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Abstract

This document outlines the operational service and environment definition (OSED) for the Performance Assessment Solution (SOL399/SOL1 of MultiModX, TRL2). SOL399/SOL1 developed a multimodal performance framework, with a set of key performance indicators (KPIs) and associated measurement mechanisms, and to provide a multimodal modelling and evaluation framework, supporting the evaluation and design of strategic multimodal operations and the evaluation and design of tactical multimodal operations and disturbance and disruptions mitigation solutions.

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Nominative authoring compliance

The beneficiaries/consortium confirm(s) the correct application of the Grant Agreement, which includes data protection provisions, and compliance with GDPR or the applicable legal framework with

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MultiModX

INTEGRATED PASSENGER-CENTRIC PLANNING OF MULTIMODAL
NETWORKS

MultiModX

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Table of contents

Abstract	1
1 Executive summary	7
2 Introduction	10
2.1 Purpose of the document.....	10
2.2 Scope	10
2.3 Intended readership	11
2.4 Background	12
2.5 Structure of the document.....	13
2.6 Glossary of terms.....	13
2.7 List of acronyms	16
3 Operational service and environment definition (OSED).....	18
3.1 SESAR solution 399: a summary	18
3.2 Detailed operational environment	24
4 Key assumptions	55
5 References	61
5.1 Applicable documents	61
5.2 Reference documents	62
Appendix A Stakeholder identification and benefit impact mechanisms (BIM)	64
A.1 Stakeholders identification and expectations	64
A.2 Benefits impact mechanisms (BIM)	66
Appendix B Potential impact of multimodality on SESAR Performance Framework.....	68
B.1 Scope of the analysis	68
B.2 Analysis of potential impact of multimodality on SESAR Performance Framework.....	68
B.3 References for Appendix B.....	73
Appendix C Input data sources examples	74
C.1 Strategic Multimodal Evaluator inputs	74
C.2 Tactical Multimodal Evaluator inputs	75
C.3 References for Appendix C.....	75
Appendix D Use Cases Description	76
D.1 Multimodal Performance Framework.....	77

D.2	Strategic Performance Evaluation	80
D.3	Tactical Performance Evaluation	86
D.4	Disruptions Evaluation.....	93
D.5	References for Appendix D.....	97
Appendix E	– Operational requirements	98
E.1	Multimodal Performance Framework.....	98
E.2	Strategic Multimodal Evaluator	99
E.3	Tactical Multimodal Evaluator.....	100

List of tables

Table 1: glossary of terms	15
Table 2: list of acronyms.....	17
Table 3: Solution 399 scope	23
Table 4: Example of possible policy packages.....	29
Table 5: Digital catalogue of indicators summary	40
Table 6: Use Cases summary for SOL399/SOL1.....	50

List of figures

Figure 1: Performance Assessment – Multimodal Performance Framework Concept	18
Figure 2: Performance Assessment – Strategic Evaluator Concept	20
Figure 3: Performance Assessment – Strategic Planned Network Evaluator Concept	21
Figure 4: Performance Assessment – Tactical Evaluator Concept	22
Figure 5: Mapping of clusters of regional archetypes to NUTS2 regions in EU (note – grey regions are not clustered due to lack of data or not part of EU)	28
Figure 6: Mapping of clusters of regional archetypes to NUTS2 regions in Spain	28
Figure 7: Tactical Evaluator model	43
Figure 8: Tactical Multimodal Evaluator input generation from Strategic Multimodal Evaluator output	45
Figure 9: SOL399/SOL1 – Use Cases diagram	46
Figure 10: High-level possible interaction between Use Cases of SOL399/SOL1	51

Figure 11: BIM managing multimodality operating cost	69
Figure 12:. BIM managing swaps of slots mechanism	70
Figure 13: BIM potential reduction in demand	71
Figure 14. BIM disruption management pre-departure	72
Figure 15: BIM disruptions management dynamic cost indexing	73

1 Executive summary

The Performance Assessment Solution (SOL399/SOL1) aims to develop a multimodal performance framework and a multimodal modelling and evaluation platform for strategic (planning) and tactical (on the day of execution) operations. As such, **SOL399/SOL1 can be understood as a system enabler that supports external Solutions**. It is a framework and a set of tools to evaluate multimodality and solutions applied in this context. In the scope of MultiModX, SOL399/SOL1 is, therefore, an **optional enabler for SOL400/SOL2** (Scheduling Design Optimiser) and **SOL401/SOL3** (Disruption Management Solution). Those solutions can be evaluated independently, but SOL399/SOL1 provides a framework and tools for their assessment.

The **performance framework** builds on the work from previous multimodal research projects and extends the work with collaboration with other SESAR ER and IR initiatives.

The multimodal modelling and evaluation platform is divided into two distinct parts:

- A **Strategic Multimodal Evaluator**, which focuses on the evaluation of flight schedules, rail timetables and other infrastructure characteristics, e.g., minimum connecting times intra and inter-modes, to assess mobility from a passenger-centric perspective, providing metrics at the region, the infrastructure (airport, rail station) and the operator level. This network can be either a planned or a replanned network which considers the impact of known disruptions.
- A **Tactical Multimodal Evaluator**, which can simulate the operations as they unfold on the day of execution. This model tracks vehicles (flights and trains) and passengers, providing passenger-centric metrics, e.g., missed connections and total delays.

The three components of SOL399/SOL1 are complementary and feed into each other. However, they might have different operational and technical environments, assumptions, and stakeholders impacted by them. Therefore, they are considered separately.

First, the performance framework provides a set of indicators that could be estimated to capture multimodal mobility aspects as an initial development of a passenger experience and multimodal performance indicators catalogue. This is done from the perspective of SESAR and also considering mobility as a whole. The definition of this framework is built on some assumptions, such as the representativeness of stakeholders involved in its definition. It is assumed that the pool of stakeholders is representative of the European-wide system and captures all their needs. This is ensured by relying on MultiModX's Industry Board but also with dedicated exchanges with other SESAR ER projects (e.g. MAIA, SIGN-AIR) and IR projects (e.g. PEARL, AMPLE3, Travel Wise) in collaboration with the SESAR Passenger Experience and Multimodality Flagship.

The main stakeholders impacted by this performance framework are system performance modellers, decision-makers, infrastructure managers, and any other actor concerned with the multimodal description and monitoring of the operations.

Second, the Strategic Evaluator estimates the possible paths for passengers between regions (or infrastructure (airport, rail station)) and, after a process of clustering and filtering, obtains alternatives

that are characterised by expected total journey time (considering door-to-door mobility), cost, emissions, waiting times (difference between connecting time and minimum connecting time), type of mobility (air, rail or multimodal) and the number of services (connections). These data are then used to distribute the origin-destination demand into these possible alternatives considering passengers' preferences. Finally, passenger flows are further disaggregated into individual services. The outcome allows the analysis of mobility, including, among others, aspects related to travel time, demand and capacity imbalance, and resilience (e.g., number of connections, waiting times, expected travel time if the connection is missed). This framework enables the evaluation of planned optimised schedules such as the ones produced by the Schedule Designer Solution (SOL400/SOL2). The Strategic Evaluator can also reassign passenger itineraries if services are rescheduled, such as when replanning services when managing a network-wide disruption. In this case, the model considers the flexibility of passengers to be reaccommodated (e.g. if the same mode as originally planned needs to be used or a modal swap is allowed) and the capacity already used by other non-affected passengers to reallocate the maximum number of impacted passengers. This process enables the estimation of passenger-centric indicators (e.g. number of stranded passengers, departure and arrival delay), and the evaluation of replanning alternatives, such as the ones provided by the Disruption Management Solution (SOL401/SOL3).

The Strategic Evaluator has assumptions about the passenger archetype coverage and the calibration of the modal choice used to capture the passengers' preferences. It is also assumed that the required multimodal governance is in place (e.g. data sharing infrastructure and inter-mode agreements). The model allows for alliances intra and inter-modes to be defined. Finally, it is assumed that the origin-destination demand is fixed and that prices are known in advance for the different alternatives. Some of these assumptions can be relaxed depending on the focus of the analysis (e.g., from analysing expected demand to assessing possible mobility where only connectivity between services is considered).

As mentioned, the Strategic Evaluator provides the capabilities needed to evaluate Solutions that optimise the flight and rail schedules, such as SOL400/SOL2 - Schedule Designer Solution, as it can produce an assessment of the current network which could support the optimisers (e.g. demand preferences on itineraries or demand-capacity imbalance), and it can use the outcome of the optimiser (new flight schedules and rail timetables) as new input to assess their strategic performance. Some of its capabilities also support the assessment of replanned networks in case of disruption, as provided by SOL401/SOL3 - Disruption Management Solution.

Being a **what-if transversal multimodality evaluator**, there is a range of different stakeholders that could benefit from the Strategic Multimodal Evaluator, such as air and rail operators, infrastructure managers (airport and rail infrastructure operators), European, national, regional and city mobility-related policymakers and planners, policymakers, GDS (Global Distribution Systems) providers, and passengers' associations.

Third, the Tactical Multimodal Evaluator uses individual flight and rail schedules and passenger itineraries and simulates them through the day of operation. The Tactical Multimodal Evaluator can model the different processes involved in a passenger itinerary on their full journey (including the required connection between modes). The evaluator enables the integration of mechanisms to manage passengers' disruptions (missed connections and delays) and can compute low-level passenger-centric metrics such as delay, missed connections, duty of care, and passengers' compensation.

The Tactical Evaluator can therefore model the realisation of planned and replanned networks, enabling the assessment of the tactical performance of Solutions that optimise the flight and rail schedules, such as SOL400/SOL2 - Schedule Designer Solution (e.g. assessing the robustness of the new schedules), and of replanned networks in case of disruption, as provided by SOL401/SOL3 - Disruption management solution.

As with the Strategic Evaluator, there are many potentials uses and stakeholders who could benefit from such a tactical simulator. For example, air and rail operators, airport managers and policymakers.

2 Introduction

2.1 Purpose of the document

This document defines the operational service and environment (OSED) for SOL399/SOL1 (SOL1 of MultiModX) at TRL2. Note that as a performance framework and a set of tools to evaluate other Solutions, the models developed within SOL399/SOL1 could be considered to have achieved operational capabilities (i.e., some aspects of TRL8); in a more broad context of evaluating multimodality (including during its deployment) there are still elements to improve, and therefore we consider SOL399/SOL1 to have achieved the targeted TLR2.

