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GUIDELINE FOR ON-DEMAND MANUFACTURING

EXECUTIVE SUMMARY GREENFIELD & BROWNFIELD PROJECTS

“Today there are 30 billion NOK worth in our physical inventories on the Norwegian Continental Shelf (NCS), and up to 80% will never be used”

Brede Lærum, Equinor

THERE ARE OPPORTUNITIES TO ENHANCE RESILIENCE AND REDUCE VULNERABILITY IN THE OIL AND GAS SUPPLY CHAIN

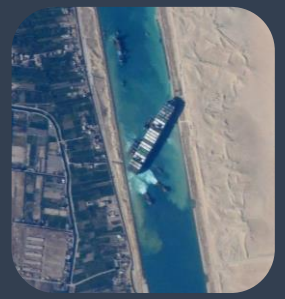
The oil and gas industry continues to innovate and contribute to global energy needs. However, challenges related to supply chain inefficiencies, sustainability, and responsiveness highlight the need for further optimization.

High inventory costs and long lead times

Billions of NOK are tied up in physical assets, many of which will never be used. Traditional manufacturing and procurement processes result in long lead times

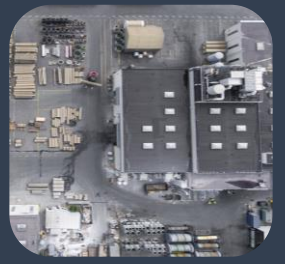
Waste and sustainability

Physical inventories often lead to surplus parts that expire or become obsolete, resulting in increased waste.



Supply chain vulnerability

Dependency on global supply chains for parts creates risks of delays and bottlenecks, especially during crises



Outsourcing of production capacity

Reliance on external production often causes inefficiencies and reduces the agility needed for operational maintenance and project demands.

These challenges highlight the need for a more resilient, agile, and efficient supply chain. **On-demand manufacturing offer a powerful, transformative solution to address these challenges**

ON-DEMAND MANUFACTURING OFFER A TRANSFORMATIVE SOLUTION TO OPTIMIZE RESOURCE EFFICIENCY AND INCREASE PREDICTABILITY

There are several benefits from transitioning from physical inventory management towards on-demand manufacturing. Among these benefits are:

Enhanced supply resilience

On-demand manufacturing can **reduce lead times from months to weeks**, improving supply chain robustness, especially for production-critical equipment.

Improved predictability

Real-time data exchange between network entities ensures greater predictability compared to traditional linear supply chains.

Cost efficiency gains

Significant cost savings through **lower replacement costs** and **extended asset lifetimes**, reducing maintenance and eliminating waste.

Lower carbon footprint

Reduced material waste, **minimized excess inventory**, and **lower transport emissions.**

Local value creation

On-demand production boosts **local manufacturing** and creates local job opportunities, supporting "homesourcing."

Reduced engineering

Enhanced design flexibility, enabling quick modifications in size, material, or design with potential for on-site testing.

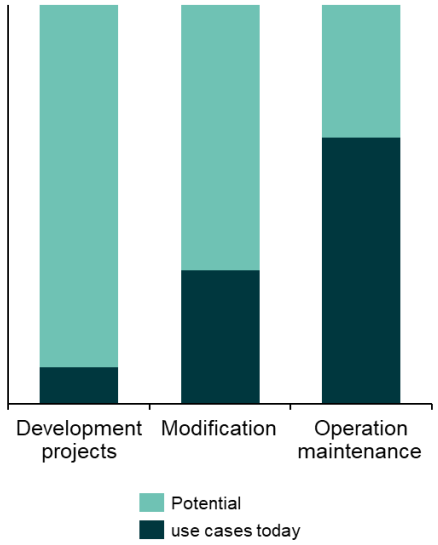
WHILE THE TECHNOLOGY IS MATURE, MULTIPLE BARRIERS, INCLUDING THE ABSENCE OF UNIFORM PRACTICES, HINDER FULL ADOPTION AND VALUE CREATION

Additive Manufacturing (AM) and Digital Inventories (DI) have technologically matured and are now capable of enabling on-demand manufacturing, offering improved supply chain resilience, cost-efficiency, and faster production cycles for the oil and gas sector.

