ACCURATE

D3.2. Human-centric Decision Support System for MAAS production adaptation

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Produced by: EnginSoft Spa: Giovanni Paolo Borzi

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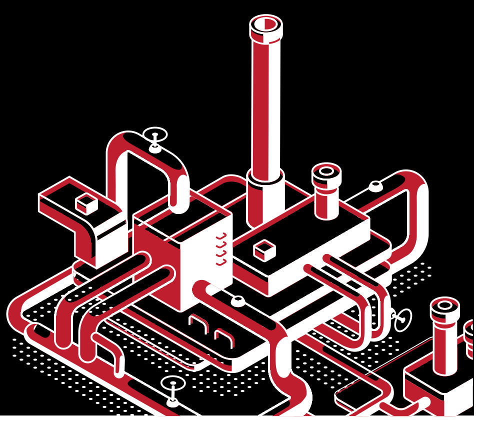

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Produced by:	EnginSoft: Giovanni Paolo Borzi
Contributors:	EnginSoft: Giovanni Paolo Borzi, Anteneh Yemane, Manolo Venturin, Simone Gregori
Work Package Leader Responsible:	Aarhus University: Rami Mansour
Reviewed by:	Razvan Purcarea, Rami Mansour, Milan Vathoopan Kannan

Dissemination level	
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	PP = Restricted to other programme participants (including the EC)
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Terms and abbreviations

DOA	Description of Action
DT	Digital Twin
DSS	Decision-Support System
MaaS	Manufacturing-as-a-Service
WP	Work Package
WIP	Work in Process
DES	Discrete Event Simulation
C&S	Circularity and Sustainability
eLCA	Environmental Life Cycle Assessment
sLCA	Social Life Cycle Assessment
ERP	Enterprise Resource Planning
GUI	Graphical User Interface
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
MES	Manufacturing Execution System
MCDM	Multi-Criteria Decision-Making
MRP	Material Requirements Planning
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OTD	On-Time Delivery
PCB	Printed Circuit Board
SC	Supply Chain
SMT	Surface Mount Technology
UC	Use Case (as pertaining to the ACCURATE project)

Public Summary

This deliverable is a result of the ACCURATE project which aims to increase the competitive abilities of European manufacturing through manufacturing-as-a service (MaaS), digital twins (DTs), and decision support systems (DSS).

One of the primary objectives in ACCURATE is designing a Decision Support System supporting human-centred decision making in MAAS environments. Work Package (WP) 3 aims to addresses this research objective, within the scope of individual nodes (i.e., manufacturing facilities) within a MaaS system. The overall ambition in WP3 is to deliver the knowledge and tools for supporting the adaptation and reconfiguration of production processes within MaaS nodes from the perspective of resiliency, sustainability, and human-centricity. WP3 enables the creation of DT modelling frameworks and associated DSS, with the above goals supporting MaaS nodes to perform simulation-based performance prediction, robust optimisation, and consequently responsive control of production processes.

This deliverable reports the progress in WP 3 towards the definition for a human-centric DT-based DSS, that enables MAAS nodes to simulate, optimize, and control their production processes, and managing disruptions. The deliverable covers work performed in Task 3.5. Results from these tasks, aligned with results from WP 2, WP 3, WP 6 and WP 7, have shaped the requirements for a digital thread linking together information from the production digital twins, connected to the Pilots data sources, enabling decision-makers to perform resilient operation and respond to disruptions by production reconfiguration.

Results include the methodologies together with the operational and functional requirements for creating the human-centric DSS. These results also include the integration of production-level simulation-based DTs capable of measuring resilience and performance indicators of production lines for MaaS nodes under nominal operating conditions and under disruptions, as well as their integration in the system for supporting scenario-based production optimization, control and adaptation.

1 Introduction

1.1 About this deliverable

Deliverable 3.2, titled "Human-centric Decision Support System for MAAS production adaptation", provides details on the definition of a human-centric DT-based DSS, that enables MAAS nodes to simulate, optimize, and control their production processes, and managing disruptions. Accordingly, this deliverable presents the requirements and formulation of a digital thread supporting human-centred decision making in MAAS (T3.5, M12 – M22, lead: ES). This digital thread should link together information from the production-level digital twins, connected to the MAAS digital backbone, enabling human decision-makers to take just-in-time or prognostic actions to reconfigure production in response to disruptions. Two specific configurations of the digital thread to support MAAS production adaptation are presented:

i. resilient operation: involving the configuration of simulation-based multi-criteria decision support systems for production planning and optimization, that ensures resiliency of production systems to disruptions, and evaluating trade-offs in costs, C&S performance, production performance, due to resilient (yet potentially non-optimal) operation, and
ii. responsive operation: simulation-based, online decision support systems for production monitoring, dynamic optimization & control, as well as insight generation services for supporting human-experts respond to production disruptions.

The resilient operation digital thread aims to analyse an industrial system to identify actions to improve resilience objectives vis-à-vis potential disruptions (prescriptive approach); the responsive operation digital thread aims to apply simulation-based DTs to analyse the impact of actual disruptions on an industrial system to identify actions conducive to loss minimization and accelerating recovery from the disrupted state (reactive approach).

1.2 Document structure

To support these Deliverable objectives, the document is divided into three chapters, dealing the following aspects:

- **Chapter 2: Human-centric DSS for MAAS production adaptation towards resilient and responsive operation: objectives and requirements.** This chapter provides an analysis of the DSS-related requirements collected by the Consortium. As such it summarises requirements described in D3.1 - Frameworks for Resiliency- and Sustainability-Oriented Production Digital Twins, and D7.1 - Pilots' deployment strategy. These requirements are analysed towards different objectives, i.e. human-centricity, resilient and responsive operations, circularity and sustainability. Such requirements are then consolidated to provide a basis for the DT-based DSS digital threads.
- **Chapter 3: Digital threads for human-centric DT-based DSS.** This chapter develops the design of the DT-based DSS aimed at supporting the adaptation and reconfiguration of production processes within MaaS nodes (i.e., manufacturing facilities) from the perspective of resiliency, responsiveness, sustainability, and human-centricity. A layered representation and building blocks view for the DSS and interacting services is provided according to the architectural principles set forth by D6.1 - High-level ecosystem architecture. The purpose of each component is detailed to provide a clear separation of concerns and the interaction among them is exemplified. Examples towards resilient and responsive operations are provided. A DT API is designed to further clarify the nature of the integration between the DSS and

production-level DTs. Finally, a mapping of the requirements identified in Chapter 2 and the DT-based DSS modules is provided to further clarify the scope of the application.

- **Chapter 4: conclusions and future work**. The implementation status (M22) and planned future work towards the digital thread implementation (T6.3, T6.4, T7.2) are summarised.

1.3 Relation with other tasks and deliverables

This Deliverable 3.2 provides the foundational requirements and architectural framework developed for the human-centric DT-based DSS. It sets a clear basis for future work regarding the DSS further implementation, validation, and continuous improvement. This deliverable builds on the outcomes of different ACCURATE tasks in order to identify operational and functional requirements. As such it relates to the following WPs and Tasks:

- WP2: T2.5 "Concept for framework integration of semantic solution module" (DT registry): the outcome of this task is described in D2.2 "Matchmaking model and DT registry service". D2.2 introduces the DT registry application, that provides a unified environment for browsing, managing, and documenting Digital Twins. Thanks to a standardised set of APIs, DTs instances created through this application can then be directly utilized by the DSS.
- WP3: T3.1 "Functional Requirements Engineering", T3.2 "Resilience-Oriented Circularity & Sustainability Assessment", T3.3 "Resilience-Oriented Production Modelling and Simulation". The outcomes of these tasks are described into D3.1 "Frameworks for Resiliency- and Sustainability-Oriented Production Digital Twins". D3.1 provides a comprehensive set of requirements for simulation-oriented DTs, the DSS and C&S models that are further analysed and integrated here.
- WP5: D5.1 – Decentralised Data Space infrastructure provides the architecture and implementation details of the Decentralized Data Space Infrastructure developed for the ACCURATE project. The DT-based DSS design presented here aligns with the architectural principles detailed in D5.1, to foster the DSS integration within the ACCURATE ecosystem.
- WP6: T6.1 "Service architecture, system modelling and infrastructure": the outcome of this task is described in Deliverable D6.1 "High-level ecosystem architecture". D6.1 provides the high-level design of the ACCURATE ecosystem architecture and defines the general approach for designing, documenting and integrating the ACCURATE services, such as the DT-based DSS.
- WP7: T7.1: "Scenarios definition and environment set-up": the outcome of this task regarding DSS-related Pilots' UCs is described in D7.1 "Pilots' deployment strategy". D7.1 provides a detailed description of the challenges each Pilot's faces and develops the operational requirements of the corresponding UCs. Such requirements are further analysed and integrated here towards the DT-based DSS definition.

2 Human-centric DSS for MAAS production adaptation towards resilient and responsive operation: objectives and requirements

2.1 Human-centric DSS objectives

ACCURATE has specific goals and objectives that include the implementation of a Human-Centric Decision Support System (DSS). As described in the DOA, the DSS will enable timely, optimal and robust SC and operations design, planning, stress testing, reconfiguration and recovery for manufacturing value chains.

The ACCURATE DSS will enable the definition of decision support workflows and scenario evaluations, addressing complex SCs and critical value chains while maintaining the intellectual property of all involved parties. The ACCURATE DSS will integrate the collaboratively shared data and models to provide decision makers with performance, resilience, environmental, sustainability and circularity KPIs evaluations, linked with the EU resilience dashboard indicators.

Such implementation is linked to project-level KPIs: a subset of KPIs that are directly linked to the DSS are summarised in the table below.

Table 1 Project-level KPIs linked to the DSS

Section 1.1.1. objective	KPI code	KPI description and targets
Objective 1 - Better understanding unforeseen events' impact on manufacturing and industrial production	KPI1.1	Implementation of human-centred DSS for at least 3 MaaS value chains, enabling scenario-based analysis of events, stress tests execution, and definition of preventive and corrective actions
	KPI1.2	DSS enabling sustainability, performance stability, resilience, and viability assessment via validated indicator sets (consisting of at least 10 individual indicators)
	KPI1.3	Number of disruptive events scenarios/applications considered for pilots ≥2
Objective 4 – Improving the circularity and sustainability performance of manufacturing networks	KPI4.3	Number of cases piloting and validating ACCURATE C&S DSS tool ≥2
Objective 5 – Making Manufacturing as a Service technically and economically viable	KPI5.2	Semantic interoperability demonstrated by functioning semantic collaboration of the individual modules by using standards (matchmaking, DT registry)

DSS human-centricity will support the following ACCURATE outcomes:

- implementation of a collaborative, scenario-based decision support workflow
- collaborative and multi-sided valued creation in the ACCURATE Ecosystem

Key principles of a human-centric solution include designing for real-world scenarios and using technology to augment human capabilities and foster collaboration. In particular, the DSS should enable EU manufacturing value chains stakeholders (human decision-makers) to collaboratively perform detailed scenario modelling and simulations, and to swiftly identify and enact preventive and reactive actions.

Figure 1 Scenario-based decision support workflow (ACCURATE DOA)

Stakeholders of the ACCURATE ecosystem include decision makers at manufacturing and logistics companies (e.g. production managers, SC planners), as well as service and solutions providers (e.g. ERP, MES providers, models and DT providers).

Additionally, the DSS will support human sensemaking processes by combining DT-based and data-driven methods that gather, process, and summarize data, and user-driven methods that allow humans to input their domain knowledge or data-driven insights during exploration and decision-making tasks. These vertical (DT and data-driven) and horizontal (decision support workflow) integration need to support both resilient and responsive digital threads.

To this end, the ACCURATE Consortium identified different and numerous requirements related to the envisioned DT-driven DSS; such requirements have been described in the following documents:

- Deliverable D3.1 “Frameworks for resiliency- and sustainability-oriented production digital twins”: specifies functional requirements for models and DTs and their integration with the DSS
- Deliverable D5.1 “Decentralized Data Space Infrastructure”: provides requirements for data and services integration with the ACCURATE data space and marketplace
- Deliverable D6.1 “High-level ecosystem architecture”: specifies the general ACCURATE framework architecture, including the DSS, its modularity and the interaction with the different layers and services
- Deliverable D7.1 “Pilots’ deployment strategy”: links the DSS to the general ACCURATE project objectives and KPIs, defines DSS application to a subset of the Pilots’ Use Cases

The following paragraphs further analyse, detail and align such requirements to ensure the ACCURATE human-centric DSS design and digital threads implementation. Such analysis starts from the use-case related operational and functional requirements that have been identified in D7.1, integrates and aligns with requirements stemming from DTs design (described in D3.1) and lastly align with architectural and infrastructural design of ACCURATE ecosystem and framework (D6.1, D5.1).

2.2 Operational and functional requirements stemming from identified Use Cases

The project-level perspective has been translated into more specific requirements to support ACCURATE Pilot’s use cases. More precisely, D7.1 summarises the ACCURATE project objectives and KPIs, linking a subset of the Use Cases to the envisioned DSS implementations (Table 2).

Table 2 Use Cases supported by DSS implementations

Use Cases supported by DSS implementations		
Airbus	**Continental**	**Tronico**
UC1: SC disruption monitoring by DT-based simulation	UC1: SC stress-test in the very high complexity context	UC1: Supply Chain stress test and optimization
UC2: SC design support by identification of hidden critical suppliers/material	UC2: Optimization of material flow along the supply chain	UC2: Production planning – batch sizing decisions
UC3: SC design recommendations for better absorption and swift adaptation	UC3: Integration of production planning with production control	UC3: Production control - Scheduling, dispatching and shop floor control
UC4: Integrated assessment of Supply and Internal value chains by means of DTs		

Central to these Decision Support System (DSS)-oriented use cases is the development and integration of simulation-based Digital Twins (DTs) that model complex, interconnected processes across multiple scales, levels of spatial and temporal granularity, and timeframes. These DTs are intended to incorporate both predictive and prescriptive analytics, supporting decision-making under normal and abnormal (disrupted) operating conditions within the value chains under study. Such use cases can further be classified with respect to their implementation focus: SC-oriented (green background), internal VC-oriented (blue background), and multi-level (grey background).

