RE4DY

MANUFACTURING DATA NETWORKS

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Project Partners

Number	Participant organisation name	Acronym
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2	CHALMERS TEKNISKA HOGSKOLA AB	Chalmers
3	INTERNATIONAL DATA SPACES EV	IDSA
4	VOLKSWAGEN AUTOEUROPA, LDA	VWAE
5	ASSECO CEIT AS	CEIT
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7	FILL GESELLSCHAFT MBH	FILL
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12	DATAPIXEL SL	DATA
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24	GRUPO S 21SEC GESTION SA	S21SEC
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28	SWITZERLAND INNOVATION PARK BIEL/BIENNE AG	SSF
29	GF MACHINING SOLUTIONS AG	GFMS ADVMAN
30	FRAISA SA	Fraisa SA
31	SIEMENS SCHWEIZ AG	SIE

Executive Summary

This deliverable represents the first result of WP2 (tasks T2.1 and T2.2) of the RE4DY Project. This document is the first release of the Digital 4.0 Continuum Reference Architecture for Active Resiliency (WP2) at M9. The deliverable defines the managerial rules and procedures that will be followed by the RE4DY consortium across the whole project duration.

The main objective of tasks T2.1 and T2.2 is to elicit pilot requirements, develop the reference data fabric and network of cognitive digital twin sharing scenarios of RE4DY, along with the integrated resilient manufacturing and supply network engineering framework and strategies. This deliverable D2.1 (Manufacturing & Supply Chain Active Resiliency Model) specifies the RE4DY integrated resiliency engineering model, framework, strategies and services.

The tasks will be responsible for an integrated elicitation at a pilot level of the distributed data usage for active resiliency and their large-scale trialing. An exhaustive analysis of technical, functional and non-functional requirement elicitation will be performed as well as clustering and generalization to define the distributed computing & data sharing scenarios. This task will also address the definition of the demand and supply driven active resiliency strategies that will be applied and adopted by the various pilots in the context of the WEF manufacturing global response initiative and the resiliency compass framework.

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Acronyms

Acronym	Definition
MDN	Manufacturing Data Network
RBV	Relative Business Value

1 Introduction

This is the first deliverable to report the progress of Work Package 2, with the objective of defining the scope and the requirements of the pilots and to present the RE4DY Resiliency Framework.

1.1 Scope and organisation

This document, together with deliverable D2.2, lay the foundations for the development of the experiments in WP 4 & 5, as they explain what each of these pilots consist of. Also, this document reports the design of the RE4DY Resiliency Framework.

This deliverable, is organised as follows:

Chapter 2 addresses the specification of the pilots, where there is a subchapter for each of the pilots, and within each pilot there are three sections: a general overview (whit a small description of the pilot, the main objectives and the participants in the pilot) and then the business requirements and the pilot specification, where it will be described in each case what has to be considered in the definition of each of the pilots.

Chapter 3 focuses on the design process of the RE4DY Resiliency Framework. It includes three sections, the first one to present the background, a second one to report the methodology used to design the model and one last section to present the framework itself.

2 RE4DY Trials

2.1 The RE4DY pilot implementation approach

The RE4DY manufacturing data network (MDN) concept to shorten time-to-market increasing manufacturing competitiveness relies on:

1. Cross-disciplinary collaboration: Improving data flow between plant systems and business applications enables cross-disciplinary collaboration.
2. Iterative improvement: Adding connectivity to products enables manufacturers to release a product with a basic feature set and iteratively add advanced features through firmware updates.

However, traditionally, analytics have been performed on "Give me your data, and we will try and bring out some insights out of it".

The RE4DY agile MDN concept is rooted on a Relative Business Value (RBV) approach that advocates evolving such strategies putting data at the centre of the business strategy and starting from the strategic business decision and then workout "the data behind the decision and the gaps". The RE4DY concept has been derived to support such business operation for Industry 4.0. Data will be at the service of the business strategy and avoiding that business strategies are limited by the "data available". RE4DY will obviously be compatible with traditional analytic strategies but will empower Industry 4.0 with more agile big data/ai frameworks for data-centric decision making and digital business model development. For that reason, the RE4DY concept provides the required enablers and integrated framework for increased level of trust and agility in the establishment and exploitation of data assets across networks of data governed by stakeholders in "Integrated Value Networks".

The RE4DY Relative Business Value (RBV) MDN decision support framework for Factory 4.0 assumes that from a business strategy definition, highly distributed data networks will need to be established across workforce, things, systems and businesses and the distributed data will need to be filtered and processed to extract meaning and value, either at the edge or in the cloud.

2.2 The Trial Handbook Methodology

As this is the first deliverable of WP 2, it is the perfect document to introduce the methodology used to gather the important information in the project in order to fulfil the reporting of the project in the most efficient way. This methodology is based on the analysis and adaptation of Requirements Engineering techniques and methodologies carried out in FITMAN[1].

Each pilot in the project will have a Handbook to collect the information source for all tasks dealing with the RE4DY 4.0 trial implementation.

Each Trial will write and be responsible of its own deliverables and of the gathered information, however in order to better coordinate and align the development of activities inside the ten trials, the handbook will provide a common structure to gather and present data. This approach will also:

- Facilitate the work within the different trial factories
- Prevent overlapping among tasks
- Avoid duplication of efforts
- Ensure the schedule accomplishment

From previous analysis of the different methodologies, it is clear that an iterative approach is the most suitable method when dealing with the definition of requirements, no matter the type of project we are attempting.

Most of the methodologies propose a sequence for the whole process of requirements definition, including in most cases different steps that can be summarized in: understanding of customers' context, elicitation, analysis, negotiation, and evaluation/definition. In the proposed FITMAN approach also a trusted method for data acquisition has been defined that was created on the basis of the methodology of Wellington[2] created in "Research Methods for the Social Sciences". The Wellington methodology follows a 4-step method:

1. Brainstorming
2. Classifying and categorising
3. Creation of the guide
4. Interview schedule

[1] FITMAN is a FI-PPP Phase II project, developing and applying Future Internet (FI) technologies to manufacturing industries.
[2] Wellington, Jerry, and Marcin Szczerbinski. Research Methods for the Social Sciences. London: Continuum International Publishing, 2007

The FITMAN revision of Wellington consists on the adaptation of the steps to the real requirements centred on our Ecosystem's use case. Thus, the steps to be followed are:

1. Conceptual design. Approach discussion and agreement
2. Classifying and categorising the content
3. Creation of the template/interview
4. Template and Interview schedule

The specific procedure to gather the information will therefore follow the next steps:

1. Conceptual design. Approach discussion and agreement: In this stage, we developed an initial idea to attempt the data gathering and define a first version of the questionnaires that was discussed with the rest of the work packages 1 and 2 participants. After an initial agreement, we planned a schedule for a review and second release of the questionnaires.
2. Classifying and categorizing the content: In this phase, we discussed, analysed and reviewed the content we need to include in the questionnaires and the format of the different paragraphs to achieve a certain degree of harmonization and quality.
3. Creation of the template/interview: After the classification and categorization of the content that the questionnaires had to contain, we develop a final version of the questionnaire that was delivered to the Trials. We also planned the preliminary content of the interviews in order to assure accomplishment of schedule and effectiveness.
4. Template and Interview schedule: We finally entered in an iterative phase where interaction with the trials was done to assure understanding, length, coherency and quality of the information delivered. This phase holds the delivery and feedback of questionnaires and the interviews for final adjustments, corrections and fulfilment of required information.

The questionnaire has been completed after several meetings among the stakeholders involved in the process, where a careful analysis of the relevant information to be collected has been carried out. These meetings and interviews had the purpose to clarify the contributions made and to fine-tune further refinements in the elicitation process. The collected information is incorporated into a master document.

The workflow implemented for the generation of the present document is presented in Figure 1.

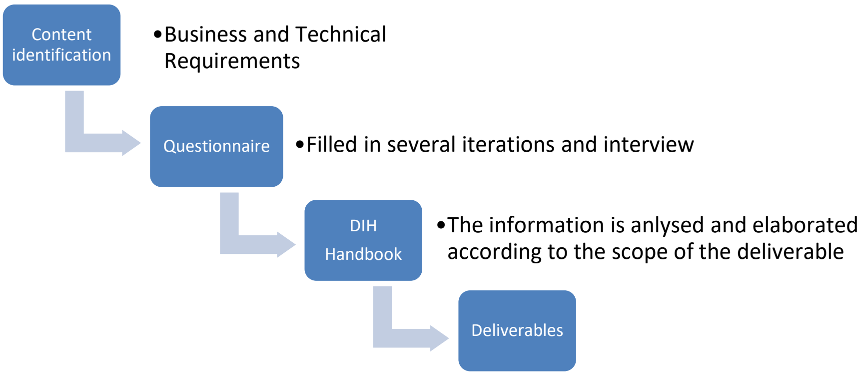


Figure 1 - RE4DY Information gathering workflow

2.3 VW Pilot: Connected resilient logistics design & planning pilot

2.3.1 Pilot Overview

2.3.1.1 General description

Volkswagen Autoeuropa is a brownfield plant established back in the early 90's. It is a plant driven by low cost, practical and simple operational solutions in order to accommodate frantic production uptimes. The chief objective is to deliver the planned daily vehicle production with the lowest cost possible for manufacturing and logistics, which is why efficient and reliable solutions are preferred in order to keep up with the required uptimes of a high output plant.

This mindset to pursue simple reliable solutions has placed the plant on the spotlight of the Volkswagen Group. Throughout the years, the plant gained a reputation within its competitors as reference for innovative low cost and trustworthy solutions. This is significant important and relevant for the Volkswagen Autoeuropa because, expensive operational solutions are often discarded since, they deemed the investment costs high against low returns which, do not generate attractive business cases. This effect results from the low cost working force running on the plant. On the other hand, plants in the proximity of the headquarters often embrace sophisticated expensive projects simple because the returns are much higher due to the steep labor costs found in central Europe.

In short, for the current global economy, Volkswagen Autoeuropa preferably follows a rationale where processes at their core see a constant scrutiny for optimization to keep costs at a minimum.

The plant also stands out as one of the highest achievements of foreign investment in the country. Collaboration between Portuguese and German governments have been fruitful for both parties. For example, the region where the plant is currently located has fetched a much desirable modernization, social stability and job security. Naturally, this region has seen a significant growth in the automotive sector thanks to the influence of Volkswagen Autoeuropa, which relies on strategic JIT suppliers to reduce logistics costs as much as possible.

From a Group level, it has been noticed an increase in early initiatives on digitalization and modernization in order to reduce complexity, human dependency and increase resilience as an effort to adapt and place a strong foothold into new mobility technologies i.e.: electrification.

Volkswagen Autoeuropa does not compete outside its circle of influence, meaning that plants within Volkswagen Group primarily sought sustainability with the assignment of high output products. In other words, the key performance indicators that face the highest examination are the ones that tell a story of assurance to comply with a product with high demand from the public. This mindset triggers plants to reduce their operational costs to a minimum. As simple as it may sound, this is a task, which requires significant effort to pull together because; the current political and economic framework is often fertile on issues, which only the most resilient and flexible plants can handle at reasonable costs, i.e.: supply chain shortfalls, geo political issues, etc.

In additional to this, plants also compete to be as attractive as possible to new mobility solutions, which translate into a significant shift in the industry from combustion to electric engines. This ordeal brings an additional layer of complexity with tremendous challenges to the whole supply chain and manufacturing processes. Well establish brown field plants (like Volkswagen Autoeuropa) must find creative solutions to adapt their production to these new initiatives with the lowest financial impact, otherwise, the group will deem unfit such a plant for a future investment in such products.

2.3.1.2 Objectives

It is clear that within the Volkswagen ecosystem, there is a growing emphasis to develop solutions for the logistics processes through digitalization and data analytics. Each plant of the Volkswagen Group is witnessing a slow but steady deployment of innovative technology on these domains (digitalization and data analytics). These deployments are, so far, either impactful simple solutions that assist employees in everyday tasks, i.e.: BOTS or, deep structural IT initiatives to organize and deploy data from major legacy systems into one central location. The primary goal of the latter initiative is to make this data easily accessible to everyone, through a fluid user experience, enabling and empowering logistics planning specialists with the necessary information to generate key insights about the logistics processes.

Such initiatives will most likely take several years before it reaches the high level of quality targeted by the Group, however, Volkswagen Autoeuropa has invested considerable effort on early developments of similar concepts, although at a smaller scale by dealing (for the most part) with the data generated by its own logistics processes.

The foreseeable benefit of such strategy is to ease the deployment process of these new technologies. Take the example of the first European initiative (BOOST 4.0) where, the logistics data silos where broken down for comprehensive logical connections converting a complex multiple sources data environment into a single source system.

This early initiative is already collecting significant financial benefits through incremental optimizations of the logistics process, thus a full scale up to a central sophisticated platform promoted by the Volkswagen Group could expect to bring further benefits at a higher scale.

In short, the main objective of RE4DY at Volkswagen Autoeuropa is to extend the work already developed on BOOST 4.0 by building on top of the results and findings obtained. More specifically, the natural step forward is to routinely adapt on a monthly basis the logistics processes to an optimum scenario and then establish an efficient communication and deployment of that optimum scenario to the main logistics stakeholders.

Below an generalised description of the steps required to achieve the principal objectives of RE4DY:

- Step 1: insights about the logistics processes are generated based on the production requirements for the next weeks;
- Step 2: logistics planners take the data from those insights into a simulation environment in order to extract which resources are required and which are possible to optimize. Different iterations and scenarios are analysed during this step;
- Step 3: the logistics planners validate the new optimum scenario and then this information reachs all stakeholders of the logistics domain. Information must flow digitally and effortlessly, meaning that this task should only require the lowest effort from the logistics planners, i.e.: e-papers connected to a logistics main

frame, display information about which containers must be placed in the logistics areas according to the planning created by the simulation and validated by the staff;

- Step 4: information reaches all stakeholders and it is clear to every party involved what is required of them to launch the optimum scenario. On the established deployment date, the optimum system goes live.

Although being a simplified description of the main objectives of RE4DY, it serves the purpose of framing the reader into the five benefits of the initiative at Volkswagen Autoeuropa. They are:

- Autonomous / Automatic Planning: ad hoc studies are achievable with relatively ease however, the final stages of implementation of cost efficient logistics scenarios are time consuming. The issue lays on the significant effort required to deliver and consequently deploy these scenario on the shop floor. It is rewarding for a logistics planner to deliver a cost efficient scenario but the effort imposed to deploy these scenarios is unproductive at best and demoralizing at worst. Having said this, autonomous and/or automatic planning must come into the routines of logistics planners.
  The plan to achieve this status is through a system configuration, where on a monthly basis, a logistics planner is only required to validate the insights for the optimal scenario (autonomous) and then, with a simple click of a button, deploy them to the stakeholder (automatic) to change and adapt the current layouts/parts/assets on the shop floor.
  The chief benefit is to relief logistic planners of these time consuming tasks making them available to attend other significant projects with the planning department.
- Lead time reduction (design iteration and implementation time reduction): speed up implementation with the reduction of time designing optimal cost efficient solutions for logistics processes. This is achievable by relieving the main stakeholders of less sophisticated calculations tools, which are time consuming when adjusting variables is required. This accounts specially for asset efficiency calculation where a strong sophisticated simulation tool brings significant time reduction between each adjustments /scenarios.
- Overall efficiency increase (process and assets): optimization of line feeding equipment (assets) and processes thanks to optimum solutions found by the ML / Digital Twin systems on simulation environments.
- Flexibility (changeover shortening): increase in process flexibility with the reduction of the average time spent communicating and deploying adaptations of optimal scenarios to the logistics processes. This topic is significantly important to handle unforeseen or out of process situations that have impactful

consequences on the production and or logistics internal supply chain of Volkswagen Autoeuropa. Being able to adapt optimally to these vulnerabilities is key to establish resilient logistics processes and thus bringing down costs considerably.

- Operating cost reduction: optimum processes means less effort/costs with the internal stakeholders on the shop floor. Naturally, to keep the internal supply chain running smoothly, there are costs linked to each service provided thus the more efficient it is, the less costs it requires.

2.3.1.3 Participants

VWAE

Volkswagen Autoeuropa belongs to an automotive manufacturing industry located in Portugal (Palmela) since 1995 and a production plant of Volkswagen Group. It manufactures the Sharan and T-Roc models for Volkswagen and the Alhambra for SEAT, another brand of the Volkswagen Group. Volkswagen Autoeuropa plays a strategic role in the Portuguese automotive industry, as it is the largest automotive manufacturing facility in the country and is responsible for around 10% of all Portuguese exportations. The plant employs around 6000 workers and, indirectly, it employs close to 8000 people through the more than 800 suppliers that provide materials, components and parts to the facility.

