillary to the business objectives satisfaction. During the elicitation phase, more than one business requirement (BR) can be captured and linked to each BP. Thus, BRs must be collected for the digitalization scenario and partners' involvement will be required in questionnaires filling, interviews, technical meetings and phone conferences to share initial requirements. Then, BRs elicited from each use case must be organized in a database, for further processing, integration and classification, evidencing BR identification number (Req), name and description.

Req	Business Requirement	Bus. Requirement Description
BR01	Acquisition of hystorical data on tests	During threshold definition quality manager can access hystorical data on test performed for the same or similar products
BR02	Support by mobile for single test run	Testing execution should be supported by application running on a mobile device
BR03	Execution of the test program on the portable testing unit	Test program should run the same as before on portable testing unit which includes controller and actuators connected to the appliance to be tested
BR04	Support by mobile to follow multi-ple testing units	Mobile application should allow quality operator to monitor in a single screen all testing units under her-his control and to switch on the single one
BR05	Test program change	Quality operator should be able to change the test program parameter if needed on the mobile interface
BR06	Sampling rate information	Qualiy operator should be able to access sampling rule- rate for the product under testing
BR07	Sampling rate change	Quality operator if needed should be able to change statistical control sampling rule-rate on the mobile
BR08	Support for test data analysis on the mobile device	Quality operator should be supported by the mobile application right after the completion of the test run by application that propose her-him if the test just run belongs to cluster of test data normal or anomaly-unknown
BR09	Support for test data confirmation on the mobile device	Quality operator should be able to complete the test by confirm test result -code (as per as is situation and furthermore to complete this by confirm the test just run belongs to normal or anomaly cluster
BR10	Additional data by user via mobile	Quality operator should be able to input additional data (such as comments and notes) to the test data
BR11	Support for multimedia data acqui-sition via mobile device	Quality operator should be able to acquire multimedia data (such as photo or sounds) with the mobile and store them in the test result data
BR12	Data analytics for test results	Quality manager should be able to perform analysis of data clustering on test data and results by validating the relationship between each cluster and its normal-anomaly flag

Figure 20 Example of business requirements collection tool retrieved from BEinCPPS

Furthermore, in order to guarantee coherence between the scenario analysis and requirements elicitation, each elicited requirement must be linked with one of the BPs previously identified. This type of information must be collected and stored in a database (i.e. spreadsheet), or in other type of documents.

Business Process	Business Requirements (BR)
Create test rule	BR01 - Acquisition of hystorical data on tests – Critical
Execute test	BR02 - Support by mobile for single test run - Critical BR03 - Execution of the test program on the portable testing unit - Critical

Figure 21 Example of business process and business requirements link retrieved from BEinCPPS

5.3 Business requirements analysis

This action guarantees the coherence and the quality of the elicited requirements, the elimination of misleading requirements and allows creating the basis for the requirements categorization.

As no a-priori categorization framework has been suggested during the elicitation process, the requirements categorization for the Use Case must concentrate both on the relevance (in terms of priority) of the requirements and on their relevant characterizing attributes.

Thus, each BR must be categorized as follows:

- BP addressed;
- Priority (critical = must have, preferred = should have);
- World (Real, Digital, Virtual);
- Start-up/SME/LE/General Focus;
- Functional/Non-Functional type.

Req	Business Requirement	BusinessProcess	Priority	World	SME-LE Focus	NON-FUNCT.REQ
BR01	Acquisition of hystorical data on tests	Test rule creation	Critical	Digital world	General	Functional
BR02	Support by mobile for single test run	Test execution	Critical	Digital world	SME focus	Functional
BR03	Execution of the test program on the portable testing unit	Test execution	Critical	Real world	SME focus	Functional
BR04	Support by mobile to follow multiple testing units	Test execution	Critical	Digital world	General	Functional
BR05	Test program change	Test execution	Preferred	Digital world	General	Functional
BR06	Sampling rate information	Test execution	Preferred	Digital world	General	Functional
BR07	Sampling rate change	Test execution	Preferred	Real world	General	Functional
BR08	Support for test data analysis on the mobile device	Data storage and analysis	Preferred	Digital world	LE focus	Functional
BR09	Support for test data confirmation on the mobile device	Data storage and analysis	Preferred	Digital world	SME focus	Functional
BR10	Additional data by user via mobile	Test execution	Optional	Digital world	SME focus	Functional

Figure 22 Example of requirements categorization and data storage retrieved from BEinCPPS

Further grouping/categorization can be suggested.

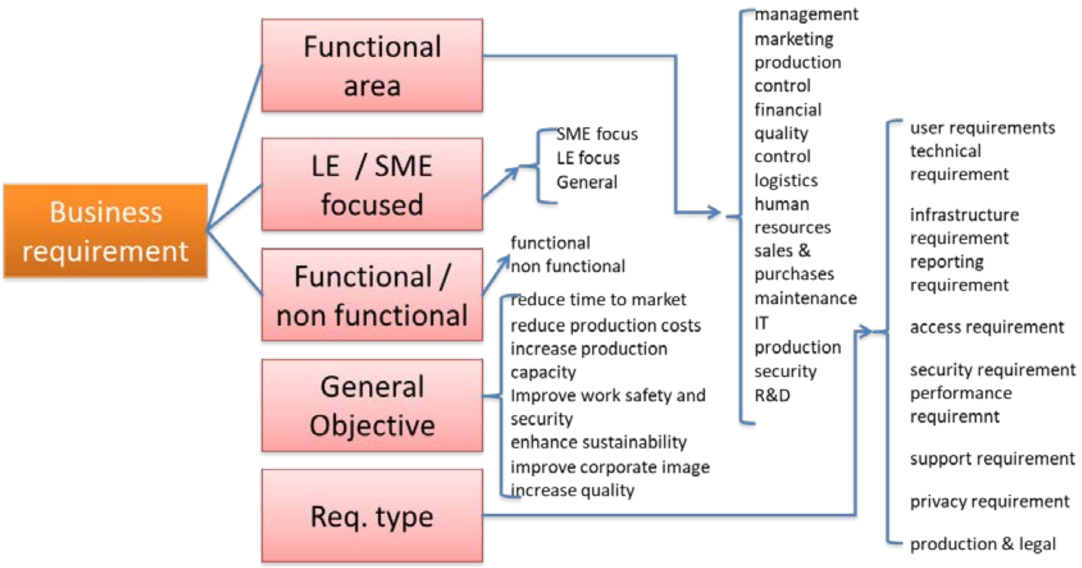


Figure 23 Data structure retrieved from FITMAN Project

5.4 Requirements specification

5.4.1 IT requirements

In the third phase of RE Framework, Requirements Specification, IT requirements have to be devised by the technical partners on the basis of the business requirements. Architecture design occurs in a way that IT requirements are matched by the IT artefacts connection in a wider IT architecture (software and hardware).

Each experiment may be deployed thanks to the identification of IT requirements linked to each business requirement and then test cases should be developed/ planned and performed.

Each of the experiments needs to specify the required resources in order to identify the corresponding DIH that is able to fulfil these requirements. Supported experiments can range from on-premises scenarios, where data does not leave the internal infrastructure, to cloud-based solutions where data is being analysed in data centres of third parties. Thus, also the classification of data is important to be considered, while discussing about the deployment scenario to support the experiment.

