

Deliverable D1.4

Certification analyses

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List of Abbreviations

AME	Additive Manufacturing Entrepreneur
EWF	European Welding Federation
CRM	Centre de Recherches Métallurgiques
DCU	Dublin City University
DTI	Danish Technological Institute
DILAPRO	Digital Laser Production
DILAFACT	Digital Laser Factory
DILACERT	Digital Laser Certification
AM	Additive Manufacturing
ISO	International Organization for Standardization
ASTM	American Society for Testing and Materials
kW	Kilowatt
VCA	Veiligheids Checklist Aannemers
IQ/OQ/PQ	Installation Qualification / Operational Qualification / Performance Qualification
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
EHS	Environment, Health & Safety
IT	Information Technology
CAPA	Corrective and Preventive Action
HR	Human Resources
ERP	Enterprise Resource Planning
STL	Stereolithography, file format
STEP	Standard for the Exchange of Product model data, file format
CSV	Comma-Separated Values, file format
PNG	Portable Network Graphics, file format
DOCX	Microsoft Word Open XML Document, file format
XLSX	Microsoft Excel Open XML Spreadsheet, file format
PDF	Portable Document Format, file format
JPG	Joint Photographic Experts Group, file format
PNG	Portable Network Graphics, file format
PBF-LB/M	Powder Bed Fusion-Laser Beam / Metal
DED	Direct Energy Deposition
NDI	Non-Destructive Inspection

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1 Executive Summary

Deliverable 1.4 of the DILAPRO project continues the effort to revolutionize European laser-based manufacturing by incorporating advanced digital technologies. It addresses the intersection of these technologies with the evolving certification processes necessary for systems like DILAFACT and DILACERT, which are at the forefront of this transformation. This document focuses on establishing pathways for digital certification of additive manufacturing, transitioning from a predominantly manual certification landscape characterized by extensive paperwork and physical inspections. This shift is crucial as the industry moves away from its traditional reliance on manual processes towards more scalable, digital solutions.

Historically, the additive manufacturing sector has operated without comprehensive international standards, complicating the certification of AM technologies due to their diversity and adaptability. Recent advancements have seen the development of AM specific standards such as ISO/ASTM 52920[1], which accommodates the inherent flexibility of AM processes while establishing a broad framework applicable across various technologies. This standard is particularly notable for allowing a customizable scope of qualification, tailored to the specific needs and capabilities of each production process.

This deliverable highlights DILAPRO's pivotal role in redefining AM certification, demonstrating the project's commitment to overcoming the foundational scepticism towards AM-produced parts. By advocating for the adoption and practical implementation of the ISO/ASTM 52920 standard, DILAPRO sets a precedent for future certification efforts, ensuring that digital advancements align with the rigorous demands of quality and compliance in the industry. The guide provided here details a first approach for using digital data in certification processes, thus paving the way for industry-wide acceptance and trust in digitally certified AM products.

The pilot lines reviewed show varying degrees of readiness for certification. Some lines are close to being ready for digital certification, while others need significant process and system upgrades. This variability underscores the need for tailored digital audit pathways to enhance certification readiness. The audit findings guide the development and refinement of DILAFACT and DILACERT, ensuring these platforms can robustly support diverse manufacturing scenarios and compliance requirements. This approach aligns with the project's goal of creating scalable, sustainability-focused solutions for the European laser-based, high-precision manufacturing industry.

[1] Additive manufacturing — Qualification principles — Requirements for industrial additive manufacturing processes and production sites

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2 Introduction

The DILAPRO project, funded by the European Union, targets the integration of digital technologies into laser-based manufacturing, aiming for sustainability and efficiency improvements. This endeavor aligns with broader objectives to advance Europe's digital and green transitions in the manufacturing sector. Central to achieving these goals are the development and deployment of two software tools, DILAFACT and DILACERT, which focus on process planning and certification for laser-based production.

Deliverable D1.4, titled "Certification Analyses," sets out to define the digital certification requirements identified from the use case definitions established in “Task 1.1 - Use case definition and requirements including business case definitions”. This deliverable will explore the feasibility of digital audits for standards compliance within the context of ISO/ASTM 52920, pertinent to additive manufacturing. The deliverable will extend to the types of digital data necessary for certification, their sources, formats, and applications, establishing a foundational framework for digital certification methodologies.

Building on the initial exploration of digital certification within DILAPRO, an analysis of the ISO/ASTM 52920 standard has been conducted to understand how sections of this standard can be audited digitally. The findings, structured in table 1, provide a clear overview of which standard requirements lend themselves to digital methods, detailing the potential digital data types, their sources, and formats that are applicable. This table serves as a practical tool for guiding the project's approach to digital certification, ensuring that efforts are aligned with achievable, digitally supported standards compliance.

Using the layout of the ISO/ASTM 52920 standard as a guide, the certification of the pilot lines and use cases is structured accordingly. Chapter 5, named “Infrastructure of the Part Manufacturer”, addresses the certification of the broader AM system, including ancillary equipment and feedstock storage, among others. This certification of the pilot lines requires a physical audit and serves as a foundation for the following digital audit assessments of process and part certifications. The preliminary results of the physical audits of chapter 5 are summarized and laid out in this document.

With the pilot line audit as a foundation, this document continues with the assessment and definition of digital certification pathways for process-generic and part-specific certifications of the use cases defined in deliverable 1.1.

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3 Physical Audit of D1.2 Pilot Lines

The physical audits conducted as part of the ISO/ASTM 52920 compliance assessment involved thorough two-day evaluations at five of the six pilot line facilities, with an audit at DTI scheduled in June 2024. These audits included comprehensive reviews of each facility's operational readiness, material management, environmental controls, and adherence to maintenance protocols. The results are represented here as a certification readiness score that reflects each pilot line's capability to meet the stringent requirements set forth by ISO/ASTM 52920. These scores serve as a baseline for determining necessary improvements and guiding the transition to more advanced digital auditing processes.

3.1 Pilot Line Summary

3.1.1 Pilot Line 1 – CRM

Pilot Line 1, operated by CRM, features the Hymax system, unique in Europe for its versatility. It utilizes Direct Energy Deposition (DED) technology with a 6-axis robot that supports multiple print heads for laser powder, laser wire, and arc wire technologies. This line primarily focuses on laser-based technologies.

Table 1: Attributes of Pilot Line 1.

Attribute	Details
Technology	DED
Laser Capability	Up to 8 kW
Materials	Stainless Steel, Aluminum, Nickel, Titanium
Build Volume	Up to 2.5 tons, up to 1.5m diameter
Environmental Control	Argon shielding, air or argon atmosphere
Existing Certifications	ISO 9001, operator training, operator VCA certified, CRM sustainable certificate in entrepreneurship
Process Details	Trajectory and build settings determination, equipment prep. and calibration, post-processing includes heat treatment, machining, and various surface treatments

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Figure 1: Photos of Pilot line 1 – Hymax

Certification-Readiness ~40 %

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3.1.2 Pilot Line 2 – Prima Additive

Pilot Line 2 is equipped with the Ianus Cell from Prima Additive, capable of various laser processes including DED for both powder and metal wire. This flexibility makes it suitable for a wide range of applications including laser welding and hardening.

Table 2: Attributes of Pilot Line 2.

Attribute	Details
Technology	DED
Laser Capability	1-6 kW
Materials	Stainless Steel, Inconel
Build Volume	1600x1200x700 mm
Environmental Control	Argon or Helium shielding
Existing Certifications	ISO 9001
Process Details	Trajectory and build settings determination, part installation and calibration, melt pool monitoring, heat treatment, and surface finishing post-processes



Figure 2: Render of Pilot line 2 – Prima Additive Ianus laser cell (DED)

~90 %

Certification-Readiness

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3.1.3 Pilot Line 3 – DTI

Pilot Line 3 at DTI features three SLM 280 machines that utilize Laser Powder Bed Fusion (LPBF). It supports a variety of metals including 316L and IN625, making it highly versatile for high-quality production. The audit of this pilot line is scheduled for June 2024 and the certification readiness has only been estimated, based on the available details.