To enable these Use Cases, the DSS will provide Decision Makers (e.g. SC managers, production managers) with features aimed at supporting decisions, e.g. to react to disruptions to minimise the loss of performance and maximise the recovery rapidity. Additionally, the DSS results may be utilized to compute hypothetical scenarios as an input to right-size the industrial system in accordance with the overall resilience objectives, therefore supporting manufacturing engineering experts and architects.

2.2.1 Use cases analysis towards resilient and responsive operations

The following paragraphs analyse the DSS-oriented Use Cases presented in D7.1 towards the identification of the two digital threads configurations, i.e. resilient operation and responsive operation. The objectives are to clarify the orientation of each UC towards one or both the threads, as well as to identify the operational and functional requirements to support such threads. Afterwards, requirements are analysed and consolidated in a functional requirement list encompassing all the Use Cases.

Airbus Atlantic Use Cases

UC1 - Supply Chain Disruption Monitoring by Digital Tool-Based Simulation

UC1 proposes a simulation-based DT system to support supply chain monitoring and disruption response. The main elements of the proposed solution are as follows:

- Identify known-unknown uncertainties to characterize repeated but unpredictable supply chain events.
- Define a nominal supply chain DT representing Airbus Atlantic's S14A supply network.
- Simulate disruptions and assess impact to inform standardized responses and decision-making.
- Develop a dynamic fulfilment network capable of adapting supplier roles and capacities as needed.
- Support sustainability and responsiveness by aligning supply chain configuration with environmental goals and customer service objectives.

The following table identifies the corresponding functional requirements and classifies them between requirements supporting the two digital threads.

Table 3 Resilient and responsive operations requirements orientation

Requirement	Resilient operations	Responsive operations
Enable scenario-based simulation of disruption	x	
Integrate DT of the nominal supply chain	x	
Identify critical parts	x	
Identify vulnerable suppliers	x	
Enable supply network design	x	
Disruption monitoring		x
Provide decision support during disruptions		x
Provide simulation-driven recommendations	x	x
Integrate sustainability considerations	x	

The analysis reveals that UC1 primarily aligns with the resilient operation approach, as it focuses on the development of a simulation-based Digital Twin for proactive supply chain risk identification and planning. Key capabilities such as nominal supply chain modelling, stress testing, and interdependency mapping support resilience-building objectives.

However, UC1 also sets the stage for a transition into responsive operation, with future goals targeting real-time monitoring, dynamic fulfilment, and decision-making support during disruptions. This progression reflects a hybrid strategy that begins with resilience and evolves toward responsiveness as the tools digital capabilities mature.

UC2 Supply Chain Design Support by Identification of Hidden Critical Suppliers/Materials

UC2 requires tools for proactively design and analyse SCs, identify vulnerabilities, and improve the SCs towards long-term risk mitigation. The main elements of the proposed solution are:

- SC design, analysis and discovery of weak points
- Stress-testing and scenario simulation (including exploration of hypothetical disruption scenarios to evaluate supply chain robustness)

- Design recommendations
- Cost-resilience trade-off analysis

Table 4 identifies the corresponding functional requirements and classifies them between requirements supporting the two digital threads.

Table 4 Resilient and responsive operations requirements orientation

Requirement	Resilient operations	Responsive operations
Enable scenario-based simulation of hypothetical disruption events	x	
Perform network analysis of SC dependencies	x	
Perform SC stress testing	x	
Identify of critical parts		
Identify vulnerable suppliers	x	
Alert generation		x
Evaluate different policies: multi-source policy, supplier consolidation policy	x	
Model and compute cost-resilience trade-off	x	
Support for future real-time responsiveness		x

It can be concluded that UC2 is oriented primarily towards resilient operations, as it is rooted in proactive design improvement, vulnerability discovery, and long-term supply chain risk mitigation. In fact, it emphasises stress-testing for rare events, critical path analysis, and strategic sourcing recommendations.

UC3 - Supply Chain Design Recommendations for Better Absorption and Swift Adaptation

UC3 proposed solution revolves around embedding the supply chain DT and stress-testing capabilities into Airbus Atlantic's business processes and decision frameworks. To achieve such objective, the following solutions are required:

- A DT should be developed to simulate, assess and optimize inventory strategies and policies for various parts and scenarios.
- The DT should use data exchange to anticipate disruptions
- The DT should incorporate frameworks like Low-Certainty-Need Supply Chain (LCNSC) and Active Usage of Resilience Assets (AURA) to provide a structured approach to integrating these recommendations

The corresponding functional requirements and their classification are provided in Table 5 below.

Table 5 Resilient and responsive operations requirements orientation

Requirement	Resilient operations	Responsive operations
Enable simulation-based inventory management strategy assessment	x	
Enable simulation-based inventory policy optimization	x	
Use of resilience frameworks (i.e. LCNSC, AURA)	x	
Support resource allocation and planning adherence	x	
Support DT data exchange		x
Support responsive demand-supply matching		x
Enable rapid adaptation to production stoppages		x
Compute cycle time and delivery KPIs	x	x

UC3 analysis reveals its orientation towards both resilient and responsive operation requirements. The core focus is on resilience, involving strategic inventory and supplier management, integration of resilience frameworks, and embedding digital twin insights into business processes to shorten lead times and improve planning. Simultaneously, UC3 advances responsiveness through enabling real-time collaboration, adaptation, and enhanced operational agility. These features facilitate swift reactions to disruptions, particularly production stoppages, thereby improving delivery reliability.

UC4 - Integrated Assessment of Supply and Internal Value Chains by Means of Digital Twins

Use Case 4 focuses on the development of adaptive and robust planning capabilities through integrated Digital Twins (DTs) that cover both supply chain and internal value chain activities. The goal is to dynamically respond to disruptions and changes, enhancing on-time delivery (OTD) performance and sustainability KPIs. In this context, external disruptions propagate from the supply chain issues (e.g. as studied in UC1-UC3), while internal disruptions include e.g. unavailability of production assets (e.g., jigs and tools).

The solution requires:

- simulation-based manufacturing system DT development, through analysis and modelling
- models parametrisation and linking to data sources (e.g. MES) on a frequent basis to maintain up-to-date DT states
- Implementation of optimization loops leveraging supply chain DTs and internal value chain DTs
- multi-criteria optimization and scenario evaluation, to assist decision-makers in dynamically reconfiguring production plans

The corresponding functional requirements and their classification are provided in Table 6 below.

Table 6 Resilient and responsive operations requirements orientation

Requirement	Resilient operations	Responsive operations
Enable simulation-based inventory management strategy assessment	x	
Enable simulation-based inventory policy optimization	x	
Use of resilience frameworks (i.e. LCNSC, AURA)	x	
Support resource allocation and planning adherence	x	
Support DT data exchange		x
Support responsive demand-supply matching		x
Enable rapid adaptation to production stoppages		x
Compute cycle time and delivery KPIs	x	x

This analysis reveals that UC4 embodies a hybrid digital thread integrating resilient and responsive operational strategies. Its primary emphasis on multi-level digital twin integration and data-driven decision support supports prescriptive resilient planning. At the same time, it enables reactive, responsive control to dynamically synchronize operations across supply and internal value chains, ensuring robustness, agility, and sustainability in production planning.

Continental Use Cases

UC1 - SC stress-test in a very high complexity context

Continental's supply chain is highly complex, involving ~10,000 components and 350 suppliers, spanning multiple tiers and regions. The network is exposed to disruptions with suppliers struggling to meet volume requirements, especially after COVID-19. Vulnerabilities are amplified by external factors such as long lead times, demand fluctuations, and supplier dependencies. Moreover, Continental Pilot plant experiences challenges in managing production variability, inventory space, and backlog recovery. Use Case 1 aims to address these risks implementing a digital twin-based stress-test simulation. This involves:

- mapping the entire supplier network
- simulating disruption scenarios
- testing mitigation strategies.

Key disruptive events include transportation delays (e.g., a Suez Canal blockage event) and supplier shortages (e.g., a semiconductor crisis event), as well as demand fluctuations. The stress-testing simulation supports evaluating trade-offs between transport options (sea vs air), alternative suppliers, and inventory policies. The approach aims to identify bottlenecks, validate recovery strategies, and improve coordination across the supply chain. Expected outcomes include a 15% reduction in reconfiguration time and a 50% improvement in delivery performance relative to supplier commitments, enhancing resilience and reliability in global operations.

Table 7 Resilient and responsive operations requirements orientation

Requirement	Resilient operations	Responsive operations
Mapping of a multi-tier supplier network	x	
Simulation of disruption scenarios (supplier delays, transport blockages, demand fluctuations)	x	
Stress-testing recovery strategies under different disruption contexts	x	
Trade-off analysis between cost, service, and resilience (e.g., air vs sea freight)	x	
Identification of bottlenecks and vulnerability points in network	x	
Alternative supplier/transportation configuration evaluation	x	
Real-time monitoring of supplier performance and transport status		x
Dynamic adaptation of sourcing/transportation during disruption		x
Alerting and insight generation for human decision-makers		x
Scenario planning combining long-term preparedness (resilient) with short-term response (responsive)	x	x

This use case is primarily resilience-oriented, since its focus is on stress-testing the supply chain to anticipate disruptions, model vulnerabilities, and evaluate long-term mitigation strategies. The core activities require simulation, multi-criteria trade-offs, and network redesign to enhance robustness. Some responsive elements (real-time monitoring, dynamic adjustment) are included in the UC1 scope, however they play a secondary role compared to the stress-testing and strategic planning activities.

UC2 - Optimization of material flow along the supply chain

The diversity and multi-tier nature of Continental supply network create coordination challenges and increase vulnerability to disruptions. Continental Timisoara plant face demand fluctuations, missing or unusable components, limited warehouse space, and full-capacity exploitation of production lines. Additional issues in scope of UC2 include machine breakdowns, variability in production yield, and co-design changes that alter specifications late in the process. To address these complexities, this UC focuses on optimizing material flows along the supply chain by simulating demand fluctuations, component shortages, and process variability. A digital twin-based simulation will be applied to model end-to-end production processes, test scenarios, and identify inefficiencies. Key solution approaches include prescriptive analytics, predictive forecasting, and an integrated monitoring tool for EDI and customer data. These tools aim to improve production planning, reduce obsolete materials, ensure stable inventory levels, and minimize special freights.

Table 8 Resilient and responsive operations requirements orientation

Requirement	Resilient operations	Responsive operations
Simulation of production processes including variability and failures	x	
Demand fluctuation modeling and impact analysis	x	
Improve resilience through optimization of inventory levels	x	
Simulate alternative policies to address sole-supplier dependencies	x	
Perform long-term trade-off analysis (inventory vs obsolescence vs service)	x	
Monitoring of demand, delivery lead time, yields (EDI data)		x
Provide prescriptive analytics for forecasting and reactive planning		x
Compute dynamic adjustment of orders/production/distribution		x
Provide alerting and recommendations during disruptions		x
Integrated dashboard supporting both simulation and monitoring	x	x

This UC is oriented towards both resilience and responsiveness. Its scope includes long-term resilience measures such as demand fluctuation modelling, buffer planning, and scenario analysis, together with responsive-oriented solutions such as monitoring, prescriptive analytics, and dynamic optimization to respond to material flow challenges. Notably, Continental UC3 emphasises EDI-based monitoring and predictive forecasting indicating that the DSS here must act as an online, responsive decision aid as much as a resilience-planning tool. Thus, UC2 addresses responsiveness while embedding resilience strategies.

UC3 - Integration of production planning with production control

Continental's production system is highly complex, involving PCB production, testing, final assembly, and packaging across multiple independent lines. Operating 24/7 at near-full capacity, the system requires robust and adaptive planning to handle variability and disruptions. Challenges include fluctuating demand, missing or unusable components, limited warehouse space, machine breakdowns, and variability in yield and process duration. UC3 addresses the integration of production planning with production control, aiming to ensure smooth synchronization between planning and real-time shopfloor execution. Disturbances require dynamic corrective actions to avoid cascading delays, while disruptions may demand reconfiguration of the system. The proposed approach relies on simulation-based digital twins (DTs) of the manufacturing system, integrating data from ERP, MES, and WMS. These DTs will evaluate plans, model shopfloor reconfigurations, and support adaptive decision-making. Outcomes include enhanced robustness of planning, faster recovery from disruptions, improved synchronization between planning and control, and adaptive use of shopfloor redundancy. To this end, UC3 seeks to reduce performance variability, ensure on-time delivery, and strengthen the resilience and responsiveness of operations.

Table 9 Resilient and responsive operations requirements orientation

Requirement	Resilient operations	Responsive operations
Simulation of production plans under variability and disruptions	x	
Integrate robust planning for demand fluctuations and capacity	x	
Identification of feasible reconfiguration options	x	
Multi-criteria optimization of production plans (cost, performance, sustainability)	x	
Modelling of redundancy and alternative routing in production lines	x	
Real-time monitoring of shopfloor status (ERP/MES/WMS integration)		x

Dynamic rescheduling and dispatching decisions		x
Adaptive sequencing and assignment at line level		x
Human-in-the-loop support for corrective actions		x
Digital twin integration to connect planning with control	x	x

This UC is oriented towards both resilience and responsiveness. While it prioritizes resilient planning through simulations, redundancy modelling, and reconfiguration strategies to ensure robustness against long-term variability and disruptions, at the same time it explicitly requires responsive capabilities, including dynamic rescheduling and adaptive sequencing to react to disturbances at the shopfloor.