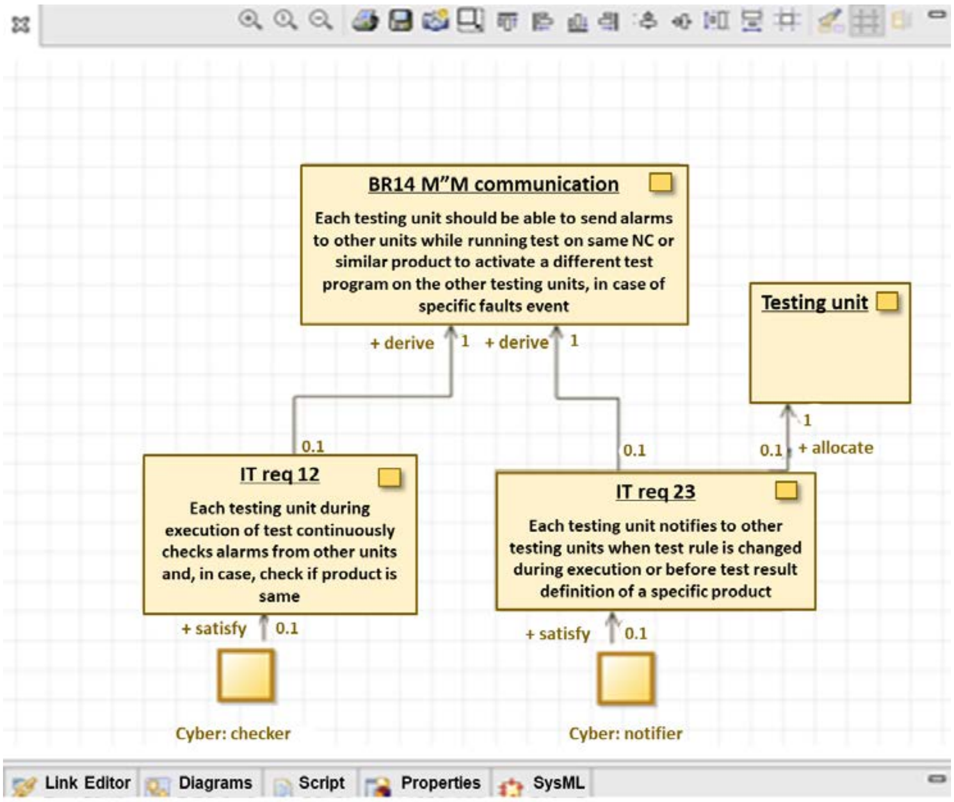


Figure 24 Example of relation between IT requirements and business requirements

This action overlaps with the next RE Framework step, Verification and Validation, as the continuous check of coherence between the partially developed IT architecture proposed as solution allows the verification of the right functioning of the developed solution and feedback mechanisms. Thus, the feedbacks and recommendations coming from this process of "deploy-check-iterate" must be traced in order to create a story that can be then generalized and serve as "lessons learnt".

5.4.2 Technical indicators

In order to evaluate both the overall IT solution to be deployed and the IT components included in the architecture to be designed, technical indicators have to be defined. These indicators will serve the next RE Framework process in the technical assessment of the experiments that will be conducted.

Due to the fact that MIDIH is a phase III project (for further details please refer to Chapter 1.4), the evaluation of IT components is often not related to the development of new and *ad-hoc* artefacts, but more to the usage of already available (close to market) solutions. Thus, the technical evaluation process can be intended to address the accessibility of the already available on the market components fitting MIDIH project purposes and to evaluate the required effort needed to integrate and adopt this IT artefacts for the development of specific (depending on each Use case needs and requirements and Industrial Experiments features) IT systems/solutions along MIDIH project. Therefore, technical indicators intended for the evaluation of single IT components are expected to assess the openness, interoperability maturity and applicability of each IT artefact's ability to be integrated with other IT artefacts concurring in the development of a MIDIH complex IT system/solution.

Below a proposal for technical indicators that can be validated through the Industrial Experiments.

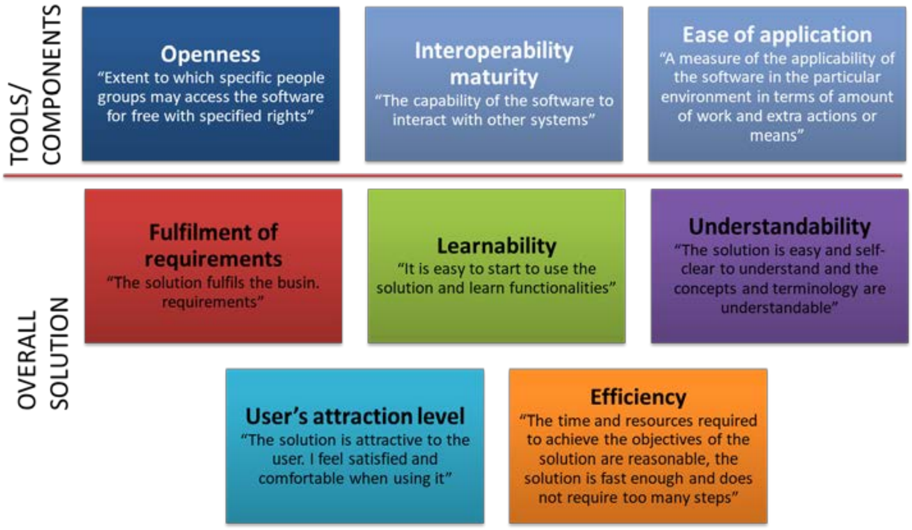


Figure 25 Technical indicators retrieved from BEinCPPS project

In WP2 tools and methods will be identified to analyse the technical functional requirements of the experiments and map these with the supported technologies and functionalities of the MIDIH platform. Therefore, a detailed description of the experiments using a topology with functional building blocks or flow charts will help to analyse what MIDIH platform components are required to support during the transition of the AS IS to the TO BE situation. Furthermore, utilizing tools will help during the iterative evaluation procedure if the MIDIH platform is fulfilling the requirements of the Industrial Experiments.

5.5 Requirements validation

Verification and Validation (V&V) in Industrial Experiments provides evidence that the IT solution (software components and associated products) satisfies system requirements at the end of each life cycle activity, solves the right problems and satisfies intended use and user needs. This methodology aims at verifying, validating and evaluating an IT solution from its conception to final release and implementation in real-life, trial settings. Verification is enacted with test case development and testing (matching system functionalities to IT requirements) and respond to the question “Does the IT solution deployed match the technical specification and expectations?” Validation covers how and how much the system functionalities match the user/stakeholders needs identified in the first phases of the project and respond to the question: “Does (and to what extent) the solution deployed matches the user/business requirements and expectations?”.

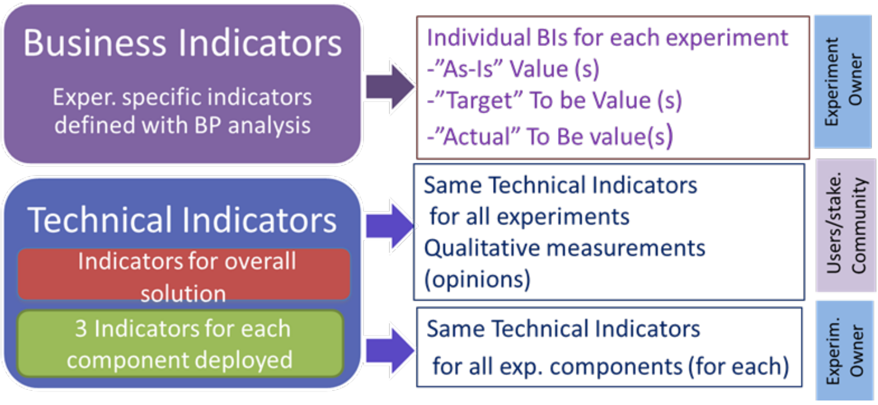


Figure 26 V&V assessment overview retrieved from BEinCPPS

The approach to technical assessment of the industrial experiments and of the IT solutions that will be deployed addresses human behaviors and realities, and data are not statistically analysed but commonly used for validating the findings through cross-verification by use of data from multiple sources (data triangulation). A statistical analysis of data is out of scope, as data characteristics (amount and variety) do not create the conditions to proceed with a statistical analysis of the data. Among the various research methods, case studies will be preferable, as the source of data are the observations of human worlds and behaviors. Any further documents or data that will be available for the experiments evaluation will be included. All the information must be collected, stored and uploaded in a case study database.