Table 3: Attributes of Pilot Line 3.

Attribute	Details
Technology	PBF/LB-M
Laser Capability	2x400W and 2x700W lasers
Materials	Stainless Steel 316L, IN625, Copper, Aluminum, Titanium
Build Volume	280x280x360 mm
Environmental Control	Nitrogen or Argon shielding, controlled oxygen levels
Existing Certifications	ISO 9001
Process Details	Includes calibration of scan field and laser overlap, substrate preheating, and extensive post-processing such as support removal and CNC milling



Figure 3: Photo of Pilot line 3 – SLM280

Certification-Readiness ~70 % (estimated)

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3.1.4 Pilot Line 4 – Fieldmade

Fieldmade's NOMAD03 microfactory, a mobile unit equipped with a DMG MORI LASERTEC 30 SLM machine, is tailored for producing metal parts on-site. Its portability is key for applications requiring rapid onsite production.

Table 4: Attributes of Pilot Line 4.

Attribute	Details
Technology	PBF/LB-M
Laser Capability	600 W fiber laser
Materials	Stainless Steel 316L, IN625
Build Volume	300x300x300 mm
Environmental Control	Argon or Nitrogen shielding
Existing Certifications	ISO 9001, ISO 52920
Process Details	Build file prep, machine calibration, in-situ monitoring with cameras and sensors, and post-processing including support removal and machining

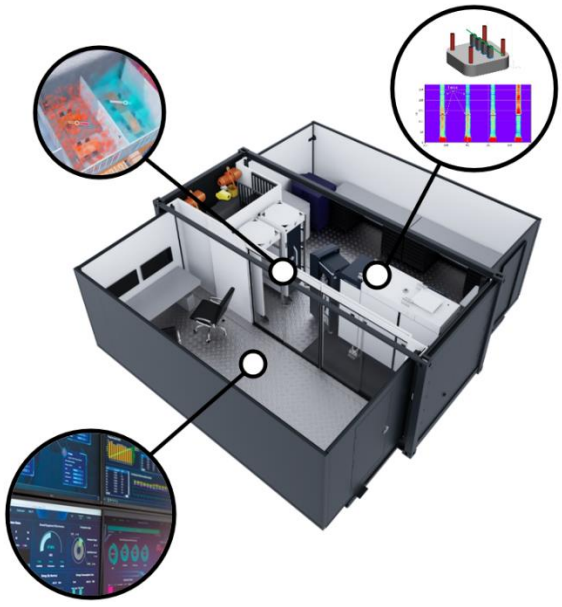


Figure 4: Render of Pilot line 4 – NOMAD 03 Microfactory



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3.1.5 Pilot Line 5 – DCU

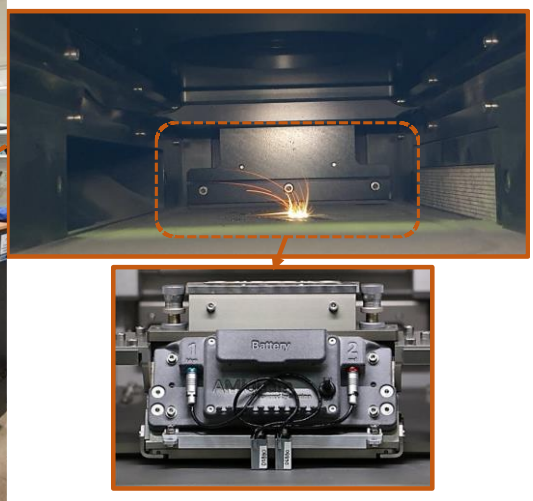
DCU's AconityMINI SLM machine is situated within the Aconity 3D Printing Lab, offering high precision in manufacturing complex metal components. It's equipped with advanced sensors for real-time monitoring.

Table 5: Attributes of Pilot Line 5.

Attribute	Details
Technology	SLM
Laser Capability	200 W Nd:YAG laser
Materials	Stainless Steel 316L, IN625, IN718
Build Volume	Ø140 mm x 190 mm
Environmental Control	Argon shielding, build plate heating up to 800°C
Existing Certifications	ISO/ASTM 52911-1-19, ISO/ASTM 52950-21, ISO/ASTM 52910-18, F3056-14(2021), F3055-14a(2021), F3184-16(2023), ISO/ASTM 52908-23, ISO/ASTM TR52905-EB, ASTM E1004-23, ASTM E1316, ISO 12716:2001, ASTM E749-12
Process Details	Features high-precision temperature and environmental control, post-process heat treatment



Pyrometer Setup



Eddy Current Sensor Setup

Figure 5: Photos of Pilot line 5 – Aconity 3D Printing Lab

~40 %

Certification-Readiness

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3.1.6 Pilot Line 6 – DCU

The second pilot line at DCU focuses on laser texturing and surface hardening, utilizing a dual laser system that includes a femtosecond and a fiber laser. This line is geared towards high precision and surface treatment applications.

Table 6: Attributes of Pilot Line 6.

Attribute	Details
Technology	Laser texturing and hardening
Laser Capability	4W femtosecond and 1.5 kW fiber laser
Materials	Stainless Steel 316L, IN625, IN718
Build Volume	80x80 mm
Environmental Control	Standard room conditions
Existing Certifications	-
Process Details	Utilizes advanced monitoring systems including ambient oxygen sensors and pyrometry for high precision texturing

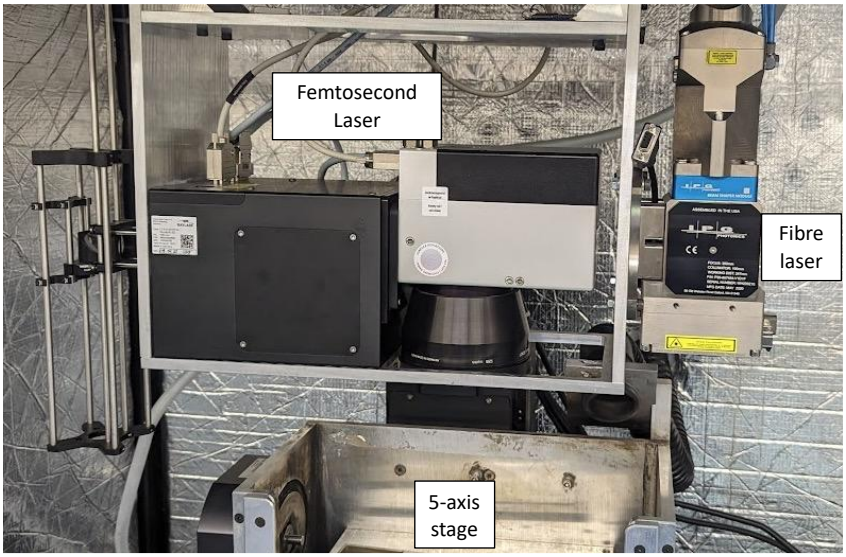


Figure 6: Photo of Pilot line 6 – Laser Processing Equipment



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3.2 Preliminary Observations of the ISO/ASTM 52920 Physical Audits – Chapter 5

The physical audits essential for ISO/ASTM 52920 compliance of primarily chapter 5 have revealed several critical facets of operational readiness and standard adherence within the research institutes of DILAPRO. These findings not only underscore the current necessity for physical audits in certain contexts, but also provide a contrasting backdrop to highlight the capabilities and efficiencies of digital auditing for other aspects of the ISO/ASTM 52920 certification process.