Tronico Use Cases

UC1: Supply Chain stress test and optimization

UC1 addresses inventory management under fluctuating demand forecasts at Tronico. Currently relying on manual decision-making, the supply chain lacks tools to model, simulate, and respond to disruptions. The objective is to support decision makers by implementing simulation-based tools to perform stress-testing supply chain scenarios. The objectives include optimizing inventory replenishment, reducing waste and shelf occupancy, improving financial metrics, and fostering supplier collaboration. By simulating disruptions and automating inventory decisions, Tronico aims to increase visibility, adaptability, and resilience throughout the supply chain. The case emphasizes digital transformation and proactive planning as key levers.

Table 10 Resilient and responsive operations requirements orientation

Requirement	Resilient operations	Responsive operations
Simulation of supply chain disruptions (stress testing)	x	
Multi-criteria decision support for inventory strategies	x	
Use of digital twins for scenario analysis and planning	x	
Data analytics integration	x	
Demand forecast trend analysis	x	x
Optimization of replenishment timing for perishable goods	x	
Dynamic evaluation of component availability and supplier delays	x	x
Monitoring and responding to demand forecast fluctuations		x
Support for human decision-making during disruption events		x

Tronico UC1 is primarily oriented towards resilient operations, with a strong focus on simulation-based, proactive planning and multi-criteria optimization to prepare for and mitigate the impacts of supply chain disruptions. However, it also integrates key components of responsive operations such as real-time monitoring, and support for human decision-makers to act swiftly in the face of change. Therefore, it can be concluded that the use case supports both resilient and responsive operations, with a heavier emphasis on resiliency through strategic foresight and systemic improvements.

UC2: Production planning – batch sizing decisions

UC2 focuses on optimizing batch sizing decisions within Tronico's production planning process. The current approach is manual, relying heavily on experience rather than data, resulting in inconsistent batch sizes, underutilized resources, and inefficiencies. The objective is to develop a data-driven DSS to determine optimal batch sizes based on production constraints such as machine capacity, WIP, and demand. Objectives include improving production efficiency, standardizing batch sizing, and enhancing resiliency. The solution includes scenario analysis, standardization of constraints, and integration with planning tools. The use case aims to improve system responsiveness, reduce waste, and make production planning more robust in the face of changes and disruptions.

Table 11 Resilient and responsive operations requirements orientation

Requirement	Resilient operations	Responsive operations
Data-driven solver for optimal batch sizing decisions	x	x
What-If scenario analysis for evaluating batch sizing strategies	x	
Consideration of production constraints (machine capacity, storage, tooling, etc.)	x	
Support for adjustment based on changes in demand or specifications		x
Enhanced monitoring and detection of batch-related production inefficiencies	x	x
Multi-criteria decision making: evaluation of trade-offs (cost, lead time, WIP, defect risk)	x	
Support to human decision makers (e.g. sales and production managers)		x

Tronico UC2 supports both resilient and responsive operations. Resilient operations are supported by its focus on structured, data-driven planning, optimization under constraints, and scenario analysis. These approaches help future-proof the system against inefficiencies and disruptions. At the same time, its support responsiveness by enabling human decision-makers to adapt to demand or product changes by dynamically adjusting batch sizes as conditions evolve, what-if analyses and integration with existing systems.

UC3: Production control - Scheduling, dispatching and shop floor control

UC3 addresses inefficiencies in Tronico's production control, especially around scheduling, dispatching, and WIP management in the company's high-mix, low-volume environment. Manual workflows management and lack of visibility lead to blockages, resource underutilization, and poor responsiveness to customer-driven disruptions. The use case proposes the implementation of simulation-based digital twins, automated scheduling systems, and a DSS to enable real-time production monitoring, dynamic prioritization, scenario analysis, and finite capacity scheduling. By modelling constraints and evaluating dispatching strategies this use case aims to improve resilience, responsiveness, and overall production efficiency.

Table 12 Resilient and responsive operations requirements orientation

Requirement	Resilient operations	Responsive operations
Simulation-based digital twin for production system modelling	x	x
Monitoring of WIP and shop floor dynamics		x
Automated scheduling system considering finite capacity and disruptions	x	x
Data integration from ERP and monitoring systems	x	x
Scenario analysis and what-if evaluation (e.g., demand changes, customer specification changes)		x
Evaluation and selection of dispatching policies to reduce changeover and improve efficiency	x	
Traceability of lots and tasks to detect bottlenecks and improve production flow	x	
Collaborative decision-making support among schedulers, project managers, and operations staff	x	x

Tronico UC3 is oriented towards both resilient and responsive operations, with a well-balanced emphasis on resilience through predictive modelling and system simulation, and responsiveness through real-time monitoring and decision-making. As such, this use case is a robust example of a hybrid approach, equally targeting resilience and responsiveness in production control. It enables proactive strategies via scenario analysis and digital twin modelling, while also supporting reactive capabilities through automated scheduling and dynamic resource allocation. The integration of the proposed human-in-the-loop DSS reinforces responsiveness, making the system more adaptive to unplanned disruptions.

2.3 Use cases analysis towards a human-centric DSS

This paragraph further analyses DSS-oriented UCs to identify the expected usage and interaction with the system by human and other actors (e.g. DT registry, DTs). Therefore, each UC is further described from the decision makers point of view and Use Case diagrams are proposed to visually map the DSS functionality by showing how the different actors interact with a system to achieve their goals.

2.3.1 Airbus Atlantic Use Cases

UC1 - SC disruption monitoring by DT-based simulation

Airbus Atlantic faces complex supply chain risks due to global dependencies, cost-driven supplier selection, and late product changes. The objective of UC1 is to develop a Digital Twin-based simulation tool to monitor disruptions, simulate known-unknown events, and identify vulnerable suppliers across the end-to-end network. This tool will enable proactive, data-driven decision-making, improve supply resilience, and reduce reactivity in crisis scenarios. The ultimate goal is to strengthen operational stability, minimize part shortages, and build an adaptive, disruption-resilient supply chain. The corresponding Use Case diagram is provided below.

Figure 2 Airbus Atlantic UC1 use case diagram

UC2 - SC design support by identification of hidden critical suppliers/material

UC2 aims to enhance Airbus Atlantic's supply chain resilience by identifying hidden critical suppliers and materials that pose high disruption risk. Using network analysis and stress-testing, the goal is to uncover supply bottlenecks and single points of failure, especially those not immediately visible. Simulating deep disruptions (unknown unknowns) allows for proactive redesign of the supply network. Expected outcomes include reducing critical missing parts, improving supplier reliability (incoming OTD > 90%), and shortening reconfiguration lead time from three months to one. The use case supports informed decision-making through cost-resilience trade-off analysis, supplier consolidation, and robust inventory strategies—ultimately building a more agile, reliable, and disruption-ready supply chain. A corresponding use case diagram is presented below.

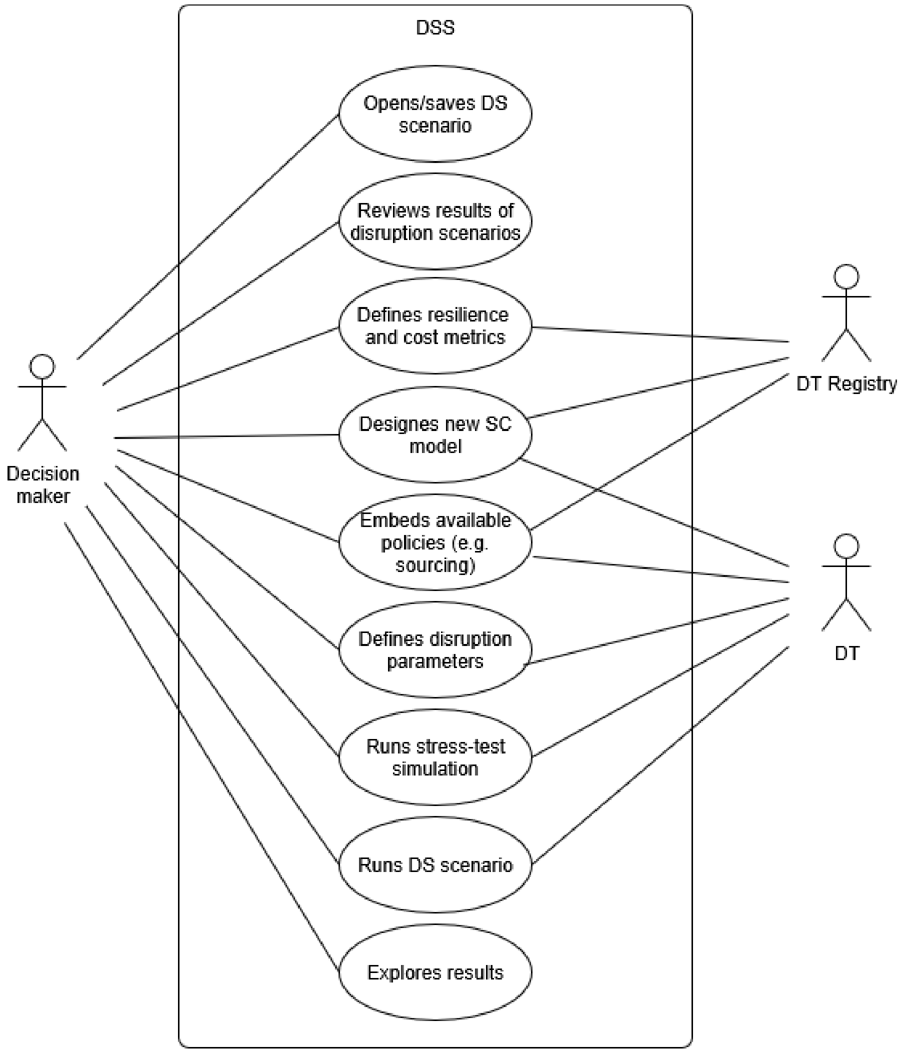

Figure 3 Airbus Atlantic UC2 use case diagram

UC3 - SC design recommendations for better absorption and swift adaptation

UC3 aims to accelerate Airbus Atlantic's industrial readiness by integrating digital supply chain twin and stress-testing into core business processes. It targets a 20% reduction in development lead time and a cut in reconfiguration time from three months to one. The use case addresses process inefficiencies, resource constraints, and misalignments between program design and industrialization. It delivers strategic recommendations on inventory and supplier management, enabling faster adaptation to disruptions. The integration of AI-enabled frameworks (e.g., LCNSC and AURA) enhances decision-making and resilience. Expected outcomes include improved planning adherence, reduced rework, smarter resource allocation, and a supply chain better equipped to absorb shocks and respond swiftly to change. The corresponding use case diagram is provided below.

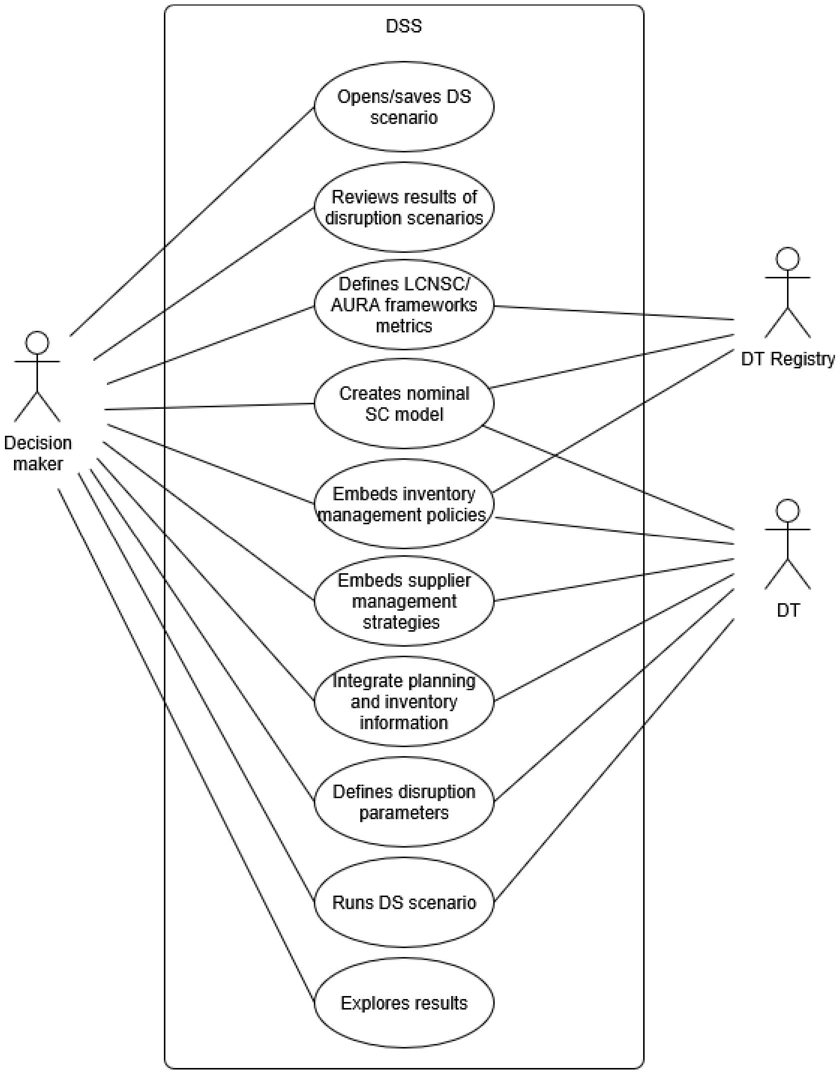

Figure 4 Airbus Atlantic UC3 use case diagram

UC4 - integrated assessment of Supply and Internal value chains by means of DTs

Referring to the Use Case description available in D7.1, the following actors interactions with the DSS can be derived:

- the decision maker will be able to define a decision support scenario either by loading a previously saved one, or by defining a new one.
- The decision maker will be able to load a production plan in an appropriate format. To enable the integrated assessment of the supply and internal value chains, e.g. against demand fluctuations, it is expected that the production plan can cover one or more weekly periods with an appropriate information granularity.
- once the scenario is identified, the corresponding DTs are selected and the DSS will access the DT registry to fetch information regarding the DTs configurable attributes and available KPIs, that the decision maker can then confirm or select. The DT registry will also provide to the DSS user a list of the available optimisation methods (e.g. single point evaluation, DOE evaluation, multi-criteria optimization).