These technologies are currently used ad-hoc for Maintenance activities, where factors like delivery time, cost, and downtime drive the decision to produce parts using AM. However, operators see significant potential for AM and DI in Development projects, major Modifications, and through a more sustainable spare parts philosophy within Maintenance processes.

Despite several proven AM use cases, barriers still hinder full adoption, including knowledge gaps, process ambiguity, limited contract structures supporting AM/DI, and restricted access to essential services. Also, there is no standardized approach to the use of AM among operators and project deliveries on the Norwegian Continental Shelf (NCS).

Overcoming these barriers will require industry-wide collaboration to establish standardized guidelines and frameworks. This will allow the industry to fully capitalize on the benefits of on-demand manufacturing and DI.



THE INDUSTRY HAS INITIATED A PROJECT AIMED AT ESTABLISHING A PROCESS GUIDELINE TO STREAMLINE AM/DI ADOPTION ACROSS GREENFIELD AND BROWNFIELD PROJECTS

Objective of initiative

- **Establish a uniform industry practice** for adoption of Additive Manufacturing (AM) and associated services in combination with Digital Inventories (DI) for both greenfield and brownfield processes to enable on-demand manufacturing
- **Promote on-demand manufacturing/AM** as a viable alternative to traditional sourcing of parts and services, supporting the supply chain, operational efficiency, maintenance, and procurement strategies.
- **Function as a support tool** for project execution and **raise competence** and knowledge within the industry
- **Support existing services** in Offshore Norway's Collabor8 portfolio
- The guideline functions as **supporting tool for operators to adapt their management systems** in accordance with new ways of working and assist as a basis for the development and design of contracts.

What the guideline includes

The guideline is divided into three key sections, tailored for each delivery type (Development, Modification, and Maintenance projects). Each section covers:

- ✓ **Definition of delivery types:** Outlines the scope of the delivery type and AM/DI's relevance
- ✓ **Main process phases and Decision Gates (DGs):** Highlights the key phases, decision points, and underlying activities per delivery type
- ✓ **Opportunity areas for AM/DI:** Identifies specific areas within each process where AM/DI implementation has value
- ✓ **Detailed AM/DI applications:** Offers an in-depth breakdown of AM/DI implementation within each process, covering stakeholders involved, recommended actions, and important considerations for successful adoption.

Involved companies

As these projects are complex and involves several stakeholders and organizations, it has been imperative to acquire input from a wide range of stakeholders, including operators and EPCI contractors.

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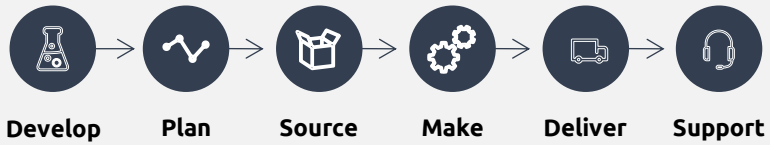
TO REAP THE FULL BENEFITS OF ON-DEMAND MANUFACTURING, THE INDUSTRY MUST GRADUALLY MOVE TOWARDS DIGITAL SUPPLY NETWORKS (DSN)

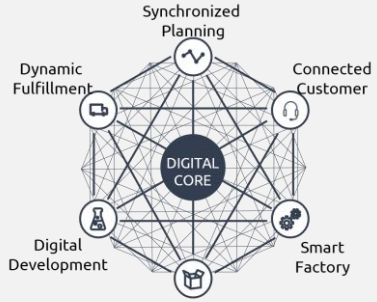
Current supply chains are constrained due to their stepwise and rigid nature - moving to digital networks will unlock greater flexibility and speed

Traditional, linear supply chains



- × Frictions
- × Delays
- × Inefficiencies
- × Bullwhip effect
- ↑ Inventories
- ↑ COGS
- ↑ Out-of-stocks
- ↓ Transparency
- ↓ Agility
- ↓ Velocity

Digital Supply Networks (DSN)



- ✓ Agility
- ✓ Velocity
- ✓ Transparency
- ↓ Inventories
- ↓ COGS
- ↑ On Shelf Availability (OSA)
- ↑ Traceability
- ↑ Product safety