Principal Observations:

1. **Operational Readiness of AM Systems:**
   The AM production readiness working steps, are in many research institutes currently tailored more towards experimental use rather than scaled production. This configuration lacks critical components and setup configurations required for high-volume manufacturing, demonstrating a significant gap in meeting industry-standard production capabilities. In general, all user & AM system interactions, needs a specification.
2. **Material Management:**
   There were notable issues with powder management that included risks of contamination due to improper storage and handling practices. Additionally, the storage areas often lacked proper labelling and organizational systems, which are crucial for maintaining material integrity and ensuring safe and efficient material usage.
3. **Facility Layout:**
   The spatial arrangement of print rooms, post-processing areas and storage facilities frequently did not align with industry best practices. This improper layout leads to operational inefficiencies and increased risks of contamination, which could negatively impact production output and worker safety.
4. **Environmental Monitoring:**
   Adequate monitoring and control of environmental factors such as humidity and temperature were often missing. Such oversight can critically affect the consistency and quality of AM processes, as precise environmental conditions are essential for optimal material handling and part fabrication.
5. **Maintenance and Cleaning Protocols:**
   Regular maintenance schedules and effective cleaning protocols were frequently not in place or inadequately implemented. This lack of proper maintenance and cleaning can lead to increased equipment wear and tear, potential failures, and a decrease in the overall quality of the manufactured parts.

While these audits address foundational compliance and safety issues, the transition towards digital auditing methodologies as explored in the subsequent chapters presents an opportunity

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to streamline and enhance the efficiency of compliance processes. Digital auditing offers powerful tools for real-time monitoring and documentation, reducing the reliance on labour-intensive physical audits and allowing for more dynamic and responsive compliance practices.

In chapters to follow, we delve into how digital auditing can complement and, in some instances, replace physical audits, thereby accelerating the certification process while ensuring state-of-the-art standards are met. This digital transformation is crucial as we advance towards a more integrated and technologically advanced manufacturing landscape.

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4 Defining Digital Certification Pathways for Laser-Based Manufacturing Use Cases

4.1 Mapping of the ISO/ASTM 52920 Standard for Digital Auditing

Table 7: DILAPRO Digital Audit Data Collection Overview for ISO/ASTM 52920. Chapters that can fully be audited digitally are highlighted in orange.

Standard Section	Title	Digital Auditing Possibility	Type of Digital Data	Source of Data	Data Format	Examples of Use
5.1	Environmental health and safety (EHS)	In part	EHS Reports, Compliance Documents	EHS Management Software, Compliance Software	PDF, DOCX	Compliance with Environmental Health and Safety Standards
5.2	Waste disposal	In part	Waste Disposal Records	Waste Management Systems	PDF, DOCX, XLSX, JPG, PNG	Documentation of Proper Waste Management Practices
5.3	AM system installation	In part	Installation Reports, Environmental Conditions	Installation Documentation, Environmental Monitoring Devices	PDF, DOCX, XLSX, JPG, PNG	Validation of Equipment Installation and Environmental Conditions
5.6	**IT infrastructure**	**Yes**	**Network Architecture Diagrams, Security Protocols**	**IT Management Systems, Security Software**	**PDF, DOCX, XLSX**	**IT Security Assessment and Network Integrity Checks**
6.1	General (Manufacturability assessment and review)	In part	Design Review Documents, Feasibility Reports	Design and Review Platforms	PDF, DOCX, XLSX	Preliminary Design and Manufacturability Reviews
6.3	Manufacturing assessment and review	In part	Process Capability Studies, Manufacturing Records	Manufacturing Execution Systems, Process Monitoring Tools	PDF, DOCX, XLSX	Documentation of Manufacturing Processes and Quality Assessments
7.1	**General (Qualification of the additive system operations)**	**Yes**	**Process Maps, Equipment Qualification Records**	**Process Mapping Tools, Equipment Vendor Documentation**	**PDF, DOCX**	**Equipment and Process Qualification for Manufacturing**
7.3	**Validation planning**	**Yes**	**Validation Plans, Risk Assessments**	**Risk Assessment Software, Quality Management Systems**	**PDF, DOCX**	**Planning and Documentation of Validation Activities**
7.4	**Qualification [installation operation and performance (IQ/OQ/PQ)]**	**Yes**	**IQ/OQ/PQ Documentation, Calibration Records**	**Calibration Software, Equipment Vendor Documentation**	**PDF, DOCX, XLSX**	**Documentation of Installation, Operation, and Performance Qualification**
7.6	**Documentation and tracing of the process steps**	**Yes**	**Manufacturing Process Documentation, Traceability Records**	**Document Management Systems, ERP Systems**	**PDF, DOCX, XLSX**	**Traceability of Manufacturing Steps and Quality Documentation**
7.7.2.1	**Data check**	**Yes**	**3D Design Validation Reports**	**Design Software**	**PDF**	**Verification of Design against Specifications**
7.7.2.2	**Geometrical adjustments for manufacturing**	**Yes**	**Design Modification Records**	**CAD Software**	**PDF, DOCX**	**Documentation of Design Changes**
7.7.2.3	**Part placement**	**Yes**	**Placement Strategy Documents**	**Planning Tools**	**PDF, XLSX, JPG, PNG**	**Optimization of Part Placement for Build**
7.7.2.4	**Support generation**	**Yes**	**Support Structure Design Files**	**Support Generation Tools**	**STL, STEP, JPG, PNG**	**Design and Validation of Supports**
7.7.2.5	**Slice data generation**	**Yes**	**Slicing Parameter Files**	**Slicing Software**	**STL, STEP, PDF**	**Setup of Machine for Specific Builds**

Standard Section	Title	Digital Auditing Possibility	Type of Digital Data	Source of Data	Data Format	Examples of Use
7.7.2.6	Data archiving	Yes	Digital File Archives	Document Management Systems	PDF, DOCX, XLSX	Archiving of Project Files for Traceability
7.7.3.1	Feedstock control	In part	Feedstock Quality Reports	Quality Control Systems	PDF, DOCX, XLSX	Validation of Feedstock Quality
7.7.3.2	Storage	In part	Storage Condition Logs	Storage Management Systems	PDF, XLSX, JPG, PNG, CSV	Monitoring of Optimal Storage Conditions
7.7.3.3	Preparation of feedstock (if applicable)	In part	Feedstock Preparation Records	Preparation Equipment	PDF, DOCX, XLSX	Documentation of Feedstock Preparation Process
7.7.3.4	Transport into AM machine	In part	Feedstock Transport Documentation	Logistics Management Systems	PDF, DOCX	Ensuring Safe Transport of Feedstock to Machine
7.7.3.5	Transport from AM machine	In part	Used Feedstock Handling Logs	Waste Management Systems	PDF, DOCX, XLSX	Managing Used Feedstock Post-build
7.7.4.1	AM machine preparation	In part	Machine Setup Reports	Machine Configuration Tools	PDF	Documenting Machine State Pre-build
7.7.4.2	Set-up of build cycle	In part	Build Configuration Files	Build Setup Software	PDF, DOCX, XLSX	Recording Build Parameters and Configurations
7.7.5.1	AM machine operation	In part	Operational Data Logs	AM Machine Software	PDF, CSV	Logging Operational Parameters during Build
7.7.5.2	Build cycle monitoring	In part	Real-time Monitoring Data	Monitoring Systems	PDF, DOCX, XLSX, CSV	Monitoring Build Parameters in Real-time
7.7.5.3	Data backup and archiving	In part	Process Monitoring Logs	Data Storage Solutions	PDF, DOCX, XLSX, CSV	Archiving Monitoring Data for Review
7.7.6.1	Conditioning within the build space	In part	Conditioning Process Records	Conditioning Equipment	PDF, DOCX	Documenting Part Conditioning Post-build
7.7.6.2	Part removal	In part	Part Removal Documentation	Manual Documentation	PDF, DOCX	Logging Removal of Parts from Machine
7.7.6.3	Secondary processing	In part	Post-processing Treatment Records	Post-processing Equipment	PDF, DOCX, XLSX	Records of Heat Treatment, UV Curing, etc.
7.7.6.4	Single part handling	In part	Handling and Processing Logs	Handling Equipment	PDF, DOCX, XLSX	Documentation of Manual Handling Steps
8.2	Personnel requirements	Yes	Training Records, Qualification Certificates	HR Management Software, Training Platforms	PDF, DOCX, XLSX	Documentation of Personnel Qualifications and Trainings
8.3	Non-conformities	Yes	Incident Reports, Corrective Action Plans	Incident Management Software, CAPA Software	PDF, DOCX, XLSX	Documentation and Management of Quality Incidents
8.5	Quality controls	Yes	Quality Inspection Reports, Test Results	Quality Control Software, Test Equipment	PDF, DOCX, XLSX, JPG, PNG	Quality Inspections and Test Result Documentation

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4.2 The Variable Scope of Qualification of the ISO/ASTM 52920 Standard

The ISO/ASTM 52920 standard for additive production allows for the determination of a scope of qualification (chapter 7.2) on a case-by-case basis. This is a key consideration of the standard, as it allows for the certification of AM production sites despite the substantial flexibility and variability intrinsic to additive manufacturing technologies. The scope of the qualification can therefore vary greatly depending on what is required from the particular production site. The two primary focuses of the scope are on part-specific qualification and process-generic qualification, but it is important to note that the scope is not a black and white matter but can fall anywhere in between those two extremes. The determination of the scope is crucial for adapting the qualification to the unique demands of each scenario, whether driven by risk assessments, use-cases, or regulatory requirements.