- It will now be possible for the decision maker to run the decision support scenario, visualise and explore the results and make decision on actions, e.g. allocation of production orders towards manufacturing resources, selection of material flow options etc.

A corresponding use case diagram is provided below.

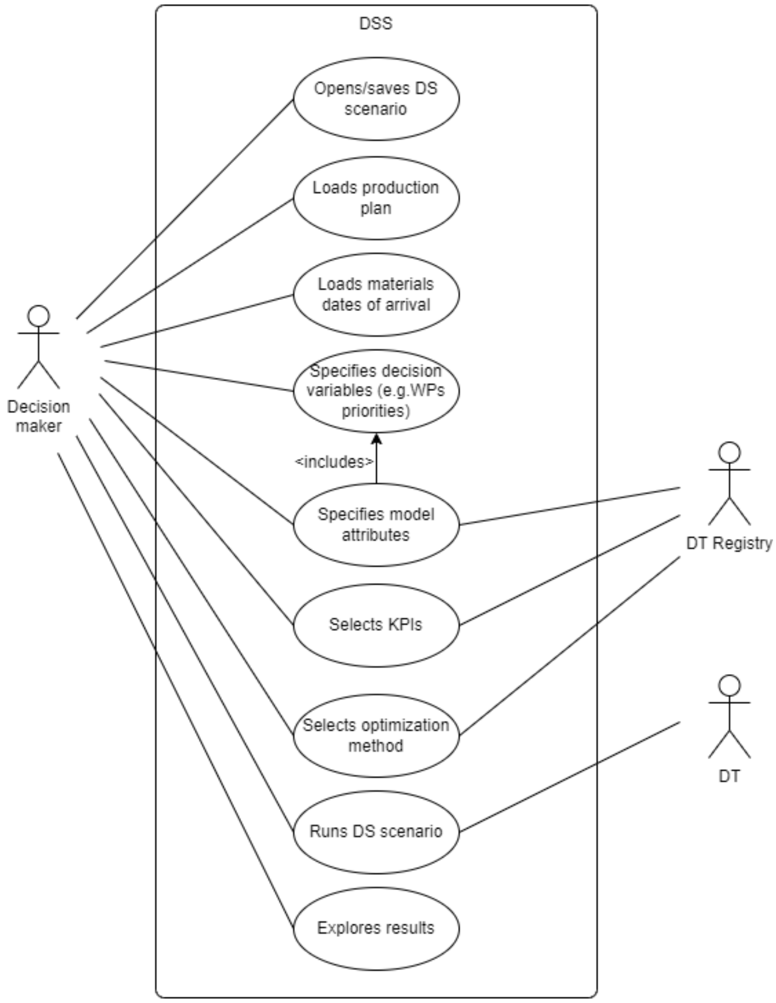

Figure 5 Airbus Atlantic UC4 use case diagram

2.3.2 Continental Use Cases

UC1 - SC stress-test in the very high complexity context

Continental's UC1 addresses the challenge of managing a highly complex, multi-tiered global supply chain with over 10,000 components from 350 suppliers. The goal is to enhance supply chain resilience through simulation-based stress-testing using a digital twin. By modelling the entire supplier network and simulating disruptions (e.g., transportation delays, supplier failures), Continental aims to identify hidden vulnerabilities, improve recovery strategies, and optimize network design. Key objectives include reducing reconfiguration time by 15% and improving delivery performance by 50% against supplier commitments. This use case empowers decision-makers to proactively evaluate trade-offs, adapt logistics strategies, and ensure continuity in a high-mix, high-volume environment. The different actors interaction is captured in the following use case diagram.

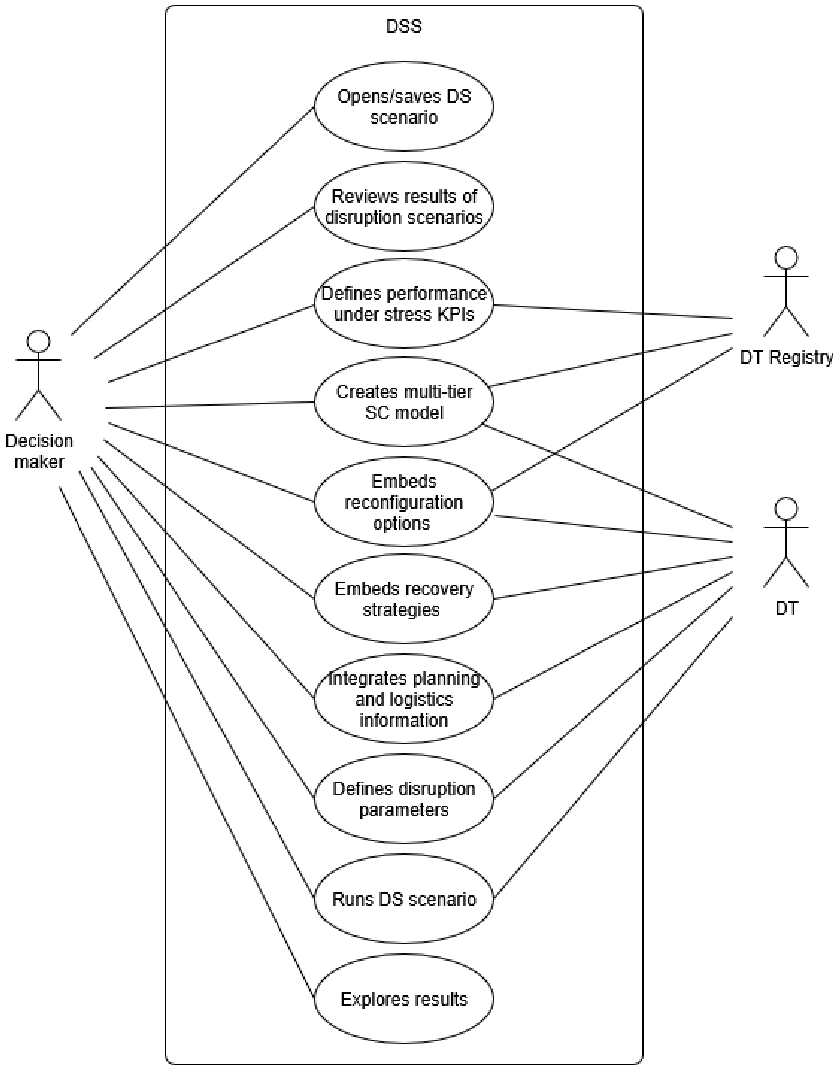

Figure 6 Continental UC1 use case diagram

UC2 - Optimization of material flow along the supply chain

Continental's UC2 targets optimization of material flow in a highly variable and capacity-constrained supply chain. With over 300 components per product and 65 global suppliers, disruptions such as demand fluctuations, missing or unusable parts, and machine breakdowns challenge planning and stability. This use case proposes a simulation-based tool and integrated dashboard to centralize EDI/customer data, model production flows, and forecast disruptions. Decision-makers aim to minimize obsolete inventory, reduce special freight and logistics costs, and ensure high customer satisfaction. The expected outcome is a robust, data-driven planning framework that can adapt material ordering, production, and distribution dynamically across time horizons while enhancing operational continuity and supply reliability. The following use case diagram depicts the interaction between the DSS and the use case actors.

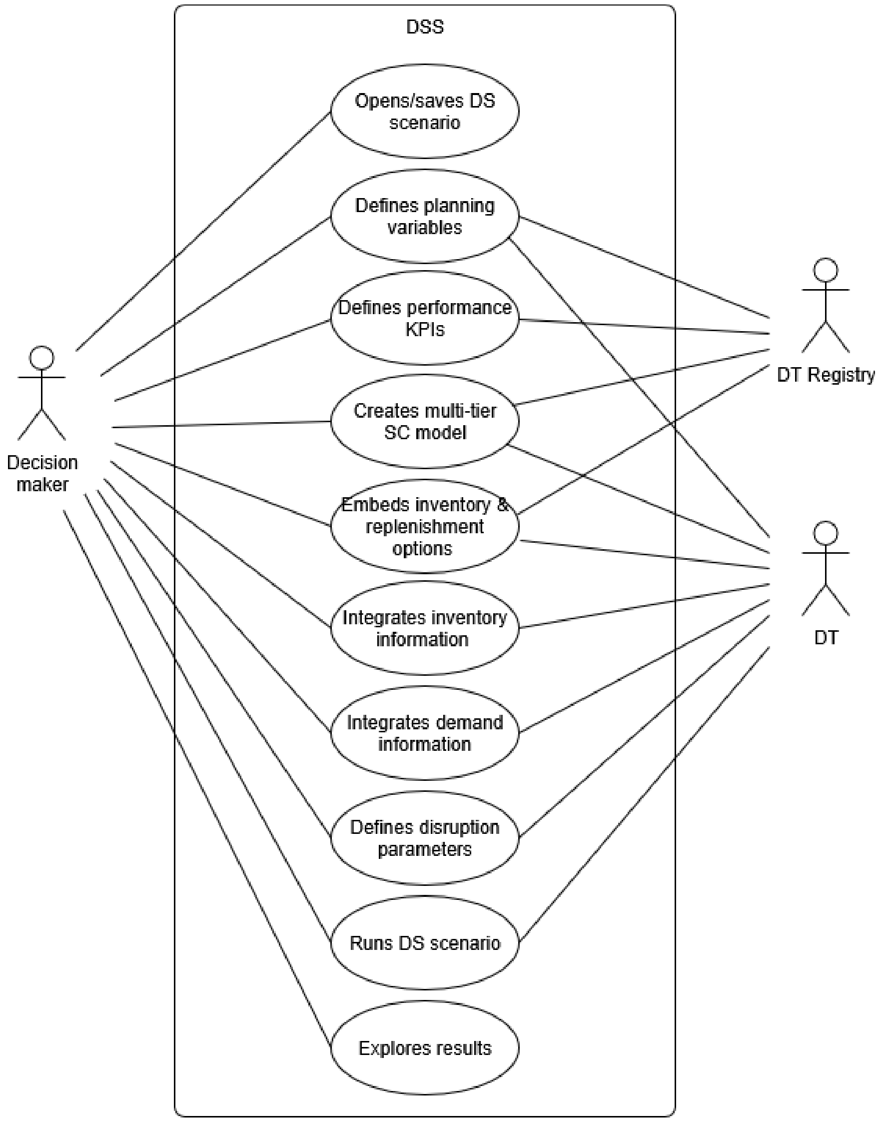

Figure 7 Continental UC2 use case diagram

UC3 - Integration of production planning with production control

Continental's UC3 targets the integration of production planning and control in a highly automated, 24/7 manufacturing environment with complex multi-stage operations. Disruptions—ranging from missing components and machine breakdowns to yield variability—frequently challenge planning robustness. This use case proposes a simulation-based digital twin to model the production flow (from internal warehouse to final assembly), enabling fast reconfiguration, resilience to disturbances, and optimization of key decisions (sequencing, assignment, dispatching). Thanks to data integration (e.g. from ERP, MES, WMS data sources), feasible configurations can be identified. The goal is to maintain throughput, reduce rescheduling needs, and align production performance with cost, delivery, and sustainability KPIs. A corresponding use case diagram follows.

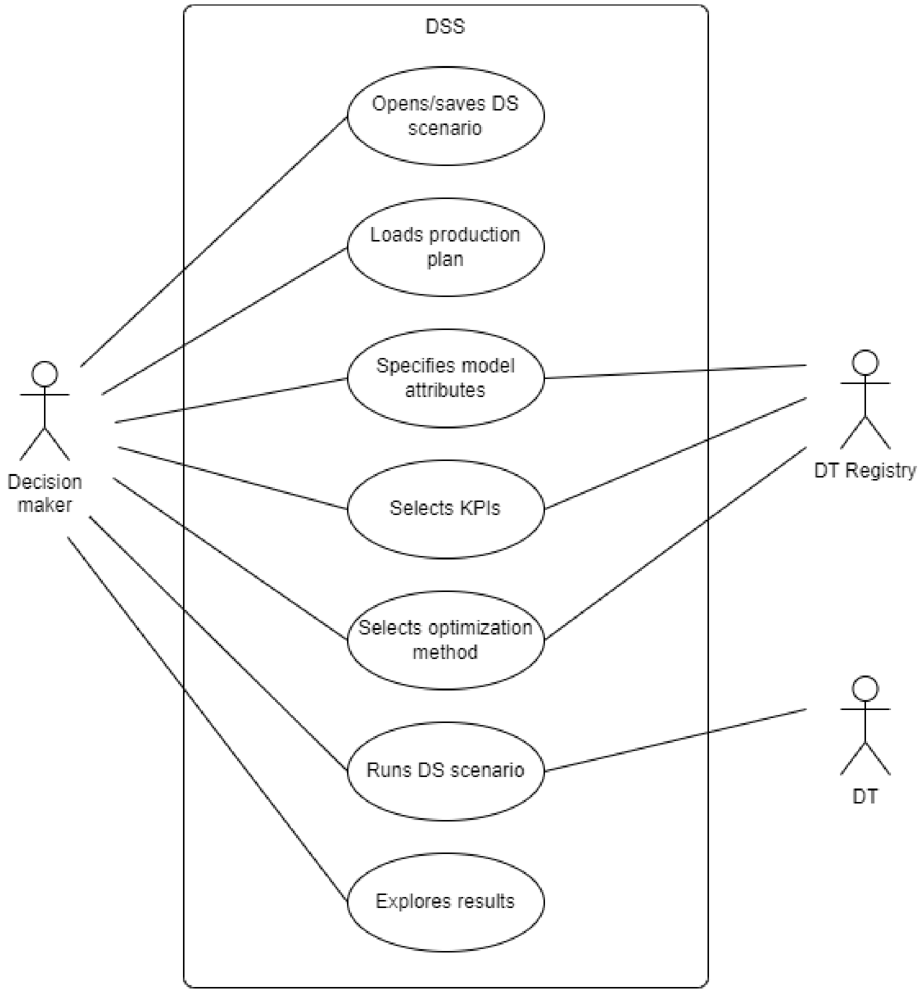

Figure 8 Continental UC3 use case diagram

2.3.3 Tronico Use Cases

UC1 - Supply Chain stress test and optimization

Tronico's current supply chain approach lacks visibility and resilience, especially under fluctuating demand and supplier disruptions. This use case aims to digitally transform operations through a simulation-based digital twin that enables stress-testing of disruptions, optimization of inventory policies, and prediction of risks. By analysing the demand forecast and inventory policies, Tronico can minimize immobilized stock, reduce obsolescence, and enhance cash flow, reduce stockouts or excesses. The initiative targets improved agility, lower working capital requirements, and a more efficient, resilient supply chain. A corresponding use case diagram is presented below.