The factory covers an area of 2 million square meters: 900,000 square meters are factory premises and 1,100,000 square meters belong to the industrial park. In 2017, Volkswagen Autoeuropa focused on launching a new product - the T-Roc, and a new work system that will lead to a significant increase in production volumes.

The plant covers the entire automotive creation chain from the press shop, body shop, paint shop to assembly. With the introduction of the T-Roc, a Bicolour line has been built that offers 29 different colour combinations and also offers 600 possible combinations of roof, exterior and cockpit finishes. The Toolmaking Business Unit within the Industrial Park employs 189 people and produces tools for the Group. The factory also produces parts for other brands of the Volkswagen Group, which in 2017 had a business volume of 17.2 million euros.

Volkswagen Autoeuropa is one of Europe's most modern automotive production facilities. It was designed using advanced technology and continuously incorporates the latest developments in automation and computerized production control, in order to meet the high standards required for manufacturing a quality product.

UNINOVA

UNINOVA - INSTITUTO DE DESENVOLVIMENTO DE NOVAS TECNOLOGIAS (UNINOVA) is a multidisciplinary, independent, and non-profit research institute employing around 180 persons, located in the metropolitan area of Lisbon. It was formed in 1986 by the Faculty of S&T of the University Nova de Lisboa (FCT-UNL - www.fct.unl.pt), a group of industrial associations, a financial holding, and up to 30 companies. It is an active partner of Madan Parque (www.madanparque.pt), a business facilitator and accelerator, incubating Micro and SME's through several layers of support to entrepreneurial activity.

The main aim of UNINOVA is to pursue excellence in scientific research, technical development, advanced training and education. By working closely with industry and universities, technological innovations are transferred into profitable business concepts and existing products further developed to match new industrial requirements. Due to its tight connection with the University and Madan Parque, UNINOVA has, since its foundation, hosted and supported the development of several PhD thesis, as well as the creation of several successful spin-offs. The institute is strongly committed to eEurope and to Lisbon Strategy being involved in many activities that support/enable the developments and actions towards the knowledge economy. GRIS has managed and participated in many national and international research programs (ESPRIT, BRITE, IMS, IST, ICT, NMP, INNOVA etc) with experience in RTD in industrial systems interoperability, future internet enterprise systems, e-learning and e-training activities, and standards based activities (e.g. ISO TC184/SC4). The group also coordinated the IMS SMART-fm framework creating a community (funStep community) with more than 700 members, and also supported the launch of several spin-off companies using research results.

The impact and results achieved through these activities is both on the academic and scientific community, with papers published in chapters of books, international scientific journals and conferences. These results are also in use by industrial research projects addressing big data, IoT and interoperability topics, and have been source for further scientific and technical innovations towards seamless interoperable environments and Industry 4.0. These include standardisation communities. The work developed resulted in several international awards.

CTS-GRIS is the UNINOVA department that is involved in RE4DY, providing expertise in the domain of AI and Big Data processing. Within these domains, some of the technical focus areas which we address are:

- Methods for data collection, cleaning and fusion, supporting integration across transactional systems, operational data stores, BI (Business Intelligence) platforms, MDM (Multi-Dimensional Data Modelling) hubs, the cloud, and other Big Data platforms.

- Distributed data and process mining, predictive analytics and visualization at the service of industrial decision support processes, including the development of data-driven approaches such as linear regression, using historical large datasets.
- Real-time complex event processing over extremely large numbers of high volume streams, as for example the development of anomaly detection mechanisms aiming to find patterns in data streams that do not conform to expected behaviours.

The group is being involved in several projects related with AI and Big Data Processing, namely:

- AIDEAS-101057294, "AI Driven industrial Equipment product life cycle boosting Agility, Sustainability and resilience"
- I4Q-958205, "Industrial Data Services for Quality Control in Smart Manufacturing".
- VesselAI- 957237, "Enabling Maritime Digitalization by Extreme-Scale Analytics, AI and Digital Twins".
- ZDMP- 825631, "Zero Defect Manufacturing Platform"
- BOOST-780732, "Big Data Value Spaces for COmpetitiveness of European COnnected Smart FacTories 4.0".

CEIT

ASSECO CEIT AS (CEIT) is an innovative technological company with a strong R&D focus providing companies with comprehensive solutions in the field of technical and process innovations, industrial automation, and optimization as well as intelligent internal logistics. It is a one-stop shop in the field of industrial digitization and is a strong partner for manufacturing a logistics companies using Industry 4.0 tools.

The team of CEIT consists of specialists in industrial engineering, electrotechnics and informatics who create innovative solutions to help companies identify and remove bottlenecks. They solve specific tasks as well as design complex systems from the concept to production of the first series of products, from designing workplaces and production lines up to their maintenance, verification and optimization while employing simulation as well as planning and production management with the maximum use of capture technologies. Smart mobile robots, automated production lines, virtual training systems, Digital Factory tools – these are just a few of our innovative solutions.

The company is based in Slovakia and successfully operates on a pan-European level. Its customers include major industrial companies, especially in the automotive, engineering, chemical and electrical industries. Asseco CEIT, a.s. has been a member of the international Asseco Group since 2017.

Among commercial activities the company has been involved in several R&D projects on national and international level, to name a few:

- Intelligent Sensor Structures for Autonomous Production Systems (national project)
- Innovative Solutions for Propulsion, Power, and Safety Components of Transport Vehicles (national project)
- Integrated Modular System of a Factory Twin (national project)
- Hydealist - Hybrid Storage and Fast Charging for AGV in Logistics (international project)
- enerHUB - Platform for Value Optimization of Industrial Battery-Electric Vehicle Fleets Using Digital Twins and Artificial Intelligence (international project)

2.3.2 Business Scenarios

2.3.2.1 Logistics of the Future: Connected Resilient Logistics Design & Planning

Current Business Scenario

The logistics of delivering the parts to the assembly line play a key role in the success of a car company and consequently, any optimization to the logistics environment reduces substantially the production cost of a vehicle.

Throughout the years, Volkswagen Autoeuropa has done numerous optimizations in its logistics process namely, with the introduction of AGV's and with the implementation of auxiliary sequencing tools. Having this said, the process is still heavily reliable on manual procedures, which in turn render the system dependable of human interaction with demanding labour activities and, deprived of communication/integration between some systems.

GT Process – Stock Out

Dashboards are available to study optimum financial scenario

Experimentation to test different variables on optimum scenario is difficult

Update is necessary on a monthly basis but it is not done because it is time consuming for logistics planners.

GT Process – Picking

Sheets of papers to display information raise significant issues. The main one being the high effort required from logistics planners to update process (physically moving from office to bahnhof, waste of paper to update process).

The current method of displaying information does not allow to forecast eventual updates to the process, i.e.: logistics operators don't know which parts are to be updated in the process.

GT Process – Transport / Line Supply

Dedicated line feeding assets for GT Process which are not fully optimized.

Recalculations or adjustments on asset occupation are laborious. It takes considerable effort to perform this analysis.

No further studies for asset optimization are performed.

GT Process - Overall

Communication to stakeholders of new scenarios for GT Process is not efficient

Low flexibility to deploy new scenarios does not take full potential of the financial benefits

In general, the process is not resilient

Future Business Scenario

GT Process – Stock Out

Business Process 1: Monthly routine to update ideal parts for GT Process.

- list ideal part numbers for GT Process
- enable inputs from planning specialist to test different scenarios
- deploy efficiently final scenario

GT Process – Picking

Business Process 2: Digitalization with e-paper display.

- display information of current part numbers
- display information of incoming part numbers when new scenario is ready for deployment
- enable remote update for planning specialist

GT Process – Transport / Line Supply

Business Process 3: Asset optimization.

- simulate the routes required to deliver the parts from the new scenario
- data analysis from simulation and test different scenarios
- deploy optimum scenario (asset optimization)

GT Process – Overall

Vision: automation, big data and digitalization (diagram).

Goals: adaptive planning based on continuous analysis of AS IS versus TO BE scenarios.

Calculation of optimal process configuration through simulation.

Automation of process planning with sustained KPI monitoring and insights extracted from big data and simulation analysis.

Optimal resources are calculated for the system. These configurations are shared automatically with the logistics service provider.

This is digitalization of the planning process.

It reduces costs with the increase of productivity.

Business Objectives

- The main Business Objectives of this pilot are:
- Productivity increase.
- Overall equipment efficiency.
- Product cost reduction – reduction in logistics cost up to 5%.
- Operating cost reduction.
- Lead time reduction (agility).
- Design iteration time reduction (speed to market)-
- Configuration accuracy increase (customization).

2.4 AVL Pilot: Collaborative ecosystem resilient product/production system engineering for electric battery pilot

2.4.1 Pilot Overview

2.4.1.1 General description

The Battery Innovation Center (BIC) (Figure 2) was created with the aim of being able to work out for the first time both battery modules and an energy-efficient production or recycling process for battery modules and to optimize and validate them in a near-series environment. All common core processes of battery module production can be demonstrated at fully automated stations. Regardless of cell type, cell voltage and degree of integration, all steps of module production can be mapped. With the industrial robots in the BIC, AVL can also serve the battery development goals of "cell-to-body" and "module-to-chassis", which are becoming increasingly important for car manufacturers. Another important innovation of the BIC is the production-technical safeguarding of large-scale production in a real industrial environment. In the pilot line, the production process designed simultaneously during module development can be tested in detail under real conditions. In this way, battery modules can be manufactured in the BIC from individual production at A-sample level to construction batches of several hundred pieces under complete monitoring of defined quality characteristics.

Figure 2 - Battery Innovation Center (BIC)

The most far-reaching innovations of the battery module were the first realization of an 800 V battery with immersion cooling, in which the cooling medium (dielectric fluid) directly surrounds the cells. To keep the module compact, a flat busbar was welded directly onto the cells. An innovative flat and flexible circuit (FPC - Flexible Print Circuit) was used as a temperature and voltage tap. An enclosure was realized in the form of an innovative monoframe concept into which the battery cell stack is inserted. Then the end plates are welded to the monoframe, and a thermally conductive paste is injected to ensure a good connection to the cooling plate.

The AVL pilot based for the development of the RE4DY project is a Flexible center for production-oriented manufacturing of prototype battery modules and packs (Figure 3). The characteristics of this manufacturing center are:

- Assembly process development for specific assembly procedures in battery production
- Close-loop feedback to product development (DfM - Design for manufacturing)
- Serve higher volumes in A- & B-sample prototypes
- Provide capacity for field test fleets, racing series and C-samples
- Provide industrialized designs and processes “ready for ramp-up”
- Leveraging of engineering business for battery development
- Verify Eco-Design products in respect to recycling and cost
- Fusion of Function & Process Development

Figure 3 - Overview of the AVL pilot in RE4DY project

2.4.1.2 Objectives

The objectives for the end user pilot (AVL) are in line with the targets of the project:

O1: Establish a resilient manufacturing engineering reference framework for digital smart products & production value ecosystems in connected factories 4.0

Developing a general model for jointly optimizing individual and value chain industrial process efficiency, sustainability and reliability .

O2: Increase big data pipel ines, data, digital thread and digital twin autonomy and interoperability with a set of open Digital 4.0 continuum toolkits for value networks of "Data as a Product"

Integrating the distributed data management operations and increase data and pipeline reusability and portability.

O3: Accelerate and reduce implementation costs of integrated intelligence and active knowledge in holistic cognitive & collaborative connected factory 4.0 Zero X smart manufacturing

Increasing efficiency, scale and trust building in distribute d Industrial Internet value networks set up & data sharing

O4: Democratize industrial data spaces and cognitive digital twins maximizing commercial impact, optimizing up/re skilling needs and adoption (manufacturing and digital)

Identifying access to data sets and support to build resilient DT processes and become trusted value network prosumers.

2.4.1.3 Participants

AVL

AVL List GmbH ("AVL") with its headquarters in Graz, is one of the world's leading mobility technology companies for development, simulation and testing in the automotive industry, and in other sectors. Drawing on its pioneering spirit, the company provides concepts, solutions, and methodologies for a greener, safer and better world of mobility. AVL constantly expands its portfolio of high-end methodologies and technologies in the areas of vehicle development and testing. With a holistic approach - from the ideation phase to serial production - the company covers vehicle architectures and platform solutions including the impact of new propulsion systems and energy carriers. To achieve the vision of climate-neutral mobility, AVL drives innovative and affordable solutions for all applications - from traditional to hybrid to battery and fuel cell electric technologies. As a global technology provider, AVL's offerings range from simulation, virtualization and test automation for product development to ADAS/AD and vehicle software. The company combines state-of-the-art and highly scalable IT, software and technology solutions with its application know-how, thereby offering customers extensive tools in areas such as Big Data, Artificial Intelligence, Cybersecurity or Embedded Systems. Furthermore, AVL is striving towards a safe and comfortable driving experience for everyone and brings a comprehensive understanding of assisted and automated driving functions in different vehicles and environments into play. AVL's passion is innovation. Together with 10,700 employees at more than 90 locations and with 45 Tech and Engineering Centers worldwide, AVL is supporting customers in their mobility ambitions. In 2021, the company generated a turnover of 1.6 billion Euros, of which 12% are invested in R&D activities to ensure continuous innovation.

In recent years, AVL has extended its development portfolio to SOP- and industrialization projects for all powertrain elements. Within these production development projects, an early focus on industrialization aspects concerning manufacturability, costs, product quality and product documentation is key for product success. Services within product development and production of battery, e-drive, combustion engine, transmission, fuel cell and controls are also in place.

Especially on battery topics our main objective is the development and the prototyping of modules and battery systems for (auto)mobile use from all three different cell types on the market. The central focus is the combination of product development and new production processes for an optimal product design with an emphasis on eco-design and reusability. For applications ranging from two-wheeled to marine, which provides a high degree of flexibility in the dimensions to be processed.

Worldwide service provider through a worldwide and strongly interconnected network of development and engineering knowledge, AVL is able to cover all powertrain development aspects e.g. assembling packs and modules. Additionally, the Graz headquarters has its own testing center which covers all requirements for tests from single cell to pack level.

With the opening of the Battery Innovation Center in mid-2021, which aims to drive the innovation of production processes and further development of batteries and integration concepts, AVL has the possibility to process the industrialization of batteries at a previously unknown scale in parallel with product development.

IMAGE (H2020 GV-13-2017 ProjNr.:769929): Innovative Manufacturing Routes for Next Generation Batteries in Europe. This project has started in November 2017. Knowledge regarding battery chemistries and production of live component will be a valuable input for this initiative

Productive 4.0 (H2020 ECSEL 2017 ProjNr.: 737459): Productive4.0 is an ambitious holistic innovation project, meant to open the doors to the potentials of Digital Industry and to maintain a leadership position of the industries in Europe. All partners involved will work on creating the capability to efficiently design and integrate hardware and software of Internet of Things (IoT) devices. Knowledge related to smart production and especially (a) automation and (b) usage of data analytics in the production will be a valuable input.

Battery Innovation Center (FFG national funded): The goal of the Battery Innovation Centre (BIC LAB for short) is to create a facility that allows the assembly of both conceptual and production-ready high-voltage battery prototypes using automated manufacturing techniques. The BIC initiative is intended to provide an industrially relevant R&D platform for module and pack production in the automotive sector, with the aim of strengthening and improving innovations and competencies along the entire value chain in the e-mobility sector.

BICnextGen (IPCEI on batteries II - EuBatIn): In this project AVL is now targeting to enhance the overall quality within module and pack production starting at the incoming inspection of different cell types throughout the complete assembly process. In addition, AVL will develop new processes within the module production to reduce overall cost and efforts. Furthermore, the topic of zero net CO2 production environment will also be covered by our project in detail and is supposed to end in a lighthouse factory approach.

FILL Gesellschaft m.b.H

FILL, founded in 1966, is one of the world's leading ideas manufacturers for production systems in the fields of automotive, aerospace, sports, energy, wood & construction. The products include machinery and equipment in the fields of aluminum foundry technology, metal cutting, woodworking and plastics or composite / fiber composite automation. Since 1997 FILL is ISO 9001 certified.

Since 2007, FILL has been intensively active in the area of product-accompanying software applications and services. The focus is on additional applications for machine data acquisition and productivity optimization.

The implementation of a digital strategy in machine and plant development has been a central focus of work for many years, ranging from virtual commissioning and data technology production monitoring to automated condition monitoring solutions in the service area.

Fill overs a wide range of digital solutions:

FILL CYBERNETICS is an essential constituent of Fill machines and systems. From the monitoring of complex individual operations and production data (e.g., machining, energy efficiency, lifecycle costs) to seamless component traceability through to automated system optimization by means of artificial intelligence (AI), Fill covers the entire bandwidth of required solutions, platform-independent dashboards designed to customer specifications provide an optimum overview and enable detailed analyses

CYBERNETICS ANALYZE Is the analysis platform for recording and storing relevant machine parameters to visualize both the health status and the efficiency of the machine and processes for production, maintenance, and planning. With the help of self-learning algorithms, you are able to continuously increase your quality and efficiency.