The digital collection of data can make an audit more effective, cheaper, and faster. The rough distinction of part-specific versus process-generic qualification is even less pronounced in a digital audit regarding what data needs to be collected, but differences can still be identified.

In process-generic certification the focus lies on the qualification of the entire process chain, as there is a clear need for flexibility and the capability of the production of various parts of variable geometry and requirements. With the scope of qualification adjusted the respective ways, the focus of the qualification shifts towards a broader process validation approach. It is of high importance, that the part producer can maintain the highest quality and reliability in the production of a wide range of parts. A clearly documented process in form of an elaborate process map and very clearly defined standard operating procedures along the entire process chain are of the highest importance, starting with a thorough manufacturability assessment and review. Mitigation strategies need to be determined in response to a thorough risk assessment that can be used for each new part to permit continuous production on a state-of-the-art quality level.

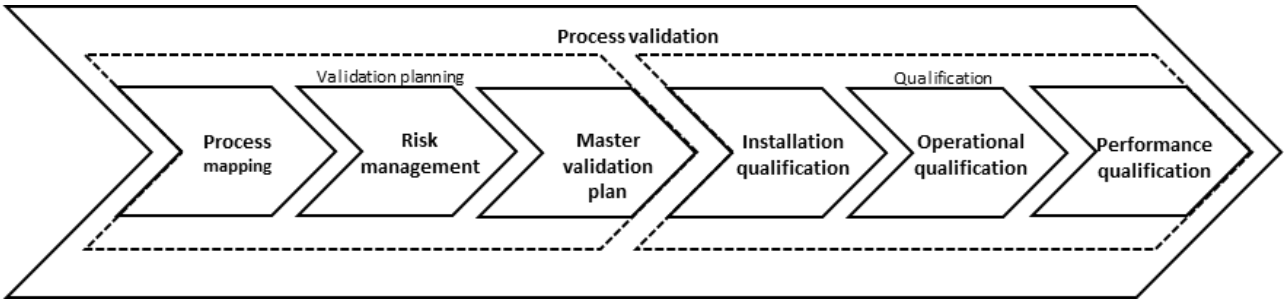


Figure 7: Process validation flow chart, courtesy of Qualified AM GmbH i.G.

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Part-specific qualification generally builds on top of process-generic qualification and the qualification of the process chain is still a requirement, even in cases where the focus lies very strongly on the production of a highly specific part in large quantities. This is a distinct strength of the ISO/ASTM 52920 standard, as even highly specialized production sites never have to give up the flexibility and adaptability that is the hallmark of additive manufacturing. Nonetheless, in case of part-specific qualification that builds on top of process-generic qualification, a key difference can be identified in the audit of the chapter 7.7.2, which is much more in-depth in part-specific qualification, where the manufacturing data preparation must be carefully audited to be in compliance with the standard. While these are the most fundamental differences depending on the scope of qualification, the differences do not end there, but also affect the approach to other parts of the standard to reflect the defined certification requirements.

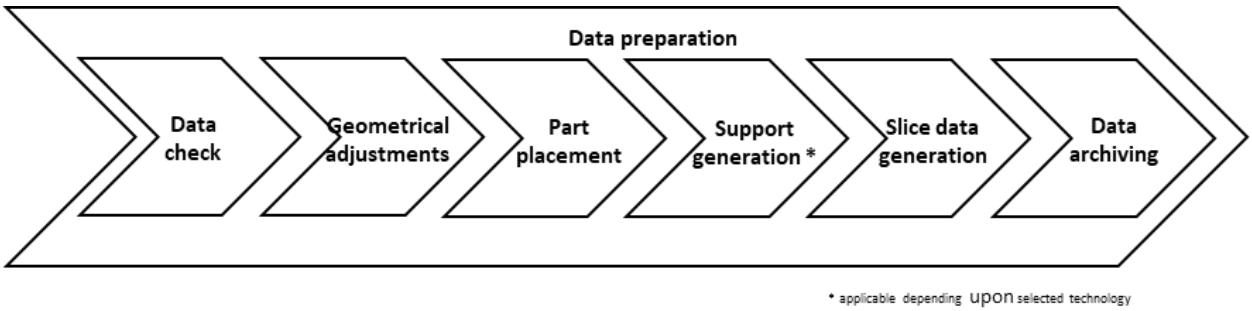


Figure 8: Steps of the data preparation, courtesy of Qualified AM GmbH i.G.

The scope of qualification therefore can be seen as a measure that determines how broadly the process validation is applied and to what extent the data preparation is audited. In both scenarios, data can be collected digitally for both audit and re-audit. Most of this data comes in form of process documentation, but especially for part-specific qualification, CAD data also plays an important role and can be made available digitally with ease.

5 Assessment of D1.1 Component Use Cases for Digital Audit and Certification

5.1 Certification Approaches: Overview

To assess the scope of qualification the component use cases will be inspected individually to gauge the focus of the digital audit. The results are preliminary, and the scope will continuously be adjusted and updated during the audit to always meet the specific requirements of each case accurately. The weight of the part-specificity (see ISO/ASTM 52920, chapter 7.2) is judged by

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inspection of the part risks and use case, and will be assessed as a percentage, with 0% part-specificity representing a purely process-generic qualification and 50% part-specificity representing an even balance of process and part qualification. The part-specificity contrasts process-genericness and cannot exceed 50%. This is the case because process qualification is a quintessential part of the ISO/ASTM 52920 certification and **always** serves as a foundation for each audit and subsequent part-specificity evaluation.

For the evaluation of part-specificity, the part-risk is determined first. This contains elements such as part criticality, environmental conditions, material, manufacturing process, etc. These factors come together to allow an evaluation of the part-risk, which is then weighed against the specific use-case, especially whether parts are mass-produced, a small batch production, single items, prototypes, or other. The use case is ultimately what determines the part-specificity of the certification, but the part-risk can have a notable impact on it, as low part-risk also reduces the need for part-specific qualification. Ultimately, the evaluation of part-risk, part-specificity and process-genericness is complex and a fundamental necessity for the proper determination of the scope of qualification.

Exemplary determination of part risk and specificity.



Table 8: Overview of the digital audit focus for the D1.1 use cases.

Use Case	Scope of Qualification
(C1) Valve Bracket	Process-Generic Qualification
(C2) Valve Wheel	Process-Generic Qualification
(C3) Spring Shoe	Part- Specific Qualification
(C4) Fuel Valve	Part- Specific Qualification
(C5) Rock Drill Chuck	Process-Generic Qualification
(C6) Control Valve	Process-Generic Qualification
(C7) Centrifugal Impeller	Part-Specific Qualification
(C8) Mold Repair	Process-Generic Qualification
(C9) Pump Diffuser	Process-Generic Qualification
(C10) Launch Interface Ring	Process-Generic Qualification

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5.2 (C1) Valve Bracket: Process-Generic Qualification

5.2.1 Use Case Summary

Table 9: C1 Use Case Details.