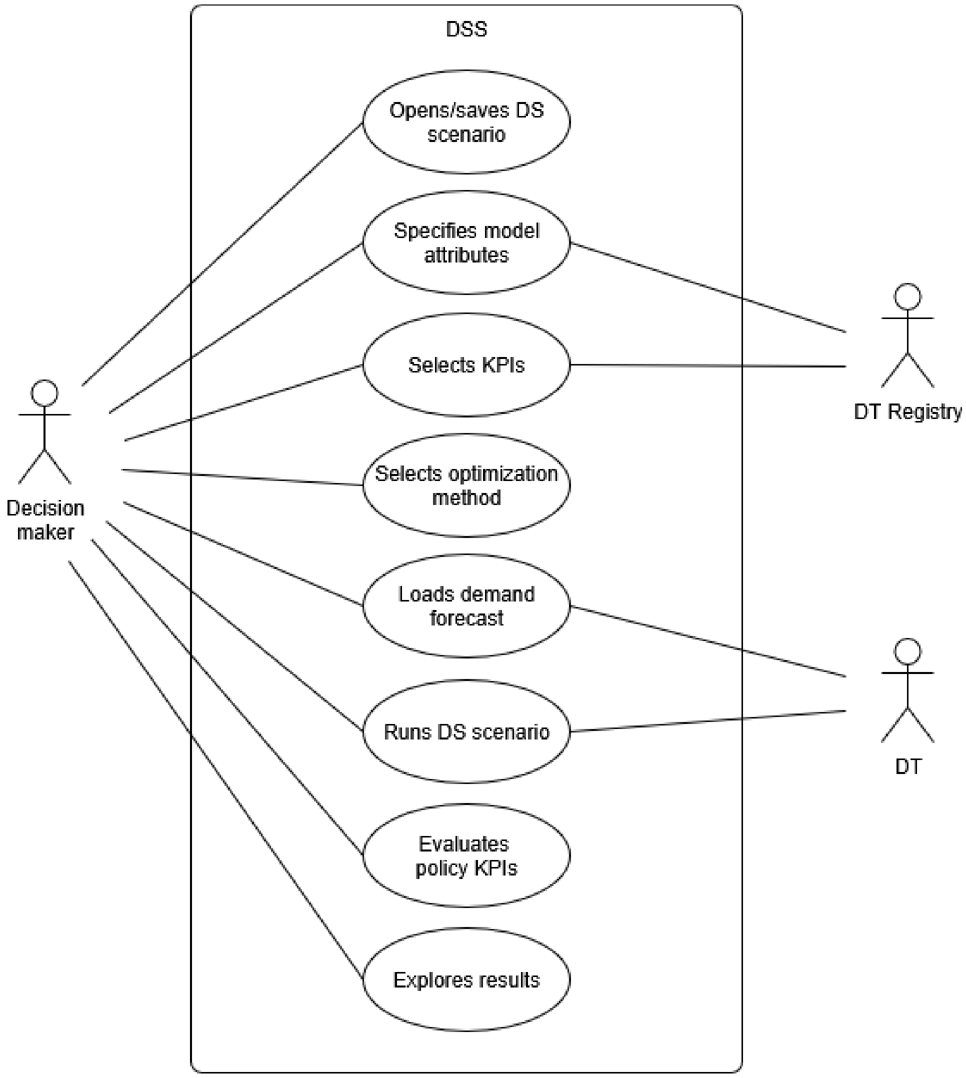

Figure 9 Tronico UC1 use case diagram

UC2 - Production planning: Batch sizing decisions

Tronico currently defines production batch sizes based on experience, lacking a standardized, data-driven method. This leads to underutilization of key equipment (e.g., CMS lines at 20–30% capacity), production bottlenecks, and poor responsiveness to demand changes. The use case aims to implement a batch sizing solver that leverages production data, machine constraints, and demand variability to recommend optimal batch sizes. This solver will support What-If scenario analysis, enabling proactive decision-making and robust scheduling. Standardizing batch sizing across product families will reduce inefficiencies, improve WIP flow, and increase equipment utilization. The approach will enhance coordination between sales and production, reduce costs, and boost on-time delivery and responsiveness. A use case diagram representing the interaction between the DSS and actors is provided below.

Figure 10 Tronico UC2 use case diagram

UC3 - Production control: Scheduling, dispatching and shop floor control

Tronico faces challenges in production control due to manual WIP management, lack of real-time visibility, and unpredictable lead times causing delays and bottlenecks. This use case targets improved scheduling, dispatching, and shop floor control by implementing a data-driven, simulation-based Decision Support System (DSS) integrated with digital twins. The DSS will enable real-time monitoring of production lots, dynamic resource allocation, and scenario-based What-If analyses to optimize workflows, reduce downtime, and improve responsiveness to disruptions such as late customer changes. The system will support collaborative, informed decisions to boost throughput, on-time delivery, and overall production efficiency and resiliency. The corresponding use case diagram is provided below.

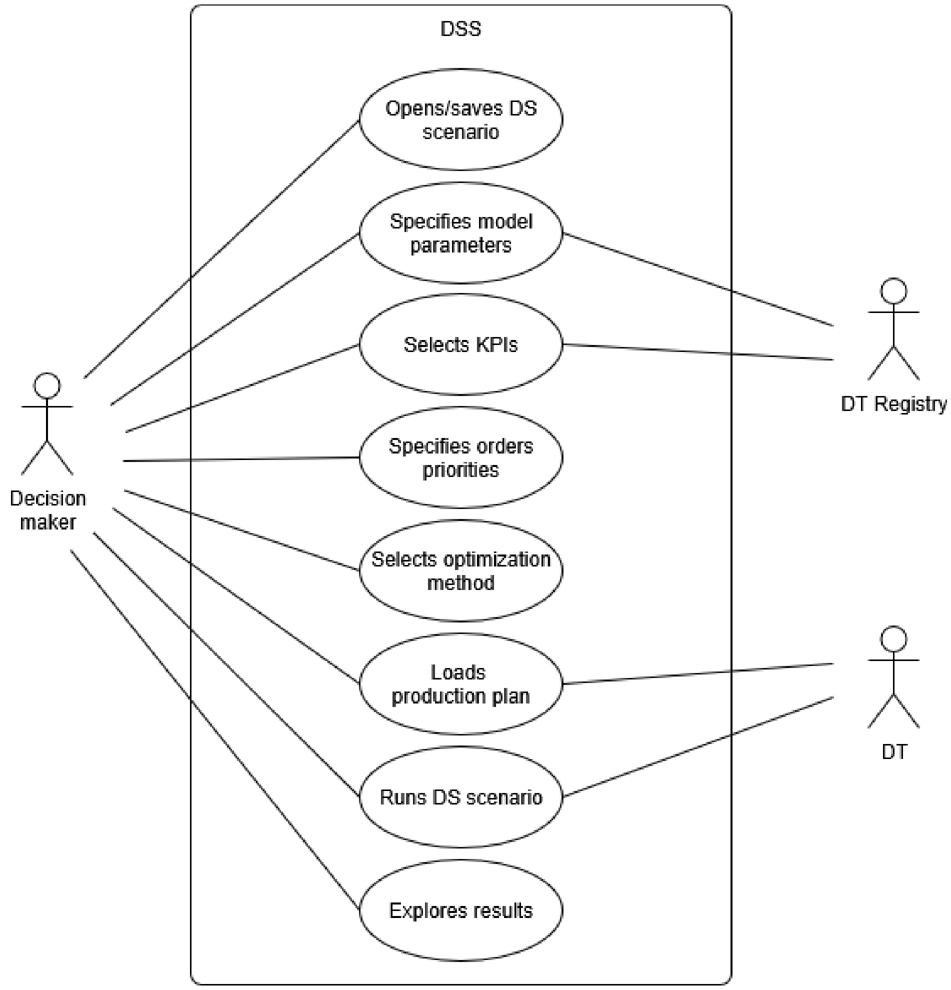

Figure 11 Tronico UC3 use case diagram

2.3.4 Use case requirements consolidations towards human-centric, resilient and responsive operations

The requirements identified analysing the 10 Pilots UCs for human centric, resilient and responsive operations support are further consolidated and generalised in the following Table 13, where functional requirements are listed. It should be noted that such requirements do not necessarily apply to the DSS per se, instead they should be implemented by the aggregated integration of ACCURATE tools and solutions.

Table 13 Consolidated requirements towards human-centric, resilient and responsive operations

ID	UCs	Functional requirement	Resilient operations	Responsive operations
HRR1	AIRBUS UC1, UC3, UC4; CONTI UC1, UC2, UC3: TRONICO UC1, UC2, UC3.	Support data integration from different sources, e.g. MES, ERP, SC management systems	✓	✓
HRR2	AIRBUS UC3, UC4; CONTI UC1, UC3; TRONICO UC3.	Support asynchronous DTs data updates, e.g. for DT parametrisation	✓	✓
HRR3	AIRBUS UC1, UC3, UC4; CONTI UC1, UC2, UC3: TRONICO UC1, UC2, UC3.	Support data aggregation and pre-processing, e.g. ELT or ETL	✓	✓

HRR4	AIRBUS UC1, UC2, UC3, UC4; CONTI UC1, UC2, UC3: TRONICO UC1, UC2, UC3.	Support DTs integration at different system levels	✓	✓
HRR5	AIRBUS UC1, UC2, UC3, UC4; CONTI UC1, UC2, UC3: TRONICO UC1, UC2, UC3.	Support execution of both analytical- and simulation-based models (e.g. DES) DTs	✓	✓
HRR6	AIRBUS UC4; CONTI UC3: TRONICO UC2, UC3.	Enable creation of optimization workflow, encompassing multiple models and DTs	✓	✓
HRR7	AIRBUS UC4; CONTI UC3: TRONICO UC2, UC3.	Enable orchestration of workflow execution whereas models and DTs exchange input and output data	✓	✓
HRR8	AIRBUS UC1, UC2, UC4; CONTI UC1; TRONICO UC1, UC2, UC3.	Enable evaluation of multiple scenarios on a given Use Case, e.g. on a what-if basis or policy basis	✓	
HRR9	AIRBUS UC1, UC2, UC3, UC4; CONTI UC1, UC2, UC3; TRONICO UC1, UC2, UC3.	Enable KPIs computation (for e.g. performance, resilience, sustainability evaluation)	✓	✓
HRR10	AIRBUS UC1, UC2, UC3, UC4; CONTI UC1, UC2, UC3; TRONICO UC1, UC2, UC3.	Enable multi-criteria optimization and trade-off analysis	✓	✓
HRR11	AIRBUS UC1, UC2, UC3, UC4; CONTI UC1, UC2, UC3; TRONICO UC1, UC2, UC3.	Support decisions for crisis anticipation, e.g. supplier consolidation, inventory policy optimization	✓	
HRR12	AIRBUS UC1, UC3, UC4; CONTI UC1, UC2, UC3; TRONICO UC1, UC2, UC3.	Support decisions for crisis mitigation, e.g. planning or system reconfiguration		✓
HRR13	AIRBUS UC3, UC4; CONTI UC1, UC2, UC3; TRONICO UC2, UC3.	Provide a shared platform for collaborative evaluation of actions, e.g. with suppliers and stakeholders		✓
HRR14	AIRBUS UC2; CONTI UC1, UC2; TRONICO UC3.	Provide a monitoring feature; generate alerts, warnings		✓
HRR15	AIRBUS UC1, UC2, UC3, UC4; CONTI UC1, UC2, UC3; TRONICO UC1, UC2, UC3.	Support documentation and traceability of decisions	✓	✓
HRR16	AIRBUS UC1, UC3, UC4; CONTI UC1, UC2, UC3: TRONICO UC1, UC2, UC3.	Enable integration with existing business processes	✓	✓
HRR17	AIRBUS UC1, UC2, UC3, UC4; CONTI UC1, UC2, UC3; TRONICO UC1, UC2, UC3.	Provide User interfaces and tools for scenario data visualization and exploration	✓	✓

From the analysis of the individual UC orientation a prevalence of hybrid use cases, i.e. oriented towards both resilient and responsive operations, can be identified. Furthermore, Table 13 testifies the pervasiveness of such requirements across the Pilots and use cases.

2.3.5 Operational and functional requirements stemming from models and DTs definition

In this paragraph we analyse the requirements described in D3.1 to identify the corresponding explicit or implicit requirements for the human-centric DSS towards either resilient or responsive manufacturing systems.