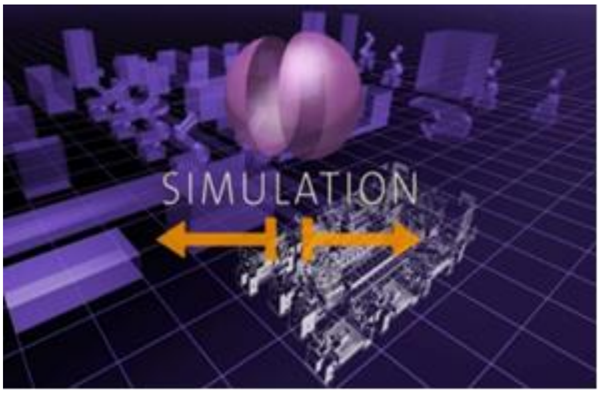


Figure 4 - Cybernetics Simulation

With CYBERNETICS SIMULATION system concepts and production processes can be simulated in-house in the planning phase and thereby checked for cycle time and feasibility. The insights gained flow into the system concept and result in optimized solutions. CYBERNETICS SIMULATION also enables simulation of third-party solution proposals and handling of complex engineering orders.

FILL occupies a key role in process automation and data organization for complex manufacturing facilities and has the necessary human resources and infrastructure to implement automated production lines. The project-specific priorities are the data technology preparation of own machines, the development of IT infrastructure and the provision of machine and production data from linked process flows.

With more than 120 software engineers as well as state-of-the-art workstation equipment, FILL has the necessary resources to professionally handle such projects. FILL has extensive experience in data management of customer and research projects.

Figure 5 - Fill the Future Zone

The technologies used include not only PC software development and control programming (SCL .NET, C ++, etc.) but also WEB services (eg JSON, XML), communication protocols (eg OPC DA, OPC UA) and many others.

The FILL FUTURE ZONE is a high-tech center for the advancement of digitalization, software engineering, and mechanical development. It provides a look into the future of machine production. Virtual and real processes form a symbiosis, thereby opening completely new opportunities.

Fill will access accumulated knowledge of the following projects and apply it in this pilot:

- DIMOFAC GA 870092 - H2020. Digital & Intelligent MOdular FACtories - Establish a pan-European ecosystem of pilot lines of modular manufacturing deployed across an ecosystem of well-established FoF testbeds with a plug-and-produce data infrastructure, based on digital threading and digital twinning, and featuring a wide range of production plug-and-produce modules across different industrial domains: i) multi-materials manufacturing ii) additive manufacturing iii) flexible assembly lines.
- Boost 4.0 GA 780732 - H2020. BOOST 4.0 project addresses the need for development of large-scale experimentation and demonstration of data-driven connected smart Factories 4.0 by demonstrating in a measurable and replicable way, a shared data-driven Factory 4.0 model through 10 pilot factories.
- IOTWINS GA 857191 - H2020. IoTwins is an European project that will work to lower the barriers for the uptake of Industry 4.0 technologies to optimize processes and increase productivity, safety, resiliency, and environmental impact. IoTwins approach is based on a technological platform allowing a simple and low-cost access to big data analytics functionality, AI services and edge cloud infrastructure for the delivery of digital twins in manufacturing and facility management sectors.
- PLEDGER GA 871536 -H2020. The Pledger project aims at delivering a new architectural paradigm and a toolset that will pave the way for next generation edge computing infrastructures, tackling the modern challenges faced today and coupling the benefits of low latencies on the edge, with the robustness and resilience of cloud infrastructures.
- MetaFacturing GA 101091635 – HE. MetaFacturing focuses on a digitized toolchain for metal part production which will lead to a more resilient production process with respect to the raw materials used (e.g. recycled materials), reduces operator effort and cost, and reduces scrap due to out-of-specification parts. The envisaged approach will exploit all available data in the process, starting from material data, in-process measurements, end-of-line quality control and sampling-based product valida.

Visual Components

Visual Components is recognized as a global leader in the manufacturing simulation industry and a trusted technology partner to many of the leading brands in industrial automation. Founded in 1999 by a Finnish-American team of simulation experts, Visual Components started with a humble goal – to make factory design and simulation technology easier to use and more accessible to manufacturing organizations of all sizes. Visual Components, which recently has become part of the KUKA group, is headquartered in Espoo (Finland) and has subsidiaries in Michigan (USA) and Munich (Germany) along with a global network of partners and resellers.

Visual Components offers a 3D factory simulation suite that consists of a set of innovative tools which set the standard for modern simulation. The simulation suite gives machine builders, system integrators, and manufacturers around the world a simple, quick, and highly cost-effective way to build and simulate their total process solutions.

As technology provider, Visual Components contributes with its knowledge and expertise in Factory Simulation and Visualization technologies. Visual Components 3D simulation software will allow creating virtual scenarios for the AVL pilot and extending the experience to other pilots in the project. Visual Components is also involved in the standardization initiatives related with Industry 4.0, as member of the IEC SC 65E committee will push the introduction of the standards developed in RE4DY in the new standardization initiatives of the IEC group.

Visual Components has a demonstrated experience developing 3D manufacturing simulation software and solutions for the industrial automation community. The 3D simulation tools developed and the know how in the factory simulation domain and in automation systems will bring to RE4DY an important background to develop digital twins that mirrors the real factory along the entire production life cycle, enhancing quality and reducing errors using big Data. The open interfaces available in the simulation solutions will allow to incorporate and extend the latest technologies in interoperability and communication aligned with Industry4.0. This will enhance the reusability of data and the efficiency in the design and implementation of new production systems.

Visual Components has experience accumulated in relevant projects that will use in this pilot:

- L4MS. Logistics for Manufacturing Systems. L4MS will provide complete digitalization solution (Open Platform for Innovations in Logistics [OPIL] + Visual Components®) to enable cost effective deployment of exceptionally small and flexible robotics logistics solutions requiring no infrastructure change, no production downtime and no in-house expertise, while making investment in logistics automation extremely attractive for manufacturing SMEs. The experience acquired in data communication will be used and extended in AVL Pilot.

- F2Fit –Factory2Fit. Empowering and participatory adaptation of factory automation to fit for workers. Developing the Factory of the Future by developing solutions to make the factory environment more flexible and adaptable. Despite Smart Factories are characterized by increasing automation, workers are essential in the factory of the future. Factory2Fit will provide the tools for maximizing the capabilities of the worker in the development of the factory of the future. AVL pilot will take advantage of the know-how of this project at the moment of developing more intuitive interfaces to minimize errors when handling large amounts of production data.
- LIAA – LEAN INTELLIGENT ASSEMBLY AUTOMATION. LIAA aims to keep assembly jobs in Europe by creating and implementing a framework that enables humans and robots to truly work together in assembly tasks. Co-working allows the senses and intelligence of the human to be complemented by the strength and endurance of the automation and so obtains the best from each of them, reducing repetitive injuries and costs and enhancing job satisfaction and the average length of time that a worker can continue in the same job. During the engineering and manufacturing phase AVL pilot will make use of the communication interfaces developed.
- SkillPro - Skill-based Propagation of “Plug & Produce”-Devices in Reconfigurable Production Systems by AML. Intelligent production machines and 'plug-and-produce' devices for the adaptive system integration of automation equipment, robots and other intelligent machines, peripheral devices, smart sensors and industrial IT systems. The innovative AML communication interfaces developed in SkillPro will be reused and extended during RE4DY and the AVL pilot will take advantage during the configuration and runtime operations handling big data.

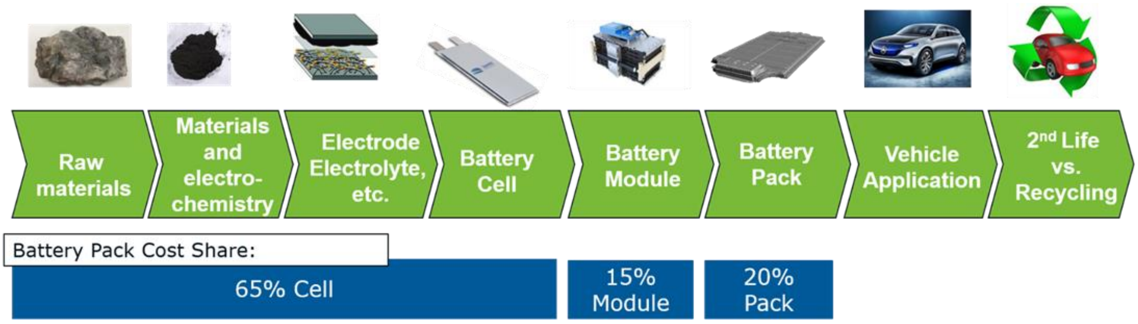
2.4.2 Business Processes

2.4.2.1 AVL, Fast deployment of configuration cell

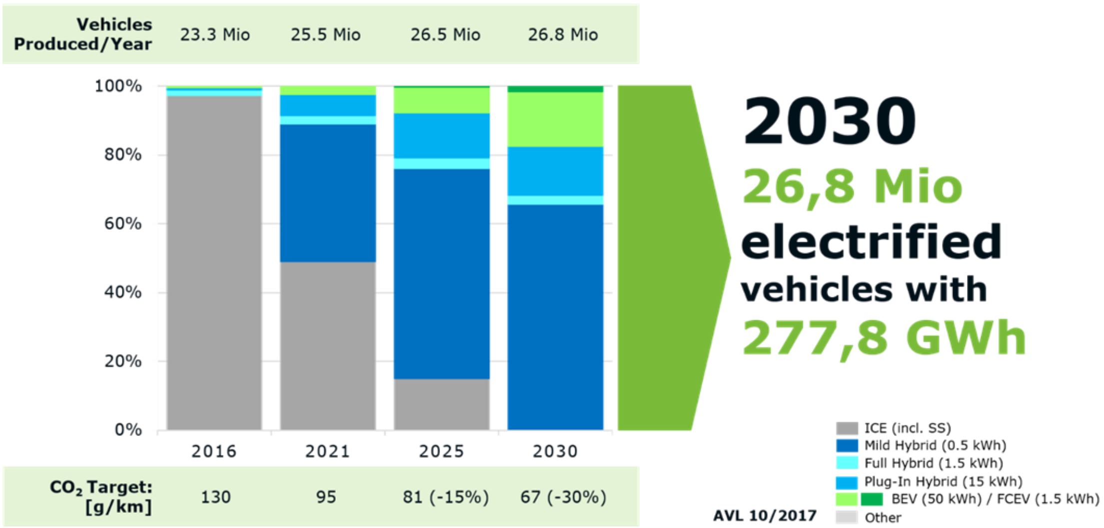
Business Present Scenario

As an independent service provider in battery technology, AVL offers a full package of innovative tailored solutions to address the challenge of clean e-mobility. Our dedicated products and services cover the entire battery development process – from the assessment and selection of a single cell to SOP of a fully validated battery pack.

Mechanical and thermal pack integration into the vehicle feature with low cost design, performance, serviceability, energy efficiency and recyclability.



Currently AVL has only a small market share compared to the whole market share available in the battery value chain. The focus lies on the module, pack and vehicle application, not from manufacturing perspective but from engineering service provider perspective. In that case the market share is relatively small compared to competitors which are focusing on manufacturing topics.



The AVL prediction for the vehicle share in Europe till 2030 can be seen. As it can be seen, till 2030 26,8 million vehicles will be electrified and the need for traction battery solutions will increase dramatically. Therefore, AVL want to be prepared to be a part of the battery value chain and use the opportunity to grow with the increasing market.

On the one hand AVL is providing prototype manufacturing and process development for their customers as well as on the other hand AVL will perform production and plant planning for the series production of the OEM. During the product development process and the production planning process the overall IT solutions like data share over the values chain will be analyzed and developed to guaranty the traceability and product quality.

Business Objectives

Based on the VDI 2206 - Design methodology for mechatronic systems a new engineering process will be designed. The macro-cycle (Figure 7) can be divided into six sections.

- Requirements
- System design
- Domain-specific design
- System integration
- Assurance of properties
- Modelling and model analysis

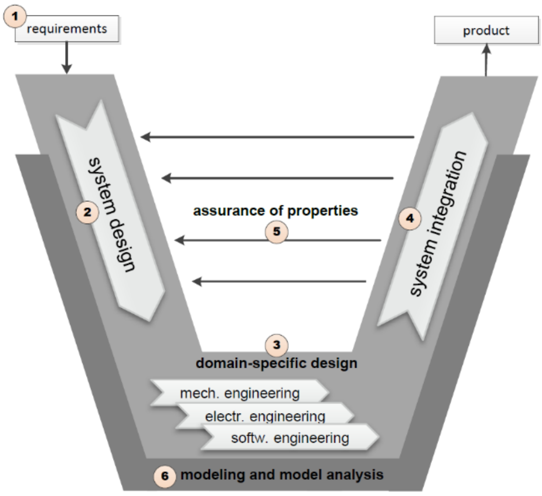


Figure 6 - VDI 2206 - V model as macro-cycle

The V-model describes the development of mechatronic systems based on a systematic analysis of the requirements and a distribution of the requirements and loads among the individual disciplines. The detailed development then takes place in parallel and independently of each other in the individual disciplines. The results are then integrated into subsystems and systems and validated regarding compliance with the requirements.

The new proposal for an integrated business process for smart digital engineering using big data extends the V-model by (Figure 6)

1. Agile model management & development process
2. Data analytics process (involving e.g. machine learning methods)
3. Service development process
4. Simulation based release process

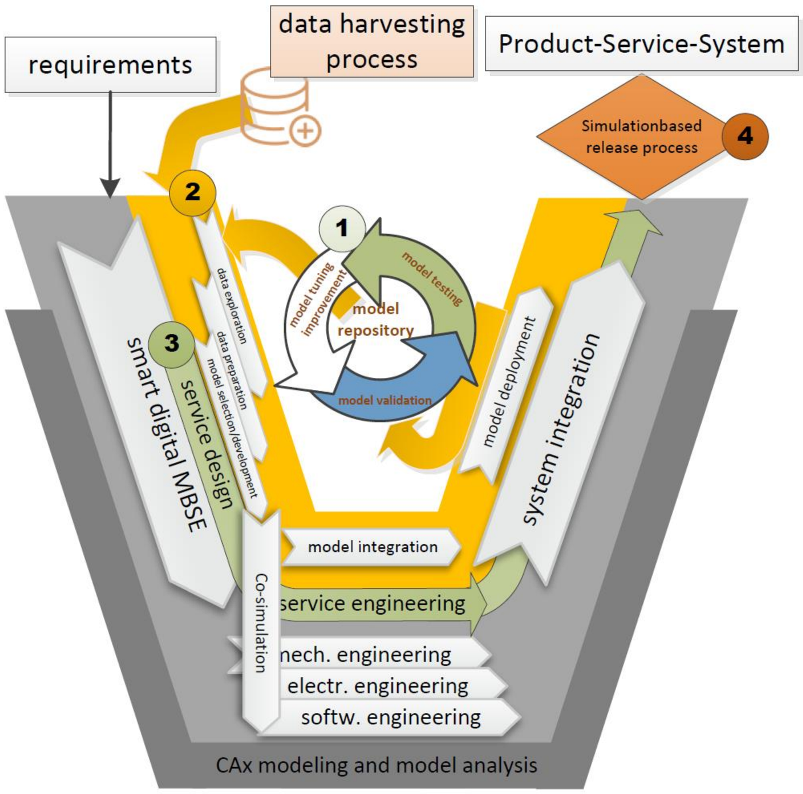


Figure 7 - Smart digital engineering process using big data (based on VDI 2206)

2.5 GF Pilot: Collaborative ecosystem integrated machine tool performance self-optimisation pilot

2.5.1 Pilot Overview

2.5.1.1 General description

The trial will take place at the Swiss Smart Factory[3] (SSF) in Biel, which is part of the Switzerland Innovation Park Biel/Bienne (SIPBB). The Swiss Smart Factory is an extensive test and demo laboratory for Industry 4.0 on 1000 m2, which, among other things, consists of a large production line for the manufacture of quadcopter and hexacopter drones in batch size 1. The production line demonstrates innovative manufacturing concepts and is

[3] https://www.youtube.com/watch?v=rnKOkLpi8v4

built and operated with more than 70 companies. It serves, among others, as an international test bench for data sharing in the POC-series with NTT and SIEMENS and in the EU-Project DIMOFAC. The test and demo infrastructure will be extended by the tool machine GF MILL P800 and Fraisa World, and many more solutions of the technology partners.

Figure 8 - Swiss Smart Factory will host the pilot

Figure 3, GF Milling Machine Mill P 800 U

Currently there is no multi-cloud ecosystem that connect the various actors in the Machine Tool sector to enable data-drive, cross-company services. Other companies in the Machine Tool sector are also somehow "physically" interconnected with each other, but do not have a common multi-cloud solution to exchange data and do further analysis on this data.