This document describes the operational environment in detail, including the operational characteristics and the roles and responsibilities impacted by SOL399/SOL1. Furthermore, it describes the detailed operating method of SOL399/SOL1, its improvements regarding the previous operating method for the strategic and tactical evaluation of multimodal journeys, and the indicators considered in the multimodal performance framework.

By providing a detailed definition of the operational service and environment, this document aims to facilitate the successful implementation and operationalization of the different components of SOL399/SOL1.

2.2 Scope

The OSED presents the operational service and environment of the Performance Assessment Solution. The overall scope of the OSED covers the definition of the operational characteristics foreseen as part of the SOL399/SOL1 of MultiModX.

The Performance Assessment Solution is divided into three components. These will be described in the document, while their detailed functionalities are described in the associated Functional Requirement Document (FRD) [23]:

1. A **Multimodal Performance Framework** provides a set of PIs and KPIs that capture the mobility's multimodal aspects. Focusing on extending the scope of performance assessment and monitoring to include the passenger experience, this framework is developed from two perspectives: from a SESAR point of view, identifying which PIs and KPIs could be considered as part of an extension of the SESAR Performance Framework, and from a general mobility perspective, where the focus is put on regions and infrastructures to understand how mobility between them is performed in a multimodal context. This is the starting point to build a passenger experience and multimodality performance indicators catalogue.
2. A **Strategic Multimodal Evaluator model**, which can assess the mobility between regions (and infrastructure) given a set of flight and rail schedules and timetables, infrastructure characteristics (e.g. connecting times between modes), origin-destination demand and their characteristics. The Strategic Evaluator should be able to compute the strategic-related multimodal PIs and KPIs defined by the Multimodal Performance Framework. The Strategic Evaluator can assess any given set of schedules; this means that the outcome of the Schedule Generator Solution (MultiModX's SOL400/SOL2) can be used as input by the Strategic

Evaluator, enabling the iterative assessment of different coordinated schedules solutions. The Strategic Evaluator can also reassign passenger itineraries to updated schedules, for example, reallocating passengers impacted by a network-wide disruption when services are updated (as done by the Disruption Management Solution (MultiModX's SOL401/SOL3).

3. A **Tactical Multimodal Evaluator model**, which can assess a day of operations, including the *nominal* disturbances of the system and larger disruptions. This evaluator can integrate mechanisms (solutions) that facilitate the multimodal journey of passengers (e.g. fast-track processing at airports), and can assess the realisation of any of the outcomes from the Strategic Evaluator (planned or replanned network).

The development of SOL399/SOL1 **addresses the Objectives O2 and O3 of the project** as stated by the Grant Agreement (GA):

- **To develop a multimodal performance framework**, including a set of key performance indicators (KPIs) and the associated measurement mechanisms, that enables the comprehensive and rigorous assessment of the performance of multimodal transport systems and multimodal solutions.
- **To develop a multimodal modelling and evaluation framework**, to be integrated into a **Performance Assessment Solution** that supports the design, development and assessment of strategic and tactical multimodal solutions, with focus on scheduling and disruption management.

Once again, it is worth reiterating that SOL399/SOL1 can be understood as a **system enabler that supports external Solutions**. This means that SOL399/SOL1 can evaluate the performance of SESAR Solutions, mechanisms and other more broad elements such as policies considering a full multimodal performance framework, developed with a mobility and passenger-centric approach.

Solutions such as SOL400/SOL2 or SOL401/SOL3 could be evaluated independently with ad-hoc modelling, but SOL399/SOL1 provides more advanced performance evaluation capabilities and a relevant and standardised performance framework.

2.3 Intended readership

The readers of this document would typically include a range of stakeholders involved in the rail and aviation industry, transportation planning, and policy-making. These may include SESAR JU, SESAR IR Projects, SESAR ER projects, EU-Rail, airlines, airports, rail operators, train stations, transportation planners, policymakers, urban planners, researchers and academics, consultants and advisory firms, technology developers, and environmental organizations. Obviously, an intended reader are the partners on the MultiModX project and those responsible for the development of SOL400/SOL2 and of SOL401/SOL3 to ensure that the processes and usage are aligned. This is particularly relevant for SOL400/SOL2 which will utilise some of the outcomes of SOL399/SOL1 Strategic Multimodal Evaluator as input within their op

2.4 Background

Multimodal Performance Framework

Previous work has focused on computing ad-hoc PIs to capture multimodal aspects of mobility. Noteworthy are the works conducted by previous SESAR ER projects Modus and TRANSIT [21, 28], which already reviewed the current ICAO [19] and SESAR performance schemes [26]. Both projects developed multimodal indicators that account for aspects such as door-to-door travel time, travel time reliability, monetary cost for the passenger, regional connectivity and accessibility, environmental impact, and resilience.

When considering the multimodal aspect of transport, the focus naturally shifts from vehicle-centric to passenger-centric indicators. Foundation work on passenger-centric metrics in Europe was led by the University of Westminster in the POEM project (Passenger-Oriented Enhanced Metrics), putting the passenger at the centre of monetised KPIs with corresponding policy implications.

The expected evolution of the SESAR Master Plan considers the inclusion of Passenger Experience as one of the areas where PIs and KPIs will be developed. This contributes to the focus on passengers, extending the flight-centric vision of the ATM system. Other current research projects are working on these aspects and will coordinate some of their activities with the work to be conducted as part of SOL399/SOL1, namely, SIGN-AIR [27], MAIA [20], PEARL [25], AMPLE3 [14] and Travel Wise [31]. The Passenger Experience and Multimodality Flagship will further develop these activities.

Strategic Multimodal Evaluator

The detailed representation of multimodal transport supply as a layered network (multiplex) enables the evaluation of coordination mechanisms, but it is computationally challenging given the high number of alternatives that may be available for performing a trip. Previous research conducted by TRANSIT [16] has already shown how considering schedules and low-level demand data are required to understand passengers' alternatives and their preferences when using the network.

Tactical Multimodal Evaluator

The transport network is subject to different types of disruption during its operation, from day-to-day minor delays, infrastructure issues, and congestion to more severe disruptions blocking elements in the system (e.g. weather which closes an airport) or significantly dropping the capacity (e.g. runway closure) and system-wide disruptions (e.g. volcanic eruption). It is therefore important to model the realisation of the planned mobility network as passengers' experience can be significantly negatively impacted, and mechanisms (and Solutions) could be put in place to alleviate these.

In the context of multimodality, it is important not only to focus on the modelling of flights (or rail services) but also on the passengers and their full itineraries. Previous research has shown that passengers might experience disruptions very differently than airlines (and flights) [16, 18, 22]. In the context of multimodality, these discrepancies are expected to increase. Moreover, airlines' operational decisions tend to be underpinned by their expected operating costs, which might vary as a function of passenger experience.

Mercury, is a gate-to-gate (extended to door-to-door) flight and passenger mobility simulator specifically developed to tackle these considerations in many previous research projects [17, 18].

Mercury has been successfully used for the evaluation of door-to-door mobility considering intra-airport processes (kerb-to-gate, gate-to-kerb) and first-last mile [18].

2.5 Structure of the document

This document describes the operational and technical characteristics of the Performance Assessment Solution (SOL399/SOL1). First, the detailed operational environment is explained in Section 3.2, which describes the operational characteristics, the roles and responsibilities involved in the solution, and the applicable standards and regulations. Note that this is differentiated for the three components of SOL399/SOL1. Then, the detailed operating method is developed, along with the improvement to the current operating method. The different use cases are described. Finally, Section 4 details the key assumptions under which this solution has been developed. The document is complemented by five Appendices:

- Appendix A – Stakeholders' identification and benefit impact mechanisms (BIM) provides a detailed description of possible stakeholders that could benefit from SOL399/SOL1;
- Appendix B – Potential impact of multimodality on SESAR Performance Framework provides an analysis on how multimodality overall could impact the current Performance Framework;
- Appendix C – Input data sources examples provide information on which possible data sources can be used to model the mobility networks;
- Appendix D – Use Cases Description contains the detailed descriptions of the Use Cases of SOL399/SOL1, and
- Appendix E – Operational requirements contains the operational requirements of the three components of SOL399/SOL1.

Finally, it is worth reminding the reader that the functionalities (and functional decomposition) of the components of SOL399/SOL1 are described in detail in the Functional Requirements Document (FRD) [23]; particularly relevant is Appendix A of the FRD (Appendix A – Input/Output formats) of that document, where the input and output of the Strategic and Tactical Evaluator are detailed (including their format).

2.6 Glossary of terms

Term	Definition	Source of the definition
Air network disruption	Significant ATFM regulations or closures at airports.	Own elaboration
Disruption	Rail or air network disruptions, which are known in advance and produce a significant reduction in supply on the infrastructure of the networks.	Own elaboration
Disruption package	Set of disruptions that are applied at the same time to the planned network.	Own elaboration

Itinerary	A succession of services (flights or trains) which represent a possible trip for a passenger.	Own elaboration
Multimodal supporting mechanisms	Mechanisms that tactically support passengers through their multimodal journey, e.g. fast-track at airports dedicated to multimodal passengers to reduce potential missed connections. These mechanisms modify the default behaviour of elements in the system.	Own elaboration
[infrastructure] Node	Airport or rail station	Own elaboration
Logit model	A statistical model which calculates the probability of choosing a specific alternative for each passenger archetype when presented with several options for travelling between a given OD pair.	Own elaboration
OD pair	Origin and Destination pair. Refers to the start and end points of each passenger's journey. The number of O&Ds also indicates the size and complexity of a network.	ATPCO Glossary
Passenger itinerary	Number of passengers assigned to an itinerary.	Own elaboration
Path	A succession of nodes (airports, rail stations) in the graph which represent a possible or potential succession of nodes to travel from a given origin to a given destination	Own elaboration
Planned network	Instantiation of a strategic experiment computed by the Strategic Performance Evaluator consisting of: supply (flight schedules and rail timetable), demand (passenger itineraries) and infrastructure (access/egress times, minimum connecting times, inter-modes connecting times, passenger processing times).	Own elaboration
Planned tactical network	A planned network in the format required by the Tactical Evaluator (see Annex A from FRD [23]).	Own elaboration
Policy package	Set of policies to be considered/applied to the network: short-haul bans, frequent flyer levy, rail incentivisation, CO ₂ costs, and level of integrated ticketing. These policies are grouped meaningfully. See Table 4 and the Experimental Research Plan (ERP) for more information on	Own elaboration

	policy packages that are planned to be evaluated [24].	
Possible path	A succession of nodes (infrastructure (airport or rail station)) that could be used to travel from a given origin to a given destination, respecting the minimum connecting times of the services involved.	Own elaboration
Potential path	A succession of nodes (infrastructure (airport or rail station)) that could be used to travel from a given origin to a given destination independently of minimum connecting times of services.	Own elaboration
Rail network disruption	Reduced throughput at nodes (rail stations) and/or links, and/or closure of links.	Own elaboration
Service	A given flight or specific train between two stations .	Own elaboration
Strategic experiment	A specific network defined by supply (flight schedules, rail timetable), demand (origin-destination demand matrix per passenger archetype), infrastructure (access/egress times, minimum connecting times, inter-modes connecting times, passengers processing times), configuration parameters (for the Strategic Evaluator, e.g., clustering thresholds) and policy package (set of policies to be considered by the network). See Annex A of FRD for information on format and parameters.	Own elaboration
Tactical experiment	A planned tactical network (supply (flight schedules, rail timetable), demand (passenger itineraries) and infrastructure (access/egress times, minimum connecting ties, inter-modes connecting times, passenger processing times)) in the format required by the Tactical Evaluator (see Annex A from FRD [23]) and any other additional required data by the Tactical Evaluator to simulate the network (e.g. disruptions, flight plans).	Own elaboration

Table 1: glossary of terms

Note, that Appendix D - Use cases description has additional terms defined in Auxiliary definitions within the respective Use cases.