In particular the following D3.1 chapters and paragraphs yield DSS requirement:

- Chapter 2 Functional requirements engineering

  - Paragraph 2.1 Integration and interoperability requirements
  - Paragraph 2.2 Models needed to be developed
  - Paragraph 2.3 Resilience-oriented production models
- Chapter 4 Resilience indicators for a MaaS system
- Chapter 5 Sustainability indicators for a MaaS system
- Chapter 6 Ontologies for architecting circular and sustainable MaaS systems

Each relevant paragraph of D3.1 is analysed, and the results are summarised in a tabular format. It should be noted that D3.1 focuses on DTs from the resiliency and sustainability angles without providing a distinction between resilient and responsive operations; in fact, the identified DTs and KPIs can be integrated in either digital thread. Therefore, the following analysis does not explicitly classify the requirements into the resilient / responsive categories.

D3.1 paragraph 2.1 lists a set of functional requirements for the models (e.g. sustainability and circularity models) as well as the DTs to ensure seamless integration and interoperability. The following table aligns and translates such requirements into corresponding DSS requirements.

Table 14 Translation of D3.1 integration and interoperability functional requirements

ID	Original requirement	Applies to	Translates into corresponding DSS requirement
II1	Structured Output Delivery: Models should deliver outputs in a structured format compatible with other user tools/models as requested by the client tool.	Models and DTs	Define or reference a common schema or interface standard (e.g. JSON schema, OpenAPI)
II2	Orchestration and Status Declaration: Models intended for use in orchestration with other systems must declare their status to facilitate automatic data exchange	Models and DTs	DSS should provide an orchestration framework. A mechanism for status declaration should be defined.
II3	Containerised Deployment: If a DT is to be invoked by an external function or client, it should be provided as a container that includes all dependencies required for its execution.	DTs	A base image standard should be specified, including a container registry, a versioning approach, and compliance with runtime environments
II4	Configurable Data Exchange Location: DTs should support access through a configurable data exchange location for communication with external functions or clients.	DTs	A DT Registry entry should require an API endpoint for DT interfacing. DTs communication with data sources is responsibility of the DT.
II5	Control Bus Implementation: DTs should implement a control bus to support single-point evaluation, streamlining integration with external systems.	DTs	The orchestrator design should support asynchronous execution modes as needed, e.g. by supporting message queues, REST APIs
II6	Data Exchange Responsibility:"Black box" DTs are responsible for managing data exchange with the data sources required for their execution.	DTs	DSS should provide an orchestration framework including a mechanism to manage alive/ready completed/failed runs of the DT

II7	Data Exchange Responsibility: in case a white box DT integration is required, the client (e.g., DSS) is responsible for orchestrating data exchange with the data sources required for the DT's execution.	DTs and DSS	DSS architecture should enable the integration of data sources. Note: the original requirements is not aligned with the DSS design decisions. It has therefore been realigned.

Regarding the distinction between Black-box and White-box digital twins, the following definition within ACCURATE will be used. A black box digital twin focuses on input-output relationships, is often built without prior knowledge of the internal structure or physics of the system it represents and, therefore, may provide limited explainability or interpretability. This is the case for a sustainability model that provides a computation of a specific KPI provided that some input values are available, or even for a machine-learning model trained on specific datasets. A White-box Digital Twin is based on first-principles modelling or physics-based simulation, therefore encapsulating knowledge of the internal mechanisms and structure of the system it represents. Such DTs may be built using known physical equations or other laws describing the behaviour of a system (e.g. queuing theory). A White-Box digital twin is usually created by experts with knowledge of the system and provides high interpretability (i.e. experts can understand why it behaves a certain way). White-box DTs are usually more costly to develop and more computationally intensive with respect to black-box DTs. Crucially though, a white-box DT can model novel conditions, i.e. it can extrapolate and provide information beyond the experimentally available scenarios and corresponding data.

D3.1 paragraph 2.2 collects functional requirements for models and DTs to support the adaptation and reconfiguration of production processes. The following Table 15 aligns and translates such requirements into corresponding DSS requirements.

Table 15 Functional requirements supporting production processes adaptation and reconfiguration

ID	Original requirement	Applies to	Translates into corresponding DSS requirement
PPAR1	Models must provide robust output capabilities to meet various performance evaluation needs: Quantitative measurements: Assess and measure performance under specific scenarios defined by user inputs.	Models and DTs	DSS should provide means to analyse output results corresponding to given inputs.
PPAR2	Models must provide robust output capabilities to meet various performance evaluation needs: Key Performance Indicators: Supply a comprehensive list of available KPIs to ensure the model aligns with task requirements.	Models and DTs	DSS should support semantic information for the KPIs computed by models and DTs to support performance evaluation needs
PPAR3	Models must provide robust output capabilities to meet various performance evaluation needs: Compute performance metrics across the following categories:	Models and DTs	DSS should support semantic information facilitating the categorisation of performance KPIs

	i. Process-Chain Level ii. Circularity and Sustainability		

Furthermore, D3.1 paragraph 2.3 provides concepts of resilience-oriented production models design, with examples towards identified Use Cases. This paragraph identifies a common architectural structure for the development of a white-box DTs. Such structure clarifies that the DT requires data sources whose content and format are highly specific of the DT itself. This input data may include information about e.g. current orders, planning, scheduling, system WIP, etc. However, given the variety of Use Cases identified in ACCURATE, and the different levels of the envisioned DTs, such information is complex to generalize. Therefore, the following separation of concerns between the DSS and the DTs is proposed:

- The DTs will directly manage access to data sources required to parametrise the models that are independent from the decision-making process (e.g. WIP data).
- The DSS will manage the DTs input data that drive the optimization and decision-making process, e.g. a decision variable for the selection of a manufacturing system policy.

Such requirements are summarised and translated in the following Table 16.

Table 16 Functional requirements supporting simulation-based DTs integration into the DSS

ID	Original requirement	Applies to	Translates into corresponding DSS requirement
SB1	A simulation-based DT provides the modelling of the manufacturing system with the level of detail and orientation (e.g. performance computation) required by the UC. It integrates information regarding the manufacturing system, e.g. products and families, BOMs, processes, workstation and resources, material handlers. Such information is static in the sense that it is embedded in the DT design and does not change over multiple scenario execution.	White-box DTs	DSS should provide an orchestration framework including a mechanism to manage the initialisation of the DT to allow its connection to data sources and parametrisation.
SB2	A simulation-based DT execution requires data sources to provide specific input information regarding e.g. the status of the manufacturing system, WIP, production orders, scheduling. The DT is designed to utilise such information as input data and/or to parametrise itself.	White-box DTs	DTs will directly manage access to data sources required to parametrise the models. The DSS should enable the initialisation of the DT to allow its connection to data sources and parametrisation.
SB3	Simulation-based DTs require input variables to drive the optimization process (e.g. decision variables)	DTs	The DSS will manage the DTs input data that drive the optimization and decision-making process

D3.1 chapter 4 provides a survey of the methods of resilience evaluation. The survey considers both the 'Preventative' (including Modularity, Redundancy, Robustness & Reliability) and 'Active/Reactive' (including Reconfigurability, Absorption, Recovery/Rapidity & Reusability/Flexibility) perspectives. This research identifies the most prevalent methods of manufacturing systems resilience evaluation are equations- and simulation-based models (individually and in combination), whereas simulation models are mostly applied to optimization problems to minimize one of the different losses caused by the disruption event. Moreover, all the surveyed resilience indicators are quantitative and can therefore be linked to the production-level DTs developed in ACCURATE. Chapter 4 analysis yields the requirements listed in Table 17.

Table 17 Translation of functional requirements enabling resilience evaluation into DSS requirements

ID	Original requirement	Applies to	Translates into corresponding DSS requirement
RE1	Equation-based models, often based on computing formulas involving few terms, are required to compute some resilience indicators.	Models	DSS should support integration of equation-based models.
RE2	Integration of complex, simulation-based models and DTs, mostly used to compute measures of losses due to disruption, is required.	Models and DTs	DSS should support integration of simulation-based models and DTs.
RE3	To evaluate resiliency of a manufacturing system, equation- and simulation-based models can be used individually or in combination.	Scenario evaluation	DSS should provide an orchestration framework capable of integration equation- and simulation-based models and DTs in a single scenario evaluation workflow
RE4	Resilience indicators computation may require either upstream or downstream data (upstream and downstream from the manufacturing system point of view)	DTs and DSS	DTs will directly manage access to data sources required to parametrise the models. The DSS should enable the initialisation of the DT to allow its connection to data sources and parametrisation. The DSS will manage the DTs input data that drive the optimization and decision-making process

D3.1 chapter 5 provides overall strategies to integrate C&S indicators in the context of ACCURATE Pilots and Use Cases. The conclusions recommend the use of streamlined indicators for critical processes as a means for quantifying and monitoring sustainability performance related to material use: such indicators make use of computation of measures of process wastes (e.g., expired components, scrap, other wastes) produced, or consumption of materials measures (e.g., consumables, tools, etc.), per component/process. From the DSS perspective, where the C&S performance is included by the human decision-maker in the set of optimization KPIs, this requirement translates in the requirement to integrate such measures, assuming they can be obtained as models or DTs output, into the overall scenario evaluation (Table 18).

Table 18 Translation of functional requirements enabling C&S evaluation into DSS requirements

ID	Original requirement	Applies to	Translates into corresponding DSS requirement
C&SE1	Computation of C&S KPIs based on measures of process wastes or materials consumption is required.	DSS	DSS should support integration and execution models and DTs that compute measures of process wastes or materials consumption, or that utilize such measures to compute C&S KPIs.

Similar considerations apply for sLCA indicators integration into the DSS scenario analysis. In particular, it is envisioned that sLCA indicators can be computed from measures obtained from simulation-based (e.g. DES-based) models or DTs, such as the manufacturing system personnel working hours. Therefore, we can derive the following requirement (Table 19).

Table 19 Translation of functional requirements enabling sLCA evaluation into DSS requirements

ID	Original requirement	Applies to	Translates into corresponding DSS requirement
SLCAE1	Computation of sLCA KPIs based on measures (e.g. personnel working hours) is required. Such measure may be computed by means of DES models.	DSS	DSS should support integration and execution models and DTs base on DES models.

D3.1 chapter 6 deals with challenge to effectively utilize ontologies to support decision making in a MaaS environment towards C&S. The scope of this research is mostly linked to ACCURATE MaaS Framework and Data Space. However, some indications for the envisioned DSS design can be identified. In particular, it is stated that the ontology-enabled matchmaking can be applied to identify configurations of MaaS environment participating entities (e.g. MaaS nodes) for the targeted sustainability score, therefore identifying a reduced (optimization) space. The output of this first step (a reduced space of the possible combinations) can subsequently be used for DT-based simulation and optimisation deriving an optimised ecosystem configuration for the given C&S score. Such indications can be translated into the need for the DSS to support constraints on the variables representing the decision space to model such reduction (Table 20).

Table 20 DSS requirements derived from ontology-based matchmaking application to a MaaS challenge

ID	Original requirement	Applies to	Translates into corresponding DSS requirement
OMM1	Ontology-based matchmaking can compute a reduced space of possible combinations therefore constraining the decision space.	Data	DSS should support constraints definition to guide the optimization process towards feasible solutions.

The analysis summarised in Table 14 to Table 20 provides functional requirements supporting the digital threads towards a human centric DSS. Such requirements are translated into a DSS modular architecture. The following chapter details the envisioned architecture and provides a clear separation of concerns among the different modules.

3 Digital threads for a human-centric DT-based DSS

3.1 Architectural considerations

3.1.1 Introduction and objectives

This paragraph provides architectural considerations for the Human-centric DT-based DSS design. Such considerations align with D6.1 – High-level ecosystem architecture.

3.1.2 Architectural principles

The DSS design should align with the principles stated in D6.1. In particular:

1. Federated and Decentralized Design: avoid central data aggregation by enabling **federated service execution**, **distributed deployment**, and **local data processing**. Participants maintain full control of their digital assets while integrating via common interfaces and shared governance.
2. Data Sovereignty by Design: sensitive data (e.g., production KPIs, supplier relationships, cost structures) never leaves the organizational perimeter. Instead, the system relies on compute-to-data strategies and smart contracts to **run analytics locally** and **share only insights or aggregated KPIs**.
3. Semantic Interoperability: interoperability is not just syntactic but semantic. All services and **data assets are described using shared ontologies**, **metadata standards** (e.g., JSON-LD, RDF), and **classification models**. A common vocabulary ensures compatibility across domains and organizations.
4. Modularity and Loose Coupling: **components are developed as microservices**, independently deployable and versioned. This allows flexibility in configuration, scalability, and reuse. **Interfaces follow RESTful standards** and use OAuth2/OpenID for secure access control.
5. Layered and Scalable Architecture: **a layered design separates infrastructure, middleware, orchestration, and application logic**. Each layer can scale horizontally and evolve independently. The architecture can integrate additional services and participants without significant rework.
6. Trust and Compliance: trust is embedded via **decentralized identity management, verifiable credentials, and policy-driven access control**. Compliance with Gaia-X Trust Framework and EU data protection regulations (e.g., GDPR) is ensured by design.

ACCURATE components should leverage a layered approach reflecting the RAMI 4.0 service-oriented architecture, whereas each element is clearly positioned. In particular, RAMI 4.0 references the different layers as follows:

- Business processes: value added services, e.g. DSS,
- Functions: shared/enabling services, e.g. DT Registry, DTs, Compute-to-data
- Information: data sources, e.g. MES, ERP
- Communication: communication protocols, e.g. OPC-UA, MQTT
- Integration: sensing layer, e.g. sensors, PLCs, connectors
- Physical things: physical manufacturing facilities, resources and assets

Additionally, all ACCURATE software components should be described using a structured methodology that defines their functionality, interfaces, dependencies, and deployment context. In particular, each component is described using the following structured template.