Industry	Partner	Laser Technology	Material
Oil & Gas	FIELDMADE – PL4	PBF-LB/M	Stainless Steel 316L

A valve bracket required for mounting an indicator switch to a valve in an oil installation. Originally flawed in design, the bracket was redesigned and produced using AM technology to meet urgent operational demands.



Figure 9: Valve Bracket

Key Functional Requirements:

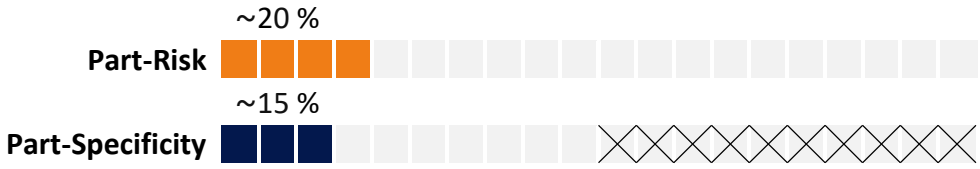
- Securely fix the position of an indicator device relative to the valve stem.
- Endure marine environmental conditions throughout the project's lifetime.

Business Case Overview:

The urgency to avoid operational delays necessitated a quick redesign and production, showcasing the rapid prototyping and manufacturing capabilities of AM. The main benefit of using DILAPRO's digital certification methods is significantly reduced lead times by eliminating extensive physical testing.

5.2.2 Scope of Qualification

The low criticality of the component, coupled with the well-suited material and risk reduction due to design considerations lead to a low part-risk assessment. The resulting reduced need for part qualification and the specific use case of single-item production led to a low part-specificity of approximately 10% and a primarily process-generic qualification.



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5.2.3 Digital Auditing Possibilities

Certifying a production line for the ability to produce one-off parts of high criticality like the Valve Bracket moves the scope of qualification towards process validation. It necessitates a certification framework that not only assesses the production line's current capabilities but also its adaptability and responsiveness to unique manufacturing challenges. This scope ensures that the production line is not only capable of mass production but is also fine-tuned and flexible enough to meet the stringent quality and performance standards required for critical one-off components in sectors like oil & gas.

5.2.4 Emphasis of Digital Certification

Table 10: Critical features for process certification of the C1 use case.

Process Control Data	Information on the settings and parameters of the equipment used in the repair process, which can be monitored and logged digitally.
Validation planning	Thorough mapping of the entire production process, including a thorough and all-encompassing digital risk assessment.
IQ/OQ/PQ	Qualification of systematic and documented processes of ensuring that equipment is correctly installed, operates according to its intended design, and performs consistently in meeting specified criteria, respectively.
Quality Assurance Methods	Digital records of tensile testing, density measurements, microstructure assessment and photography for inspecting and verifying the quality of the part to ensure adherence to requirements.
Continuous Improvement and Feedback	Inspection of process data, facilitating adjustments and optimizations in the process for consistent quality.

5.3 (C2) Valve Wheel: Process-Generic Qualification

5.3.1 Use Case Summary

Table 11: C2 Use Case Details.

Industry	Partner	Laser Technology	Material
Oil & Gas	FIELDMADE – PL4	PBF-LB/M	Stainless Steel 316L

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A safety feature introduced at an oil installation rendered manual operation of a valve impractical. This use case involves redesigning the valve wheel to improve ease of use while maintaining the new safety standards, utilizing AM technology to swiftly implement these necessary changes.



Figure 10: Valve Wheel

Key Functional Requirements:

- Enable manual operation of the valve for the lifetime of the platform.
- Endure marine environmental conditions throughout the project's lifetime.

Business Case Overview:

The redesign enhances ergonomics, significantly reducing material wastage compared to traditional machining, making AM a more suitable solution for low-quantity production. DILAPRO's digital certification capabilities further minimize the lead time, from design to deployment, by replacing physical testing with digital simulations and process monitoring.

5.3.2 Scope of Qualification

Similarly to C1, the part-risk is reduced due to specific design and material considerations. The reduced risk and single-item production lead to a low part-specificity of approximately 10% and a process-generic scope of qualification.



5.3.3 Digital Auditing Possibilities

The same specifications as for the valve bracket apply. The Valve Wheel necessitates a certification framework that not only assesses the production line's current capabilities but also its adaptability and responsiveness to unique manufacturing challenges. This scope ensures that the production line is not only capable of mass production but is also fine-tuned and flexible enough to meet the stringent quality and performance standards required for critical one-off components in sectors like oil & gas.

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5.3.4 Emphasis of Digital Certification

Table 12: Critical features for process certification of the C2 use case.

Process Control Data	Information on the settings and parameters of the equipment used in the repair process, which can be monitored and logged digitally.
Validation planning	Thorough mapping of the entire production process, including a thorough and all-encompassing digital risk assessment.
IQ/OQ/PQ	Qualification of systematic and documented processes of ensuring that equipment is correctly installed, operates according to its intended design, and performs consistently in meeting specified criteria, respectively.
Quality Assurance Methods	Digital records of tensile testing, density measurements, microstructure assessment and photography for inspecting and verifying the quality of the part to ensure adherence to requirements.
Continuous Improvement and Feedback	Inspection of process data, facilitating adjustments and optimizations in the process for consistent quality.

5.4 (C3) Spring Shoe: Part-Specific Qualification

5.4.1 Use Case Summary

Table 13: C3 Use Case Details.

Industry	Partner	Laser Technology	Material
Oil & Gas	FIELDMADE – PL4	PBF-LB/M	Inconel grade 625

A piece of machinery was fitted with dampeners to mitigate the risk of damage during transport. This “spring shoe” is a complex bracket component designed to be part of the dampening system.

Key Functional Requirements:

- Fit mounting points of equipment and spring.
- Transfer load to springs, mitigating dynamic loading from harsh driving conditions.

Business Case Overview:

Designed for a niche application with low volume, the spring shoe necessitates a high-strength, high-cost material for structural integrity. DILAPRO's advanced simulation tools play a crucial role in ensuring 'first-time-right' printing,



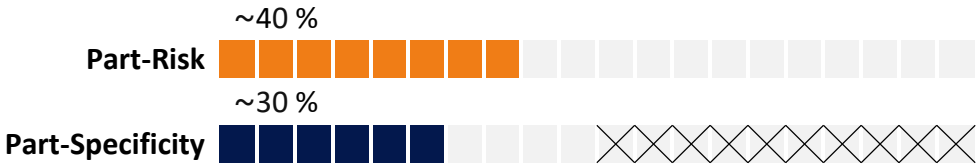
Figure 11: Spring Shoe Damper

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significantly enhancing the production efficiency and confidence in successful outcomes. The expected benefit is a reduction in lead time and increased reliability in production without the need for extensive physical testing.

5.4.2 Scope of Qualification

Both design and material selection mitigate the risks of part-failure. However, the criticality of the part is high, due to its high load-bearing application. As such, part-risk can be rated at an approximate 40%. The use case of very small-batch production still permits the determination of a matching 30% part-specificity.



5.4.3 Digital Auditing Possibilities

For part-based certification, the scope of qualification is focused precisely on the manufacturing of parts of a pre-determined geometry with further specified part requirements. This involves a detailed analysis of design specifications, material properties and final part inspections. Digital tools and data play a crucial role in facilitating this certification by providing precise, efficient and verifiable methods for print cycle monitoring. Section 7.7.2 of the ISO/ASTM 52920 standard is of special relevance and lends itself particularly well to digital auditing and certification.

5.4.4 Emphasis of Digital Certification

Table 14: Critical features for part-based certification of the C3 use case.

Design Verification	CAD data for the data preparation assessment and suitability of the chosen manufacturing method.
Testing data of co-built artifacts	Maintenance of digital logs containing data from destructive testing of co-built artifacts.
Manufacturing Process Quality	Capturing sensor data on process parameters (laser power, material feed rate, ambient conditions) to validate the manufacturing process to remain within a defined window.
Dimensional Accuracy and Surface Quality	Use of digital imaging and scanning to verify dimensions and surface conditions against the requirements.