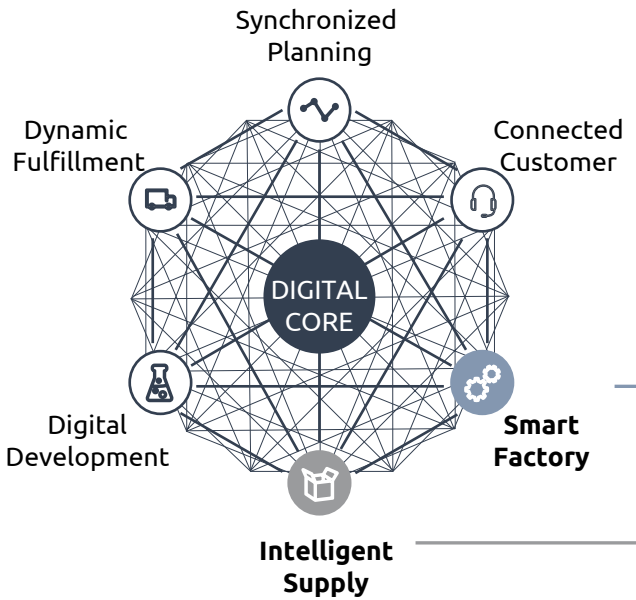
- Current supply chains operate **stepwise**, with each step relying on the previous one, leading to delays and inefficiencies.
- Limited information flow causes **silos**, resulting in a "**bullwhip effect**" where small demand changes lead to large fluctuations across the supply chain.
- Companies hold **large "just in case" inventories** to mitigate risks, increasing costs and reducing flexibility, while transparency remains low.

- DSNs use **real-time data through DI** to provide full visibility and control over inventory levels and processes.
- **Synchronization** across the supply chain reduces the need for large inventories and enables faster, data-driven decision-making.
- DSNs improve agility, transparency, and traceability, ensuring all stakeholders can **respond quickly** to market changes and deliver safer, more reliable products efficiently.

THE SUCCESS OF ON-DEMAND MANUFACTURING DEPENDS ON THE SEAMLESS INTEGRATION OF DIGITAL INVENTORIES (DI) AND FLEXIBLE MANUFACTURING TECHNOLOGIES, SUCH AS ADDITIVE MANUFACTURING (AM), IN WORK PROCESSES

On-demand manufacturing allows for parts and components to be manufactured only when needed, rather than in advance and stored as inventory. It combines the flexibility of AM for rapid production of parts with the real-time control and resource optimization provided by DI. These systems are integrated through DSN, ensuring smooth coordination and responsiveness across the entire supply chain.

Digital Supply Networks (DSN)



Smart factory → On-demand manufacturing methods

- **Additive Manufacturing (AM)**: Fully digital manufacturing method, add material based on a 3D model *(main focus of guideline)*
- CNC machining: Digital manufacturing method, start with a billet, remove material based on a 3D model
- Rapid casting: Standard casting, but 3D print the mold.
- Post treatment: methods such as heat treatment, post machining, surface treatment and QA/QC. Crucial to ensure functional parts with right quality.

Intelligent supply → Digital Inventories (DI)

- DI acts as the **digital backbone** that **manages parts and resources**, offering real-time tracking and control.
- DI **connects** all the relevant **stakeholders** (e.g., manufacturers, suppliers, and operators) by providing instant access to critical data, ensuring better coordination and faster response times.

MULTIPLE USE CASES EXISTS FOR HOW ON-DEMAND MANUFACTURING ENHANCES PROJECT DELIVERY

Obsolete parts

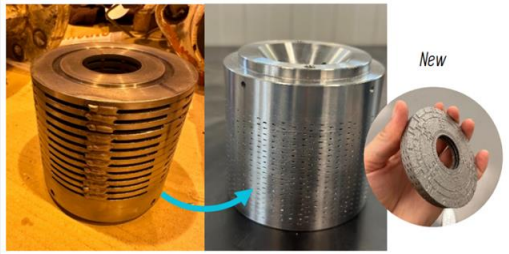
- **Gullfaks**: Rather than replacing several entire connection boxes, polymer screws are now 3D printing at Meisle in Bryne.
- **Business Case**: Estimated cost savings of 100MNOK per year, faster delivery time and reduced environmental footprint