2.7 List of acronyms

Term	Definition
ABM	Agent Based Model
API	Application Programming Interface
ATFM	Air traffic flow management
ATM	Air traffic management
ATS	Air traffic services
CNS	Communication navigation surveillance
DCB	Demand Capacity Balancing
DES	Digital European Sky
ERP	Exploratory research plan
FRD	Functional Requirements document
GA	Grant agreement
GDPR	General Data Protection Regulation
GDS	Global Distribution Systems
GTFS	General Transit Feed Specification
ID	Identifier
KPA	Key Performance Area
KPI	Key Performance Indicator
MCT	Minimum Connecting Time
MTOW	Maximum Take-off Weight
NOP	Network Operation Plan
NUTS	Nomenclature of territorial units for statistics
OSD	Operational service and environment description
PI	Performance Indicator
SESAR	Single European sky ATM research

SESAR 3 JU	SESAR 3 Joint Undertaking
TRL	Technology Readiness Level
WTC	Wake Turbulence Category

Table 2: list of acronyms

3 Operational service and environment definition (OSED)

3.1 SESAR solution 399: a summary

Multimodal Performance Framework

The multimodal performance framework developed as part of SOL399/SOL1 relies on a literature review of previous work in the field and interaction and feedback obtained from stakeholders and other related research projects. As shown in Figure 1, the framework identifies three levels of development of potential multimodal indicators:

- Level 1 are indicators currently part of the SESAR3 Performance Framework. These indicators will have, by their nature, a stronger focus on the gate-to-gate component of the passenger journey. Work will be conducted to identify how multimodality could impact the SESAR Performance Framework's currently considered PIs and KPIs.
- Level 2 comprises indicators that are currently (or are planned) to be at least modelled by research projects. These will mature some aspects of passenger experience and focus on multimodal considerations such as reliability.
- Level 3 contains more ambitious indicators that aim to capture the total experience of passengers in their door-to-door journey. These will represent indicators that can be more desirable but currently not feasible due to several limitations, such as data availability.

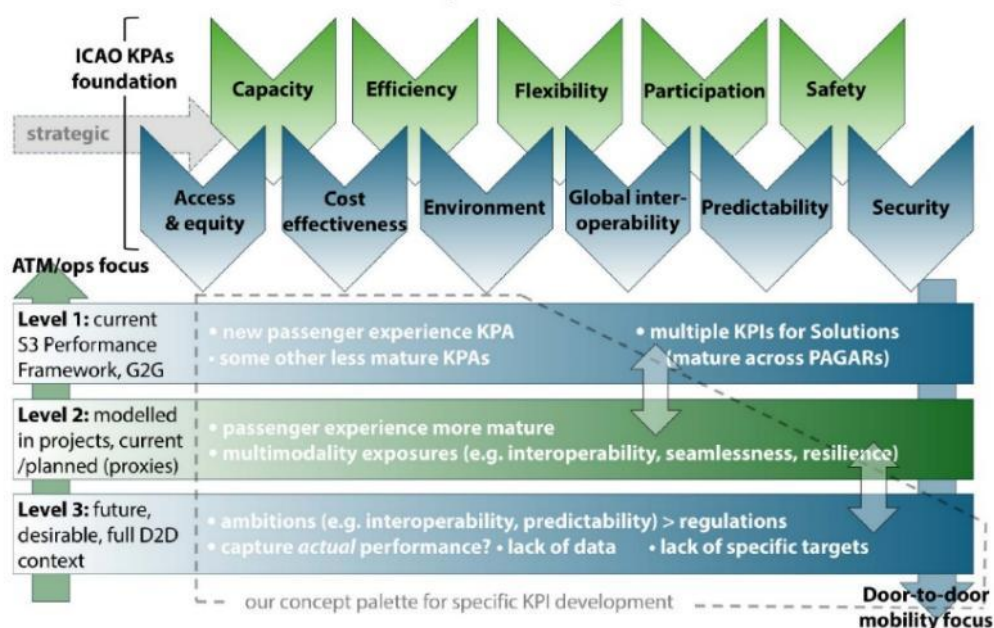


Figure 1: Performance Assessment – Multimodal Performance Framework Concept

It is worth noticing how the same aspects could be found at different levels, e.g. interoperability is a multimodality exposure (at Level 2) while part of the ambitions for full door-to-door performance at Level 3.

The work performed by SOL399/SOL1 on the further definition of this multimodal performance framework represents an improvement to the EU mobility system as these aspects are currently not monitored and are out-of-scope of the system's considerations.

This work is linked to a survey launched at the SESAR Innovation Days in November 2024, and subsequently distributed to the PEARL and AMPLE3 consortia, in the same month, to extend project and Solution inclusion in this initiative. The broader objectives are:

- To build an **open access, digital catalogue** of indicators across the three levels;
- To carry out a two-way **gap analysis** between the 'capabilities' in the SESAR Target Architecture and the indicator catalogue;
- To further review the state of the art at the **European policy and strategy** level to establish what indicators (and data) are necessary **at Level 3** to model/monitor the corresponding goals/impacts.

The results will be fed into the ongoing KPI development work of PEARL and, hence, the SESAR Performance Framework. SOL399/SOL1 organised the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop held on 15 January 2025 (at the University of Westminster, London), attended by members of the MultiModX, PEARL, AMPLE3 and SIGN-AIR projects (*inter alia*; and as reported under separate cover). In that workshop, three break-out groups were held to discuss indicators of passenger experience and multimodality with an airport focus, an airline focus and wider multimodal aspects; a fourth break-out group reviewed and discussed the SESAR capability model and how multimodality is considered. Specific indicators (arrival delay, cancellations due to ATFM and reactionary delay) were already identified as candidates to be part of the passenger experience KPA and able to be considered in the context of PEARL Performance Framework development activities at Level 1. Others, such as arrival punctuality to the final destination, missed connections, and kerb-to-gate time, were discussed to be further developed at Level 2 and Level 3.

These are the first steps towards creating the open-access digital catalogue, which should be a live space that evolves along the gap analysis as the conditions of the operational environment change (e.g. datasets available, deployment of data collection and processing, etc). SOL399/SOL1 aims at starting and supporting these activities that should be developed further by the Multimodality and Passenger Experience flagship.

The digital catalogue of indicators is currently available (as of June 2025) in Confluence, a wiki-like collaborative site managed by Nommon: <https://nommon.atlassian.net/wiki/external/MzA2ZTJmMjU5MDUyNDNIYzlkNDBmNTMwOTRlMDY4MGY>. Note that currently, members of MultiModX, SESAR 3 Scientific Committee, PEARL, SESAR3 Joint Undertaking Multimodality and Passenger Experience flagship, SIGN-AIR and MAIA have access as contributors to the collaborative site, while the catalogue is accessible via the link publicly in view mode. This digital catalogue defines, therefore, a live document which is expected to evolve as different projects define and re-utilise the performance indicators. Finally, it is worth mentioning that the code of MultiModX Evaluators (which includes the implementation of the indicators) is public in the project GitHub repository (<https://github.com/UoW-ATM/MultiModX>).