- Type of evidence: mainly open ended 'interview like' evidence (email, questionnaires) which do not need transcript.
- Experiment assessment for each use case, with five indicators concerning use cases assessment and overall solution CPPS level assessment, and relevant lessons learned.
- IT artefacts assessment for each champion, with three technical indicators and lessons learned acquired by using each artefact.

The following paragraphs are dedicated to the Industrial Experiments assessment in terms of business needs achieved, technical goodness of the deployed system/solution, the level of satisfaction of the system/solution users, etc. In order to carry on this evaluation, tools for information collection regarding Industrial Experiments (i.e. questionnaires, tables, etc.) will be suggested. All the information collected by use of these tools (further tools can be proposed along the project if they better suit data collection from Industrial Experiments) should be stored in a database for further analysis, processing and comparison among different Industrial Experiments or for other activities that will be considered relevant to MIDIH project purposes.

When approaching an evaluation process, the definition of the evaluator is a relevant issue. In this case the role of the evaluator can be played by different entities involved in each Industrial Experiment such as the Use Case partner, other industrial and technical experts part of the network of the Use case's partner that play a significant role in the Industrial Experiment design/development/deployment, other stakeholders (as DIH/CC experts or analysts) that also play a significant role in the experiment. Furthermore, the evaluator usually is not just one, but more than one evaluator should be selected in order to avoid bias in the evaluation process. The evaluator/s selection will be done along the project. It is good practice that one of the evaluators is the Use Case's partner and that this figure is always required to express his/her opinion during the experiment evaluation process.

5.5.1 Business assessment

This section includes business assessment that have to be performed the first half of the project (first-iteration of the project). In particular, the compliance with the identified BR during the experiment has to be evaluated and the achievement of the business objectives has to be measured according to the specific indicators. The evaluator for business assessment activities is usually the Use Case's partner.

5.5.1.1 *Business requirements (BRs) assessment*

The identified BRs (with the exclusion of those planned for the second-iteration phase of the project) have to be checked. The aim is to verify whether they have been fulfilled during experimentations and, if not, which are the main reasons and issues faced.

Business Requirements (BR)	BR Fulfilled (Yes/No)	Comments
BR01 - Acquisition of historical data on tests	*Yes*	*If No, explain the main reasons*
BR02 - Support by mobile for single test run	*Yes*	*If No, explain the main reasons*
BR03 - Execution of the test program on the portable testing unit	*Yes*	*If No, explain the main reasons*

Figure 27 Example of Business requirements assessment retrieved from BEinCPPS

5.5.1.2 *Business performance indicators (BPIs) assessment*

A set of BPIs has been identified for each of the selected business processes during the first process of the RE Framework. For each indicator, an "AS IS" value, measured during the first RE Framework step, has been linked to a "Target" valued the use case desires to achieve. The latter is then compared with the "Actual" value that will be measured after the solution implementation. The following table reports the assessment of the BOs, according to the identified BPIs.

Business Process (BP)	Business Objectives (BO)	Business Process Indicator (BPI)	BPIs "As is" value	BPIs Target "To be" value	BPIs Actual value measured	Comments
F1 - To create test rule	To minimize time for new rule generation	New rule generation time	*40'*	*10'*	*25'*	*Value still on learning curve.*

Figure 28 Example of business objectives assessment retrieved from BEinCPPS

5.5.2 Technical Assessment

Differently from the business assessment, is likely to involve more than one evaluator to run the technical assessment of the experiment. Evaluators can be both industrial and technical stakeholders involved in the experiment (for further detail please refer to paragraph 5.4) to have a complete evaluation of all the aspects of the experiment deployed. The evaluation process involves exchange information among the evaluators and the Industrial Experiment representatives (these figures may overlap).

5.5.2.1 *Experiment assessment*

The experiment assessment of each Industrial Experiment can be performed by the selected evaluators with interviews and semi-structured questionnaires and indicators in common to all experiments.

The technical assessment of each experiment focuses especially on the point of view of SMEs and has been performed by using the technical indicators.

User's assessment indicators:

- Fulfilment of user requirements;
- Learnability;
- Understandability;
- User attraction level;
- Efficiency.

The five indicators concerning user assessment have to be evaluated by the evaluators by use of questionnaire. One questionnaire has to be filled in for each experiment, and by each evaluator.

Overall solution level indicators:

- CPPS functionalities level;
- CPPS automation level.

The two indicators for the overall solution, related to level of CPPS functionalities and automation, can be evaluated by means of interviews, conference calls and email exchange with the Industrial Experiment representatives.

5.5.2.1.1. User's satisfaction assessment indicators

The questionnaire analysis has to be performed essentially focusing on five indicators from the point of view of User satisfaction of the deployed experiment. The following table presents the five indicators related to the assessment questions that would be useful to provide to the evaluator with the questionnaire.

Indicator	Question
Fulfillment of user requirements	The solution fulfills the business requirements, that is, at least 75% of "planned" business requirements have been met at the current date
Learnability	It is easy to start to use the solution and learn functionalities
Understandability.	The solution is easy and self-clear to understand and the concepts and terminology are understandable
User attraction level	The solution is attractive to the user. I feel satisfied and comfortable when using it
Efficiency	The time and resources required to achieve the objectives of the solution are reasonable, the solution is fast enough and does not require too many steps

Figure 29 Indicators for experiment assessment retrieved from BEinCPPS

A common scale has to be adopted in order to allow results coming from different experiments comparable. For this reason, as assessment scale for experiments indicators' evaluation a 5-point Likert scale can be adopted (refer to Chapter 4.1.5.2.2). The higher is the grade given by the evaluator, the higher the agreement that the evaluation is positive.

5.5.2.1.2. Overall solution assessment indicators assessment

Then interviews and email other approaches will be used for the analysis of the main architectural structure of the industrial experiments, including IT artefacts and their main connections in the experiment. Furthermore, this way two more indicators have to be included into the analysis aiming at evaluating the solution deployed from by addressing its functionalities and the level of automation guaranteed.

5.5.2.1.2.1 *CPPS functionalities level*

In order to evaluate the deployed functionalities of the TO BE system, it has to consider the main functionalities the deployed system/solution is expected to provide. Then, a qualitative indicator – based on a qualitative (i.e. Likert scale) can be used to address the level of satisfactions in terms of functionalities effectively provided by the CPPS compared to the initial Use Case needs and requirements.

CPPS functionality	Description
Production Embedded System for local processing capabilities	Embedded systems are on-board of equipment which previously did not have local processing
Production sensing and actuation	Sensors collect data and actuators implement actions
Production communication capabilities	Communication networks enable M2M and or factory level communication

Figure 30 Example of CPPS functionalities retrieved from BEinCPPS

The CPPS functionalities level indicator has to be devised by discussions with Industrial Experiment representatives, in order to prepare a questionnaire in which the level of CPPS functionalities is to be assessed subjectively at first.

5.5.2.1.2.2 *CPPS automation level*

A second indicator intended to the evaluation of the CPPS automation level has to be devised by discussion with Industrial Experiment's representatives and project technical partners. A qualitative evaluation scale (i.e. Likert scale) has to be associated to each CPPS automation level in order to guarantee the evaluation rationale.