Reduced lead time

- **Norne FPSO**: 3D print mounting flange (diameter: 3-meter, weight: 3-ton, material: steel and Inconel) for thruster. Design owned by Kongsberg Maritime, produced at Wellmax in Larvik.
- **Business case**: Reduced lead time by 30 weeks (from 40 to 10), reduced risk of downtime, costs savings of reduced downtime

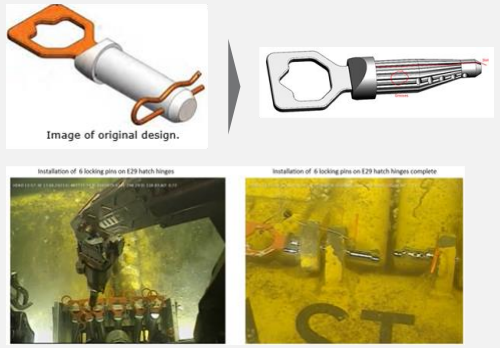
Obsolete part recycled powder

- **BALDER FPSO**: Printing of an obsolete cage for valve in recycled 316L powder.
- **Business case**: Estimated cost savings of 56%, Reduced lead time by 59 days (from 84 to 25), cut CO2 emissions by 40%, reduced energy consumption by 31%, and enabled a single piece design



Redesign on-demand

- **Goliat:** CNC machined produced on-demand of a redesigned subsea pin.
- **Business case:** Produced in 14 days. No qualification requirements, tested and approved according to NORSOK.



ADDITIVE MANUFACTURING (AM) AND DIGITAL INVENTORIES (DI) OFFERS STRATEGIC ADVANTAGES FOR BOTH GREENFIELD (DEVELOPMENT) AND BROWNFIELD (MODIFICATIONS & MAINTENANCE) PROJECTS

GREENFIELD

BROWNFIELD

Development

Development - / Greenfield projects focus on **developing new resources**, following concept studies and sanctioned by an approved PDO/PAD/PUD. These projects are complex, span several years, and involve multiple disciplines across several phases.

Modifications

Modification projects involve **changes or extensions to existing equipment and facilities**, requiring updated technical documentation. Includes change projects and reconstruction outside of maintenance or operational investments.

Maintenance

Maintenance projects cover all **maintenance activities** for offshore **facilities, land plants, and pipelines**, including inspection, preventive and corrective maintenance, and maintenance support.

Guideline

Development Project

For On-demand Manufacturing & Digital Inventories

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EARLY INTEGRATION OF AM/DI INTO DEVELOPMENT PROJECTS LAYS THE FOUNDATION FOR FASTER EXECUTION, COST EFFICIENCY, AND A MORE SUSTAINABLE AND FLEXIBLE PROJECT DESIGN

Recommendations and actions

Early integration of AM/DI: Ensure that AM/DI considerations are taken into account from the start and integrated into early project phases, including risk assessments, procurement strategies, and design processes, to avoid rework and delays.

Standardize AM/DI adoption: Establish clear guidelines and expectations for AM/DI across all processes to ensure that stakeholders and suppliers are aligned.

Local production focus: Encourage the use of local production through AM/DI to reduce environmental footprint, reduce lead times, and enhance cost-efficiency throughout the project lifecycle.

Streamline logistics and maintenance: Refine logistics and maintenance strategies to include AM/DI, allowing for just-in-time delivery of spare parts and reducing downtime during operations.

Focus on sustainability and recycling: Use AM/DI to reduce material waste, promote recycling, and support environmental sustainability throughout the asset lifetime.

Key outputs of AM / DI

Flexibility in project execution
Real-time manufacturing and customizable designs allow for greater adaptability and innovation in project execution.

Reduced lead times
Just-in-time production facilitated by AM/DI minimizes procurement delays and keeps projects on schedule.

Reduced lifetime costs
Lower operational and downtime risks through smarter AM/DI integration across the asset lifecycle.