2.5.1.2 Objectives

The tool machine sector started the journey towards "servitise" their products, i.e. develop data-based add-on service around the physical asset. However, major obstacles in realizing data-based services on top of industrial assets are:

- Variety of proprietary data and scattered data silos in-between service providers and users, not designed to be connected to other services
- Unclear situation in terms of data security and ownership reduce the willingness to share data in-between companies
- Critical mass for pay-per-use business models missing, e.g. risk of under-utilization of the machine

It requires a framework to create an open, transparent data ecosystem, where data and services can be made available, collated, and shared in an environment of trust. To overcome the current limitations, the Machine Tool pilot will adopt the RE4DY Framework to ensure cross-company, multi-cloud data sharing ecosystem.

The pilot will represent a process optimization in the machine tool domain, building combined services with data from all involved actors: OEM machine tool builders, tier 1 tool producers, machine tool end-users, etc. (compare Figure 9).

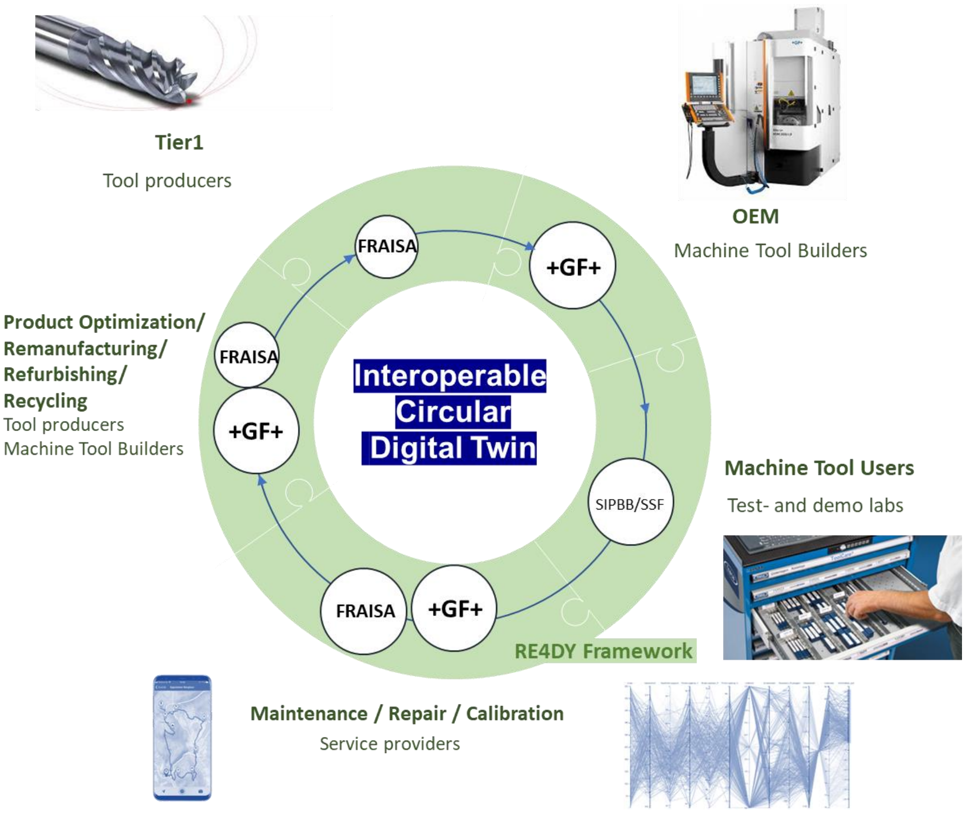


Figure 9. The various actors in the Machine Tool pilot.

The consequent adoption of the RE4DY Framework to the machine tool sector allows cross-company data sharing in multi-cloud environments. This leads to more complete and integrated data sources, which ultimate leads to better decision making with clear benefits for the machine tool end-users:

- Increased reliability of machining processes, and thus improved quality of the produced products
- Increased transparency and autonomy of machining and supply chain processes, and thus reduced manual efforts
- Reduced energy consumption during machining processes, and thus reduced environmental footprint of the produced products
- Increased diagnostic and predicative capabilities, and thus better data-driven services such as auto-diagnostics, predictive maintenance and predictive planning of manufacturing and supply chain processes.

2.5.1.3 Participants

GF

GF Machining Solutions is one of the world's leading providers of complete solutions for precision components and tools manufacturers and the mold-making industry. The portfolio includes milling, EDM, laser texturing, laser micromachining, and additive manufacturing machines. Additionally, the division offers spindles, automation, tooling, and digitalized solutions backed by unrivaled customer services and support. With its solutions, the division advances energy-efficient and clean manufacturing. The digital, My rConnect" platform represents the starting point for the RE4DY framework integration.

GF Machining Solutions serves different market segments, from traditional mould and die manufacturing industries, to Aerospace, Automotive and Medtech. Component production industries like aerospace and medical define a key target for the project as they focus on high strength materials (Ni based, superalloys, Titanium alloys, etc), which are very demanding for tooling and general maintenance, besides the requirements in terms of surface quality and productivity.

Average use of machines is over 6000 hs per year in those milling production centers, and most of end users are equipped with automation and software systems that manage the materials and tools into robotised lines. Periodic maintenances are scheduled for the equipment based on knowledge bases and mainly machining times records. The main challenges for those customers are to avoid unforeseen interruptions and part defects, which can lead to high maintenance or scrapped part costs.

Figure 10, GF's P800 Mill

GF has participated to EU projects Boost 4.0 and Qu4lity, focused on the implementation of a Digital twin for the Milling production process and the milling manufacturing process, and has defined a framework within the GF My rConnect infrastructure which can be deployed to the specific use case of RE4DY regarding predictive maintenance applications and circular economy.

FRAISA

FRAISA SA is a Swiss high precision milling tool manufacturer and delivers over 1 Mio tools per year to worldwide customers. 90% of machines systems and tools are exported to the automotive, aerospace, and industrial machine industry, to medical device manufacturers and microsystems industry. In 2020 FRAISA has developed with SIPBB, the IoT-connection from their tools to the "FRAISA World" platform. This approach is unique in the machine tool industry and will be expanded by integration in the RE4DY framework in order to combine it with additional important manufacturing data sources.

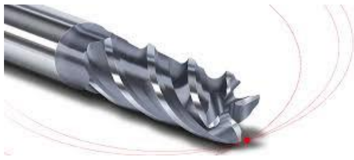


Figure 11, Fraisa tool example

FRAISA offers solutions tailored precisely to the latest market demands, even when it comes to unusual industry requirements. Our high product quality and industry-specific research are of enormous benefit to customers from various sectors, such as toolmaking, medical technology, and precision engineering. Our focus is on the continuous development of innovative high-performance tools, such as milling cutters, drills, taps, and inserts.

Siemens

Digital Industries is an innovation and technology leader in industrial automation and digitalization. In close cooperation with our partners and customers, we are the driving force for the digital transformation in the discrete and process industries.

The heart of our offering is our Digital-Enterprise-Portfolio. It offers enterprises of every size and type products, end-to-end solutions, and services for integrating and digitalizing the entire value chain. Optimized to meet the specific needs of each industry, they support our customers in shortening their development times and increasing the flexibility, productivity, and environmental efficiency of their production processes. To make this possible, we work closely with our customers and partners in ecosystems and on cloud-based platforms.

Digital Twin for the product (Product-PLM)

The digital twin of the product is created as early as the definition and design stage of a planned product. This allows engineers to simulate and validate product properties depending on the respective requirements: for example, is the product stable, and is it intuitive to use? Does the car bodywork offer the lowest possible air resistance? Do the electronics operate reliably? Whether it involves mechanics, electronics, software, or system performance, the digital twin can be used to test and optimize all of these elements in advance.

Digital Twin for the tool machine (Machine-PLM)

The same applies to the digital twin of production. It involves every aspect, from the machines and plant controllers to entire production lines in the virtual environment. This simulation process can be used to optimize production in advance with PLC code generation and virtual commissioning. As a result, sources of error or failure can be identified and prevented before actual operation begins. This saves time and lays the groundwork for customized mass production, because even highly complex production routes can be calculated, tested, and programmed with minimal cost and effort in a very short time.

Data Sharing Platform (Mindsphere)

In turn, the digital twin of performance is constantly fed with operational data from products or the production plant. This allows information like status data from machines and energy consumption data from manufacturing systems to be constantly monitored. In turn, this makes it possible to perform predictive maintenance to prevent downtime and optimize energy consumption. And some companies use data-driven services to develop new business models, as shown in the example of mechanical engineering firm Heller. At the same time, data-driven knowledge about systems like MindSphere – the open, Cloud-based IoT operating system from Siemens – can be fed back into the entire value chain all the way to the product system. This generates a completely closed decision-making loop for the continuous optimization process.

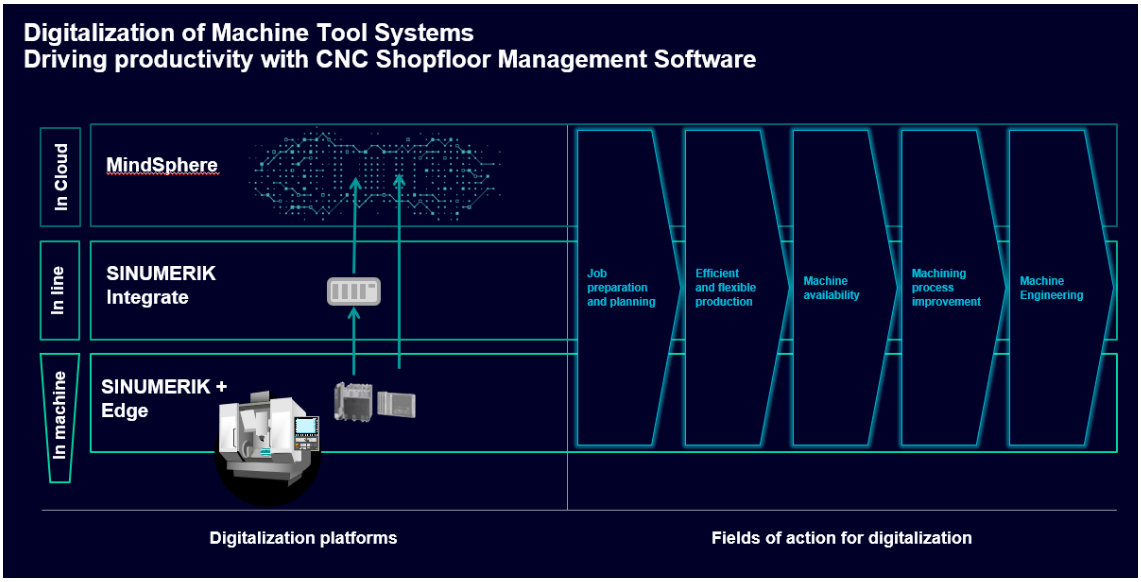


Figure 12, Siemens digitalization strategy for CNC machines

Atlantis Engineering

ATLANTIS Engineering is an SME highly experienced in developing services and innovative products for the manufacturing industry, emphasized on offering decision support for management and optimisation activities related with assets' life cycle. By taking advantage of the streamlining of various maintenance related data and processes, the company supports stakeholders of the manufacturing community (and more) to understand and prioritise smart and efficient solutions towards cognitive manufacturing by implementing cutting-edge Industry 4.0 strategies. ATLANTIS' software products are based on failure mode analysis, real time and historical data and multiple methods to interpret machine's operation. Development of predictive/condition-based services assists manufacturers in obtaining a holistic view of their plant performance and thus, choose more competitive and agile management options.

ATLANTIS so far, has successfully participated in organizing of hundreds of Technical Departments of manufacturing companies, service companies, and has expanded beyond manufacturing domain. Hospitals, hotels and ports have been benefitied by the implementation of its in-house developed Computerised Maintenance Management System (CMMS) and Predictive Maintenance Platform, which is an integrated cognitive maintenance platform for the Industry of the Future.

The company's R&D Department has supported several European Founded projects, producing quality work by sharing knowledge and expertise, collaborating with other project partners and pilots (Z-Bre4k, QU4LITY, BOOST4.0, Z-Fact0r and others).

ATLANTIS is also a member of the European Factories of the Future Research Association (EFFRA) and the Industrial Data Spaces Association (IDSA) participating in the development of international standards for data sovereignty. It is considered among the first organizations to join the Digital Factory Alliance (DFA), which aspires to facilitate data-driven factory transformation. Furthermore, the company's CEO, Mr. Cosmas Vamvalis, is the Chairman of the European Federation of National Maintenance Societies (EFNMS, www.efnms.org).

Additionally, the company is an active member of the Technopolis AI Cluster (ai-cluster.gr/members/), which brings together research institutions and private businesses with exceptional capacity and expertise in Artificial Intelligence, along with public sector policy makers and industrial players in different market segments (i.e. triple-helix collaboration model). The aim of the Cluster is to foster the digital transformation of the Greek industry in Central Macedonia towards the Industry 4.0 vision and goals, with the main leveraging factors being the big data exploitation and the adoption of AI technologies. The company is also member of the DIH "Agile Manufacturing of the Future (Agile4.0)"; and a member of the Competence Centre for Industry 4.0, from Design to Implementation (I4ByDesign) - both focusing on Industry4.0 technologies. Finally, the company is a member of the Chorus Cluster (http://www.choruscluster.org/), which is a technological Cluster operating in the fields of Clean Energy, Clean Tech and Circular Economy.

Moreover, ATLANTIS is organizing or is the facilitator of the following high-profile and exposure international events and forums: The annual "Greek Maintenance Forum" (www.maintenance-forum.gr); EuroMaintenance, a world-wide reference event on Industrial Maintenance and Manufacturing (http://www.euromaintenance.org); Technology Forum (http://technology-forum.eu), a forum to address the most recent developments on big data, cloud computing, semantic web, sensor networks, software engineering, simulation and signal processing.

ATLANTIS is certified for quality management (EN ISO 9001:2015) and for the security of information (ISO 27001:2013).

CORE

Background/History

CORE Innovation Center NPO is a subsidiary of CORE Innovation & Technology OE, aiming to provide individuals, industries and companies with opportunities to reach their true potential, to make industries smarter and greener, more sustainable and more socially inclusive. Having grown significantly since 2016, we currently participate in 25 Research and Innovation EU Projects and collaborates with more than 260 partners across Europe. Industry 4.0 is our main research and innovation focus, offering tailor-made solutions to attach meaning to data in several industrial sectors and use cases using Artificial

Intelligence technologies. Our activities are focused on predictive analytics, simulation and optimization algorithms, innovation management, facilitating and co-designing use cases, testing pilots and field trials. The target industries include manufacturing, process, mining, energy, and transport.

Expertise & Technological Focus

- Innovation Management & Exploitation: CORE Innovation Centre bridges real market needs of the industry with innovative applied research drawn from scholarship, while always keeping global societal challenges in mind. We use our concept and business-model engineering approaches to co-design and co-create innovation, helping to develop new products and services that can have an immediate impact on industry and on society.
- Technology: Advances in a range of technologies – the Internet of things (IoT), big data, machine and deep learning, and edge and cloud computing – offer us the means to maximise potential, of both people and entities.
- IoT: A network of physical objects – or "things" – embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the Internet.
- Machine Learning: Machine learning algorithms build models based on sample data – known as "training data" – in order to make predictions or decisions, without being explicitly programmed to do so.
- Deep Learning: Deep learning is a class of machine learning algorithms that use multiple layers to progressively extract higher-level features from raw input.
- Web App design: The design stage encompasses several different aspects, including user interface design (UI), usability (UX), content production, and graphic design.
- Edge computing: Edge computing is a distributed computing paradigm that brings computation and data storage closer to the location where it is needed, in order to improve response times and save bandwidth.
- Big Data: Big data is a field that seeks to analyse, systematically extract information from, or otherwise deal with data sets that are too large or too complex to be handled by traditional data-processing application software.

2.5.2 Business Scenarios

2.5.2.1 Multi Cloud Platform

Current Business Scenario

The businesses of the three companies are somehow interacting but still very separated. Basically, all three companies have their own businesses and services described in chapter 1 of this trial handbook. In the context of the pilot project, the process is described from the perspective of the end user. E.g., An end-user is buying a milling-machine from GF. The hardware and software are either purchased once or billed periodically based on customer needs. To operate the milling-machine, the end-user must buy milling-tools. These tools are supplied e.g., by Fraisa. In addition to the milling-tools, Fraisa is also offering Software-parts, which are e.g., billed periodically, based on customer needs. The customer is therefore buying the milling-tool and the milling-machine from two different companies. The customer is responsible for checking the wear of the tool and must have it reworked or replaced by Fraisa. Furthermore, the user may use SIEMENS software to design the desired components and for PLM. From his point of view, he does not benefit from a link between the three companies.