Strategic Multimodal Evaluator

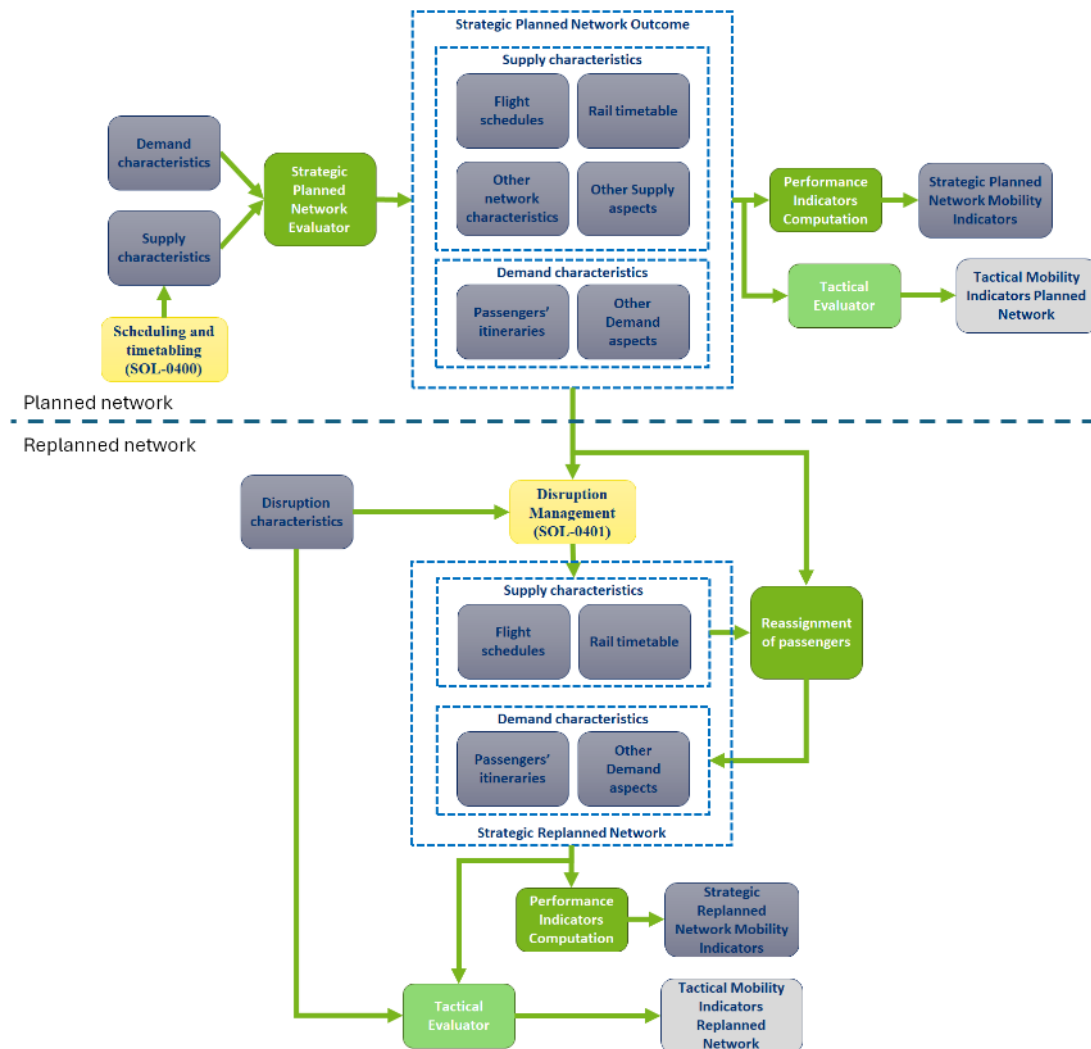


Figure 2: Performance Assessment – Strategic Evaluator Concept

As shown in Figure 2, the Strategic Multimodal Evaluator is responsible for building and analysing the planned (and replanned) network. It comprised of three main elements:

- **Strategic Planned Network Evaluator**, which, from the characteristics of demand (OD demand) and supply (flight and rail schedules) and infrastructure aspects, computes the materialisation of the supply and demand characteristics in the network. For information about the input, intermediate output, and final output, see Appendix A – Input/Output format from the FRD [23], and for example of datasets used to create such inputs, see Appendix C – Input data sources examples in this document.
- The supply could be any flight and rail schedules, including the outcome of the Scheduling Design Optimiser (MultiModX's SOL400/SOL2) aiming to improve the connectivity between air and rail layers. Figure 3 presents more details on this element; as shown, possible itineraries

along the rail and air network that allow passengers to fulfil their journeys are computed. These are grouped into equivalent clusters of itineraries with a similar performance from a passenger preference perspective (e.g. similar total travelling time, cost, emissions). Then, the demand is distributed to passenger flows who would like to use different alternatives (services). These alternatives can be purely air or rail options or a combination of both (multimodal journeys). Finally, passengers are assigned to services, generating individual passenger itineraries.

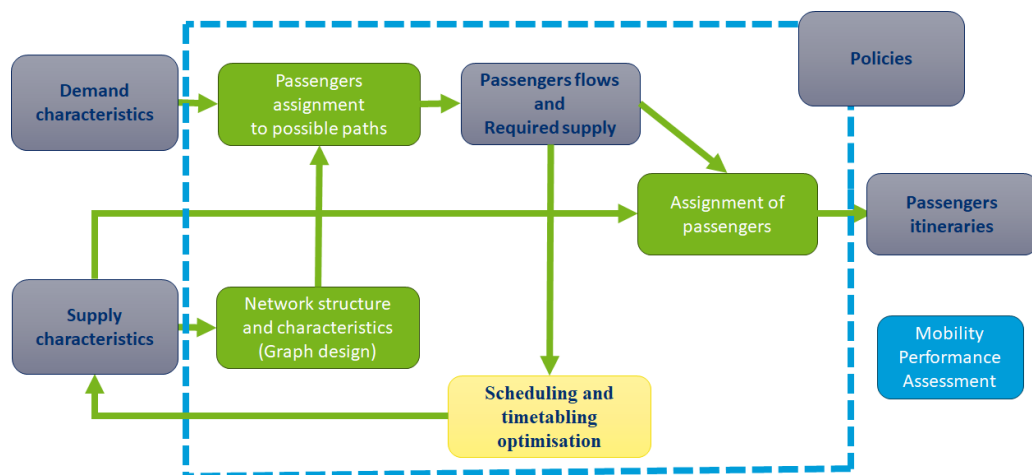


Figure 3: Performance Assessment – Strategic Planned Network Evaluator Concept

- Passenger Reassignment on Replanned Network**, which assesses the impact of modifying the supply (flight schedules and rail timetable) on the already planned operations. When disruptions impact the network in a significant manner, the air and rail operators could consider changing their services (e.g. adjusting flight schedules and rail timetables, cancelling services). This replanning of operations to maximise the supplied demand while considering the limited system capacity is the objective of MultiModX's Disruption Management Solution (SOL401/SOL3). Therefore, the outcome of the Disruption Management Solution is new flight schedules and rail timetables, which modify some of the originally planned operations. As shown in Figure 2, the Strategic Evaluator can then reassign the demand of passengers impacted by these changes. The overall process is similar to the Strategic Planned Network evaluation, but the passenger demand is already in the form of passenger itineraries, and only passengers impacted by the replanned operations are considered. Replanned operations due to disruption without being optimised can also be analysed, e.g. cancelling flights (or train services) which were planned to operate to a closed airport (or via a closed rail link) or delaying flights due to ATFM regulations. Different constraints can be imposed on which alternative itineraries are valid for the replanning of affected passengers (e.g. forcing them to keep the same mode or allowing the usage of an alternative route to reach their final destination).
- Performance Indicators Computation**, which computes mobility performance indicators when considering the outcome of the Strategic Planned Network Evaluator. These computations are part of the general model and implemented in ad-hoc libraries.

The Strategic Multimodal Evaluator presents several advancements with respect to the current operations and state-of-the-art tools. For example, one could evaluate the impact on the mobility of

different policies impacting the supply (e.g. taxes and bans), the impact of changes on infrastructure (e.g. changes to minimum connecting times), business models (e.g. alliances for inter-mode operations), etc.

Tactical Multimodal Evaluator

The Tactical Multimodal Evaluator of the Performance Assessment solution simulates a day of operations in the network, tracking individual flights and passengers. As shown in Figure 4, the input to the Tactical Evaluator is the individual flight schedules, rail timetables, passenger itineraries and any other tactical, operational parameters (e.g. probability of ATFM regulation, turnaround times). For information on the input and output data related to multimodality needed, see Appendix A – Input/Output format from FRD [23]; for information on the calibration of the model and other parameters, see [18]; for a description of the input data sources needed see Appendix C – Input data sources.

The model can simulate disturbed conditions, such as day-to-day nominal delays, and stressed nominal conditions (e.g. ATFM regulations or delays on the ground system linking the rail stations with the airports). Therefore, The Tactical Multimodal Evaluator can assess how the planned operations (as derived from the Strategic Multimodal Evaluator) unfold on the day of operations. Mechanisms can be implemented and integrated into the platform to assess their performance in supporting multimodal journeys (e.g. fast-track at airports for delayed multimodal passengers). Finally, if larger network-wide disruptions, which require some replanning of operations instead of a reactive approach when managing passengers and services, are experienced, the network would be replanned (as presented in the Strategic Multimodal Evaluator description), and the Tactical Multimodal Evaluator could then assess this new network.

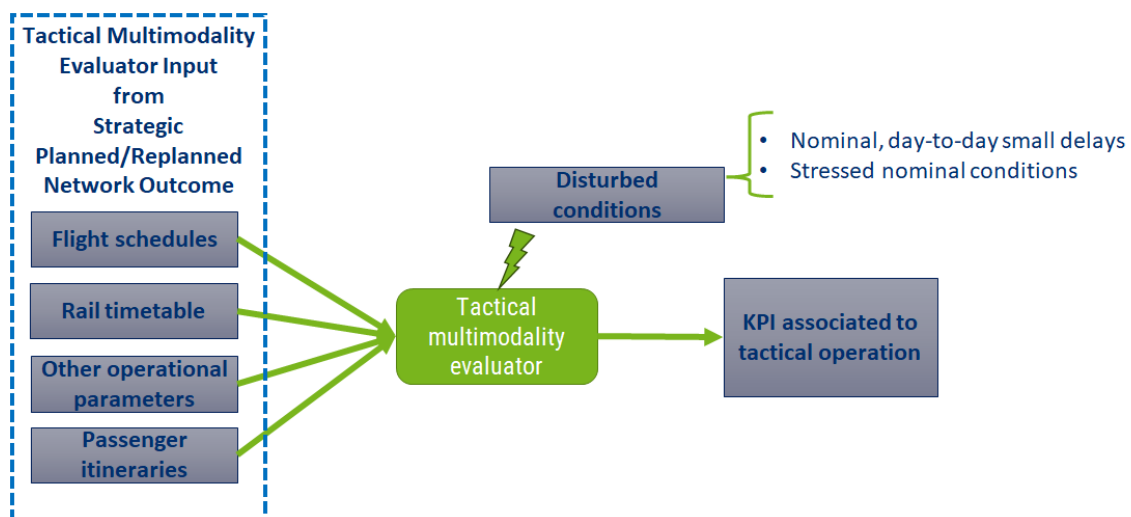


Figure 4: Performance Assessment – Tactical Evaluator Concept

The Tactical Multimodal Evaluator extends the Mercury ABM platform developed over several SESAR ER projects from a gate-to-gate simulator to a full multimodal evaluator [17, 18, 30]. The platform can track individual flights, trains and passengers. This facilitates the computation of very low-level passenger-centric indicators, such as, among others, missed

connections, waiting times and total journey times. Note that a different model could have been used as the bases for the development of the multimodal tactical evaluation capabilities, Mercury provides an ideal platform as it already considers the behaviour of stakeholders (particularly airlines) in the gate-to-gate operations and includes capabilities to evaluate mechanism and Solutions by modifying such behaviours. Moreover, Mercury is open-source and extensively documented. The gate-to-gate modelling capabilities of are assumed in MultiModX and the focus in this document is the description of the requirements relating to the multimodal components of the evaluator.

The SESAR solution ID, title and definition, consistent with the SESAR architecture or any update (if required) after the validation activities. Any update shall be managed through the SESAR change management process.