Table 21 Template for ACCURATE software components description

Component name	Unique identifier for the component
Category	Core type (e.g., MaaS, DSS, DT, Middleware, UI, Integration)
Functional description	Summary of the component's main role and responsibilities
Input / output	Expected input and output data formats (incl. semantic types, APIs)
Interfaces	REST, gRPC, MQTT, WebSocket, or file-based interfaces
Dependencies	Required external services, libraries, or other components
Execution context	Whether the component runs centrally or at a local (pilot) node
Deployment format	Docker container, VM, native app, etc.
Security and IAM	Authentication/authorization methods, token usage, ID federation support
Monitoring / logging	Available observability metrics and interfaces

The following chapters embed these principles and recommendations in the DSS design.

3.2 Design of a human-centric DSS to support resilient and responsive operations

3.2.1 Introduction

This paragraph presents the ACCURATE DSS architecture. The architecture representation follows the recommendations set forth in D6.1 regarding design principles, layered approach and components structured description. Additionally, a levelled block view representation is provided to clarify each components role and purview a clear separation of concerns.

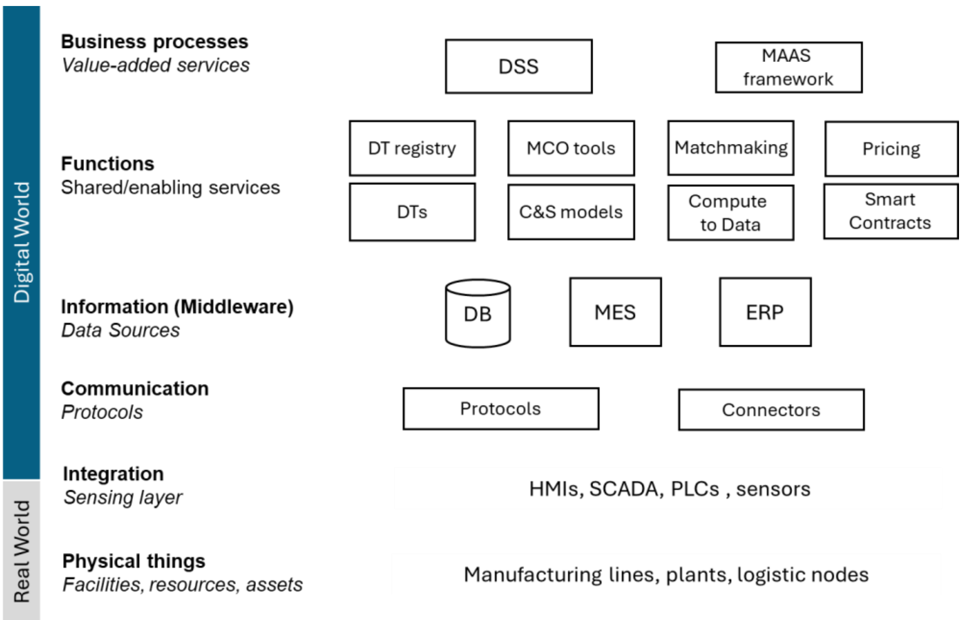

Figure 12 Layered representation of ACCURATE services

Figure 12 presents a high-level layered representation of ACCURATE services according to RAMI4.0. The following paragraphs provide a building block and a runtime view of the DSS system.

3.2.2 Building block view

This 1st level provides an overall view of some of the major ACCURATE components and services. This building block view provides a static, modular and data-centric representation of the overall system. In this schema, arrows represent interfaces and dependencies among components.

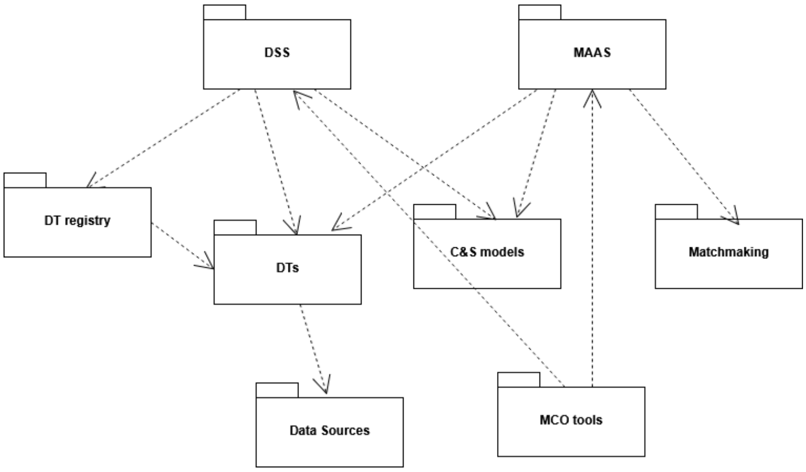

Figure 13. building block view – 1st level representation.

The following diagram provides a 2nd level view of the DSS components.

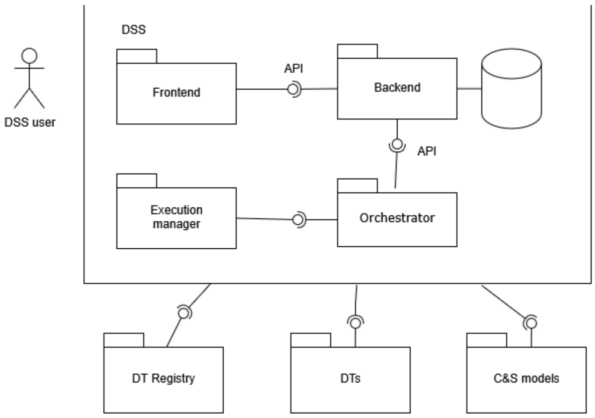

Figure 14. ACCURATE building blocks – DSS components 2nd level representation.

The components subdivision implements the principles of modularity and separation of concerns at the basis of the ACCURATE framework. In this approach, each DSS module interacts with the others through defined APIs, enabling a distributed architecture that can be implemented e.g. as a set of interconnected services. This approach offers flexibility, scalability and resilience. This approach also allows for rapid development thanks to a clear interface between modules.

3.3 3rd level building block view

3.3.1 DSS supporting selected use cases

Below the individual components on the 3rd level are described by means of summary tables, providing each component purpose, scope, persistency approach, i/o formats.

<table>
<tr><td>System name</td><td colspan="2">DSS Frontend</td></tr>
<tr><td rowspan="2">Purpose of the system</td><td colspan="2">The purpose of this module is to allow the user to interact with the DSS stack on a scenario basis through a web browser.</td></tr>
<tr><td colspan="2">Operation: a wizard-like frontend. The DSS User will load a decision support scenario, configure the scenario, run the scenario, visualise the results.</td></tr>
<tr><td rowspan="4"></td><td>Information inputs</td><td>Input format</td></tr>
<tr><td>● Web application forms</td><td>● JSON</td></tr>
<tr><td>Information outputs</td><td>Output format</td></tr>
<tr><td>● Web application, e.g. tables, charts</td><td>● JSON</td></tr>
<tr><td>Persistency</td><td colspan="2">Stateless. The data is persisted by the DSS Backend module.</td></tr>
<tr><td>Responsible partner</td><td colspan="2">ES</td></tr>
</table>

<table>
<tr><td>System name</td><td colspan="2">DSS Backend</td></tr>
<tr><td rowspan="2">Purpose of the system</td><td colspan="2">The purpose of this module is to manage Use Case data and scenarios to implement the decision support flow. It is responsible of the orchestration of the other DSS modules.</td></tr>
<tr><td colspan="2">Operation: the Backend responsibilities are data manipulation and business logic integration. Includes and manages the DSS database. Accesses the DT registry module to obtain DT’s information, such as endpoints, configurable parameters, input, output, semantic information. Invokes the Sensing module to obtain the configurable parameter estimates.</td></tr>
<tr><td rowspan="4"></td><td>Information inputs</td><td>Input format</td></tr>
<tr><td>● Standard API</td><td>● JSON</td></tr>
<tr><td>Information outputs</td><td>Output format</td></tr>
<tr><td>● Standard API</td><td>● JSON</td></tr>
<tr><td>Persistency</td><td colspan="2">API driven. The data is persisted into an SQL database.</td></tr>
<tr><td>Responsible partner</td><td colspan="2">ES</td></tr>
</table>

<table>
<tr><td>System name</td><td>Workflow manager</td></tr>
<tr><td rowspan="2">Purpose of the system</td><td>Provides a framework to create, manage, orchestrate an optimization workflow. The workflow includes nodes that represent an abstraction of DTs or computational nodes.</td></tr>
<tr><td>Operation: the optimization workflow is created by a privileged user and integrated into a decision support scenario. The workflow information is persisted by the DSS Backend,</td></tr>
</table>

	however an internal persistency mechanism is provided to support workflow execution.	
	Information inputs	**Input format**
	• Standard API	• JSON
	Information outputs	**Output format**
	• Standard API	• JSON
Persistency	Internal persistency mechanism during execution. Input, outputs and the workflow are persisted by the Backend.	
Responsible partner	**ES**	

System name	**Execution manager**	
Purpose of the system	Provides the execution layer for the workflow. Invokes DTs and computational nodes.	
	Operation: this component is invoked by the Workflow manager. Implements the workflow execution layer. Implements standard APIs to test a DT status (e.g. DT online, DT offline, sanity check) and execute the DT/computational node by providing input and fetching output. Implements a DT single point evaluation mechanism.	
	Information inputs	**Input format**
	• Standard API	• JSON
	Information outputs	**Output format**
	• Standard API	• JSON
Persistency	Stateless.	
Responsible partner	**ES**	

3.3.2 ACCURATE Shared services

System name	**DT Registry**
Purpose of the system	Allows an Ecosystem Actor to register a new DT. Provides information to configure, test and execute a DT. Provides semantic information regarding DT's input, output (e.g. KPIs), configurable parameters to other ACCURATE services.
	Operation: provided as a service in the Ecosystem to enable different DSS use cases. When utilised by the DSS, this module is invoked by the Backend to obtain information on a DT. The actual DT execution is out of scope of this module.

	Information inputs	**Input format**
	• Standard API	• JSON
	Information outputs	**Output format**
	• Standard API	• JSON
Persistency	Persists the DT information into an SQL database.	
Responsible partner	**ES**	

System name	**DT (Digital Twin)**	
Purpose of the system	Provides an executable model representing a digital replica of a target system.	
	Operation: a Digital Twin requires data connections that enable convergence between the physical and digital states at an appropriate rate of synchronization (ISO/IEC 30173). In ACCURATE the data connections are either provided by the DT itself (black box) or are managed by an external orchestration mechanism (white box).	
	Information inputs	**Input format**
	• Standard API	• JSON
	Information outputs	**Output format**
	• Standard API	• JSON
Persistency	May provide an internal persistency mechanism to support its execution.	
Responsible partner	**AU, IAO, ES, IMT, HR, Pilot Partners**	

System name	**Data Source**	
Purpose of the system	Provides a mechanism to deploy models and execute them on actual Pilot's data.	
	Operation: When utilised in the context of the DSS, this module is invoked to parametrise a DT. E.g. it accesses a Pilot's MES system, gathers past cycle time information for workstation A, executes a model to compute the average cycle time over the last 30 working days, provides this value to the client (DT). As such, a data source is highly dependent on the corresponding DT. It is executed in the infrastructure layer e.g. of the Pilot or MAAS node. It is supported by the Data Space technologies to assure data security, identity management and sovereign data sharing policies.	
	Information inputs	**Input format**
	• Standard API, file system	• JSON, Python, other
	Information outputs	**Output format**

	• Standard API, file system	• JSON, Python, other
Persistency	Stateless. In general, DT parameters may not be persisted. Parameters estimation models may be persisted e.g. as Python scripts.	
Responsible partner	**Same as the DT responsible partner, Pilots**	

3.4 Digital Twin API design

3.4.1 Introduction

The digital thread development requires linking together information from the production-level digital twins. Crucial to satisfying this requirement is providing a standard mechanism to connect diverse DTs, e.g. at machine, line or department levels. Therefore, this chapter provides a design for APIs aimed at integrating the DTs and the DSS, designed to be modular, extensible, and maintainable, providing clear separation of concerns between the two components.

3.4.2 Requirements for a DT lifecycle management

Modern web applications demand robust, high-performance, and scalable frameworks that can manage complex interactions between components, i.e. the DSS execution manager and DTs applications. One critical architectural feature in such frameworks is the application lifecycle management. This mechanism can be described as the structured handling of startup and shutdown processes. At a minimum, the framework should execute specific logic at two crucial moments:

- during application startup, to initialize resources.
- during application shutdown, to clean up or release those resources.

This capability is essential for predictable, safe, and efficient operation of web applications, especially those operating in asynchronous or distributed environments as envisioned for the ACCURATE Ecosystem.

Furthermore, to support effective lifecycle management, a web framework should provide a structured entry point for lifecycle logic that runs once during the application's runtime. Moreover, it should support for synchronous and asynchronous operations therefore ensuring compatibility with both blocking (synchronous) and non-blocking (asynchronous) I/O operations. Furthermore, it should be able to provide error and exception safety, guaranteeing that shutdown logic is executed reliably, even in cases where the application terminates due to unhandled exceptions or system signals.

This approach will provide clear benefits, such as:

- improved stability and reliability.
- support of a decentralized, scalable architecture.
- improved testability and modularity.

3.4.3 Proposed DT APIs

To support a decentralized, modular and scalable architecture, the envisioned ACCURATE DT APIs should implement a set of endpoints, as proposed below.