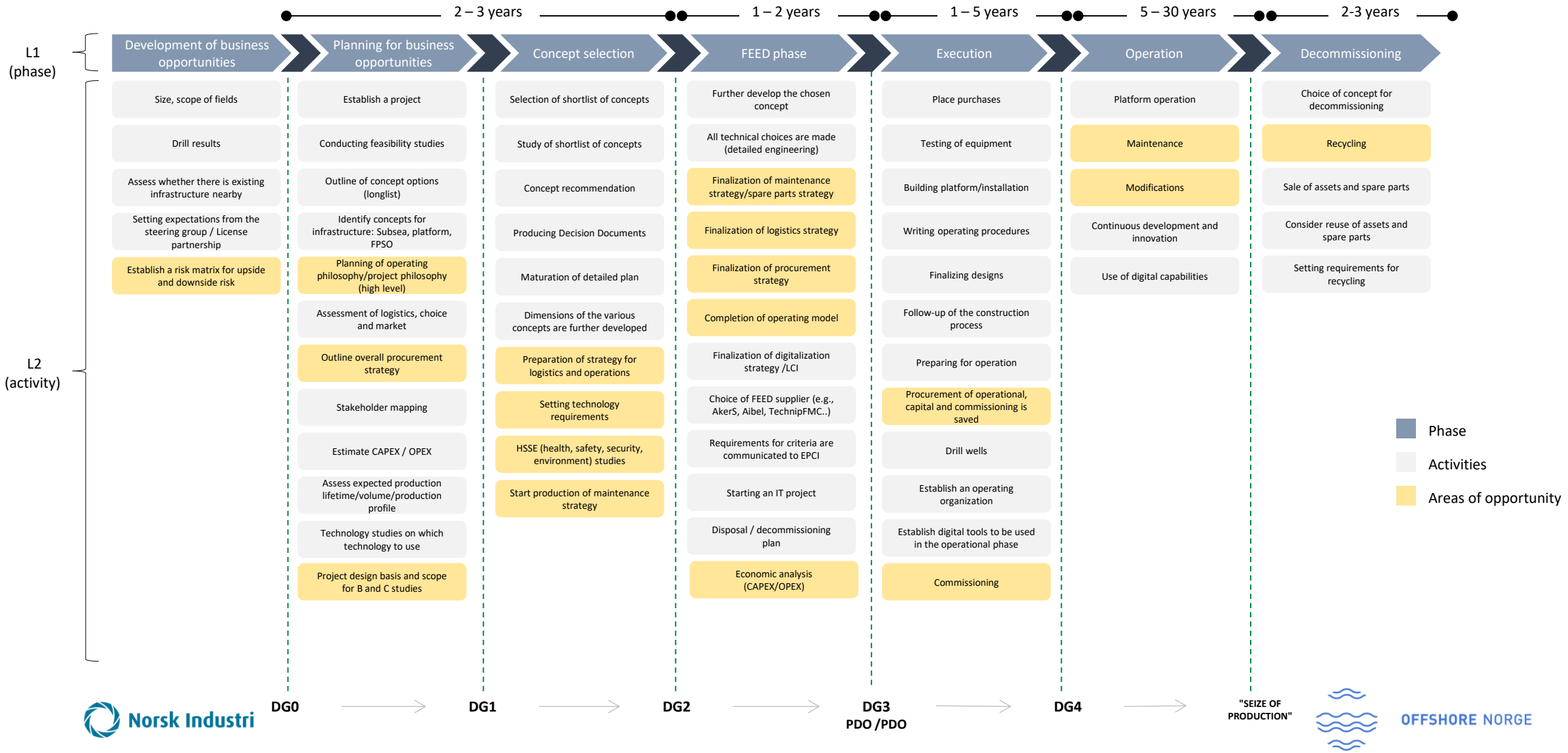
Improved sustainability
Lower emissions, reduced waste, and more sustainable material use through on-demand production.

Supply chain resilience
Local production reduces dependence on global supply chains, minimizing the risk of material shortage.

See appendix for more details

KEY AM/DI INTEGRATION OPPORTUNITIES ACROSS THE DEVELOPMENT LIFECYCLE

See appendix for details per identified area of opportunity, including recommended actions for implementation in company management systems



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Guideline

Modification Project

For On-demand Manufacturing & Digital Inventories

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INTEGRATING AM/DI INTO MODIFICATION PROJECTS ENABLES MORE AGILE, COST-EFFECTIVE UPGRADES WHILE MINIMIZING OPERATIONAL DISRUPTIONS

Recommendations and actions

Integrate AM/DI into technical assessments: Early technical assessments should evaluate AM/DI possibilities, such as repair, replace, or improve functionality, ensuring that options for AM/DI are part of the decision-making process from the start. Extended lifetime should be the primary option