Level	Description
5	Full control: CPPS is able totake all decisions without any intervention from the human (HIGH)
4	Automation: the CPPS guides the human during its task by taking most of the decisions and leaves adaptation to the human (MEDIUM)
3	Tool: Human guides the CPPS and is in charge of the majority of decisions (LOW)
2	Manual: CPPS only provides data to the human, who is in charge of all decisions (LOW)
1	Everything is done manually by the operator (LOW)

Figure 31 Example of CPPS automation levels and related evaluation scale levels retrieved from BEinCPPS

5.5.2.2 *IT artefacts assessment*

The technical assessment has to be performed on MIDIH components and tools used in the experiments. As mentioned in previous sections (Chapter 1.4), MIDIH is a phase III Project, thus the technical analysis of IT components that constitute the deployed IT architecture are not designed and planned during the project but selected from the tools already available on MIDIH platform. However, it is still relevant to understand whether the IT components characterizing the IT architecture are easy to use, costly in terms of financial sources and effort for deployment and use in the current IT and physical structure of the use case. In order to guide this evaluation, a questionnaire can be designed and shared with the evaluators. The IT artefacts to be included into the assessment are chosen by each evaluator among the components experimented as a part of the solution (the rationale behind this choice have to be declared) or, if not, experimented alone.

In order to be able to get the overall picture of the IT artefacts performances, the following common indicators have to be devised, as in the following Table 10.

The indicators proposed are associated to qualitative measures, and a qualitative assessment scale has to be adopted for the indicators evaluation among the partners. In order to differentiate the IT artefacts assessment procedure from the one proposed for the experiments evaluation, a different scale can be adopted, such as a Likert scale (refer to Chapter 4.1.5.2.2).

Table 8 IT artefacts assessment indicators

Technical Indicator	Description
Openness	Extent to which specific people groups may access the software for free with specified rights
Interoperability maturity	Capability of the software to interact with other systems
Ease of application	Measure of the applicability of the software in the particular environment in terms of amount of n work and extra actions or means

5.5.3 Lesson learnt

Lessons learned must be collected for each experiment and for each IT artefact by submitting questionnaires to the evaluators. The evaluators will be asked to give their subjective point of view on the performed experiments and IT artefacts according to open-ended questions concerning the following relevant elements to be addressed:

- Major obstacles
- Key learning
- Best practices
- Next steps

5.5.3.1 *Experiment level*

Questionnaire	*Please fill in light blue cells below with the general experiment information*
Experiment/use case	X
Area object of experiment	Y
Number of experiments	1
Geographical Location	1
Number of factories/structures addressed	1
Period	Year/mm/dd
Number of participants	2
Number of participants roles	2

EXPERIMENT TECHNICAL INDICATORS	Average grade of the experiment by participants in a 5 (I strongly agree) to 1 (N/A) scale
Fulfillment of user requirements: "The solution fulfils the business requirements, that is, at least 75% of planned (*) business requirements have been met at the current date"	4,00
Learnability: "It is easy to start to use the solution and learn functionalities"	4,00
Understandability: "The solution is easy and self-clear to understand and the concepts and terminology are understandable"	4,00
User attraction level: "The solution is attractive to the user. I feel satisfied and comfortable when using it"	4,00
Efficiency: "The time and resources required to achieve the objectives of the solution are reasonable, the solution is fast enough and does not require too many steps"	4,00

(*) planned = the business requirements that were assigned for this first experiments phase (listed in sheet PLANNED BUSINESS REQUIREMENTS)

Experiment qualitative analysis from technical point of view	*Please fill in light blue cells below by using some brief sentences, max 120 w*
Major obstacles	To access a robust and reliable cloud system Data analytics required more analysis efforts than expected.
Key learning	Integrated development of artifacts enable a quick startup. Design tools adoption (e.g business process modeling) facilitates development.
Best practices	Implement a modular CPS-ization architecture to ease up both development and startup phase
Next steps	Better integrate data analytics capability. Analysis and development of sampling rate change and m2m communication functionalities

Figure 32 Example of questionnaire for the evaluation of industrial experiments retrieved from BEinCPPS

5.5.3.2 *IT artefacts level*

Lessons learned must be collected for each IT artefact by submitting questionnaires to the different type of evaluators (Experiment owner / user / technical expert).

Design/Runtime	Run-time
Period	Y
Number of evaluators	1
Number of evaluators roles	Experiment owner / user / technical expert

IT ARTIFACT TECHNICAL INDICATORS	Average grade of the IT artifact by participants in a 3 (very high) to 0 low) scale
Openness: "Extent to which specific people groups may access the software for free with specified rights"	3
Interoperability maturity: "The capability of the software to interact with other systems"	3
Ease of application: "A measure of the applicability of the software in the particular environment in terms of amount of work and extra actions or means"	1

Experiment qualitative analysis from technical point of view	*Please fill in light blue cells below by using some brief sentences, max 120 word*
Major obstacles	Task Orchestration for CPPS is based on the run-time of Activiti BPMN, however custom components needed to be developed to interact with different systems. Moreover, the configuration of the run-time is sometimes cumbersome, as many configuration files and dependences need to be deployed. The management of active processes is not straightforward.
Key learning	The Task Orchestration is the perfect complement to the Activiti BPMN and offers a flexible way of interacting with other systems.
Best practices	Using Activiti BPMN to model the process to be run is desirable as it is to use the default REST interface to interact with other systems
Next steps	To create -when needed- classes to implement the next steps of the Activiti BPMN model and try to make them general as much as possible - and possibly releasing them as Open Source.

Figure 33 Example of questionnaire for the evaluation of IT artefacts retrieved from BEinCPPS

5.5.4 Recommendations and suggestions

After the technical assessment, recommendations must be provided by evaluators, evidencing improvement suggestions. Recommendations and suggestions are intended to technology providers, such as those who have provided components and tools and to technical experts who have integrated the IT artefacts to create the IT system/solution. Comments come from the lessons learned collected from the technical assessment questionnaires. Extra actions are required on the improvement of technical characteristics that result to not fully satisfy the user's expectation.

6 Digital Open Platform RE Framework: approaches and tools

6.1 Scenario analysis and requirements elicitation

The scenario definition activity is determined by the creation of a Digital Open Platform which is also the main objective of the WG2 of the Digitising European Industry (DEI) initiative, who is in charge to defining the next-generation of the Digital Platform; therefore, main outputs of this work, as well as the guidelines and recommendations provided by the Industrial Internet Consortium (IIC) and the Working Group for Industry 4.0, in their respective Industrial Internet Reference Architecture (IIRA) and the Reference Architecture Model for Industry 4.0 (RAMI 4.0), will be taken into account. In this way, the approach of the three-tier architecture provided by the IIC and the manufacturing hierarchy levels across the six layers of the IT representation of Industry 4.0 will also be considered.

As mentioned in the Working Group 2 for Industry 4.0 report, taking into account the convergence of key technological trends, who drives the Digital Innovation, including connecting "things" to the digital space (driven by IoT – embedded software, sensors, actuators, connectivity, low power ICT, etc.); creating value from knowledge (driven by (Big) Data, HPC, cloud computing etc.); and deploying autonomous systems (driven by robotics, automation, machine learning, etc.). Together these trends facilitate digital innovation in products, processes, services and business models in all industry sectors. Therefore, in addition to specific requirements that will be given by the different pilots, starting from the basis that the main objective of an Industrial Digital Platform is to acquire, view, and analyse data from the plant operations and turn it into actionable information, there are some essential features that the digital open platform must contemplate:

- Use open standards: due to the vast number of brownfield plants existing, it is mandatory to standardize the data and data models to be able to integrate these plants in a real industrial solution, by translating this data into an interoperable format.