The justification for the solution, i.e., why it matters, referring to the Digital European Sky (DES) strategic research and innovation agenda (SRIA) or the European ATM master plan.

SESAR solution ID	SESAR solution title	SESAR solution definition	Justification (why the solution matters?)
SOL399	Performance Assessment Solution	The Solution provides a Multimodal Performance Framework and Evaluators, supporting the assessment of strategic (historical, optimised, replanned networks) and tactical multimodal operations under different policies and disruptions considerations.	The expected evolution of the SESAR Master Plan considers the inclusion of Passenger Experience as one of the areas where PIs and KPIs will be developed. There is a need for a platform that enables the evaluation of mobility considering the joint operations of air and rail services, enabling the assessment of flight schedules and rail timetables under different assumptions (e.g. integrated ticketing between operators) and policies (e.g. CO₂ emissions costs) and conditions (e.g. with disruptions). The transport network is subject to different types of disruption during their operation. It is therefore important to model the realisation of the planned mobility network as passengers' experience can be significantly negatively impacted, and mechanisms (and Solutions) could be put in place to alleviate these.

Table 3: Solution 399 scope

As described, none of the components of SOL399/SOL1 modifies or interacts directly with any SESAR Solution and cannot be integrated directly into the SESAR architecture as they provide a transversal multimodal performance framework. SOL399/SOL1 is a standalone Solution with applicability across diverse operational environments. SOL399/SOL1 is therefore a system enabler which support external solutions.

Therefore, the different evaluation platforms could support the assessment of SESAR Solutions on the overall mobility framework. For example, by modelling and integrating some SESAR Solutions (e.g. UDPP, EAMAN or Total Airport Management (TAM Solution 1 from PJ04)) into the Tactical Evaluator, the impact of these Solutions on the overall passenger mobility could be evaluated.

Some SESAR capabilities from AMPLE3 D2.6 – Transformation View 2024 [15] that SOL399/SOL1 could impact have been identified (see Functional Requirements (FRD) [23]).

The collaboration with PEARL and AMPLE3, along with other ER and IR projects under the Passenger Experience and Multimodality Flagship, is worth mentioning as it supports the assessment of how multimodality aspects could impact the SESAR architecture and capabilities. In this context, as part of the 15th of January 2025 workshop on ‘Multimodality and passenger experience in the SESAR Performance Framework’, attended by members of the MultiModX, PEARL, AMPLE3 and SIGN-AIR projects (inter alia; and as reported under separate cover), certain “operational capabilities” of the Transformation View were discussed, focusing on terminology changes to various ‘multimodal’ elements, such as “Airport connectivity – door-to-door journey facilitation” instead of “Aerodrome accessibility – door-to-door journey disruption management” or “Single ticketing” to be written as “(Single) Ticketing” to reflect that this also includes one-leg (air) tickets (not only multi-leg air and/or multimodal). As part of these activities, some performance indicators were also already identified and are candidates to start populating the digital multimodal and passenger experience performance indicators catalogue.

Finally, the operational requirements for the components of SOL399/SOL1 are collected in Appendix E -- Operational requirements.

3.1.1 Deviations with respect to the SESAR solution definition

There is no planned deviation from the original solution definition.

3.2 Detailed operational environment

3.2.1 Operational characteristics

First, it is worth mentioning that it is assumed that the European ATM operational environment is assumed to be similar to the current operational environment. Required multimodality governance and enablers are in place (e.g. integrated ticketing and data exchanges), but no significant changes to the ATM operational environment are envisioned by SOL399/SOL1. In terms of the multimodality governance the main actors involved will be airlines and rail operators, as these need to provide information on their schedules, timetable, seats available and ticketing costs. Moreover, the estimators assume that it is possible to book multimodal trips, i.e., a trip for which some segments are flights and others are rail. This required the assumption that the governance required for

integrated/single ticketing is in place. SOL399/SOL1 estimators allows for the definition of *alliances* which define which operators can provide jointly tickets for a given journey. Therefore, the models are flexible enough to account for different ticketing policies (e.g. Iberia might sell tickets combined with Renfe, but Ryanair might not). As described in Appendix C, there are many different datasets that are assumed to be available to do the strategic and tactical evaluation (Appendix A of the FDR provides more details on these [23]). Finally, besides the data exchanges required by the multimodal governance framework, other datasets are required which relate to the infrastructure (e.g. from an airport and rail station perspective information on minimum connecting and passenger processing times). These additional datasets are not necessarily part of the multimodal governance framework but required to estimate the total travelling time and which itineraries are possible, as explained in Appendix A of the FRD [23].

It is worth remembering that SOL399/SOL1 is not an enabler of multimodality per se, but a performance framework and evaluators to assess air-rail multimodal networks (it is an enabler for other Solutions as it supports their evaluation, but it is not required for their deployment). Therefore, aspects related to data and commercial exchanges are assumed to be available (see Assumptions A4 and A5 in Section 4). As SOL399/SOL1 provides a Multimodal Performance Framework and a transversal multimodal evaluator for strategic and tactical operations. Therefore, the focus is on the type of mobility operational environment in which multimodality could be evaluated in a meaningful way. Some of the solutions that SOL399/SOL1 evaluates could require some operational changes (e.g. how ATFM regulations are managed if SOL401/SOL3 is deployed), but this is beyond the scope of SOL399/SOL1.

The Multimodal Performance Framework can be applied to any operational context involving passengers with multimodal journeys. The framework should extend the current Performance Framework to include passengers and the strategic (planned) and tactical (realisation) scope. As explained below, multimodal journeys will be more widely available in some particular operational contexts.

The Performance Assessment Solution (SOL399/SOL1) aims to develop a **transversal performance assessment** solution divided into a multimodal performance framework and a multimodal modelling and evaluation platform for strategic (planning) and tactical (on the day of execution) operations.

Therefore, even if the assessment can be applied to any air/rail mobility network, the most relevant operational environment to assess the planning of networks in the context of multimodality is, as explained below, long-distance trips where connectivity and multimodality can provide complementarity to reach less connected regions. Other aspects to consider in the operational environment are the policies that could be deployed to incentivise multimodality and/or to limit aviation, as SOL399/SOL1 could evaluate how the multimodal network can support the overall demand between regions.

To identify sub-operational environments in which to assess the impacts of multimodality, it is pertinent to cluster the regions of Europe (European regional archetypes) to identify areas with similar mobility needs and characteristics so that results on the strategic and tactical evaluating of networks conducted on those regions can be extrapolated to others in the European context. More detailed analysis could be performed by focusing on different types of infrastructure nodes (e.g. hubs or regional airports) and regional characteristics (e.g. peripheral or insular areas).

On the tactical realisation of the planned network, it is relevant to identify types of air and/or rail network disruptions that could benefit from multimodality, with the reallocation of impacted passengers on alternative services, and/or be mitigated by using a Disruption Management Solution, such as SOL401/SOL3.

Finally, besides those aspects, the infrastructure characteristics could be further examined to identify sub-operating environments that could be assessed separately.

The following sections describe in more detail some of the aspects explained above to identify these operational environments that could benefit from SOL399/SOL1.

3.2.1.1 Overall multimodal operational aspects considerations

Overall, multimodal performance will be relevant in the case of:

- Mid-long distance mobility where air and rail options can be comparable in terms of travel time, can complement each other (e.g. having multi-leg trips with more than one mode of transport), require connections;
- With a multimodal governance in place which enables the selling and operation of multimodal air-rail tickets (i.e., a passenger buying a ticket which allows them to connect between air and rail services);
- And tactically, to assess the impact of disruptions in the rail and/or air network.

3.2.1.2 European regional archetypes

European regional archetypes are identified at NUTS 2 level to map ‘travel regions’ types in Europe. The different European regions are classified based on the degree of applicability of multimodal solutions. This will facilitate the evaluation of the impact of multimodality at this ‘travel regions’ level, which could then be extrapolated to other regions of the same level even if not explicitly modelled. This creates, therefore, different sub-operational environments based on these regional archetypes.

Once the regional archetypes are identified, passenger archetypes are associated with them, thus estimating the average compositions of passenger archetypes within a certain regional archetype. This could facilitate the creation of new experiments by distributing origin-destination demand between regions to demand per passenger archetype.

The clustering of the regions is performed considering:

- Socio-demographics (e.g. population density, shares of the population in different age brackets)
- Tourist volumes (e.g. arrivals at tourist accommodation)
- Transport infrastructure (e.g. number of airports, railway line density)
- Innovativeness (e.g. share of the population who ordered goods or services over the Internet)

The analysis identified 3 regional archetypes within Europe which can be considered as sub-operating environments (see Figure 5 for a map of the three regional archetypes at EU level and Figure 6 for a map of the regions within Spain, for more information the reader is referred to D3.1 – Scenario definition [39]):

- 1) Advanced urban regions with strong travel activity (e.g. Madrid (ES30), Catalonia (ES51), Île de France (FR10))
 - a) Population: Regions with the highest population and population density (suggesting that these are regions with high development); with a young population (higher share of 0-24 years old range and lowest share of 45+ population),
 - b) Economic indicators: Highest monthly per capita disposable income from all three regions, with high e-commerce and high innovation factors.
 - c) Transport: Highest per capita air and rail traffic per capita among all regions; few number of airports with high average number of passengers, and highest railway line density.
 - d) Trips: Highest air, rail and total trips per capita from all regions; strong preference for rail travel; and very high tourist arrivals.
- 2) Conservative regions with median travel activity (e.g. Galicia (ES11), Aquitaine (FR61), Lazio (IT14))
 - a) Population: Median population; mix of urban and rural regions with old population (highest share of people 45+).
 - b) Economic indicators: Close to highest monthly per capita disposable income; median level of e-commerce with moderate innovators.
 - c) Transport: Low levels of air traffic and medium levels of rail traffic per capita; highest number of airports and median level of railway line density.
 - d) Trips: Median levels of rail and total trips per capita, and below median levels of air trips per capita; second highest number of tourist arrivals.
- 3) Emerging rural regions with low travel activity (e.g. Andalusia (ES61), West Finland (FI19), Southern Region Ireland (IE05))
 - a) Population: Regions with lowest population from the three clusters with low density, indicating rural or peripheral regions; high share of population in the 0-24 age bracket and highest share of 25-44 years old population.
 - b) Economic indicators: Lowest monthly per capita disposable income with a median share of e-commerce; dominated by emerging innovators.
 - c) Transport: Lowest levels of air and rail traffic per capita; high number of airports but below average number of departing passengers by air; the cluster has median levels of railway line density.
 - d) Trips: Lowest levels of air, rail and total trips per capita with a high preference for air travel; and lowest number of tourist arrivals.