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5.5 (C4) Fuel Valve: Part- Specific Qualification

5.5.1 Use Case Summary

Table 15: C4 Use Case Details.

Industry	Partner	Laser Technology	Material
Space	DCU – PL5	PBF-LB/M	Inconel grade 718

A critical component used to support a launch vehicle's rocket engine in a cryogenic environment. This component is essential for securing the engine during operations extending from sea-level to low-earth orbit conditions.



Figure 12: Fuel Valve

Key Functional Requirements:

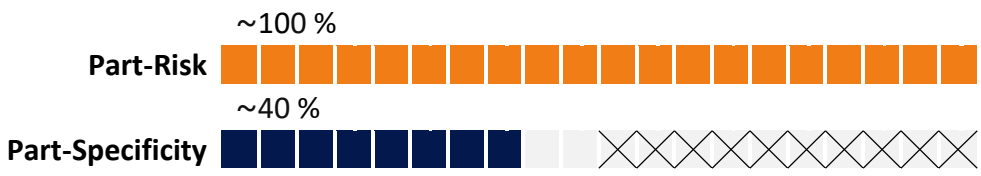
- Securely hold the launch vehicle rocket engine in place under extreme environmental conditions.

Business Case Overview:

This component, subjected to extreme operating conditions where failure could result in mission loss, demands rigorous quality control and testing. The part is produced in low volumes but incurs high costs due to extensive quality requirements. DILAPRO enhances this process by enabling additive manufacturing methods that meet these stringent quality controls on the first print, thereby reducing risks and costs associated with traditional manufacturing.

5.5.2 Scope of Qualification

The component is used in extreme, high stress, environments under extreme stress. There is no redundancy, and the part is mission critical. The component therefore demands high precision and accuracy. In total, this leads to a part-risk evaluation of 100%. The small-batch production slightly reduces part-specificity, but still leads to an assessment of approximately 40%.



5.5.3 Digital Auditing Possibilities

The extraordinary requirements for this function critical part make it a prime candidate for part-based certification. The scope of qualification is focused precisely on the manufacturing of parts

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of a pre-determined geometry with further specified part requirements. This involves a detailed analysis of design specifications, material properties, and final part inspections. Digital tools and data play a crucial role in facilitating this certification by providing precise, efficient, and verifiable methods for print cycle monitoring. Section 7.7.2 of the ISO/ASTM 52920 standard is of special relevance and lends itself particularly well to digital auditing and certification.

5.5.4 Emphasis of Digital Certification

Table 16: Critical features for part-based certification of the C4 use case.

Design Verification	CAD data for the data preparation assessment and suitability of the chosen manufacturing method.
Testing data of co-built artifacts	Maintenance of digital logs containing data from destructive testing of co-built artifacts.
Manufacturing Process Quality	Capturing sensor data on process parameters (laser power, material feed rate, ambient conditions) to validate the manufacturing process to remain within a defined window.
Dimensional Accuracy and Surface Quality	Use of digital imaging and scanning to verify dimensions and surface conditions against the requirements.

5.6 (C5) Rock Drill Chuck: Process-Generic Qualification

5.6.1 Use Case Summary

Table 17: C5 Use Case Details.

Industry	Partner	Laser Technology	Material
Mining	DCU – PL6	Laser Texturing	Tool Steel

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This use case involves the components of a rock drill, specifically the drill bit/shank and the corresponding chuck. These components are crucial for efficient drilling operations in mining and quarry drilling applications, requiring interference fits and surface hardening to enhance durability and performance.



Figure 13: Rock Drill Chuck

Key Functional Requirements:

- Connect parts of the rock drill cutting train and facilitate efficient cutting.
- Achieve maximal durability to withstand rugged geotechnical conditions.

Business Case Overview:

Rock drill components are subjected to extremely harsh conditions that typically lead to rapid wear. Utilizing laser texturing and hardening technologies not only extends the lifespan of these parts but also offers significant cost benefits due to reduced replacement frequency. Although the production costs are higher due to additional processing, the market demand for more durable components justifies the investment. This use case also aims to tap into new market sales by offering parts that outlast traditional options.

5.6.2 Scope of Qualification

The part is susceptible to overloading, which is addressed by careful consideration of the surface texture depth. The resulting high part-risk of approximately 50% likely cannot be represented in the part-specificity, as the approach of laser texturing certification using the ISO/ASTM 52920 must likely be process-generic.



5.6.3 Digital Auditing Possibilities

Laser texturing is a highly flexible process for the surface treatment of parts and is lacking an international standard specific to it. However, the ISO/ASTM 52920 and its capabilities of process certification will be tested within the DILACERT approach for certification of laser texturing processes. This needs to be represented in the scope of qualification.

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5.6.4 Emphasis of Digital Certification

Table 18: Critical features for process certification of the C5 use case.

Process Control Data	Information on the settings and parameters of the equipment used in the repair process, which can be monitored and logged digitally.
Validation planning	Thorough mapping of the entire production process, including a thorough and all-encompassing digital risk assessment.
IQ/OQ/PQ	Qualification of systematic and documented processes of ensuring that equipment is correctly installed, operates according to its intended design, and performs consistently in meeting specified criteria, respectively.
Quality Assurance Methods	Digital records of hardness testing, wear testing, surface profilometry, microstructure assessment and photography for inspecting and verifying the quality of the part to ensure adherence to requirements.
Continuous Improvement and Feedback	Inspection of process data, facilitating adjustments and optimizations in the process for consistent quality.

5.7 (C6) Control Valve: Process-Generic Qualification

5.7.1 Use Case Summary

Table 19: C6 Use Case Details.

Industry	Partner	Laser Technology	Material
Mining	DCU – PL6	Laser Texturing	Tool Steel

A valve designed to control fluid flow in pharmaceutical or food industry applications, where maintaining purity and avoiding contamination is crucial.

Key Functional Requirements:

- Must withstand corrosion and prevent fouling to ensure purity in fluid handling.

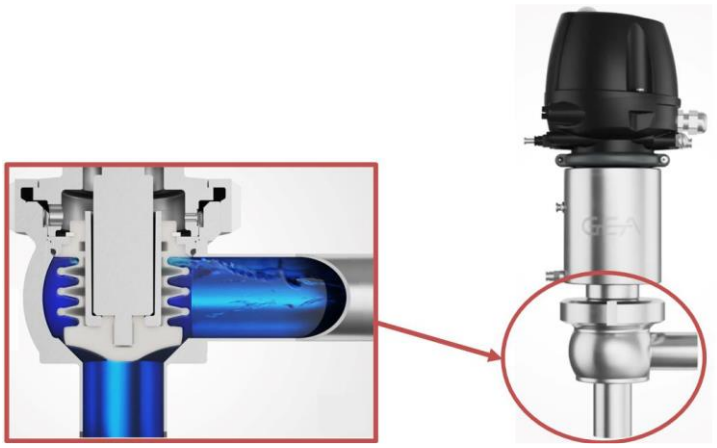


Figure 14: Pharmaceutical Control Valve

Business Case Overview:

The valve operates under strict conditions where failure could result in catastrophic contamination. High quality control standards are vital to ensure the longevity and reliability of the valve in handling sensitive pharmaceutical or food products. DILAPRO's laser processing

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methods are expected to improve product lifetime and quality, meeting stringent industry standards with first-time-right production.

5.7.2 Scope of Qualification

The high part-risk of 70% is a result of the severity of potential failure modes. As was the case with use case C5, the high part-risk cannot be represented in the part-specificity, as the approach of laser texturing certification using the ISO/ASTM 52920 must likely be process-generic.



5.7.3 Digital Auditing Possibilities

Laser texturing is a highly flexible process for the surface treatment of parts and is lacking an international standard specific to it. However, the ISO/ASTM 52920 will be tested within the DILACERT approach for certification of laser texturing processes.