- Provide the necessary mechanisms to collect, manage and analyse data from the products, machines and processes and distribute the insights from the analytics instantly to the process applications so they can respond to events timely. For this, a well-defined data and analytics stack is essential, identifying each of the necessary components in the stack and their relationship in a distributed computing scheme. A global overview could be: A lower layer, responsible for fast and scalable streaming data collection (data-in-motion), processing and analytics; a middle layer for scalable and durable data storage and management, and an upper layer for large scale and intensive batch-oriented analytics (data-at-rest).

- Have a decoupled architecture, where the three-layer architecture defined in the functional domain of the Industrial Internet Reference Architecture published by the ICC could drive the Open Digital Platform as follows: A field or lower layer where the manufacturing equipment, products and the physical facility and environment is located, and it is responsible for manufacturing planning, decision-making and execution plane - consisting of processes in the value chain and the product chain. A second layer above the previous, more focused on data and information, in charge to apply industrial analytics to the manufacturing processes, to enable intelligence for smart manufacturing, and also providing mechanisms for connectivity, data collection and analytics, in order to provide the necessary insights to the decision-making processes in the upper layer, where the business applications will be located. A Digital Platform based on this type of architecture span from the edge to the cloud as just as analytics and gives it flexibility in order to allow components or layers to execute independently while still interfacing with each other.

6.2 Business requirements analysis

When considering the requirements to be applied to an Open Platform, two main actors have to be considered: software and hardware. To define the requirements over those concepts it is used the Functional Requirements and the Non-Functional Requirements.

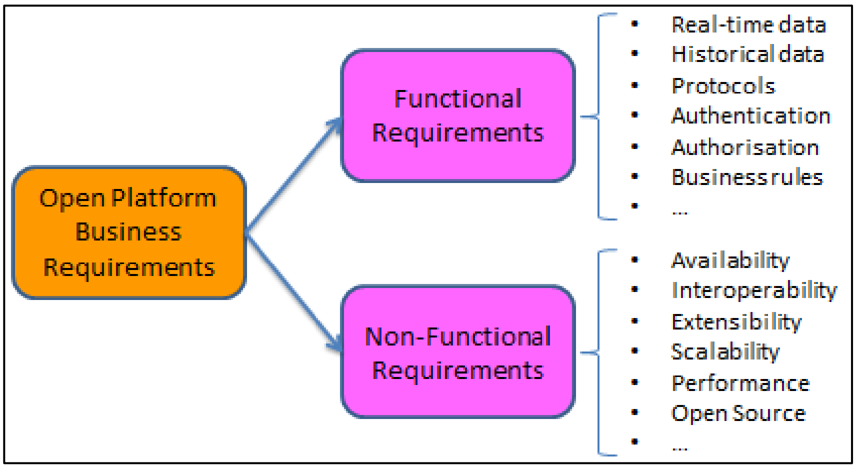


Figure 34 Open Platform Business Requirements

In software engineering, functional requirements describe what the system should do while non-functional requirements describe how the system works. In Figure 34 presented above, a set of functional and non-functional requirements can be seen that can be applied to the Open Platform. A correct definition of the requirements and the control or follow up over its completion assures to obtain the expected solution.

6.3 Requirements specification

A general overview of the main layers that participate in the Open Platform is depicted in the next figure:

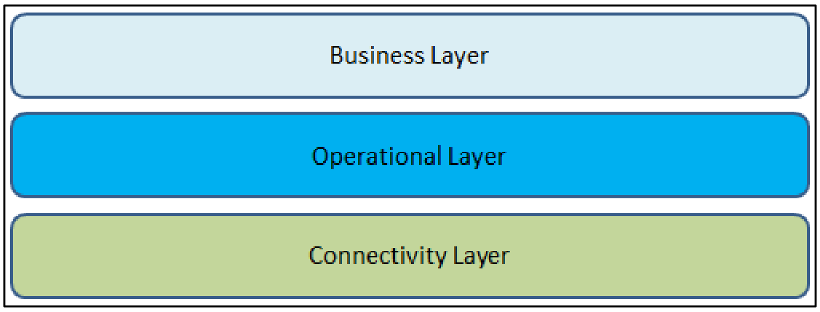


Figure 35 Open Platform Requirements Specification

In this manner, the proposed approach for the requirements specification is to be done separately per layer. In other words, each layer will have its own requirements, although a requirement might apply to several layers. More details are given below:

Connectivity Layer

Responsible for gathering data from the Legacy and IoT systems and send it to a cloud environment for further processing. In this context, functional and non-functional requirements as interoperability, protocols, real-time data, etc. are essential to define the correct requirements.

Operational Layer

Responsible for providing the main functionalities of the platform as well as the management of the infrastructure. In this layer, functionalities like big data analytics, data storage, event processing and others are included. In this environment, functional and non-functional requirements as availability, interoperability, historical data, authorisation and authentication, etc. are necessary for the definition of the requirements.

Business Layer

In charge of offering and providing the services or applications to be used at business level. At this level, functional and non-functional requirements as service level agreement, authorisation and authentication, etc. have to be considered to define the requirements.

A good manner to present those requirements might be by presenting them in table format. The next Table 9 is included as an example:

Table 9 Open platform requirement specification example

Open Platform Requirement Specification				
Requirement	**Description**	**Functional/Non-functional**	**Layer of application**	**Fulfilled (Y/N)**
REQ - 1	OPC-UA protocol	F	Connectivity	Y
REQ - 2	Availability 24/7	N	Operational	N
REQ - 3	Authorisation	F	Business	Y
…	…		…	…

6.4 Requirements validation

Regarding the Verification and Validation (V&V) processes, main validation of the Open Platform will be done by the Pilots, whenever the Platform is instantiated to be used by them. At that point, it will be possible to evaluate whether the Platform matches its expected requirements or not. In addition to this, and meanwhile the final platform is not finally available, other validation method can be applied. In this direction, what is proposed is to perform the follow up of all the defined requirements after each release of the platform. To support these activities, it could be introduced what are known as *continuous integration tools*. Using this type of tools, a predefined set of tests, defined by the user, can be automatically launched. As an example, through the definition of a simple test it can assure the correct interoperability among the different components that participate in the Platform.

Conclusions

One of the major results of the deliverable is to establish in an objective way the need to utilize a new RE approach in a CPS/IOT-driven environment populated by different stakeholders and characterized by complexity and trans-disciplinarity. These conditions challenged the definition of a generic MIDIH RE Framework to support what will be subsequently specified for and instantiated in DIHs/CCs, Industrial Experiments and Open Digital Platforms, which is one key take-away of this deliverable.

At the end, we can draw the following suggestions specified from the lesson learned we gained during the research process for the development of the content of this deliverable:

- **Account for the project context when defining the RE approach**

Choosing the right methodology for scenarios and requirements life cycle management affects requirements design, development, testing and validation. We adopted a spiral approach suitable where uncertainty in scenarios and requirements definition may importantly affect resources (time and costs) spending.

- **Support external heterogeneity (among different stakeholders) with a common approach**

It is relevant to defined a RE methodology as a "modus operandi" generic enough to provide different stakeholders (in our case DIHS/CCs, Industrial Experiments, Open Digital Platforms) with guidance and defined steps to be instantiated in any type of Business Scenario and applicable to any type of Requirements.