- API core endpoints: these endpoints provide general DT metadata, health status, and model schema information. They are stateless and useful for both humans and automated agents to understand or monitor the API.
- API session control endpoints: these endpoints manage the full lifecycle of a Digital Twin session—from creation and evaluation to reset and finalization.
- API logs & metrics endpoints: these endpoints provide access to detailed logs and runtime statistics for each session. Logs are automatically recorded during key lifecycle events and model evaluations.
- API ontology & model keywords endpoints: this module provides descriptive metadata about the Digital Twin model, exposing both a semantic ontology in JSON-LD format and a curated list of domain-specific keywords. The aim is to provide a machine-readable semantic description of the model—its variables, parameters, and available operations—using standard vocabularies such as schema.org, SOSA, and QUDT. This structure will facilitate seamless integration with e.g. the DT Registry or semantic search engines.

3.4.4 Proposed workflow and interactions

This paragraph provides a description of the designed API typical workflow and behaviour. The Digital Twin API is designed around session-based interaction, allowing clients to simulate and manage independent model instances. Below an example of the designed standard flow is provided:

1. **Initialize a session.** The DSS client starts a new session by sending a request, specifying the required model parameters (e.g. model coefficients). Once initialized and ready, the session is stored in memory and marked as ready to receive inputs.

2. **Evaluate the model.** The DSS client sends a POST request to evaluate the model, passing the session_id along with required input values. The DT runs and computes the output values. The DT may access data sources required for its execution: this is transparent to the DSS.

3. **Access logs and outputs.** All inputs and computed outputs are automatically logged and are retrieved via e dedicate endpoint.

Additionally, the API should provide additional features:

4. **Session state management.** Calling these endpoints the session can be explicitly reset to clear its state or finalized to terminate and clean up resources.

5. **Automatic cleanup.** Sessions that remain inactive beyond a configured timeout are automatically removed by a background task.

Crucially, each session should be isolated, thread-safe, and tied to a unique session_id.

The above structure results is a lightweight, robust, extensible and production-ready API tailored e.g. for mathematical model serving. The status of the API implementation is presented in D6.2 “DT-DSS and MAAS solutions – first version”, due at M22.

3.5 Human-centric DT-based DSS digital threads

Interaction among the different DSS components and the other services is further clarified with the following swim lane diagram.

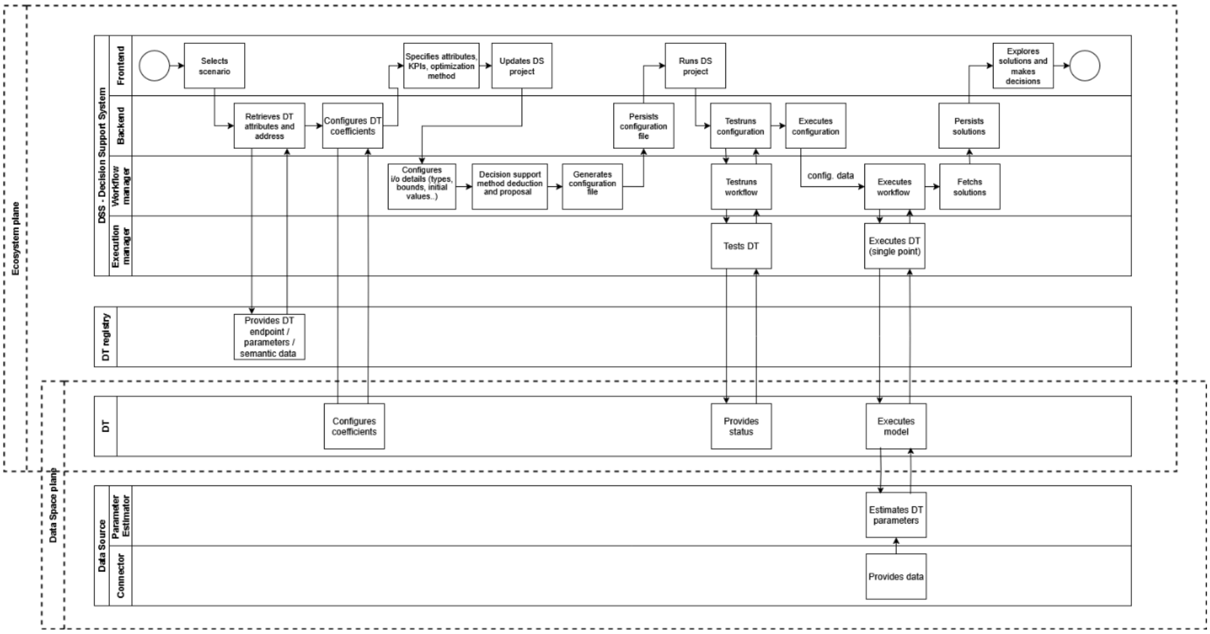

Figure 15 Swim Lane representing data flow among modules in selected DSS use cases

The following diagrams provide two concrete examples showing the sequence of actions performed by a human decision maker (e.g. planner, scheduler, or manager), the DSS and a manufacturing system DT. Figure 16 provides an example of resilient operations. The swim lane walks through the coordinated response to an event designed to maintain system performance despite disruptions, in line with resilient operation principles.

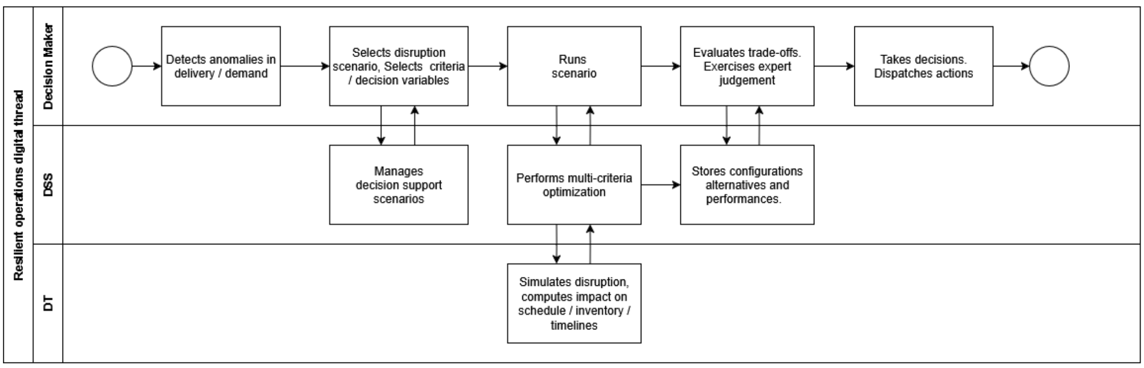

Figure 16 A digital thread towards resilient operations

Figure 17 provides an example of responsive operations. The swim lane introduces monitoring features, automatic alerts. The DSS enables an adaptive control during or immediately after disruptions thanks to the DT capabilities. Furthermore, it supports the reactive decisions relying on expert judgement.

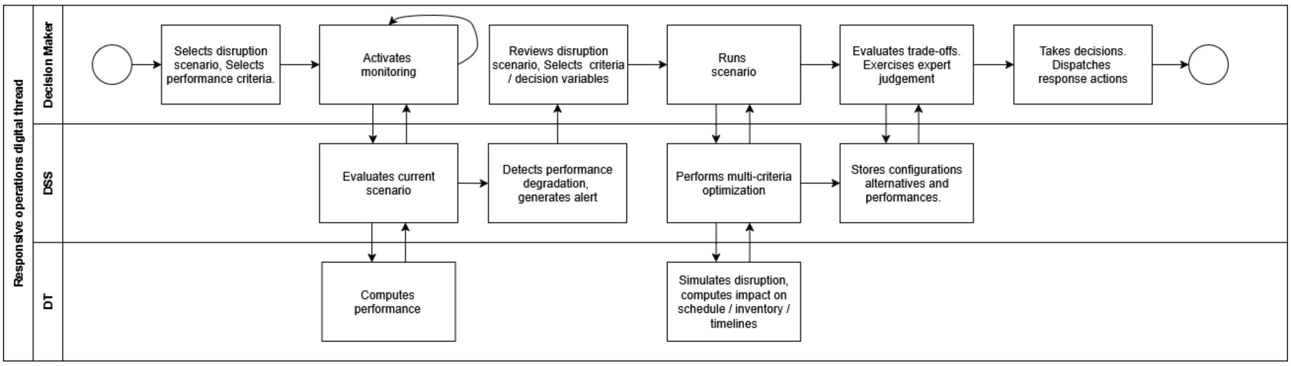

Figure 17 A digital thread towards responsive operations

3.6 Requirements mapping on the architectural layers and modules

Table 22 consolidates and maps the identified requirements to the different ACCURATE modules. This table has the objective to further crosschecks and clarify the separation of concerns and to provide a clear view of the DT-based DSS implementation scope.

Table 22 Consolidated/translated requirements and responsible modules

IDs	Requirement	Applies to module(s)
HRR1	Support data integration from different sources, e.g. MES, ERP, SC management systems	DTs, Data sources
HRR2	Support asynchronous DTs data updates, e.g. for DT parametrisation	Orchestrator, Execution manager
HRR3	Support data aggregation and pre-processing, e.g. ELT or ETL	DTs, Data sources
HRR4	Support DTs integration at different system levels	Orchestrator
HRR5	Support execution of both analytical- (e.g. equation-based) and simulation-based models (e.g. DES) DTs	Orchestrator, Execution manager (APIs)
HRR6, RE3	Enable creation of optimization workflow, encompassing multiple models and DTs (equation- and simulation-based models and DTs)	Orchestrator, Backend
HRR7	Enable orchestration of workflow execution whereas models and DTs exchange input and output data	Execution manager
HRR8	Enable evaluation of multiple scenarios on a given Use Case, e.g. on a what-if basis or policy basis	DSS as a whole
HRR9	Enable KPIs computation (for e.g. performance, resilience, sustainability evaluation)	Execution manager, DTs
HRR10	Enable multi-criteria optimization and trade-off analysis	Backend
HRR11	Support decisions for crisis anticipation, e.g. supplier consolidation, inventory policy optimization	Frontend, Backend
HRR12	Support decisions for crisis mitigation, e.g. planning or system reconfiguration	Frontend, Backend
HRR13	Provide a shared platform for collaborative evaluation of actions, e.g. with suppliers and stakeholders	Frontend, Backend
HRR14	Provide a monitoring feature; generate alerts, warnings	Frontend, Backend
HRR15	Support documentation and traceability of decisions	Frontend, Backend
HRR16	Enable integration with existing business processes	DSS as a whole
HRR17	Provide User interfaces and tools for scenario data visualization and exploration	Frontend, Backend
II1	Define or reference a common schema or interface standard (e.g. JSON schema, OpenAPI)	Orchestrator

II2	DSS should provide an orchestration framework. A mechanism for status declaration should be defined.	Orchestrator
II3	A base image standard should be specified, including a container registry, a versioning approach, and compliance with runtime environments	DSS documentation, ACCURATE repository
II4	A DT Registry entry should require an API endpoint for DT interfacing. DTs communication with data sources is responsibility of the DT.	DT Registry
II5	The orchestrator design should support asynchronous execution modes as needed, e.g. by supporting message queues, REST APIs	Orchestrator
II6	DSS should provide an orchestration framework including a mechanism to manage alive/ready completed/failed runs of the DT	Orchestrator
II7	DSS architecture should enable the integration of data sources	DTs, Data sources
PPAR1	DSS should provide means to analyse output results corresponding to given inputs.	Frontend, Backend
PPAR2	DSS should support semantic information for the KPIs computed by models and DTs to support performance evaluation needs	DT Registry
PPAR3	DSS should support semantic information facilitating the categorisation of performance KPIs	DT Registry
SB1	DSS should provide an orchestration framework including a mechanism to manage the initialisation of the DT to allow its connection to data sources and parametrisation.	Orchestrator
SB2	DTs will directly manage access to data sources required to parametrise the models. The DSS should enable the initialisation of the DT to allow its connection to data sources and parametrisation.	Orchestrator
SB3	The DSS will manage the DTs input data that drive the optimization and decision-making process	Orchestrator
RE1	DSS should support integration of equation-based models.	DT Registry, Orchestrator
RE2	DSS should support integration of simulation-based models and DTs.	DT Registry, Orchestrator
RE4	DTs will directly manage access to data sources required to parametrise the models. The DSS should enable the initialisation of the DT to allow its connection to data sources and parametrisation. The DSS will manage the DTs input data that drive the optimization and decision-making process	Orchestrator, DTs
C&SE1	DSS should support integration and execution models and DTs that compute measures of process wastes or materials consumption, or that utilize such measures to compute C&S KPIs.	DT Registry and Orchestrator
SLCAE1	DSS should support integration and execution models and DTs base on DES models.	DT Registry and Orchestrator
OMM1	DSS should support constraints definition to guide the optimization process towards feasible solutions.	Orchestrator, Optimization algorithms

4 Conclusions and future work

This deliverable defines the foundational requirements and architectural framework developed for the human-centric DT-based DSS to support resilient and responsive operations. Building upon this results, future work will focus on the further implementation, validation, and continuous improvement of the proposed DSS system (WP6). Further information on the current implementation status can be found in the following deliverables:

- D6.2 “DT-DSS and MAAS solutions - first version” (M22) provides the status and roadmap of the DSS implementation.
- D2.2 “Matchmaking model and DT registry service” (M22) provides details on the DT registry implementation.

Furthermore, in the frame of WP 7 task T7.2 “Tailoring and optimisation of developed technology bricks” and task T7.3 “Pilots implementation and validation”, the DT-based DSS will be applied to DSS-oriented use cases identified in Deliverable D7.1 “Pilots’ deployment strategy” (M16). These UCs aim to enable timely, optimal, and robust decision-making across supply chains, including design, planning, management, stress-testing, reconfiguration, and recovery.

Central to these use cases is the development and integration of simulation-based Digital Twins (DTs) that model complex, interconnected processes across multiple scales, levels of spatial and temporal granularity, and timeframes. To facilitate such development and integration effort and to assure standardisation across different DTs implementation, a “DT templating engine” has been developed and provided to the Partners. Details regarding this development are also provided in D6.2.