For the manufacturing and production of the products of GF and Fraisa, the companies are using hardware and software parts from SIEMENS. To produce tools, Fraisa is using GF machines. Vice versa GF may be using Fraisa tools for the manufacturing of their machines. This shows that the companies are already interacting together and are using products, hardware, and software of each other.

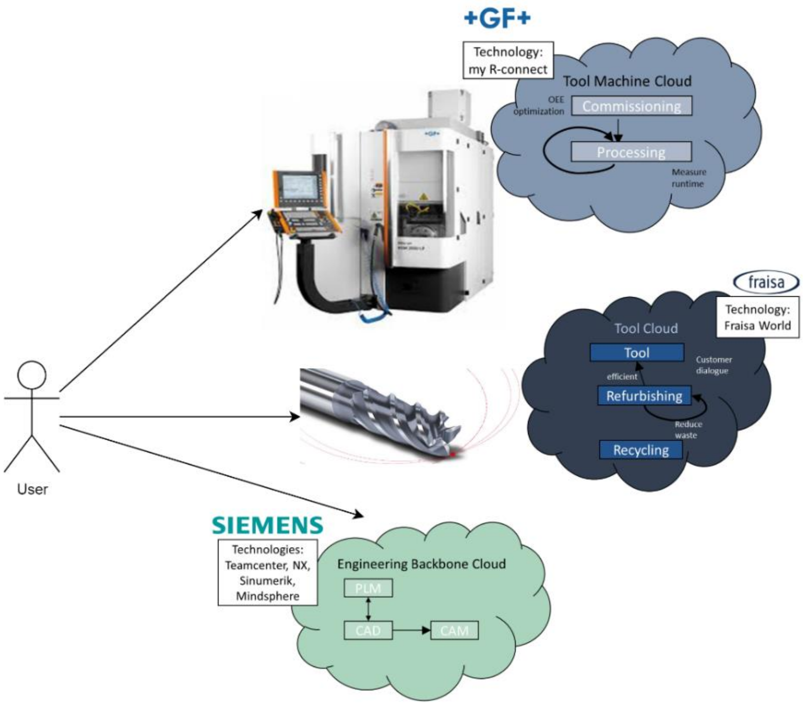


Figure 13, Current Business Scenario

Future Business Scenario

For the future business scenario, the three companies Fraisa, GF and Siemens are strongly interconnected for this process. It starts from a CAD solution of SIEMENS which is communicating the material, dimensions, tolerance, quantity etc. of a desired unit. With this information, GF can decide which machine fits best to deliver that service. Further data from GF like the cutting forces, the torque or the dynamics of the machine is exchanged and forwarded to Fraisa. The GF machine gets equipped with the appropriate tool and is ready to produce the parts ordered. While producing the parts, the machine is communicating to Fraisa if new tools are needed resp. if tools must be refurbished to guarantee the desired tolerances and quality. The RE4DY project is intended to generate processes and workflows that run stably on different hardware and software platforms, are easy to adapt, are characterized by a high degree of standards, and function reliably for our customers.

- Process-safe storage, read-in and read-out of tool information on RFID
- Robust data transfer of the information in apps
- Fast, robust error-free and customer-friendly application and geometry data import into
  CAM software
- Secure but also flexible readout of application data from the Control
- Safe but also flexible readout of the process forces and spindle torques from the machine

- Robust cloud architecture to use data in different clouds.
- Simple and robust installation of the service at the customer
- Maximum use of non-proprietary standards

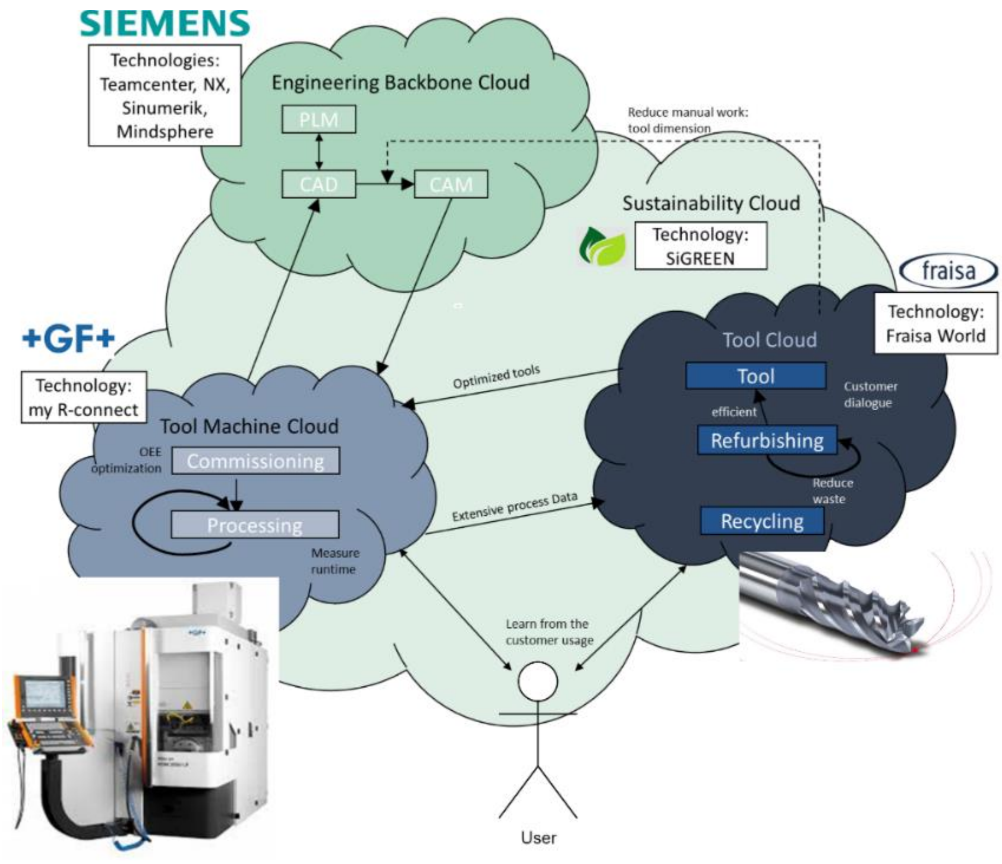


Figure 14, Future Business Scenario

Business Objectives

Table 1-Business objectives summary

#	BUSINESS OBJECTIVE	DESCRIPTION	IMPACT	EFFECT IN VALUE[4]	
BO1	Identification of the remaining tool life for tools	Tools are todays often replaced as a precaution too early. Due to identification of the remaining tool life. This means that in the future tools can be used longer in a process-safe manner and valuable resources can be conserved	- Tool can be refurbished at the right moment by Fraisa - Correct refurbishment instead of installing new tools leads to a better sustainability of the company	Cost	3
				Efficiency	4
				Quality	4
				Flexibility	4
				Innovation	4
				Sustainability	5

[4] These six categories are the ones proposed by the EU project COMVANTAGE. More information in https://cordis.europa.eu/docs/projects/cnect/8/284928/080/deliverables/001-D922MultidimensionalMetricSet.pdf

2.6 AVIO Pilot: Cooperative multi-plant turbine production with predictive quality chains pilot

2.6.1 Pilot Overview

2.6.1.1 General description

Avio Aero's factories

The trial will take place in at least two different factories. Avio Aero's plants are divided in Center of Excellence (CoEs) where each Center is dedicated to a specific value stream. A value stream is defined by different products of the same kind and usually related to a specific module of a jet engine or a technology.

Every CoE has got specific characteristics driven by the typology of components that are manufactured but the majority of the business processes can be considered in common between shops and products. In terms of hardware, shop floor machines are in the number of hundreds across different plants and in general they're connected to our IIOT platform, streaming data directly from the CNC. All Avio Aero's plants are running the same ERP and MES system, ensuring alignment of processes and proper digitalization of them.

Shop operators are able to access manufacturing instructions next to the machines, using dedicated touchscreens that can provide updated and specific information based on the work order ID.

Another important asset is represented by the so called "datalake", a central data warehouse that is storing transactional information from a variety of data sources, enabling a better correlation and the usage of dedicated dashboards built on top of business intelligence solutions.

The volume of data generated by the shops is somehow limited if compared to other industries. In the Aerospace & Defense sector, production batches are usually described as low volume / high value. A limited number of non-conformances can have a consistent impact on the inventory value and historical data are way more limited than in a high-volume production line.

Also, shop operators and manufacturing engineers are highly specialized and holders of a consistent tacit knowledge across the full spectrum of processes (routing design, standard chip removal operations, inspection, special treatments and thermal processes, additive manufacturing, etc.).

How the competitors are operating

Many competitors are operating in visual defect recognition sector, regardless of the size of the production batches, studying and implementing systems for the automatic control of defects in products that need to comply with high levels of quality and standards. The visual defect technology is applied in several parts of the process: production phases or services.

The first consists of a Data Quality Requirement (DQR) that randomly selects the pieces by applying an Acceptable Quality Level (AQL) and then inspects the sampled batch using the Tin-Soldier method. This method requires that the DQR:

1. Randomly selects apart from the lot;
2. Verifies that the part meets the requirements of the drawing (e.g., visual specification, correct identification, marking location, geometry, configuration, surface treatment);
3. Aligns the sample product(s) from the inspection batch to an inspection surface with the same orientation;
4. Visually compares the remaining parts with the selected part to identify any differences.

Where the Tin-Soldier method is not suitable (e.g., due to safety, product size or potential damage to the product), the DQR performs only the first two points of the method. The remaining parts are inspected for general damage, correct identification, marking position, geometry, configuration, surface treatment, etc.

The second inspection method, for example of a turbine, is called RVI (Remote Visual Inspection) and consists in the use of a VJ-3 articulated mechanical borescope with a diameter of about 4mm.

Borescope inspection and repair capabilities can help simplify labor, overhaul time and costs. The borescope is an optical instrument designed to assist visual inspection of narrow, hard-to-reach cavities in the engine. If something enters the motor case and affects the vanes, a borescope with a Dremel power tool-like abrasive tip can be used to repair the defect.

A further system is INSPECT, an optical inspection system which provides fast, automated and standardized inspections after each engine cycle. Developed by the INSPECT consortium (Roke, Rolls-Royce, BJR Systems, Oxsensis and the University of Nottingham), the system inspects compressor blades while the engine is spinning and identifies, classifies and measures any defects.

This inspection system combines computer vision, machine learning, and other related techniques to reliably automate inspection tasks. Using specially developed artificial intelligence algorithms, it is possible to detect, count and track pallets, as well as identify, classify and measure a variety of defects. This software has been integrated into the complex INSPECT system, providing complete end-to-end automation. Once optimized, the system has the potential to identify, classify and measure defects much faster than a human operator, while improving accuracy and repeatability. The standardized data collection system also allows new analyses to be performed which could provide further insights into engine performance throughout its service life.

Another solution adopted as visual inspection system to help check the automatic insertion of electronic components, uses BrainChip's neural network technology combined with augmented reality to provide real-time inspection for in-line electrical wire harness assembly.

Another significant active project implemented by competitors concerns the development of a system that replaces the traditional inspection processes. The new system consists of a robotic arm placed at the end of the production line, capable of moving autonomously, scanning the entire assembly and creating a 3D model with which it is possible to compare, superimpose the components and quickly understand the correct positioning.

2.6.1.2 Objectives

The implementation of the trial is targeting a platform for near real-time predictive quality on distributed multi-plant aeronautical manufacturing processes and it is based on 4 main pillars:

1. A defect detection tools based on AI/ML to support quality inspection operations, highlighting to the operator possible areas to investigate;
2. Predictive quality algorithms developed for a family of products and able to implement CIP processes;
3. A new approach to speed up training of certified inspection operators and soften the strong dependency on senior certified operators, leveraging the knowledge base created with the tool based on AI/ML;
4. A Manufacturing Digital Thread designed to enable an effective data sharing and consumption in a multi-Digital Twin environment, geographically distributed over multiple plants and ready for the extension to additional value chain players.

2.6.1.3 Participants

AVIO AERO

GE Avio S.r.l., also referred to as the Avio Aero brand, is a business of GE Aviation which operates mainly in the design, manufacture and in-service maintenance of engine modules and systems for civil and military aviation. With more than 5,200 employees and approximately $1.6 billion in revenue (2020), GE Avio is present in the entire product life cycle, from the design and development phase to production and service support. The company offers innovative technological solutions that allow customers to respond to continuous market changes. GE Avio's challenge is to develop new technologies and applications to reduce fuel consumption and CO2 emissions, produce lighter aircrafts and get better performance. Thanks to continuous investments in research and development and thanks to a consolidated network of contacts and relationships with the main international universities and research centers, GE Avio has reached a level of technological and production excellence recognized worldwide, being present with its products on approximately 80% of the aircraft that make up the global transport fleet airplane. GE Avio specializes in distinctive technologies, among which the additive manufacturing of which it is a pioneer regarding aeronautical applications.

On an organizational level, the Global Supply Chain is articulated in a complex structure which, through the planning, purchasing, individual plant management and quality control, must manage both internal resources and external suppliers.

The production plants are organized in Centers of Excellence, or specialized in the production of specific components, systems and/or services. The headquarters and the largest production plant are located in Rivalta di Torino (TO), while the other factories are located in Borgaretto (TO), Pomigliano d'Arco (NA), Brindisi, Cameri (NO), Bielsko Biala (Poland) and Prague (Czech Republic).

- Rivalta di Torino (TO) - It employs approximately 2,100 people, including general management and the research and development centre. It includes the Centers of Excellence dedicated to:

  1) the production of Mechanical Transmissions where the precision machining of gears with integral bearing raceways is mainly carried out, the heat treatments capable of giving the particular characteristics of resistance and toughness different in different areas, the superfinishing of the surfaces through refined electrochemical processes, the assembly of the mechanical transmission modules. GE Avio is among the global leaders in mechanical transmissions for aeroengines;

2) production of Turbine Rotating Components in particular turbine discs, drive shafts, interstage seals, bearing supports, static seals and structural elements. The modules and rotating components for manufacturing low pressure turbines. GE Avio produces turbine components for approximately 50% of the widebody aircraft and 65% of the narrowbody aircraft in service in global fleets.

- Borgaretto (TO), Italy - It employs about 250 people. It is the foundry dedicated to the production of aluminum and magnesium alloy castings, in particular for the Mechanical Transmission modules of aeronautical engines and helicopters.
- Pomigliano d'Arco (NA), Italy - It employs about 1100 people. It includes the Centers of Excellence dedicated to:
  1) the production of Combustors, among which the module for the LEAP engine stands out for the B737 MAX, A320neo and C919 aircraft, the best-selling engine globally and
  2) the production of high-tech Turbine Blades, including components for the GE9x engine, the largest and most powerful in the world, which powers the new Boeing 777x aircraft
  3) Component Overhaul services for civil engines.
- Brindisi, Italy - It employs about 750 people. It includes:
  1) the Frames Center of Excellence, dedicated to the production of large turbine structural parts for the main engines in the narrowbody and widebody segment, including the LEAP, the GEnx and the GE9x,
  2) the Additive Manufacturing Center of Excellence with beam electronic - DMLM - for the construction, among other things, of the parts of the new Catalyst turboprop engine
  3) the Center of Excellence Revision and Testing of Military Engines, through which the operability of the air fleets of the Italian Armed Forces is guaranteed, operating the maintenance and logistic support of the engines of the main weapon systems, both aeronautical and naval.
- Cameri (NO), Italy – It employs around 20 people. It is home to the Additive Manufacturing Center of Excellence dedicated to the 3D printing of engine components through the use of laser technologies (EBM), in particular for the production of semi-finished blades, made with titanium-aluminum intermetallic alloy, for the low pressure turbine of the GE9x engine, the largest and most powerful in the world, which powers the new Boeing 777x aircraft.
- Bielsko Biala, Poland - It employs about 550 people. Center of Excellence dedicated to the production of stator and rotor blades for low pressure turbines for various successful programs in the civil aviation market.

- Prague, Czech Republic – It employs about 450 people. Center of Excellence for the assembly of turboprop aircraft engines, including the H80 and the new Catalyst.

The GE Avio's research in the aeronautical engine sector is focused to put the company in a position to compete on the market for the next few decades, having available new technologies in time to be applied to innovative engine configurations, in relation to the objectives of industrial competitiveness in sectors of mobility and clean transport and environmental sustainability, with the development of technologies that have an impact on the reduction of carbon emissions.

Engineering Group

Engineering Group (ENG) is the Digital Transformation Company, leader in Italy and expanding its global footprint, with around 12,000 associates and with over 60 offices. The Engineering Group, consisting of over 20 companies in 17countries, has been supporting the continuous evolution of companies and organizations for more than 40 years, thanks to a deep understanding of business processes in all market segments, fully leveraging the opportunities offered by advanced digital technologies and proprietary solutions. It integrates best-of-breed market solutions, managed services, and continues to expand its expertise through M&As and partnerships with leading technology players. The Group strongly invests both in innovation, through its R&I division, and in human capital, with the internal IT & Management Academy. ENG is a key player in the creation of digital ecosystems that bridge the gap between different markets, while developing composable solutions that ultimately foster a continuous Business transformation.