- **Support internal heterogeneity (among the same group of stakeholders) with customized tools and methods**

In this deliverable, we specifically accounted for the characteristics differentiating the project's main stakeholders. The generic RE Framework was customized with specific tools, methods and guidelines to:

- Support DIHs/CCs, which live in an intricate network where different stakeholders may influence their objectives and thus performances, to understand their stakeholders' needs running a multi-perspective analysis and to undertake problem specification, negotiation, implementation and review or validation of the specifications required by customers (Chapter 4);
- Support Industrial Experiments, whose focus is on the technological side of CPS/IOT-driven digitalization by implementation of new advanced technologies and solutions for the performances betterment of processes/ value chains/ etc., in the technology transfer and digitalization process of SMEs and start-ups (Chapter 5);
- Sustain the Open Digital Platforms providers in the development of an Open Digital Platform in the technology transfer process to support SMEs and start-up towards their digitalization path (Chapter 6).

The approach presented in this deliverable will be validated and reviewed in the second iteration cycle to be reported in D2.2 (M21).

ANNEX

In this Annex, the State-of-the-Art models currently used for Requirements Engineering are described in more detail. The comparison and the potential usability for MIDIH is explained in Chapter 2.

Waterfall Approach for RE

Description and features

The Waterfall Approach (or "Model) is considered as one of the most classic RE models and it is a linear method by design which means that, compare to other methods, it misses step-back management activities. If wrong choices are made during first phases it is very often discovered at final stages. This is why, in practice, the implementation of the WM is supplemented by feedback especially in the first stages of its application.

The main idea of the WM is that the development process is to proceed sequentially into different small phases designed according to the project's final aim which is the development and deployment of the system/solution. The pre-requisite for approaching the next phase of the project is the completion of the previous phase and the approval of all the accomplished tasks within this phase. This model is simple to understand and control. All the deadlines for each phase are scheduled *a priori* and deadlines are easy to follow/control/validate.

Waterfall Model (WM) processes can be divided into five phases with slight modifications depending on the environment.

There are several implementations of WM available for various scenarios starting with four and finishing with nine phases. The main phases (steps) with respect to RE are as follows[8]:

- **Project Initiation** – Customers identification and recognition;
- **Requirements definition** – Requirements elicitation and identification of needs and impacts;
- **Analysis and Specification** – Requirements analysis and authentication to required impacts and customers' needs leads to the requirement definition and subsequently to business specification (and modelling if it is needed);
- **Development** – System/solution design and development;
- **Deployment and delivery** – System/solution delivery, deployment and verification including final validation.

Requirement Engineering establishes what the customer requires from the provider. The following description of the RE process in WM is adapted from (Sommerville & Sawyer 1999).

As part of project initiation in WM within RE there is need to identify customers (or stakeholders) and orientation of their business and collaboration possibilities. For this reasons CC and DIHs needs to build relevant collaboration platform with participation of customers as well as stakeholders. Analysis needs to involve quality management techniques for function,

[8] http://www.software-engin.com/

information and task deployment. This will include definition of normal, expected and exciting requirements. Validation phase needs to answer whether requirements are consistent with overall defined objectives (or impacts), whether requirements are appropriate with specified level of abstraction, whether there are conflicts within the specified requirements and whether outcomes fulfil customers' needs.

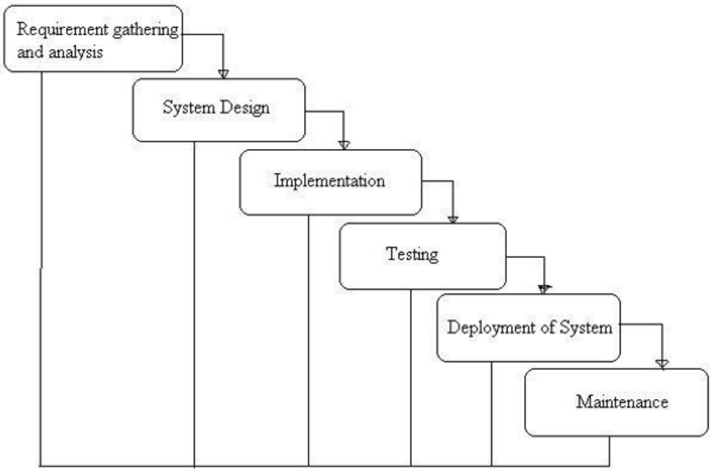


Figure 36 Waterfall Model Overview Diagram (Sommerville & Sawyer 1999)

Waterfall Model - Advantages

- Simple and easy to understand and use;
- Easy to manage as each phase has specific deliverables and a review process;
- Phases are processed and completed one at a time and phases do not overlap;
- Works well where requirements are very well understood.

Waterfall Model - Disadvantages

- Once an application is in the testing stage, it is very difficult to go back and change something that was not well-thought out in the concept stage;
- No working system/solution is produced until late during the life cycle;
- Not suitable for complex and object-oriented projects.
- Not suitable for projects where requirements are at a moderate to high risk of changing.

V Model for RE

Description and features

V Model (VM) is an enhanced version of the classic Waterfall Model whereby each level of the development life cycle is verified before moving on to the next level. With this model, systems/solutions testing explicitly starts at the very beginning, i.e. as soon as the requirements are written. Here, by testing we refer to verification by means of reviews and inspections. This helps in identifying errors very early in the life cycle and minimizes potential future defects appearing in the developed system/solution later in the life cycle.

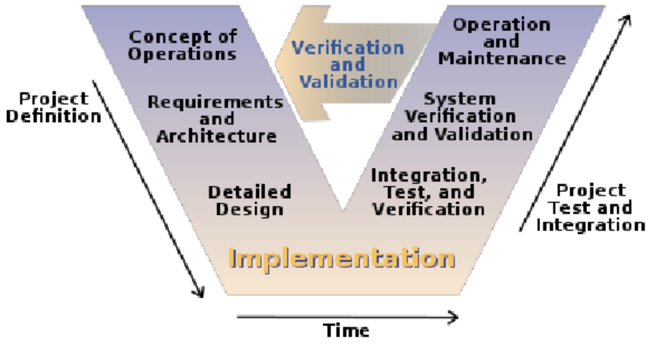


Figure 37 V Model Diagram [9]

Each level of the development life cycle has a corresponding test plan, i.e. as each phase is being worked on, a test plan is developed to prepare for the testing of the outcome (i.e. part of the system/solution) of that phase. By developing the test plans, it can specify the expected results for the testing of the system/solution for that specific level as well as define the entry and exit criteria for each level[10].

In the VM testing activities are spelled out at the same level of detail as the design activities. The system/solution is designed on the left-hand (downhill) part of the model, and built and tested on the right-hand (uphill) part of the model. Note that different organizations may have different names for the development and testing phases.

The correspondences between the left and right hand activities are shown by the lines across the middle of the V, showing the test levels from component testing at the bottom, integration and system testing, and acceptance testing at the top level.

V Model – Advantages

- Each phase has specific deliverables;
- Higher chance of success over the Waterfall Model due to the development of test plans early on during the life cycle;
- Time concern in comparison with the waterfall model is lower;
- Suitable for small projects where requirements are easily understood;
- Utility of the resources is high.

V Model – Disadvantages

- Little flexibility, like the Waterfall Model;
- Adjusting scope is difficult and expensive;
- Systems/solutions are developed during the implementation phase, so no early prototypes of the system/solution are produced;
- Difficulty in providing a clear path for problems found during testing phases.

[9] https://narbit.wordpress.com/2012/06/10/the-differences-between-life-cycle-models-advantages-and-disadvantages/
[10] https://www.utest.com/articles/waterfall-model-and-v-model-in-software-testing

The main difference between V Model and Waterfall Model is that in the former the activity of testing starts very early, which leads to lessen time and cost of the project.