5.7.4 Emphasis of Digital Certification

Table 20: Critical features for process certification of the C6 use case.

Process Control Data	Information on the settings and parameters of the equipment used in the repair process, which can be monitored and logged digitally.
Validation planning	Thorough mapping of the entire production process, including a thorough and all-encompassing digital risk assessment.
IQ/OQ/PQ	Qualification of systematic and documented processes of ensuring that equipment is correctly installed, operates according to its intended design, and performs consistently in meeting specified criteria, respectively.
Quality Assurance Methods	Digital records of biofouling resistance testing, pitting corrosion evaluation, surface profilometry, microstructure assessment and photography for inspecting and verifying the quality of the part to ensure adherence to requirements.
Continuous Improvement and Feedback	Inspection of process data, facilitating adjustments and optimizations in the process for consistent quality.

5.8 (C7) Centrifugal Impeller: Part- Specific Qualification

5.8.1 Use Case Summary

Table 21: C7 Use Case Details.

Industry	Partner	Laser Technology	Material

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Oil & Gas	Prima Additive – PL2	DED	316L deposited onto 17-4 PH

A centrifugal impeller in an oil & gas installation requires repair due to worn-down blade tips. The repair process will use DED to deposit 316L onto the existing 17-4PH base component, restoring the impeller to its original performance specifications.

Key Functional Requirements:

- Maintain performance at specified operational levels.
- Ensure longevity under operational conditions.



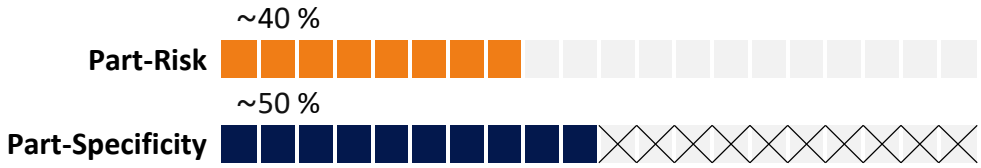
Figure 15: Centrifugal Impeller

Business Case Overview:

Centrifugal impellers in the oil & gas industry face severe conditions that rapidly degrade critical surfaces. The ability to repair impeller blades rather than replacing the entire unit offers significant cost savings and environmental benefits. DILAPRO's process simulation and monitoring are instrumental in optimizing this repair process and ensuring part qualification.

5.8.2 Scope of Qualification

The impeller is required to handle substantial cavitation forces and other stresses, leading to a high part-risk evaluation. The large number of produced end-use parts make this a prime example of part-risk and use-case leading to part-specific qualification.



5.8.3 Digital Auditing Possibilities

For part-based certification, the scope of qualification is focused precisely on the manufacturing of parts of a pre-determined geometry with further specified part requirements. This involves a detailed analysis of design specifications, material properties, and final part inspections. Digital tools and data play a crucial role in facilitating this certification by providing precise, efficient,

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and verifiable methods for print cycle monitoring. Section 7.7.2 of the ISO/ASTM 52920 standard is of special relevance and lends itself particularly well to digital auditing and certification.

5.8.4 Emphasis of Digital Certification

Table 22: Critical features for part-based certification of the C7 use case.

Design Verification	CAD data for the data preparation assessment and suitability of the chosen manufacturing method.
Testing data of co-built artifacts	Maintenance of digital logs containing data from destructive testing of co-built artifacts.
Manufacturing Process Quality	Capturing sensor data on process parameters (laser power, material feed rate, ambient conditions) to validate the manufacturing process to remain within a defined window.
Dimensional Accuracy and Surface Quality	Use of digital imaging and scanning to verify dimensions and surface conditions against the requirements.

5.9 (C8) Mold Repair: Process-Generic Qualification

5.9.1 Use Case Summary

Table 23: C8 Use Case Details.

Industry	Partner	Laser Technology	Material
Automotive	Prima Additive – PL2	DED	Tool Steel

A worn mould used for injection moulding in the automotive industry is repaired to extend its life, maintaining high surface hardness required for producing plastic parts with precision over large production volumes.

Key Functional Requirements:

- Maintain dimensional stability and surface finish over at least 20,000 cycles of operation.

Business Case Overview:

Repairing moulds rather than replacing them offers significant cost savings and environmental benefits. With DED repair technology being relatively new in the automotive supply chain, robust quality assurance systems are essential to



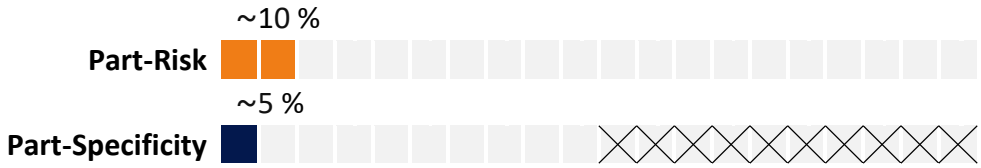
Figure 16: Worn automotive mould for repair.

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build confidence among stakeholders. This repair approach not only reduces costs but also lessens environmental impact by extending the service life of existing tools.

5.9.2 Scope of Qualification

The material chosen for the repair of the injection moulds is identical to the mould material. As such it is known to be functional, and the risks can be safely assessed. The relatively low quantity of parts to be repaired annually and the repair methodology lead to a part-specificity evaluation of 5%.



5.9.3 Digital Auditing Possibilities

The use of DED for the repair of components comes with the challenge of working on parts of a large variety geometries. As such, process certification is the most suited approach.

For process-generic certification, the emphasis shifts towards ensuring that the process itself — regardless of the specific parts produced — is conducted in a manner that consistently meets quality standards. In line with this scope of the qualification, this requires a broader approach to data collection, focusing on process parameters, control methods, and outcome-based assessments. Digital technologies enable continuous monitoring, real-time adjustments, and data-driven insights into process performance, leading to a more robust and reliable certification of the process.

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5.9.4 Emphasis of Digital Certification

Table 24: Critical features for process certification of the C8 use case.

Process Control Data	Information on the settings and parameters of the equipment used in the repair process, which can be monitored and logged digitally.
Validation planning	Thorough mapping of the entire production process, including a thorough and all-encompassing digital risk assessment.
IQ/OQ/PQ	Qualification of systematic and documented processes of ensuring that equipment is correctly installed, operates according to its intended design, and performs consistently in meeting specified criteria, respectively.
Quality Assurance Methods	Digital records of hardness measurements, operational testing, density measurements, microstructure assessments and photographs for inspecting and verifying the quality of the repair work to ensure adherence to requirements.
Continuous Improvement and Feedback	Inspection of process data, facilitating adjustments and optimizations in the process for consistent quality.

5.10 (C9) Pump Diffuser: Process-Generic Qualification

5.10.1 Use Case Summary

Table 25: C9 Use Case Details.

Industry	Partner	Laser Technology	Material
Nuclear	CRM – PL1	DED	Stainless Steel 304L

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A secondary pump diffuser used in the cooling system of a nuclear plant requires refurbishing to maintain performance and safety standards.



Figure 17: Secondary Pump Diffuser

Key Functional Requirements:

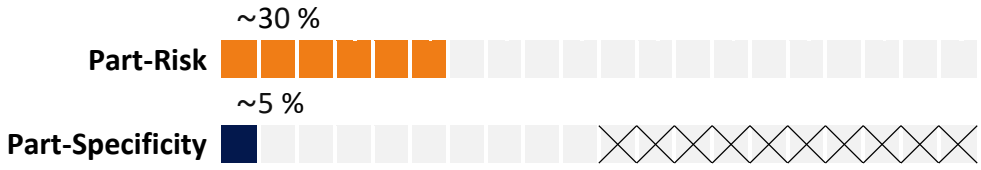
- Must operate reliably within the nuclear environment as part of the secondary cooling system.