The relevance of ENG in the Industry and Services segment is due to the ability to combine twenty years' experience with the potential offered by technologies such as Cloud, Artificial Intelligence, Digital Twin, Digital Enabler, IoT, Cybersecurity, and Big Data. Additionally, ENGIT operates within strong strategic networks and initiatives (such as Gaia-X, IDSA, FIWARE, DBVA, Eclipse, EITD, DFA, DIH4INDUSTRY, and much more), comprising leading industries, innovation and technology centres, and collaborative initiatives, etc. where it can further disseminate and promote RE4DY.

Politécnico di Milano

Politecnico di Milano is a public scientific-technological university which trains engineers, architects and industrial designers. The University has always focused on the quality and innovation of its teaching and research, developing a fruitful relationship with business and productive world by means of experimental research and technological transfer.

Research has always been linked to didactics and it is a priority commitment which has allowed Politecnico Milano to achieve high quality results at an international level as to join the university to the business world. Research constitutes a parallel path to that formed by cooperation and alliances with the industrial system. Knowing the world in which you are going to work is a vital requirement for training students. By referring back to the needs of the industrial world and public administration, research is facilitated in following new paths and dealing with the need for constant and rapid innovation. The alliance with the industrial world, in many cases favored by Fondazione Politecnico and by consortiums to which Politecnico belong, allows the university to follow the vocation of the territories in which it operates and to be a stimulus for their development.

The challenge which is being met today projects this tradition which is strongly rooted in the territory beyond the borders of the country, in a relationship which is developing first of all at the European level with the objective of contributing to the creation of a single professional training market. Politecnico takes part in several research, sites and training projects collaborating with the most qualified European universities. Politecnico's contribution is increasingly being extended to other countries: from North America to Southeast Asia to Eastern Europe. Today the drive to internationalization sees Politecnico Milano taking part into the European and world network of leading technical universities and it offers several exchange and double degree opportunities and a wide range of degree programmes entirely taught in English.

2.6.2 Business Scenarios

2.6.2.1 AI-driven Visual Inspection

Within the Avio Aero's first use case, a Machine Learning model will support the inspection operators in the visual identification of defects such as burrs, scratches, dents and nicks. For the time being, it is envisaged the possibility to devise a solution able to identify the *same type of defects on multiple products*. The fact that multiple products - even produced at different plants - can be involved, potentially widens the range of data available for training the model. Once the training is finished, it will be possible to employ the resulting Machine Learning model across different plants where visual inspection is performed on that type of defects. The task will leverage existing or to be created images datasets and, as a result, it will be possible to increase the level of accuracy in detecting defects, thus making the process *safer* reducing errors and number of customers escapes, but also *faster*.

Given the importance and value represented by the machine learning algorithm in this business scenario, an AI AAS model could be beneficial in order to provide a Common

Information Model (CIM) framework so that it enables interoperability of the developed model to be shared and deployed among various stakeholders for similar purposes. "The established informal information model for the three entities was converted into the standardized AAS modelling language to create the final concept of an AAS for AI assets. This process defined the AAS for each entity and specified corresponding grouped properties in so-called submodels. Submodels provide encapsulated properties and characteristics with the ability to derive from pre-existing standard dictionaries according to the AAS information model standard (Figure 1)" [3].

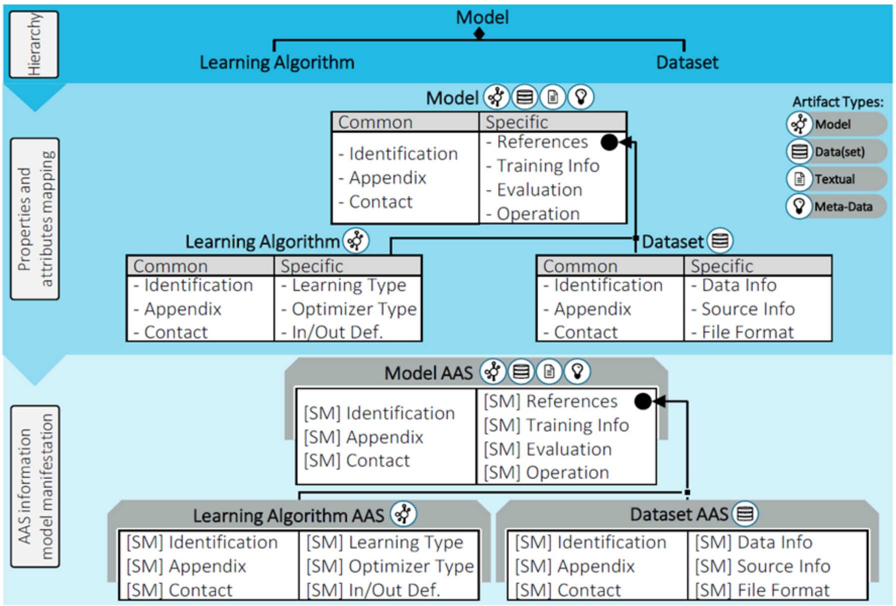


Figure 15- AI AAS AI AAS hierarchy, information model, and AAS structure[5]

The general concept of AI AAS depicted in Figure 1 could be exploited here as well, the AI AAS model in this business scenario could consist of Learning Algorithm and Dataset. The dataset contains data gathered from Avio Aero's industrial plants mentioned earlier while the learning algorithm refers to the algorithm which will be used to assist operators for inspection of the parts.

Business Objectives

The use case implementation is focused on solving some problems that impact the processes described. The visual inspection activity as of today implies a not objective identification of the defect, due to the human factor. Very often, in fact, no matter how accurate the inspection is, some defects are not properly identified, implying non-conformities and complaints from the customer. Errors or wrong decisions in the inspection process could lead to additional costs if identified during the over inspection phase or even to customer quality escapes if not timely identified.

[5] https://www.sciencedirect.com/science/article/pii/S2212827122003122

The inspection process on defects of the same type, but on different products, follows separate flows with often different specialized operators. The knowledge acquired by an operator in identifying a set of defects on a product cannot thus be exploited and applied to products present in other lines or factories. Similarly, other operators cannot benefit from the knowledge of others to be more efficient and accurate in identifying product defects.

The implementation of the use case is defining a set of business objectives with respect to the problems presented. In particular, the introduction of AI models has a double effect at the business level.

The first effect is the reduction of the Human Factor in visual inspection processes. This will allow to identify the defects present on the inspected parts with greater accuracy, supporting the operator in the identification and categorization of defects. In this way, the costs deriving from the identification of defects in subsequent stages or directly by the customer are reduced, managing customer quality escapes. Furthermore, this has a repercussion in preserving the stability of the entire production process and in the relative reputation by the customer.

The second effect is related to the Human Factor too, and it's the possibility of exploiting the knowledge present in multiple datasets without the need to consolidate them in a central repository. The inspection processes on different products based on AI models have the possibility of creating a federation in which the information exchanged does not include the data on which the model is being trained, but from the parameters learned from the models trained on the data possessed by the single processes. This allows to increase the level of accuracy in the visual inspection process on different products, supporting the operator more and taking advantage of the training done on different products.

Table 2-Business objectives summary

#	BUSINESS OBJECTIVE	DESCRIPTION	IMPACT	EFFECT IN VALUE[6]	
BO1	Reduction of the dependencies on the Human Factor to achieve more resilient processes	The visual inspection process relies only on the operators, generating possible errors	Errors or wrong decisions in the inspection process could lead to additional costs if identified during the over inspection phase or to customer quality escapes if not timely identified	Cost	5
				Efficiency	3
				Quality	3
				Flexibility	1
				Innovation	4
				Sustainability	1

[6] These six categories are the ones proposed by the EU project COMVANTAGE. More information in https://cordis.europa.eu/docs/projects/cnect/8/284928/080/deliverables/001-D922MultidimensionalMetricSet.pdf

Business Requirements

Table 3- Business Requirements

#	BIZ OBJ	REQUIREMENT	AREA	SUB HEADING	FUNCTIONALITY	PRIORITY
BR1	BO1	The tool should support inspectors in identifying defects	Production	User requirement	Functional	Critical
BR2		The tool should be able to learn from manual inputs and collect the operator' expertise	Production	User requirement	Functional	Critical
BR3		The tool should be able to automatically go through specific training sessions of the algorithm, without requiring activities from the end users.	Production	Support requirement	Non functional	Preferred
BR4		The tool should achieve an adequate level of accuracy in identifying the defects, at least aligned with the state-of-the-art defined by the literature.	Production	Performance requirement	Functional	Critical
BR5		The tool should provide a dedicated interface for supporting training sessions for the junior inspectors	Production	User requirement	Functional	Preferred
BR6		The activities required to the operator to acquire images should be approved by EHS and Unions	Production	EHS requirement	Non functional	Critical
BR7		The activities required to the operator to acquire images should have minimal impact in terms of time	Production	User requirement	Functional	Preferred
BR8		The tool should be easily applicable to different parts or product lines	Production	User requirement	Functional	Critical
BR9		The tool should ensure IP protection as per the internal policies	Production	Security requirement	Non functional	Critical
BR10		The tool should fulfill the applicable cybersecurity procedures and international regulations	Production	Security requirement	Non functional	Critical
BR11		The images acquired should be archived in such a way that the labeling information and other relevant metadata is always available regardless of the tool	Production	Security requirement	Non functional	Preferred

2.6.2.2 Near Real-time Predictive Quality

In the context of Avio Aero's second business scenario, multiple data sources will be interconnected to factually establish a Manufacturing Digital Thread creating the foundations on which Predictive Quality algorithms will be developed and operated to generate unprecedented insights into the Avio Aero's manufacturing processes. It will therefore be possible to move from a reactive to a proactive (predictive) approach to the identification of non-conformances. The RE4DY Data Space, its components and the underlying IDS principles will support, where needed, the physical exchange of data. The adherence to the IDS principles will ensure that the exchange occurs while the end user always maintains sovereignty over the datasets being shared and how they are used, also allowing for the participation of additional value chain players. When possible, these principles will also allow for a safe and sovereign exchange of data across multiple geographically distributed Avio Aero's plants. Finally, for the time being, it is foreseen that the data sources available to be leveraged will be CNC machines, measurement processes, transactional systems (ERP and MES) and quality notifications. Eventually, thanks to the developed analytics solutions it will be possible to better understand the processes and identify correlations among the corresponding produced data.

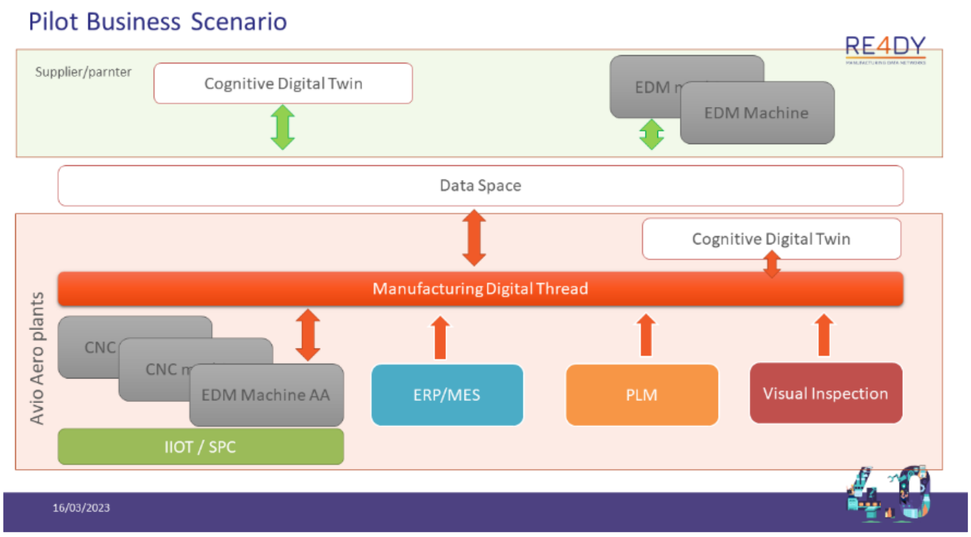


Figure 16- AVIO Pilot data space

Business Objectives

The implementation of the use case would have the main impact on the currently unexploited process data, to the benefit of process actors who manage non-conformities and the industrialization of new manufacturing processes (enabling the NPI).

The possibility of correlating the data related to the various phases of the production process allows to collect knowledge of the trends of the characteristics that identify each operation. This changes the way of managing non-conformities from reactive to predictive, going to predict which are the critical points of the process that introduce a non-conformity and therefore have an impact on the quality of the product. From a business point of view, this translates into cost optimization of the production process, as well as the stability of the process itself. Having a process under control leads to a higher quality of the product supplied and a reputation from the customer who considers the brand a synonym of guarantee and quality.

The benefits given by the correlation of data that change the management of non-conformities also concern the actors in the process who can therefore undertake analyzes and actions upstream of the non-conformity, working in synergy to make the process stable.

Creating a data space that introduces the concept of digital thread manufacturing also impacts new product (NPI) processes using untapped data. This has an important impact in terms of costs for the business, which industrializes the process guided by the data available and focusing on the most critical operations that determine product quality. Furthermore, the possibility for the business to share this information with an equipment manufacturer, allows for a return in services on some impacted process operations that consider the data and the optimizations made between data and digital twins of different processes and distributed among the customers of the data space.

The data correlation described makes the impacted processes more sustainable and flexible to variations due to the introduction of corrective operations within the production cycle. It also makes processes more efficient and innovative than the market, increasing the quality level of the final product.

Table 4-Business objectives summary

#	BUSINESS OBJECTIVE	DESCRIPTION	IMPACT	EFFECT IN VALUE[7]	
BO1	Enhance quality process stability based on cross-correlation between process datasets, not leveraged as of today	Different data streams could help in better understanding the process and keep stable the quality of the process, but as of today data is not interconnected and relations are not evident	Unstructured and unrelated data is preventing from getting an holistic view of the process and moving to a proactive and predictive approach from a quality standpoint.	Cost	5
				Efficiency	3
				Quality	5
				Flexibility	1
				Innovation	5
				Sustainability	2

[7] These six categories are the ones proposed by the EU project COMVANTAGE. More information in https://cordis.europa.eu/docs/projects/cnect/8/284928/080/deliverables/001-D922MultidimensionalMetricSet.pdf

Business Requirements

Table 5- Business Requirements

#	BIZ OBJ	REQUIREMENT	AREA	SUB HEADING	FUNCTIONALITY	PRIORITY
BR1	BO1	The solution should monitor process data and highlight potential quality issues on a given part	Production	User requirement	Functional	Critical
BR2		The solution should be able to collect data from different data source in a scalable way, based on data availability and relevance	Production	Technical requirement	Functional	Preferred
BR3		The solution should be able to automatically go through specific training sessions of the algorithm, without requiring activities from the end users.	Production	Support requirement	Non-functional	Preferred
BR4		The solution should achieve an adequate level of accuracy in identifying potential issues, at least aligned with the state-of-the-art defined by the literature.	Production	Performance requirement	Functional	Critical
BR5		The solution should provide a dedicated interface for visualizing the possible issues	Production	User requirement	Functional	Optional
BR6		The solution should provide an appropriate notification mechanism and reporting tools to inform and involve the right actors	Production	User requirement	Functional	Critical
BR7		The connection with the data space should ensure full control in terms of data exposed and should be easily maintainable and adaptable	Production	Security requirement	Non-functional	Preferred
BR8		Data exchange should be monitored and tracked with an appropriate level of logging for auditing purposes	Production	Security requirement	Non-functional	Optional
BR9		The tool should be easily applicable to different parts or product lines	Production	User requirement	Functional	Critical
BR10		The tool should ensure IP protection as per the internal policies	Production	Security requirement	Non-functional	Critical
BR11		The tool should fulfill the applicable cybersecurity procedures and international regulations	Production	Security requirement	Non-functional	Critical

BR12		The data acquired should be archived in such a way that the labeling information and other relevant metadata is always available regardless of the technological platform adopted	Production	Security requirement	Non-functional	Preferred

2.6.2.3 Resilient Training Process for Inspectors

In the third business scenario, the Machine Learning model for visual inspection developed in scenario 1 will be employed to support the training of junior quality inspectors, who currently strongly rely on the availability of senior colleagues. Such an approach will have to be promoted and discussed with the Airworthiness authorities to collect their feedback and stimulate the recognition of AI as a viable tool that could remove specific constraints on the use of human operators. The benefits for Avio Aero will be manifold. Firstly, the requirement imposed by the training of Machine Learning models concerning the availability of labelled datasets will push towards the *digitalisation* and *structurization* of the knowledge base previously owned exclusively by the senior inspectors. Secondly, the use of Machine Learning will speed up the training process and make it faster for junior inspectors to gain the required certifications. The risks associated with the availability of difficult-to-replace senior inspectors will therefore be lowered. Moreover, having more certified inspectors will also reduce the time needed for the inspection activities.