Incremental Model for RE

Description and features

The Incremental Model (IM) is defined as a "multi-waterfall" cycle approach as it is characterized by multiple system/solution development cycles where the system/solution requirements are gradually identified and included in the system/solution design and development into various parts (usually referred to as "modules") . In this model, each module of the system/solution passes through the requirement identification and definition, design, implementation and testing phases. A working version of the system/solution to be deployed is produced during the first module, working on the system/solution early on during the system/solution life cycle. Each subsequent release of the module adds functions to the previous release due to additional requirements inclusion. The process continues till the complete system/solution is developed and satisfies all the project's requirements.

Figure 38 Incremental Approach Ideographic Representation [11]

The IM works incrementally towards the deployment of the whole system/solution, adding piece by piece but expecting that each previous piece has been fully managed and finished before start approaching the next one. The process keeps on adding the pieces until the module is completed. As in the image above, the developer has thought of the application. Then he starts building it and in the first iteration the first module of the system/solution is totally ready. Likewise in the second iteration the other module is ready and integrated with the first module. Similarly, in the third iteration the whole system/solution is ready and integrated. Hence, the product got ready step by step.

[11] http://istqbexamcertification.com/what-is-incremental-model-advantages-disadvantages-and-when-to-use-it/

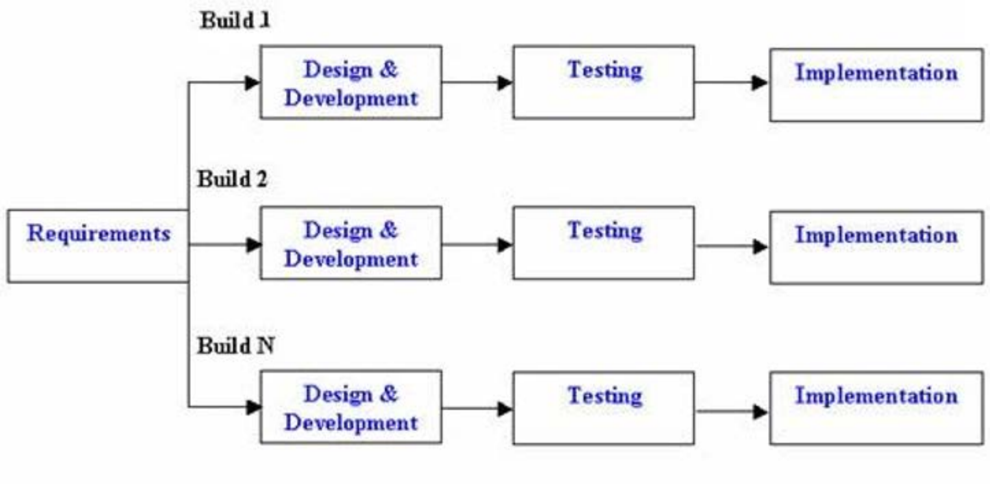


Figure 39 Incremental Model Life Cycle Diagram[12]

Incremental Model - Advantages

- Generates working systems/solutions quickly and early during the system/solution life cycle;
- Flexible - less costly to change scope and requirements;
- Easy to test and debug during a smaller iteration;
- Easy to manage risks because risky pieces are identified and handled thanks to the iterations characterizing this approach.

Incremental Model - Disadvantages

- Needs for good planning and design;
- Need for a clear and complete definition of the whole system before it can be broken down and built incrementally;
- Total cost may be higher compared to other systems/solutions RE approaches.

Rapid Application Development for RE

Description and features

Rapid Application Development (RAD) was developed by the computer scientist James Martin at IBM during the 1980s and formalised in a book published in 1991 (Martin 1991). It is an example of an evolutionary life cycle that origins from the Incremental Model and that is intended to resolve requirements maturity through iterative design activity. It is a methodology that enables organisations to develop strategically important systems more quickly while reducing development costs and maintaining quality. This is achieved by using a series of proven application development techniques within a well-defined methodology. Active user

[12] http://istqbexamcertification.com/what-is-incremental-model-advantages-disadvantages-and-when-to-use-it/

involvement throughout the RAD life cycle ensures that business requirements and user expectations are clearly understood.

In RAD model the components or functions are developed in parallel as if they were small sub-projects. The developments are time-boxed, delivered and then assembled into a working prototype. This can provide feedbacks from the reviewers or customers regarding the correctness of requirements.

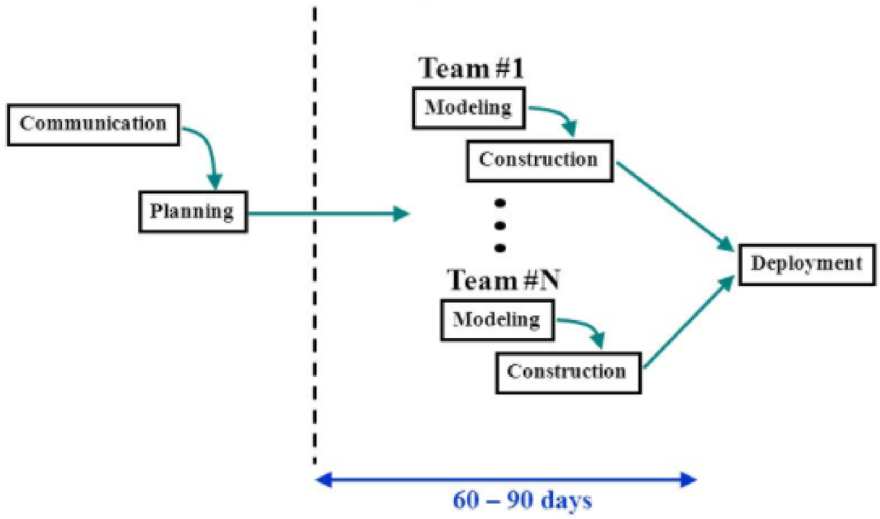


Figure 40 RAD Model Diagram (Martin 1991)

The RAD model is generally characterized by the following phases:

- **Communication:** This action works to understand the business goals and thus the information on the characteristics that should be accommodated by the system/solution to be developed;
- **Planning:** It is required because RAD model is more suitable for team-working realities where different teams work in parallel on different system/solution functions;
- **Modelling** includes three major phases:
  1. **Business modelling:** The information flow is identified between various business functions;
  2. **Data modelling:** Information gathered from business modelling is used to define data objects that are needed for the business;
  3. **Process modelling:** Data objects defined in data modelling are converted to achieve the business information flow to achieve some specific business objective. Description are identified and created for CRUD of data objects.
- **Construction:** This phase focuses mainly on the use development of the system/solution by use of multiple existing tools (it means that the system/solution deployed does not include the generation of new tools) i.e. in the software engineering automated tools are used to convert process models into code and the actual system;

- **Deployment:** This last stage establishes the basis for subsequent iterations if necessary. It includes testing of new components and all the interfaces and turnover.

RAD Model is generally characterized by the following features:

1. The system is subject to incremental development in the face of evolving requirements;
2. The system is split into a number of phases to be delivered separately (i.e. incrementally);
3. The Pareto principle applies: 80 % of the functionality can be delivered with 20 % of the effort;
4. The use of the MoSCoW method (must have, should have, could have, won't have);
5. The use of Joint Application Development (JAD) workshops;
6. he use of prototypes (especially to elicit requirements);
7. The use of integrated toolsets.

RAD Model - Advantages

- Reduced development time;
- Increases reusability of components;
- Quick initial reviews occur;
- Encourages customer feedback;
- Integration from very beginning helps managing integration issues of the different developed parts of the system/solution.

RAD Model - Disadvantages

- High dependency on requirements understanding and modelling;
- Only system that can be modularized can be built using RAD;
- Requires highly skilled developers/designers;
- High cost of modelling and developing activities.