Business Case Overview:

Repairing the pump diffuser rather than replacing it offers considerable financial and environmental benefits by reducing waste and minimizing downtime. The repair process is crucial in a nuclear context where safety and precision are paramount. Utilizing DED technology not only reduces costs but also shortens the lead time significantly, ensuring that the cooling system remains operational with minimal interruption.

5.10.2 Scope of Qualification

The large-scale part runs the risk of deformation during the repair process, while simultaneously required to maintain tight tolerances. This leads to a relatively high part-risk of 30%. Due to details laid out in use case C8, the part-specificity is evaluated at 5%.



5.10.3 Digital Auditing Possibilities

The use of DED for the repair of components comes with the challenge of working on parts of a large variety geometries. As such, process certification is the most suited approach.

For process-generic certification, the emphasis shifts towards ensuring that the process itself — regardless of the specific parts produced — is conducted in a manner that consistently meets quality standards. In line with this scope of the qualification, this requires a broader approach to data collection, focusing on process parameters, control methods, and outcome-based assessments. Digital technologies enable continuous monitoring, real-time adjustments, and

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data-driven insights into process performance, leading to a more robust and reliable certification of the process.

5.10.4 Emphasis of Digital Certification

Table 26: Critical features for process certification of the C9 use case.

Process Control Data	Information on the settings and parameters of the equipment used in the repair process, which can be monitored and logged digitally.
Validation planning	Thorough mapping of the entire production process, including a thorough and all-encompassing digital risk assessment.
IQ/OQ/PQ	Qualification of systematic and documented processes of ensuring that equipment is correctly installed, operates according to its intended design, and performs consistently in meeting specified criteria, respectively.
Quality Assurance Methods	Digital records of tensile testing, KV impact testing and NDI for inspecting and verifying the quality of the repair work to ensure adherence to requirements.
Continuous Improvement and Feedback	Inspection of process data, facilitating adjustments and optimizations in the process for consistent quality.

5.11 (C10) Launch Interface Ring: Process-Generic Qualification

5.11.1 Use Case Summary

Table 27: C10 Use Case Details.

Industry	Partner	Laser Technology	Material
Nuclear	CRM – PL1	DED	Stainless Steel 304L

A Launch Interface Ring, crucial for connecting satellites to their launchers via a clamp band that detaches at launch, ensuring successful satellite deployment.

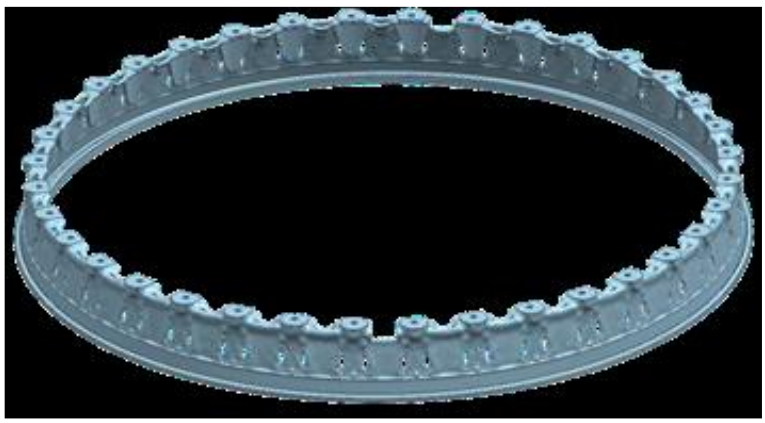


Figure 18: Launch Interface Ring

Key Functional Requirements:

- Ensure secure attachment of the clamp band.
- Maintain structural integrity under mechanical, thermal, and electromagnetic conditions experienced during launch.

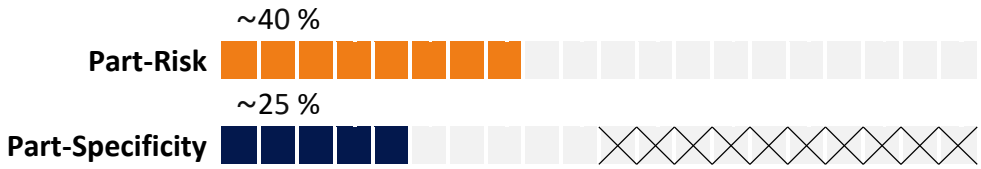
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Business Case Overview:

Producing the Launch Interface Ring via additive manufacturing significantly reduces the "buy to fly" ratio, offering substantial cost and material savings over traditional methods such as machining from large forged AA7075 ingots. The process not only shortens lead times but also minimizes material waste, aligning with financial and environmental objectives.

5.11.2 Scope of Qualification

These critical parts require tight tolerances and have to endure harsh conditions. The small production numbers, coupled with the considerable part-risk of approximately 40% lead to an evaluation of a part-specificity of 25% and a process-generic scope of qualification.



5.11.3 Digital Auditing Possibilities

In case of the launch interface ring, both a part-based certification as well as a process certification should be considered. The scope of the qualification should take the quantity of required parts into consideration, as well as their geometry. As the quantity is relatively low and the production line is also used to produce other parts, the process certification is likely the more suited approach.

5.11.4 Emphasis of Digital Certification

Table 28: Critical features for process certification of the C10 use case.

Process Control Data	Information on the settings and parameters of the equipment used in the repair process, which can be monitored and logged digitally.
Validation planning	Thorough mapping of the entire production process, including a thorough and all-encompassing digital risk assessment.
IQ/OQ/PQ	Qualification of systematic and documented processes of ensuring that equipment is correctly installed, operates according to its intended design, and performs consistently in meeting specified criteria, respectively.
Quality Assurance Methods	Digital records of tensile testing, metallography, and NDI for inspecting and verifying the quality of the part to ensure adherence to requirements.
Continuous Improvement and Feedback	Inspection of process data, facilitating adjustments and optimizations in the process for consistent quality.

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5.12 Discussion and Summary of Digital Certification Insights

The integration of digital certification methods within the DILAPRO project has yielded significant insights into the feasibility and potential advantages of digital audits. One of the primary learnings is that digital tools can greatly enhance the efficiency and accuracy of the certification process by enabling real-time monitoring and comprehensive data collection. This capability reduces the reliance on manual inspections and physical audits, allowing for more dynamic and responsive compliance practices.

Key takeaways include:

1. **Enhanced Data Collection and Analysis**
   Digital certification allows for continuous data capture and analysis, providing a more detailed and accurate picture of the manufacturing process. This includes monitoring laser power, material feed rates, ambient conditions, and other critical parameters.

2. **Improved Traceability and Documentation**
   The ability to maintain digital logs of all process parameters and testing data ensures better traceability and simplifies the documentation required for certification. This is particularly beneficial for meeting stringent standards and regulatory requirements.

3. **Real-Time Process Optimization**
   Digital tools enable real-time adjustments and optimizations based on live data, ensuring that the manufacturing process remains within specified tolerances. This proactive approach helps in maintaining consistent quality and reduces the risk of non-compliance.

4. **Streamlined Re-certification**
   The digital audit framework simplifies re-certification processes by providing a clear, verifiable trail of compliance and performance data. This reduces the time and effort required for subsequent audits and enhances overall certification readiness.

By leveraging these digital capabilities, the DILAPRO project aims to create a robust framework for certification that aligns with industry trends towards automation and digitalization. This transition supports the project's objectives of improving operational efficiency, ensuring compliance with international standards, and facilitating the adoption of advanced manufacturing technologies across the industry.

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6 Conclusion

This deliverable, focusing on the requirements for digital audits across different use cases within the DILAPRO project, notably enhances our understanding of how to leverage digital audits for both part-specific and process-generic certifications. By tailoring the scope of qualification to the unique demands of the use cases, like the production of critical one-off components, this deliverable underscore the project's commitment to advancing digital and sustainable manufacturing practices.

Through the approximate determination of the scope of qualification of the individual use cases, this deliverable contributes to the broader project aim of developing scalable, sustainability-focused solutions for the laser-based, high-precision manufacturing industry, demonstrating the potential of digital technologies to transform traditional manufacturing and certification processes.

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