3 The RE4DY Resiliency Model

3.1 Background

Recent events such as the Covid-19 global pandemic, the stressors of ongoing climate change, disruptions in industrial and supply chain operations along with digital transitions in Industry 4.0 are reminders that we live in a constantly changing and unpredictable world. Manufacturing supply chains (SCs) are experiencing increasing levels of disruptions in demand, supply, logistics (Münch et al., 2022) environmental (Bechtsis et al., 2021) etc due to related risks. In order for the planet to survive and for industries to thrive in the wake of such disruptive events, it will no longer be possible to continue with business as usual activities (Martin et al., 2004).

In this turbulent context, production systems and supply chains will need to reconfigure their strategies to be less vulnerable and survive the shocks that come with such events. Systems will hence need to be 'resilient' to be able to withstand the shocks from unpredictable and inevitable events (Redman, 2014). Building resilience for the long-term also implies that industries should integrate their resources in a manner that is compliant with sustainability paradigms (Amadi-Echendu et al., 2020). The concept of 'resilience' was formally introduced in the 70s in the field of ecology where Holling (1973) defined it as '*a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables*'.

Leveraging data-driven technologies is now of utmost urgency to achieve Zero-X sustainable manufacturing processes and value chain resiliency. It is estimated that production-related disruptions could erase half a year's worth of an organization's profits (more, if other channels in the value chain are included) (McKinsey, 2020) if they fail to incorporate suitable resilience capabilities.

One of the primary objectives of RE4DY is to demonstrate in a realistic and measurable way, a highly standardised and unified manufacturing resilience framework for product and production value networks. For factories and value chains to achieve long-term resilience and meet future EFFRA Industry 4.0 resiliency challenges, it is of strategic importance and relevance to achieve data-driven agility through the implementation of common European manufacturing sovereign data spaces.

Accordingly, this deliverable (D2.1) is part of the task T2.2 - 'Integrated resilient manufacturing and supply network engineering framework and strategies', under WP2 –

'Digital 4.0 Continuum Reference Architecture for Active Resiliency' of the RE4DY project. The task focuses on addressing the dimensions of the resilient operator 4.0, individual factory resilience as well as the value network it is a part of. The purpose of the active resilience framework that will address these dimensions, is to understand the different levels of complex interactions that take place in industrial value chains and the different data-driven capabilities and strategies (in the context of WEF manufacturing global response initiative and the resilience compass framework) that contribute to manufacturing resilience and long-term sustainable competitiveness across all phases of product and process lifecycles.

3.1.1 Resilience engineering & sustainability implications

In the last few years, an increasing number of industrial practitioners and researchers have attempted to study how to minimise the impact of disruptions by adopting resilience strategies (Ivanov et al., 2018; Münch et al., 2022) and developing resilience capabilities (Conz et al., 2020; Dabhilkar et al., 2016; Sgobbi et al., 2022) in their SCs. Few have also studied the sustainability implications of incorporating such resilience strategies and capabilities (Amadi-Echendu et al., 2020; Ates et al., 2011; Bag et al., 2019; Chari et al., 2021; Chari et al., 2022; Gatenholm et al., 2021).

However, several challenges exist currently to respond to unplanned events or disruptions, such as rigid and unreliable information systems that cannot sense trends, difficulties in balancing supply and demand, inflexible departments and so on (Joglekar et al., 2020). Hence, the corresponding capabilities and traditional solutions developed to mitigate risks cannot be static anymore, due to the vulnerabilities exposed by the Covid-19 pandemic and constantly changing business environments of future digital manufacturing processes.

3.1.2 Dynamic capabilities required for the dual transition

We are currently in a dual transition: digital transformation in the Industry 4.0 era as well as leveraging the use of these technologies to increase industrial resilience for sustainability competitiveness. Brusset et al. (2017) explicated that building resilient supply chains require an understanding of microfoundations of dynamic capabilities (Teece, 2007), which was also the focus in the study by (Chari et al., 2022). Microfoundations are those capabilities that are unique to firms and make them stand out compared to their competitors.

Some dynamic capabilities identified from previous work (Chari et al., 2021; Chari et al., 2022) for resilient and sustainable manufacturing include communication (data sharing, transparency and visibility of information flows), organisational (value capture, flexibility and agility in manufacturing operations, operational efficiency), technological (capabilities derived from Industry 4.0 technology enablers, Business Model Innovation) as well as collaborative capabilities (internal to the company and external including value chain stakeholders).

3.2 Methodology applied for building the RE4DY active resiliency framework

3.2.1 IDEF0 Modelling

The active resiliency framework was developed using the IDEF0 modelling method (IEEE, 1998) and modified based on previous work (Chari, 2021). The IDEF0 is based on an IEEE standard and can be used to provide a logical and structured representation of functions and their relationships within a system, along with requirements, potential changes, and provide decision support for implementation activities.

The top-level context diagram of the IDEF0 standard method of functional modelling has been used to develop the active resilience framework. Here, functions or the activities are showcased as boxes, the interface arrows 'control' and 'enable' the activities along with 'inputs' and 'outputs' in the system. The method allows the creation of a structured and clear blueprint showcasing how functions, their interfaces and dependencies are captured, thus providing visibility to all value chain partners. The IDEF0 model can be decomposed into sub-functions or child diagrams thus allowing a certain level of detail to be seen by zooming in or out of the functions as required. As this is the first phase of the RE4DY project whereby the various elements of the preliminary active resilience framework were identified, the different levels of decomposition were not required.

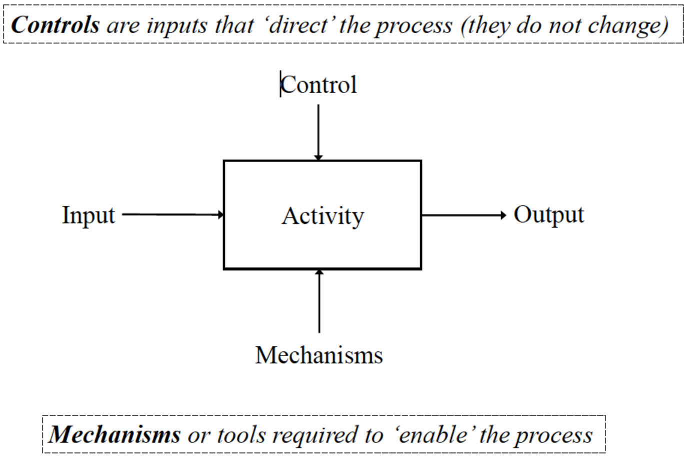


Figure 17. Top-level context diagram of an IDEF0 functional model

3.2.2 Data collection

Data collection was carried out by developing a questionnaire that consisted of 13 questions and definitions which were part of Chapter 5 of the RE4DY Trial Handbook (TH). The questionnaire was pilot tested with three manufacturing companies in Sweden along with two academic researchers before it was sent out to the pilots in the Automotive, e-Batteries, Machine & Cutting tools and Aerospace industrial domains, for their input.

The questionnaire consisted of two parts: (i) background information about the pilots and their requirements for using the RE4DY active resilience framework (ii) questions that supported the development of the framework. Some examples of questions asked were: "Please describe the internal and external disruption risks for the business process described in the previous question and describe their frequency (likelihood), how they impact operations (severity) and the levels they impact (factory, supply chain, workers, quality, etc.)."; "Please describe the corresponding disruptions due to the internal and external risks, and describe their frequency (likelihood), how they impact operations (severity) and the levels they impact (factory, supply chain, workers, quality, etc.)."

Follow-up interviews were conducted with the pilots if necessary to get an in-depth understanding of some answers.

Table 6 - Business processes chosen by the pilots that will demonstrate resilience engineering (RE) principles

Pilot	Domain	Business process for RE
Pilot 1	Automotive	Proactive bottleneck detection for car glass assembly
Pilot 2	E-batteries	E-battery pack production workflows

Pilot 3	Machine and cutting tools	ReTool process
Pilot 4	Aerospace	Sustainable and resilient jet engine production

3.2.3 Business processes for resilience engineering (RE)

The complete list of all the business processes defined by the pilots are already described in detail in Chapter 2 of the TH, but for the context of this deliverable, we describe again those specific business processes chosen by each pilot that will demonstrate the resilience engineering principles, which is shown in

. In addition, pilots also expressed their requirements for the final resilience framework.

Pilot 1 – The pilot is motivated to create an innovative resilient and cognitive design and planning for their car glass assembly process. The idea is to create a more automated, yet supervised generation of logistic processes scenarios driven by AI and digital twins for simulation, enabling the possibility to analyse different concepts of warehousing, picking and line feeding, creating an autonomous internal supply chain, enabling human workers to fine tune, select and refine the scenarios thus creating real-time plans that will decrease waiting times.

Pilot 2 - The companies in this pilot wish to address distributed engineering data spaces for collaborative and integrated engineering and life-cycle assessment of resilient e-battery products and manufacturing processes of batteries. The goal is to decrease time and cost in e-battery package production through highly customized and flexible centre for production-oriented manufacturing of proto battery modules and packs (from digital process simulation to real time process validation). The data-driven resilience strategies can help the industries to adapt and respond to unplanned disruptions thorough 'resilient-by design' products and processes.

Pilot 3 – All production-relevant data of a tool as well as specific data of a manufactured tool are already stored in an internal cloud at FRAISA and can be made available to the customer in the future via cloud or via RFID chip. The simple loading of tool information via RFID and the fast and process-safe upload of application data lead to fewer input errors and thus to higher productivity. Further linking of this data with machine data through an app called "My r Connect" provided by GF, can lead to significant process optimizations, so that further cost and resource savings can be achieved. For +GF+, there are two levels of production- the first related to the manufacturing of machines in Swiss and China sites, and the second at the level of a GF customer. At the first level, the processes comprise of machining and measurement cycles as well as quality controls processes involving machining of test parts. At the second level, customer processes relevant for the project involve mainly strategy design, machining of parts, quality controls and machine maintenance, including consumable and wear parts, tooling replacement and component repair processes.

Pilot 4 – The development of a sustainable jet engine will be coupled with sustainable and resilient distributed manufacturing processes that can convert the design intent into real products without negatively impacting the green deal objectives. Specifically, predictive maintenance algorithms will be developed for different machines involved in the production processes (e.g., furnaces, CNC machines, laser cutting, etc). These algorithms will be characterized by high reusability and easily connected to the manufacturing Digital Thread so to enable the adoption through the extended value chain (i.e., suppliers, customers, partners/competitors). The manufacturing Digital Thread will enable an effective data sharing and consumption in a multi-digital twin environment geographically dispersed across multiple locations and readily extensible to additional value chain players.

3.2.4 Data analysis

A cross-case analysis of the data collected from the four pilots enabled an understanding of the common risks, the corresponding data-driven resilience strategies and other resilience factors that could be derived in the four manufacturing domains.

3.2.5 Requirements from the pilots of the RE4DY active resilience framework

The importance of data was highlighted as an important requirement in the resilience framework. The linking of data from production to customer, i.e., the establishment of interfaces and data transfer formats from production to customer databases can lead to ideal scenarios where there is a seamless coordination between processes, component quality and tool use, which on the one hand results in a cost reduction, and on the other hand an increase in quality. In addition, digital thread data management methods to build resilient manufacturing networks for new e-battery technologies demands integration of engineering data space with engineering data fabric.

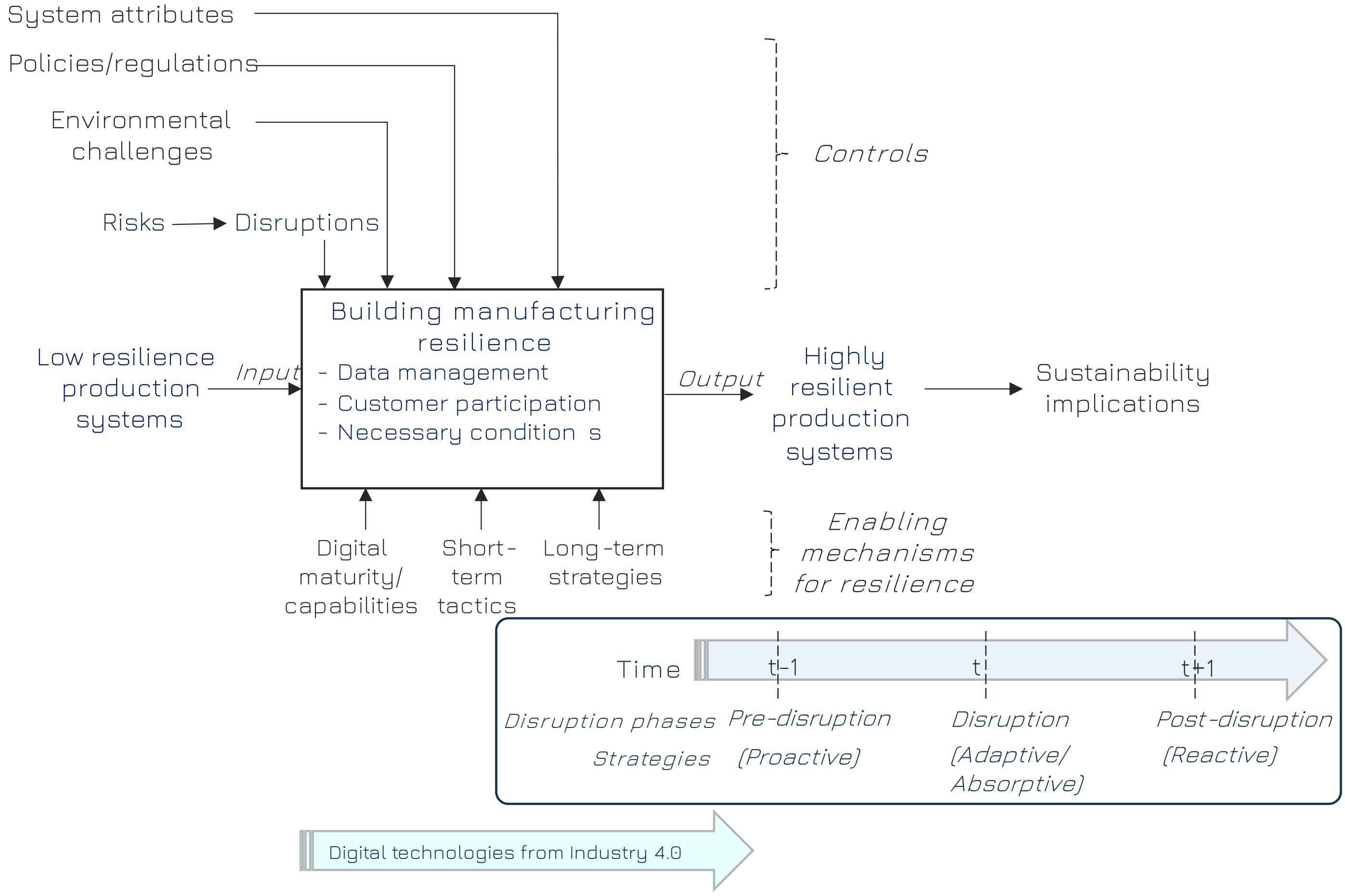
The digitalization of the factory is only a first step towards a resilient framework, that is aligned to the future conception of business processes. The study and implementation of solutions that allow production machines to expose data in a digital format defines a new framework on which business strategies can be based. Data management platforms are necessary for the classification and categorization of the collected data, defining cloud strategy and ensuring national cybersecurity guidelines. The aggregation and introduction of artificial intelligence algorithms on data correctly collected can enable prediction models in the production processes, including maintenance and manufacturing, leading to an improvement on product quality. Furthermore, beyond the improvement of product quality, a resilience framework needs to ensure that any kind of disruption can be recovered in the most efficient way, minimizing the negative impacts on the processes.

The long-term chief objective of the logistics team in pilot 1, in this new era of digitalization and industry 4.0, is to create the conditions i.e.: framework for and adaptable logistics ecosystems, resilient to external and internal factors linked to the automotive industry. Recent history has shown a great uncertainty about the future of the automotive industry i.e.: power train technologies. This key factor brings punishing complexity with the integration of new production/logistics processes for new power train technologies in brown field plants, all the while maintaining acceptable profit margins and respecting ethical, political and environmental missions. Lastly, at a material supply level, droves of volatilities and ambiguities are faced; top amongst them are for example geo-political reasons.

3.3 RE4DY active resilience model

As described in Section ¡Error! No se encuentra el origen de la referencia., the RE4DY active resilience framework will provide a holistic understanding of the different elements that industries need to consider while designing their production processes that cover all phases of the product lifecycle.