Agile Methodology for RE

Description and features

Agile development model is also a type of Incremental Model because the system/solution is developed in incremental and rapid cycles. This results in small incremental releases with each release building on previous identified functionalities for the system/solution to be developed. Each release is thoroughly tested to highlight and remove eventual mistakes. The more the development activity advances, the more mistakes become expensive or dangerous for the whole project. Testing activities ensure that the system/solution quality is maintained, which means both to deliver a system/solution free from bugs or defects, that meets requirements the project expectations and that is maintainable. It is usually used for time critical applications.

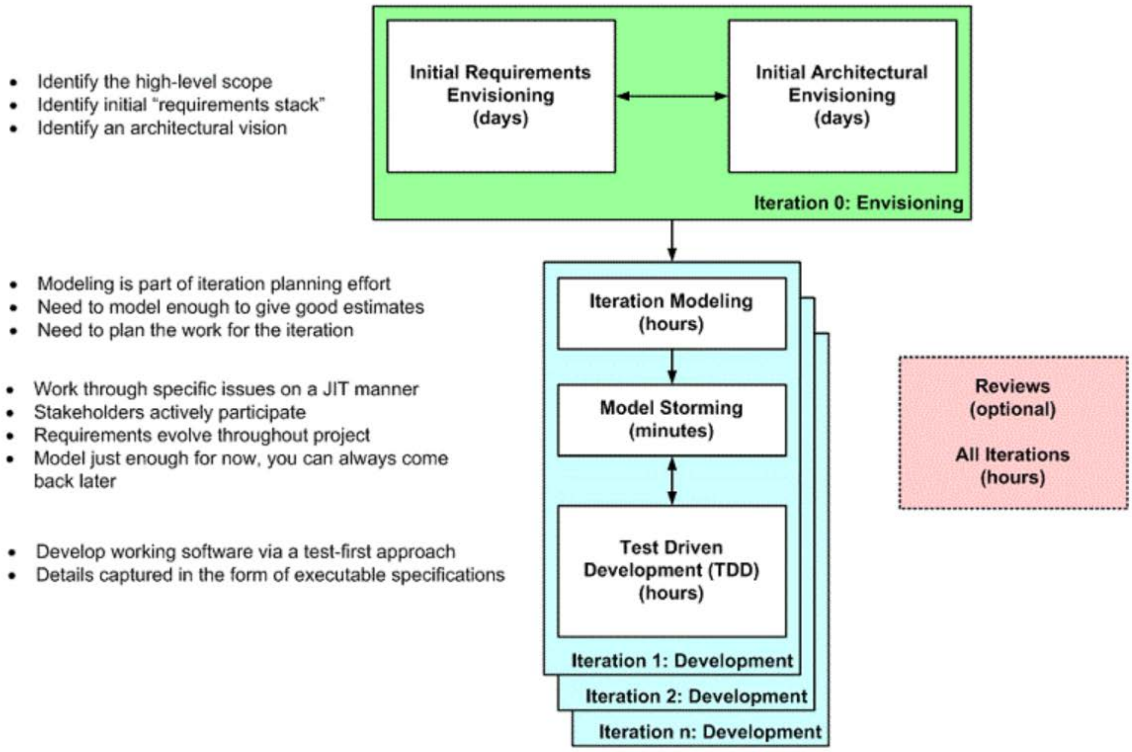


Figure 41 Agile Model Diagram (Ambler 2002)

Agile Model - Advantages

- People and interactions are emphasized rather than process and tools, i.e. face-to-face communication. Customers, developers and testers constantly interact with each other;
- Customer satisfaction by rapid, continuous delivery of useful software (working solution is delivered frequently, i.e. weeks rather than months);
- Regular adaptation to changing circumstances; and continuous attention to requirements satisfaction, design and outcome quality;
- Even late changes in requirements can be more easily managed in respect to other RE methods.

Agile Model - Disadvantages

- It can be difficult to assess the effort required to run a specific task linked to the system/solution development at the beginning of the system/solution development life cycle as changes in requirements may occur at any time;
- There is lack of emphasis on necessary designing and documentation;
- The project can easily get taken off track if the customer representative is not clear the desired final outcome;
- Need of skilled figures during the requirements identification and the development phase.

Spiral approach

Description and features

This model is best used for large projects which involves continuous enhancements. There are specific activities which are done in one iteration (spiral) where the output is a small prototype of the large system/solution to be deployed. The same activities are then repeated for all the spirals till the entire system/solution is build.

The figure below represents in a simplified way the steps involved in spiral model.

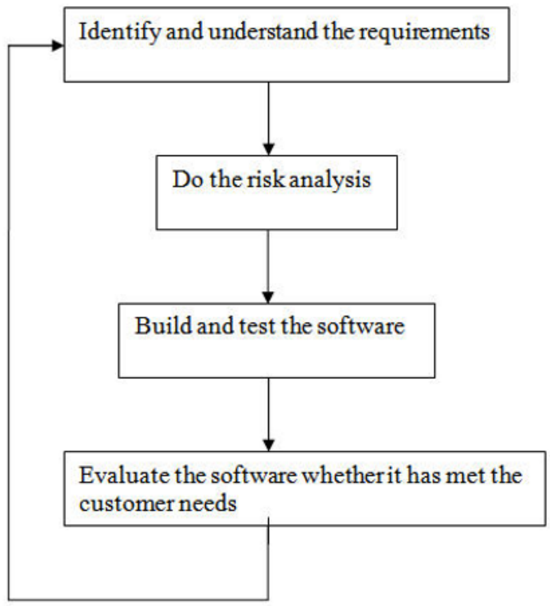


Figure 42 Spiral Model phases representation [13]

Spiral model is characterized by 4 phases:

1. Planning phase
2. Risk analysis phase
3. Engineering phase
4. Evaluation phase.

Each spiral can be termed as a loop and each loop is a separate development process in a spiral model. The four activities (Planning, Risk analysis, engineering and evaluation) form the intermediary phases of a spiral model and is repeated again for each loop.

This model is commonly used in larger projects where it can be preferable to develop and deliver smaller prototypes and can enhance them to make the larger system/solution. The implementation of this model requires experienced resources as risk analysis requires expertise and as a result this model becomes costly.

[13] http://www.softwaretestinghelp.com/spiral-model

Table 10 Activities performed in the spiral model phases (adapted from software engineering)

Phase	Activities performed	Output
Planning	-Business objectives and business requirements are studied and gathered -Activities planning (in accordance with the business objectives and requirements defined in the Planning phase) - Feasibility study	-Objectives definition -Business Requirements elicitation and understanding (finalized list of requirements) -Plans of the activities (Functional and non-functional requirements specification)
Risk Analysis	-Requirements are studied and brain storming sessions are done to identify the potential risks -Once the risks are identified, risk mitigation strategy is planned and finalized	Highlight of the risks and proposal of mitigation plans.
Engineering	-Actual development and testing of the planned activities	-Deployment of the activities -Solution implementation (test cases) summary and results
Evaluation	-Customers evaluate the solution deployed and provide their feedback and approval	-Features implemented description -Validation results and lesson learnt

Spiral model – Advantages

- Development is fast;
- Larger projects / software are created and handled in a strategic way;
- Risk evaluation is proper;
- Control towards all the phases of development;
- More and more features are added in a systematic way;
- Software is produced early;
- Has room for customer feedback and the changes are implemented faster.

Spiral Model – Disadvantages

- Risk analysis is important phase so requires expert people;
- Is not beneficial for smaller projects;
- Spiral may go infinitely;
- Documentation is more as it has intermediate phases;
- It is costly for smaller projects.

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List of Acronyms and Abbreviations

Acronym	Meaning
BO	Business objectives
BP	Business process
BPI	Business process indicator
BR	Business requirement
CC	Competence centre
DIH	Digital innovation hub
IoT	Internet of Things
RE	Requirements engineering
V&V	Verification and validation