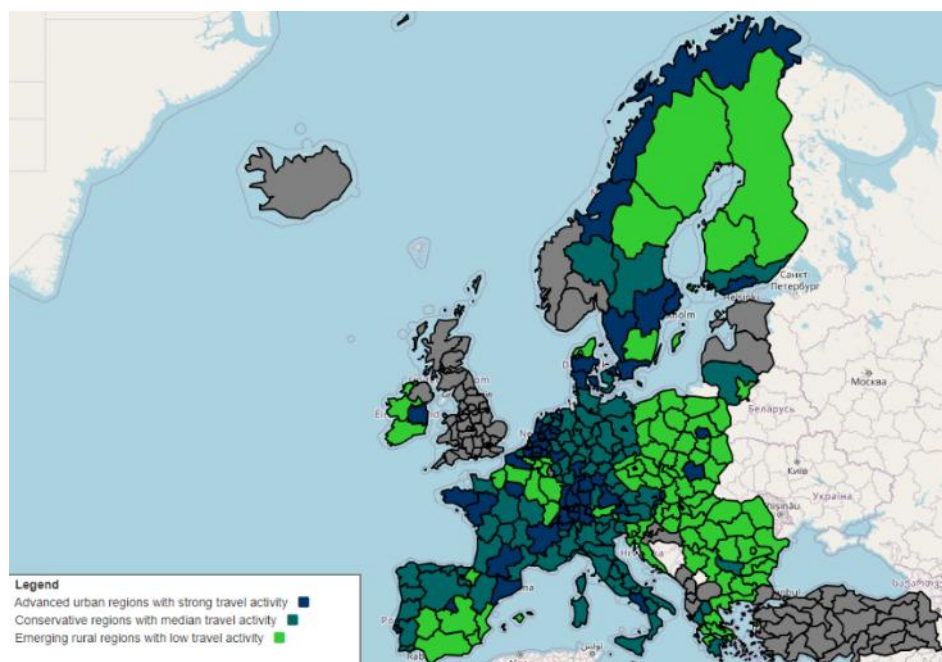


Figure 5: Mapping of clusters of regional archetypes to NUTS2 regions in EU (note – grey regions are not clustered due to lack of data or not part of EU)

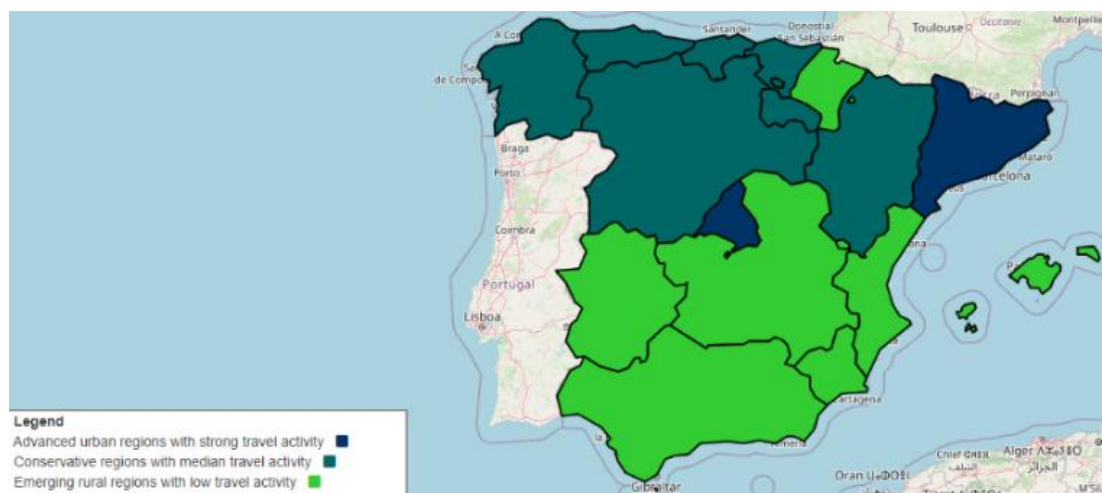


Figure 6: Mapping of clusters of regional archetypes to NUTS2 regions in Spain

3.2.1.3 Multimodality policy packages

Besides the demand characteristics, the development of multimodal networks is strongly influenced by policies. The current and future European regulatory framework and national policy environments are revised and analysed. The individual policies are described in Section 3.2.4 – Applicable standards and regulations: passenger rights and multimodality, limitation of aviation and environmental regulation. These are some of the policies for which SOL399/SOL1 can evaluate their impact on multimodal mobility.

Their impacts on operations are summarised here:

- **Passenger rights and multimodality:** Enhanced multimodal passenger rights might encourage passengers to use these travelling options. However, operators (airlines and rail) might decide to provide itineraries only with sufficient buffers to avoid liability for potential missed connections. Similarly, integrated ticketing which considers operators alliances and rebooking policies might have an impact on the possibility of passengers to use multimodal trips, by reducing the connecting time required between modes (as across check-in processes are assumed to be enhanced).
- **Limitation of aviation:** These policies focus on the banning of short-haul flights when suitable rail alternatives are present. The impact would be a shift of demand from air to rail (or multimodal) and a change on flight demand at impacted airports.
- **Environmental regulations:** In this case it focusses on aspects which penalise aviation economically (e.g. frequent flyer levy, CO₂ taxation) or incentivise rail (e.g. subsidised rail trips). The impact is disincentivising journeys which use air services by making them less appealing from an economic perspective, i.e., the sensitivity of passengers to cost might shift some of the demand to rail (or multimodal alternatives).

As SOL399/SOL1 enables for the evaluation of what-if situations, three policy packages have been defined which group these policies in a meaningful way representing different operational environments, as described in Table 4.

Policy Package	Individual policies definition
Reference (no particular policies)	• Passenger rights and multimodality: No integrated tickets • Limitation of aviation: N/A • Environmental regulations: N/A
Multimodality incentivised	• Passenger rights and multimodality: Fully integrated (respecting alliances) • Limitation of aviation: N/A • Environmental regulations: CO₂ tax applied to emissions
Multimodality enforced	• Passenger rights and multimodality: Fully integrated (respecting alliances) • Limitation of aviation: Short-haul ban if rail available between regions served by flights and rail service faster than a given threshold (2h30) • Environmental regulations: CO₂ tax applied to emissions

Table 4: Example of possible policy packages

3.2.1.4 Disruptions packages

Disruptions in the air and rail network could require the replanning of operations (as suggested by the use of Disruption Management Solution (SOL401/SOL3)). Therefore, it is relevant to identify disruption types that can be used to define operational environments to assess these solutions by the strategic and tactical multimodal evaluators. It is with noticing that the disruptions we are considering in this case need to be *large* and known in advance so that the networks can be replanned. Therefore, these distribution packages will consider things such as rail corridor and airport closures and reduced capacity and ATFM regulations applied at hub airports known when creating the NOP.

3.2.1.5 Infrastructure characteristics

Besides the previously described mobility considerations, different sub-operating environments could be defined by focusing on the infrastructure characteristics: for example, particular infrastructure nodes which are more likely to be part of multimodal connections (e.g. hub airports with rail links to the airport (or nearby)); or collection of infrastructure nodes (airports and/or rail stations) in less connected regions which provide long-distance mobility by connecting these nodes to hubs using multimodal journeys.

3.2.1.6 Summary of operational environment characteristics

As described, there are different aspects that can be considered for the definition of the operational and sub-operating environments. These will be used to create the experiments in the ERP [24] and/or to analyse the results, i.e., focusing on subparts of the network to produce performance indicators that capture the impact of multimodality on those environments. For example, computing indicators focusing on a given infrastructure node (e.g. a hub airport) after modelling a nation-wide mobility network.

The operational environments will, therefore, be a combination of regional archetypes, policy packages, and infrastructure characteristics for strategic analysis of networks, as well as disruption packages for the assessment of the impact of disruptions on the planned networks. The experiments defined in the ERP [24] will have to ensure that the different characteristics of the sub-operational environments can be captured.

3.2.2 Roles and responsibilities

None of the components developed in SOL399/SOL1 is expected to be integrated within the SESAR architecture; therefore, ad-hoc actors interacting with the Use Cases are defined. Note that these actors represent an abstraction of roles and, therefore, can be instantiated by different user; some of them are described here:

- **Multimodal Performance Expert:** In charge of assessing the impact of solutions on multimodal performance (independently of the MultiModX framework), the Multimodal Performance Framework (passenger experience and multimodal performance indicator catalogue) developed in SOL399/SOL1 will be used. This could be relevant for the SESAR capability of Service Delivery Management – Performance Management (operational) – Multimodal Performance Management (Air) as defined in [15], developed in AMPLE3.
- **Multimodality/Passenger Experience Flagship Performance Manager:** Curates the multimodal performance indicator catalogue.

- **Strategic Performance Assessment Expert:** It will broadly include any performance experts interested in multimodal indicators for planned mobility networks. A particular case would be an airline operators' schedule designer who could use the strategic evaluator to assess the schedules of the airline and their integration with rail operations. The strategic evaluator can be used to assess the connectivity provided by services and their possible interaction with rail (ground) mobility, for example, by airline and rail operators, airport management or regional policymakers.
- **Disruption Management Performance Assessment Expert:** For example, Infrastructure managers could assess how changes in the operation of their infrastructure could impact passenger experience (delays and missed connections); airlines and rail operators could assess how replanning their network can support passengers in case of disruptions.
- **Tactical Performance Assessment Expert:** For example, Airport management could use the tactical evaluator to assess the impact of mechanisms to support multimodality on missed connections given the conditions expected for the day of operations. Airlines could assess the robustness of their planned operations and assess their performance with respect to passenger delays and missed connections and, therefore, the potential impact on passenger compensation and rebooking needs.

For a more detailed example of stakeholders for the different roles, see Appendix A – Stakeholders' Identification.

3.2.3 CNS/ATS description

399/SOL1 does not have any impact on the CNS/ATS as it does not modify the tactical operation of flights.

3.2.4 Applicable standards and regulations

The multimodal performance framework defined in SOL399/SOL1 might contribute to the SESAR Performance Framework if some of these indicators are taken forward as part of an updated ATM Master Plan.