At this preliminary stage of the project, the factors identified for the active resilience framework are (Conz et al., 2020; Dabhilkar et al., 2016; Ivanov, 2022; Ivanov et al.,



2018; Martin et al., 2004; Ralston et al., 2020) - risks (internal, external, supply and demand-driven) that occur in the organisation and how these impact their value chain partners, corresponding disruptions (their frequency, severity, type [external/systemic, short-lived/enduring] and where they occur in the manufacturing environment), digital maturity and capabilities due to Industry 4.0 technological implementation (if not present, then the 'potential' capabilities from a future implementation), data management, system attributes (for instance, data modelling/meta-data available, system complexity and functionality, technology implementation, organisational infrastructure), and time-dependent resilience strategies. The above factors are relevant for the specific business processes chosen by the pilots to demonstrate resilience engineering capabilities.

Figure 18. RE4DY active resilience framework (preliminary)

Accordingly, the factors were categorised according to IDEF0 principles as the 'controls' (risks, disruptions, system attributes, environmental challenges) that impact the building of manufacturing resilience (the 'activity') and the corresponding 'mechanisms' (the digital maturity and capabilities and the time-dependent resilience strategies to mitigate the risks and disruptions) that enable the activity to take place. These are shown in Figure 18.

3.3.1 Risks and disruptions

3.3.1.1 Risks

Risks were defined as the likelihood of an adverse and unexpected event that can occur and either directly or indirectly result in a supply chain disruption and make it vulnerable). Two types of risks have been included in the present scope: internal- risks that occur within the firm and within the supply chain of the firm *(e.g.: lack of information to supplier due to forecast driven strategies of the firm, supplier going bankrupt, etc)* and external- risks that occur outside of the supply chain of the firm *(e.g.: covid-19, regulatory changes, etc)*. The pilots were asked to categorise the risks based on conditions such as frequency, severity, and level of impact (worker, factory, company, supply chain etc). Not all risks give rise to disruptions, but we focus on those risks that disrupt manufacturing operations based on the conditions described above.

Pilot 1 faces a multitude of internal and external risks. An example of an internal risk seen was due to the failure of delivering planned course of action by logistics partners in the supply chain. Examples of external risks are workforce strikes due to high gas prices, decrease in demand due to political affairs such as Brexit, the COVID-19 pandemic, the conflict in Ukraine and a supply shortage of semiconductors.

Some of the external risks seen in pilot 3 were based on data in terms of quality, missing data and manipulated data and were categorised to have high severity although low in how frequently they occurred. These were also described to impact all production levels. In addition, external risks could arise with respect to delays and disruption of supply chain for the machine components to be assembled in the factory. There is a dependency of internal risks related to delays and quality problems associated with the scheduling and replacement of components in case of sudden shortage or unavailability (external risks). Shifting these risks downstream along with value chain (customers) has repercussions too in terms of consumables, tooling and components supply for the machines and the additional costs linked to raw materials price increase as well as energy price increase, or new regulatory compliance requirements for those resources. For both levels there are cybersecurity risks which can disrupt information systems and processes managing the production.

For pilot 4, some of the Internal risks seen were (i) the lack of material due to incorrect planning in production processes or delays in material procurement from the supplier. This risk occurred at a medium frequency: medium and impacted the entire supply chain. Another risk seen was (ii) high maintenance required due to unexpected failures on production machines. This also impacted the supply chain but also the quality of products produced, and occurred with a medium frequency. The last internal risk identified was (iii) an expertise gap due to human resources turnover, with a medium frequency and impacting the quality of products produced at the factory level. Some of the external disruption risks seen were (i) geopolitical factors (wars, pandemic events, macro economical dynamics), (ii) air traffic market changes, (iii) redefinition of priorities in deliveries due to market dynamics, customers' decisions or relevant events from the fleet (Frequency: high. Level: factory, supply chain, quality, finance), (iv) cybersecurity events impacting the availability of shop floor assets or company systems (Frequency: high. Level: factory, supply chain, quality, finance, safety).

3.3.1.2 Disruptions

Disruptions are manifestations or events that occur because of risk and negatively impacts a firm's/SC's operations. They can be of two types: internal (processes and controls)- events that occur within the firm and within the supply chain of the firm and external (demand, supply and environmental)- events that occur from outside of the supply chain of the firm.

Some internal disruptions seen in pilot 1 were associated with suboptimal balance of the logistics system for the corresponding production configuration. In other words, any time a partner within the logistics supply chain fails to deliver the planned course of action then the organization faces a serious risk of bringing into a standstill the production output of the plant. This can happen due to a multitude of reasons, as mentioned above the chief amongst them are suboptimal balance/dimensioning of the systems logistics system. Frequency of such events is fair to assume as low and the impact is relatively manageable, nonetheless it exposes mainly workers and the economic viability of the plant. External disruptions have unfortunately become recurrent over recent history. These disruptions account mainly to shortfall issues with suppliers and geopolitical issues. The latter can range from strikes of work force (especially in the transportation business mainly due to high gas prices) sharp decreases in demand generated by internal political affairs (Brexit, COVID-19, conflict Ukraine / Russia, supply shortage of semiconductors). Independent of their nature, these have become frequent in recent times and their impact is profound causing enormous entropy on the factory, supply chain, workers, quality, etc.

The disruptions seen in pilot 3 were related to poor synchronization of data related risks as described in Section 3.3.1.1. Other COVID-19 related disruptions as well as the recent conflict in Europe affected supply of electronic components of machines and overall price increase of components and energy. The impact is at the level of the factory throughput and potential quality of machines. Similarly, customer-side disruptions related to tooling, component supply and maintenance delays. Cybersecurity disruptions could affect all production processes, from supply to production organization.

One of the main disruptions seen in pilot 4 due to internal risks were delays in deliveries for the customer. The frequency and severity of the disruption differed based on the type of internal risk identified in Section 3.3.1.1, For risk (i), the disruption was seen with a medium frequency, giving rise to the creation of additional inventory, new planning required, non-optimal usage of shop machines thus lower OEE. It impacted different levels such as the factory, supply chain, quality and finance; For risk (ii) the disruption took place with a low frequency and required alternative machines (if available) to be set up and used, reducing the efficiency of the shop and likely impacting other processes with lower priority. Identifying alternative machines can lead to different quality problems across the process, impacting the resilience. It impacted the factory, quality and finance levels. For risk (iii), in addition to delays in deliveries for the customer there was also an increase of costs. This requires to some extent, tacit knowledge which is a key part of the production processes. Lack of expertise can decrease the shop efficiency in terms of production and proper management of the assets. It's a clear issue for the inspection processes that relies on qualified operators: it could lead to slow down the inspection activities because of the lack of certified personnel (Frequency: low. Level: factory, quality).

Similarly, for the external risks identified in Pilot 4 and as described in Section 3.3.1.1, several disruptions were seen. For external risk (i), the disruption seen was a sudden decrease of demand and a reduction of revenues (Frequency: low. Severity: commercial or military programs slowed down or stopped, unused workforce and asset capacity in the shops, increase of company stock inventory since customers are not accepting inbound shipments. Level: factory, supply chain, quality, finance). For external risk (ii), the disruption seen was a decrease or change of customer demand (Frequency: low. Severity: commercial programs slowed down or stopped, unused workforce and asset capacity in the shops, lack of expertise on different products, readiness level of the supply chain not adequate. Level: factory, supply chain, quality, finance). For external risk (iii), the disruption was that the supply chain was unable to adapt and ensure delivery to the customer (Frequency: high. Severity (how): under/over saturation of certain production areas, lack of raw materials in inventory and/or inventory increase with unused materials, unbalanced pressure on suppliers, additional costs and inefficiencies to change production planning. Level: factory, supply chain). And lastly, for external risk (iv), the disruption was that not only was the supply chain unable to deliver to the customer, but there was also a loss of proprietary and/or customer data, loss of reputation and loss of intellectual property (Frequency: low. Severity: production assets not available/isolated, transactional systems (ERP/MES) not available, updated process information and technical data not consumable by the shop, intellectual property stolen and or publicly exposed, data encrypted and locked. Level: factory, supply chain)

3.3.2 Resilience strategies

Supply chain strategies to manage resilience are based on when the disruptive event occurred or the phase of interruption (Amadi-Echendu et al., 2020; Chari et al., 2021; Conz et al., 2020) (1) Proactive in the pre-interruption stage (2) Concurrent (adaptive or absorptive) in the interruption stage (3) Reactive strategies in the post-interruption stage. These give an understanding as to which strategies to prioritise based on the frequency and impact of the risks occurring, that can disrupt manufacturing operations. The 'pre-disruptive' phase at time t-1 depicts the time before a disruption or external event occurs where proactive capabilities/strategies are needed. The 'disruption' phase at time t depicts the time when the disruptive event occurs and requires adaptive/absorptive capabilities/strategies. The 'post-disruptive' phase at time t+1 depicts the time after a disruption occurs which requires reactive capabilities/strategies. Some of these capabilities/strategies could be developed due to Industry 4.0 technology implementations (Chari et al., 2021). The corresponding question asked in the survey to the pilots was: 'Please describe what technologies (I4.0) are used to support decision making in case of internal and external disruptions'.

Pilot 1 deploys innovative technologies to support decision-making at a plant level, but this deployment has been slow. At a local level, in the logistics control room of operations, no significant machine learning or artificial intelligence has been deployed, however, in recent years the production/quality cluster at the company has been successful on the deployment in a single use case linked to technologies of this nature. Digital strategies roll out in the logistics area, with little to no level of sophistication. That is not to say that they are not clever nor academically sound, but that they are extremely complex to maintain and often do not give the organization the confidence required to manoeuvre within the convoluted realms of the logistics supply chain. This outset slows down the reaction time of the organization and appoints only a small group of specialists who are adequately knowledgeable to deal with such responsibilities daily. In addition, pilot 1 did not see a need to cluster the technologies into the different disruption phases, as they use the same systems or technologies to deal with these three phases. Maybe the only significant change in the organization is the team's rearrangement to deal with these disruptions: increasing or decreasing labour to deal, control and follow up on the topics at hand.

The setting up of universal cloud architectures (Industry 4.0 technology enabler) is a current collaboration by FRAISA with SIEMENS and GF to share data. This along with collaborations with CAM companies for the development of the ToolExpert CAM interface are some examples of agile ways of working to develop resilient solutions. Cybersecurity risks pose a potential disruptive threat to digitally driven manufacturing operations (Simoes et al., 2013) and +GF+ currently has AI tools within IT systems that has the ability to scan potential security disruptions. Other resilience strategies included managing supply chain disruptions by anticipating delays in the supply of critical components and direct contact with those suppliers.

Mapping the technology use to the three disruptive phases revealed the following:

Table 7 - Technologies used at the different disruption phases and corresponding resilient strategies derived

Disruption phase	Technologies used	Resilience factor
Pre-disruption	RFID, cloud computing	Increase in process reliability and robustness against disturbances, process optimisation and transparency
Disruption	Not currently available	Alternative suppliers and isolation of IT components at risk
Post-disruption	Modular standardized interfaces	Flexibility in operations

At the pre-disruption phase, FRAISA has in place a secure and fast reading of tool data via RFID that significantly increases process reliability during data entry and makes the process significantly more robust against disturbance variables. The same applies to the import of application and geometry data into the CAM software. A cleanly programmed interface between ToolExpert and NX /Teamcenter forms the basis for this. The automatic storage of application data, cutting forces and torques in My r Connect provides a secure data basis for carrying out validated process optimizations. This not only increases productivity, but also process reliability, which is particularly crucial for autonomously running processes. Also, the link between the usage data and the tool wear leads to more transparency and a significant increase in the resilience of the process, while at the same time conserving resources. Finally, the use of non-proprietary standards will lead to a future data communication that is secure, fast, flexibly adaptable, but also robust. At +GF+, suppliers, material delays and price forecasts are surveyed along with the training of employees and rules for using IT communications tools. During the disruption phase, +GF+ has direct action plans that include scouting for alternative suppliers and implementation of new components in the manufacturing chain. Interruption of communication channels and isolation of potentially risk IT components. Lastly, the pilots implement recovery strategies in the post-disruption phase. For instance, FRAISA will set up the entire architecture of the system in a modular fashion with standardized interfaces. If modules are not working, they can be replaced easily thus ensuring flexibility in operations. At +GF+, assessment of risks and yearly update of mitigation measures are conducted as part of their recovery efforts.

Pilot 4 identified several technologies to manage their disruptions. IIOT is constantly used to avoid disruptions for their customers: they monitor production assets, data collected by the assets is converted in specific KPIs and asset autonomous maintenance is powered by internally developed custom digital tools. The KPIs, whether they're referred to shop floor assets or to business metrics, are based on a single source of truth (a so-called data lake) and are built with advanced analytical solutions. Cloud resources are a key element of their production strategy to scale up and deploy digital solutions faster. Digitization of manual/paper-based processes e.g. digital vouchering of operations in the shop floor, asset maintenance processes or special manufacturing processes (like galvanic treatments). SPC, statistical process control driven by data acquired from a CMM machines connected to the company network. Digital thread solutions ensure:

1. a direct connection and associativity between product and process design information across the entire lifecycle of the product
2. a precise and updated distribution and consumption of the information to the right player across the extended supply chain (e.g. design engineers, mfg engineers, shop operators, external suppliers, etc.)

Cybersecurity threats are monitored along with incident response covering the entire company perimeter: Informational Technologies (IT) and Operational Technologies (OT). In addition, Pilot 4 mentioned that they could not identify specific phases where the use of a technology is prevalent. The technologies identified are part of their business operations and they are constantly used to manage different kind of disruptions.

3.3.3 Stakeholders and dependencies

To close the Data Value Chain now, on the one hand, a dialog must be established between the customer and FRAISA ReTool so that the tool wear data of the tool can be compared with the application data of the tool. On the other hand, this data must also be mirrored into FRAISA's R&D department to develop even more customer-oriented tools. Thus, numerous stakeholders are involved in the data value chain (FRAISA tools, GF machines, e.g., Avio customer and Siemens system provider) that can map a complete data set of a tool life.

3.3.4 Barriers to adopt technologies for risk management

Pilot 1 recognised that the key issue to overcome is the deconstruction of the logistics legacy systems and their interconnections. Since a substantial number of legacy systems are under the control of the main headquarters, there are little to no incentive to study extensively how to integrate machine learning or artificial intelligence. Having said this, in recent years, a slight change was noted in tone with the introduction of technologies regulated by Amazon. The issue now is data integrity because of the different logistics planning concepts within the plants of the company.

In Pilot 3, FRAISA does not develop a completely new technology, but adapts an existing RFID Technology in a challenging environment. Extremely high chip prices, disrupted supply chains and extremely high energy prices can delay the project. The challenge in this project is to connect the already existing technologies to a new data platform. At +GF+, the main barriers for the supply chain are the availability of substitute components complying with functional and quality requirements. They do not foresee any barriers for cybersecurity technologies.

Pilot 4 identified that there was a lack of clear connection with the risks that are mitigated by the technology: innovation approached from a different perspective (e.g. optimization of production processes, not improvement of resilience); Real TRL of technologies utilized: limitations showing up only in a real production environment, despite success stories in other industries and pilots. Low TRL might also demonstrate consistent gaps into governance (costs, software version, training consistency, compliance with regulatory bodies, cybersecurity, etc.). There was also a technology gap between academic literature and technology providers: AI platform developed by technology providers are not fully aligned with the state of the art as reported by academia.

3.3.5 Sustainability implications of resilience

Pilot 1 sees mainly social and economic implications. First and foremost, it is social because currently only highly skillful tech engineers can program/tinker with these new technologies and secondly, extensive deployment of automated machine learning/artificial intelligence technologies will most likely result on a workforce downsize. On an economic level there are concerns associated with the high cash flow demand to kick start these sorts of initiatives because highly skillful tech engineers are expensive to keep and so is the IT infrastructure.

FRAISA currently sees positive implications on sustainability in terms of better utilization of raw materials, less scrap, faster and less energy consuming processes, and shorter process cycles. The machine operator can concentrate on more relevant activities and boring data input can hence be eliminated. For GF the implications are mainly economical as production is disrupted or machine costs increase and become less competitive. Social implications relate to reduction of workforce. Environmental implications relate to lower capacity to develop new sustainable products.

4 Conclusions

This deliverable provided the preliminary RE4DY active resiliency framework for the four manufacturing pilots in the RE4DY project. Data was collected through iterative phases through the chapters of the TH, specifically chapter 5. The RE4DY active resilience framework aims to provide a holistic understanding of the different factors that industries need to consider while designing their production processes that cover all phases of their product lifecycles. For future development of the final RE4DY framework, interviews have been planned with the pilots to further understand how the different resilience factors will be implemented and their impacts on the business processes chosen. A simulation model will also be proposed for risk prioritisation and the proactive planning of risk mitigation strategies to enhance the resilience of the manufacturing organisations and their value chains.

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