Integrate with legacy systems: Tailor AM/DI components to integrate with existing infrastructure, avoiding full system overhauls while ensuring that modifications meet legacy system requirements

Align AM/DI with existing business frameworks: Include AM/DI opportunities into business framing and feasibility studies to evaluate their impact on CAPEX/OPEX, ESG considerations, and cost optimization across the entire modification lifecycle

Use AM/DI for spare parts and critical component availability: Implement on-demand manufacturing with AM/DI to produce parts as needed, minimizing downtime and improving operational efficiency

Optimize procurement with DI: Ensure AM/DI capabilities are integrated into supplier agreements and digital platforms to streamline procurement processes and improve cost efficiency

Key outputs of AM / DI

Improved adaptability
Flexibility to customize components quickly based on changing operational needs

Reduced downtime risks
On-demand part production reduces downtime and improves efficiency, optimizing the planning and execution of maintenance.

Improved integration with current systems
Ability to tailor parts to fit existing infrastructures, reduces the need for full system overhauls.

Reduced costs and lead time
Custom production for specific upgrades minimizes unnecessary inventory.

See appendix for more details

KEY AM/DI INTEGRATION OPPORTUNITIES ACROSS THE MODIFICATION LIFECYCLE

See appendix for details per identified area of opportunity, including recommended actions for implementation in company management systems

L1 (phase)

L2 (activity)

Identify need	Appraisal	Feasibility study	Concept study	Definition study	Execution	Operations
Technical assessment	Establish project proposal	Modification proposal	Specify project organization	FEED engineering	Receive components	Accept modification
Decide on modification or maintenance	Business framing	Design basis	Concept development	Estimate cost	Commissioning	Handover to operations
	Categorize	Functional description	Select concept	Define equipment & resources	Test components	Transfer LCI
	Establish design basis	Evaluate possibilities	Approve funding	Assess suppliers	SPIR	
	Functional requirements	Identify maintenance philosophy, equipment and components	Identify long lead items	Set maintenance program (replace vs repair)	Maintenance procedures	
	Assess schedule and timing	Assess project schedule		Procure long lead items	Prepare for operations	
	Justifications	Perform early estimate		Proceed to execute	Detail engineering	
	Prioritize	Define tech, business case			Procure equipment	
	Risk assessment	Accept and proceed to CTR				
		Document feasability and installation method				
		Preliminary ESG impact				
		Scope of work				

Phase
Phase (Optional)
Activities
Areas of opportunity

DGA Decide on Modification → **DG0** Type of Modification → **DG1** → **DG2** Select Concept → **DG3** → **DG4**

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Maintenance Project

For On-demand Manufacturing & Digital Inventories

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INTEGRATING AM/DI INTO MAINTENANCE PROCESSES ENHANCES EFFICIENCY, SUSTAINABILITY, AND COST-EFFECTIVENESS THROUGHOUT THE ASSET LIFECYCLE

Recommendations and actions

Incorporate AM/DI into spare parts management: Operators should update spare parts lists and maintenance plans to integrate AM/DI, ensuring faster part production and reducing storage costs.

Enhance predictive and preventive maintenance: Use AM/DI to support predictive maintenance by monitoring equipment health in real-time, enabling on-demand production of parts, and reducing downtime.

Leverage AM for sustainable maintenance solutions: Utilize AM/DI to reduce resource consumption and emissions, improving sustainability and ESG performance in maintenance processes.

Improve maintenance efficiency through DI: Integrate DI into the maintenance process to optimize the procurement and management of spare parts, reducing lead times and inventory costs.

Improve repair and replacement strategies using AM: Explore the use of AM to replace or repair parts previously supplied by OEMs, ensuring faster production and preventing equipment obsolescence. Extended lifetime should be the primary option.

Key outputs of AM / DI

Extended equipment lifespan
Predictive maintenance with AM/DI helps extend service life and improve reliability by enabling quick replacement of components as needed.

Reduced downtime risks
On-demand part production reduces downtime and improves efficiency, optimizing the planning and execution of maintenance.

Reduced maintenance cost and lead time
AM/DI lowers the lead times for part production and repairs, driving down the costs of maintenance operations.