SOL399/SOL1 does not require and would not impact standards and regulations as SOL399/SOL1 are standalone transversal evaluation tools. There are assumptions about regulations being in place when assessing multimodality (e.g. the existence of multimodal governance) but not on how to use the models and framework developed within SOL399/SOL1.

The Evaluators (particularly the Strategic Evaluator) can assess the impact of changes in policies enabling the assessment of what-if situations. As presented in 3.2.1.3, there are a set of policies which have a direct impact in multimodality that can be evaluated by SOL399/SOL1. In particular:

- Passenger rights and multimodality: Regulation 261, passenger rights, multimodal digital mobility services, extension of protections for enhanced multimodal passenger rights, and level of integrated ticketing, including operator alliances and rebooking policies.
- Limitation of aviation: Short-haul flight bans.
- Environmental regulations: frequent flyer levy, rail incentivisation, increased CO₂ tax cost.

These policies can be grouped into policy packages as presented in Section 3.2.1.3.

3.2.5 Security assessment

SOL399/SOL1 provides a multimodal performance framework and a set of tools for the evaluation of planned, replanned and simulated (on the day of operation networks). None of these aspects are sensitive to security aspects. The performance framework is just the description of indicators and how these could be estimated, the evaluators are intended, in their current form, to be executed as self-contained independent tools. The input required are not expected (in the current form) to be connected to any security sensitive system, moreover the outcomes produced would be estimations of the impact of the networks (and mechanisms) on the performance indicators. This could allow for what-if assessments but do not produce security critical results either.

If SOL399/SOL1 (or some of its components) are further developed and integrated into production systems, for example as a what-if assessment tool supporting the Airport Operation Centre (APOC), focus should be given to ensure that the ingested data by the models are adequately secured. This is particularly relevant when dealing with potential commercial information (e.g. flight schedules and load factors). The Estimators, being passenger-centric tools, rely on the use of passenger itineraries. In the current version, these itineraries are estimated from the disaggregated demand as computed by the Strategic Multimodal Evaluator. This could be modified in the future by ingesting real data to produce better operational estimations on the impact of replanning of operations, e.g. using the actual passenger itineraries. In this case, the system should consider security aspects related to data protection, anonymisation of passenger itineraries and compliance with General Data Protection Regulation (GDPR).

3.2.6 Previous operating method

Multimodal Performance Framework

In the current operating method, there is a lack of an agreed definition of shared multimodal performance indicators. The Multimodal Performance Framework developed as part of SOL399/SOL1 should help to create this common ground across different SESAR Solutions. This should facilitate the evaluation and benchmarking of different Solutions with respect to passenger mobility (and multimodality in particular). The lack of multimodal performance indicators in the current SESAR Performance Framework is made evident by the limited impact of this (or the other Solutions evaluated in MultiModX (SOL400/SOL2 and SOL401/SOL3) on the SESAR indicators. This, once again, highlighted the need for additional passenger-centric (and broad mobility-related) indicators.

Strategic Multimodal Evaluator

For the Strategic Multimodal Evaluator, many tools, such as commercial trip planners, allow the estimation of possible passenger itineraries. However, these tools do not provide the possibility to analyse mobility (and multimodal) indicators considering different origin-destination demands, infrastructure and supply characteristics (flight schedules and rail timetables). When assessing the mobility and impact of different supply characteristics on mobility analysis, it tends to be ad-hoc, which makes the generalisation and applicability of the models and techniques difficult. There is a lack of tools that consider the impact of replanned operations on passengers with passenger-centric indicators (such as the number of stranded passengers or arrival and departure delay in the door-to-

door context), likewise, it is difficult to assess the impact of different reallocation possibilities for disrupted passengers into the remaining capacity of the multimodal network.

Tactical Multimodal Evaluator

Similar to the Strategic Multimodal Evaluator case, there are limited tools for the assessment of the execution of mobility on the day of operations. Stakeholders do not have a standardised tool to do these types of analyses. Different mobility models focus on particular aspects of the system (e.g. air traffic simulators), but there is no standardised approach to evaluate the robustness and the realisation of flight and rail schedules integrated into a single platform.

3.2.7 New SESAR operating method

Multimodal Performance Framework

For the Multimodal Performance Framework, SOL399/SOL1 aims to provide a catalogue of indicators (with information on how to estimate them) for the three levels previously described. An assessment of the gap between the different levels is also expected to be initiated. This gap assessment will be conducted considering different aspects of the operability of the suggested indicators, reviewing, for example, the availability of data requirements and the geographical scope where the indicator could be computed. This will generate a subdivision within Level 2 with some indicators candidate to be promoted to Level 1 (Level 2.1), and Level 2.2, which contains the rest of the indicators. As previously mentioned, SOL399/SOL1 aims at starting and supporting these activities that should be developed further by the Passenger Experience and Multimodality Flagship.

A first set of indicators was already drafted as an outcome of the ‘Multimodality and passenger experience in the SESAR Performance Framework’ workshop held on 15 January 2025 (at the University of Westminster, London), attended by members of the MultiModX, PEARL, AMPLE3 and SIGN-AIR projects (*inter alia*; and as reported under separate cover). In this workshop, indicators were described based on their Level (Level 1, Level 2 or Level 3), indicator name, definition, why they are relevant to passengers, why they are relevant to ATM, data sources needed to compute/estimate them, their scope and how to develop them further. Note that not all the indicators discussed in the workshop are relevant (or can be implemented) by the Multimodal Performance Evaluator framework (as some of them relate to the more broad ‘Passenger experience’ KPA and are beyond the scope of MultiModX). Table 5 provides an initial list of performance indicators, as available in the digital catalogue:

<https://nommon.atlassian.net/wiki/external/MzA2ZTJmMjU5MDUyNDNIYzlkNDBmNTMwOTRIMDY4MGY>. The implementation of these indicators in MultiModX is part of the open-source repository (<https://github.com/UoW-ATM/MultiModX>). These indicators are compiled from the workshop, a literature review of previous work in the field, and interaction and feedback obtained from stakeholders and other related research projects. As mentioned, these indicators should be further developed in the open-access digital catalogue through the Passenger Experience and Multimodality Flagship and coordinated with other projects, namely, SIGN-AIR [27], MAIA [20], PEARL [25], AMPLE3 [14] and Travel Wise [31]. It is worth noticing that the same indicator could have different variants (e.g. the indicator ‘stranded passengers’ could be the total number or percentage with respect to passengers with connections). These variants might have different maturity levels. Table 5 provides the highest maturity level of these variants per indicator.

Finally, indicators could be grouped in an ad-hoc Multimodality or passenger experience KPA(s), however, in Table 5 they are disaggregated into ATM related KPAs when possible. The idea is that first, it provides higher granularity on the classification of indicators, and second, some indicators relating to multimodality and passenger experience will be, by construction, more passenger-centric and further away from commonly used ATM indicators. These will naturally be at lower maturity level (L2 and/or L3). It is, however, worth it to be kept within the boarder KPAs as that informs the potential evolution of the ATM framework to include these aspects in the future.

KPA	PI Id	PI short name	PI Definition	Type	Highest Maturity Level	Source	Subpage – Indicator definition
Operational Efficiency (OPS)	OPS_PE1	Passengers processing time at infrastructure	Minutes taken to do the process from the kerb to the gate at the airport. The same opposite indicator should be considered 'Gate to kerb' and 'Gate to gate' for connecting passengers.	Strategic	L2.2	'Multimodality and passenger experience in the SESAR Performance Framework' workshop	https://nommon.atlassian.net/wiki/external/NjxZGM1NGJkYjBjNDhhYjlkMWIxMGQzNDFkMjMmMmM
	OPS_PE2	Total journey time	Strategic based on published schedules, actual based on the recorded performance on the day of operations.	Strategic	L3	MultimodX	https://nommon.atlassian.net/wiki/external/OGU00Tk2M2ZjYWQ0NGRIYzk3OGUzM2UzNmJiMDBmZDE
	OPS_PE3	Passengers time efficiency	Best possible journey time (from schedules)/actual time travel (from actual operations) [percentage]	Strategic	L3	'Multimodality and passenger experience in the SESAR Performance Framework' workshop	https://nommon.atlassian.net/wiki/external/MTU2MTcxNzVjOWJiNDIkyjkyZjEyMjYyZWJiMmYxZDQ
	OPS_PE4	Buffers in itineraries	Amount of time used as buffers in connections in itineraries.	Strategic	L3	MultimodX	https://nommon.atlassian.net/wiki/external/ZTRkNTJkN2Q4MzMzNGU4MTg3YTQ1ZmU4NjFkZWl3MjA

	OPS_PE5.1	Arrival delay (flights)	Arrival delay (at thresholds 15, 30, 45 and 60 min).	Tactical	L2.1	'Multimodality and passenger experience in the SESAR Performance Framework' workshop	https://nommon.atlassian.net/wiki/external/NmNhMzNhZTNiOTkwNDQyMmI0NjI0ZGVhYjU0YzUxZmY
	OPS_PE5.2	Total arrival delay at final destination	Difference between planned and actual arrival time at final destination. Could be disaggregated (all passengers, passengers who missed connections, passengers rerouted, etc.).	Tactical	L3	'Multimodality and passenger experience in the SESAR Performance Framework' workshop	https://nommon.atlassian.net/wiki/external/NDE1MjZlZTdhNzY2NDI0OWEwY2ViMzdiOWQ4MzAyMzk
	OPS_PE6	Cancellations due to ATFM	Percentage rate.	Tactical	L2.1	'Multimodality and passenger experience in the SESAR Performance Framework' workshop	https://nommon.atlassian.net/wiki/external/YmRIOTMxMGRkMTEzNDk2MzgwNzRiMmZiMGFIMzgwODc
	OPS_PE7	Reactionary delay	Minutes of delay of reactionary delay due to ATFM.	Tactical	L2.1	'Multimodality and passenger experience in the SESAR Performance Framework' workshop	https://nommon.atlassian.net/wiki/external/NWI0MmI3MmE2MzQzNGRiYTgxNGVjZTA5NjE1MThmNzk