Improved traceability and documentation
Better traceability and documentation of maintenance activities ensure smoother and more efficient future operations.

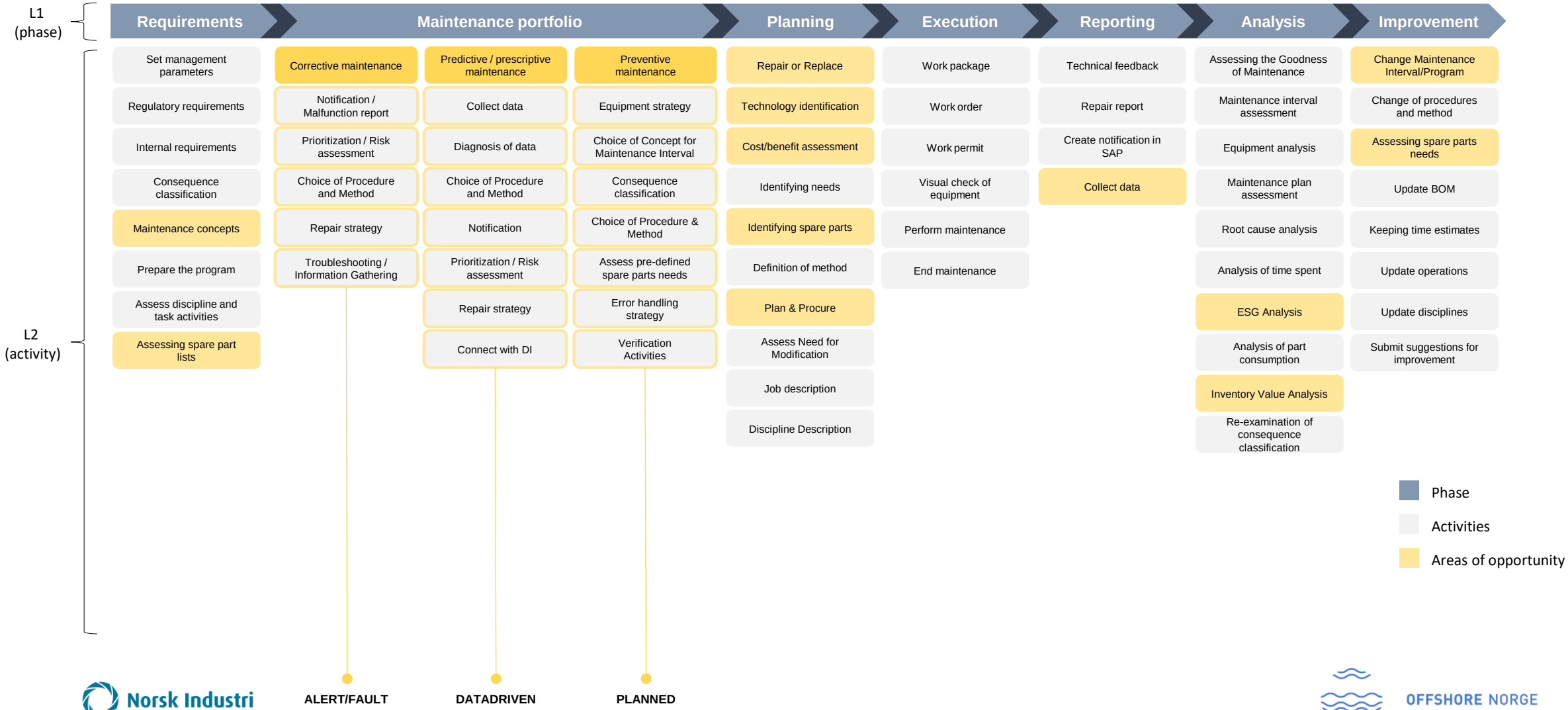
Optimized spare parts procurement
AM/DI streamlines the procurement process, reducing the need for large inventories and improving cost and environmental efficiency.

Improved sustainability
Lower emissions, reduced waste, and more sustainable material use through on-demand production.

See appendix for more details

KEY AM/DI INTEGRATION OPPORTUNITIES ACROSS THE MAINTENANCE LIFECYCLE

See appendix for details per identified area of opportunity, including recommended actions for implementation in company management systems



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