	OPS_PE8.1	Stranded passengers	Percent of pax not reaching their destination.	Tactical	L2.2	MultimodX	https://nommon.atlassian.net/wiki/external/YmVmNTI5YzYwYTlzMNDU2MTkyYzRmMGJkZmNmODQ1MTA
	OPS_PE8.2	Ratio of stranded passengers	Ratio of passengers stranded over number of passengers missing their connection.	Tactical	L3	'Multimodality and passenger experience in the SESAR Performance Framework' workshop	https://nommon.atlassian.net/wiki/external/MjMzZGVhY2QxMjQ5NGExMGFjMzYzZGNiN2ZiMiM5NDE
	OPS_PE8.3	Stranded passengers	Percentage of passengers not reaching their destination due to replanning.	Replanning	L3	MultimodX	https://nommon.atlassian.net/wiki/external/MjY4YjdiYWlxODViNGRlZWJjMGQ3ZThiZTI3MTU1MGE
	OPS_PE9	Missed connections	Percent of pax with missed connection (can be disaggregated by type of connection inter/intra-mode)	Tactical	L3	'Multimodality and passenger experience in the SESAR Performance Framework' workshop	https://nommon.atlassian.net/wiki/external/MDEyYzEyYTEyNzY3NDYyZWZkZmMmRlNjg5N2RlMTc
Interoperability (INT)	INT_PE1	Modal share	Share of transport modes in passenger itineraries on a specific origin-destination pair [percentage per mode(s)]	Strategic	L3	MultimodX	https://nommon.atlassian.net/wiki/external/ZTU4ZGRlMTk2MTkxNDgxZmE1MDU4ZWZlOWE4MjBmYTg

	INT_PE2	Seamless of travel (time)	Journey transition time (between modes and stops) [mins]	Strategic	L3	MultimodX	https://nommon.atlassian.net/wiki/external/NWYyNGE3OWVjNTdINGY0ZTg5ODc2MmUzNWQ1NGMyZjM
	INT_PE3	Infrastructure connectivity	Volume of passengers that are connecting at a given infrastructure node	Strategic	L2.2	MultimodX	https://nommon.atlassian.net/wiki/external/NGQxM2Y3MDI0NTNmNDUwYzk0YTlhYjZYTlYzDU0YWQ
Flexibility (FLX)	FLX_PE1.1	Resilience alternatives	Number of strategic (planned) and tactical (actual) alternatives available for a given origin-destination pair.	Strategic	L3	'Multimodality and passenger experience in the SESAR Performance Framework' workshop	https://nommon.atlassian.net/wiki/external/NTBIMzQ5NmQ4ZDFmNDQyMzk1YWRhMzg5ODc5ZjFIZTU
	FLX_PE1.2	Passenger Resilience replanned	Difference between planned and replanned itineraries	Replanning	L3	MultimodX	https://nommon.atlassian.net/wiki/external/NWY5MzExZW4N2JhNGExNmJiZTg5NDc5MDRIZTUzMWU
	FLX_PE2	Diversity of destinations	Number and type of destinations which can be reached from an origin	Strategic	L3	MultimodX	https://nommon.atlassian.net/wiki/external/YmJiNzYyNDJlMDJhNGFjZDk5MzgyNTVhMjE5YzU2MTI
	FLX_PE3	Resilience replanned	Captures applied changes/adaptations in the replanned schedules: -rerouted train services	Replanning	L3	MultimodX	https://nommon.atlassian.net/wiki/external/NTkxMjBiN2ZmM2Y5NDYxNDlmN2Y5Y2RmOWI1MzhlOTg

			-diverted flights -replacement services -retimed/delayed services				
Cost-Efficiency (CEF)	CEF_PE1	Direct operating cost per user	Operating cost per trip per user [Euros]	Strategic	L3	MultimodX	https://nommon.atlassian.net/wiki/external/MGI2ZmFjMzIIZmUxNGFjZGE0Zml3NWFKOTE1YTRmNWM
	CEF_PE2	Load factor	Number of passengers over number of seats per operator / mode / total	Strategic	L3	MultimodX	https://nommon.atlassian.net/wiki/external/OGIzMDc4ZTJmY2YwNDEwMml4YWVmY2JlYWM2ZGY0NTc
Capacity (CAP)	CAP_PE1	Demand served	Number of passengers that are assigned to itineraries over the total number of passengers who want to travel between a given origin-destination pair.	Strategic	L3	MultimodX	https://nommon.atlassian.net/wiki/external/YjYxYjcwZmFhYzUyNGQ2MmE5MTYyMTE0YzE3MjBmZTc
	CAP_PE2	Catchment area of airports	Distance of ground mobility (e.g. rail) from which an airport captures demand. Could be normalised	Strategic	L3	'Multimodality and passenger experience in the SESAR Performance	https://nommon.atlassian.net/wiki/external/ZDUxMDIjMjUxYWMzNGYxNDliMWZhZDhIN2ZiZDc1YWU

			by passengers using that distance.			Framework' workshop	
	CAP_PE3	Capacity available	Number of seats available between a given origin-destination pair.	Strategic	L3	MultimodX	https://nommon.atlassian.net/wiki/external/ODFhMmYwZGFmOTNkNDIwOWFiMjEzOTM1YzA0YWU0NGM
Environment (ENV)	ENV_PE1	CO ₂ emissions	Total emissions of services used (could be normalised by passenger-km considering the demand served)	Strategic	L3	MultimodX	https://nommon.atlassian.net/wiki/external/MWFiZWY2Yjc1ZDc5NGFIMWE5ZmY2OWY2ZDczMWJINTU
Predictability (PRED)	PRED_PE1	Variability	Share of passengers arriving late (within pre-defined time slot) [percentage]	Tactical	L3	MultimodX	https://nommon.atlassian.net/wiki/external/Mzk1Mzg1MWRIZTFjNDNmYWYyOGRiYTVhZWUyMTIzYmQ

Table 5: Digital catalogue of indicators summary

Strategic Multimodal Evaluator

The Strategic Multimodal Evaluator provides a platform with flexibility to adjust parameters (e.g. connecting times between modes and infrastructure) and with calibrated models which enables the evaluation of new schedules, timetables and policies with minimum intervention. The model is provided as open-source (<https://github.com/UoW-ATM/MultiModX>). The user is expected to provide information on the planned network, which includes:

- Supply information:
 - rail timetables (GTFS format),
 - flight schedules,
 - list of alliances between operators (air and/or rail) which allow the creation of integrated multi-leg trips
- Infrastructure data:
 - Regions with information on infrastructure (airports and/or rail stations) that can be accessed from them. This should include information on average access and egress times.
 - Minimum connecting times (MCT) intra and inter-mobility layers, i.e., the time required to travel from rail stations to airports (and vice-versa) and to connect between flights (at airports) and between trains (at rail stations)
- Demand information:
 - Number of passengers between regions (origin-destination demand) per passenger archetype.

Besides these, the user should provide also information on the policy package to use (if any) and the configuration parameters of the Strategic Evaluator. All these elements combined (planned network, policy package and configuration parameters) will define the strategic experiment being analysed.

For a detailed data format required by the evaluator, see Appendix A in FRD [23]. Note that the evaluator allows the use of simplified data, e.g. instead of defining regions of origin and destination, one could use directly infrastructure nodes, e.g. from airport to airport. Note that the user can provide any data as long as it respects the format defined in Appendix A of the FRD [23]. However, historical datasets are expected to be used to analyse realistic networks. See Appendix C for a list of the required inputs with examples of sources used to generate them.

The Strategic Multimodal Evaluator automatically computes possible and potential paths and the n-fastest possible itineraries between each origin and destination (by default, set to 50). For each alternative, performance indicators relevant to the passenger selection process are estimated: total travel time, cost, emissions, waiting time, number of services used, and journey type (air, rail or multimodal).

These possible itineraries are then filtered (considering Pareto dominance based on their performance) to avoid non-realistic alternatives and then clustered into equivalent alternatives for passengers. This reduces the number of alternatives per origin-destination following a data-driven approach.

Finally, a logit model is used to distribute the demand between the different alternatives. Note that these alternatives represent a group of itineraries. The logit model calculates the probability of choosing a specific alternative for each passenger archetype when presented with several options for

travelling between a given OD pair; see [23] for more details. Therefore, the obtained result is a flow of passengers who would like to use any of the individual itineraries of each cluster.

This output can be used by MultiModX's SOL400/SOL2 to estimate the preferences of passengers and optimise the schedules of flights and rail, as shown in Figure 2.

The Strategic Multimodal Evaluator's final step is to disaggregate passengers' flow into the individual services (flights and trains), considering their capacities.

Therefore, the outcome of the Strategic Multimodal Evaluator is a planned network composed of the supply characteristics (flight schedules, rail timetable, alliances), infrastructure details, and individual passenger itineraries, and the possible itineraries between regions. These datasets can then be processed to compute a set of mobility indicators (see Table 5), such as expected travelling time between regions, waiting time, reliability of connections, centrality and connectivity of infrastructure nodes.

As shown, the Strategic Multimodal Evaluator allows the assessment of many different factors, such as policies (e.g. short-haul flight ban, taxation), as these will impact the expected cost and, therefore, the probability of selecting itineraries by passengers (e.g. frequent flyer levy, CO₂ emissions cost, rail incentive), changes in infrastructure (e.g. improved MCTs, closure of links), etc. These changes will create different strategic experiments, which will then be analysed, creating their associated performance indicators (see Table 5).

Finally, the same components enable the assessment of replanned operations. By providing updated flight schedules and rail timetables, the Strategic Evaluator can compute which passengers are impacted by this replanning. Note that the replanning could be optimised or just considering the impact of a given disruption (e.g. cancelling services operating through a closed link, or delaying flights according to a planned ATFM regulation). The Strategic Evaluator will be able to estimate which passengers are affected by the replanning but just delayed and which ones need to be reaccommodated (either because one (or several) of their planned services are cancelled or because their connections are not possible with the replanned operations). For the latter, alternative paths are found. This is done considering the capacity of the system and the information on the planned itineraries (e.g. initially planned arrival time). The user can provide different configurations to define how this replanning should be conducted, i.e. considering different levels of flexibility, from maintaining mode, path and operators, to allowing passengers to select different modes following different paths, as long as they reach the final destination. This process enables the creation of replanned networks with updated flight schedules and/or rail timetables, which can be provided as cancellation of services, delayed operations and/or addition of services.. This enables the evaluation of replanning tools to deal with network-wide disruptions, such as the Disruption Management Solution (MultiModX's SOL401/SOL3).

Tactical Multimodal Evaluator

The Tactical Multimodal Evaluator extends the Mercury ABM model to multimodality [17, 18, 30].

Mercury is an open-source flight and passenger mobility model developed over 10 years on several SESAR ER projects (<https://github.com/UoW-ATM/Mercury>). The model follows an Agent-Based approach describing with Agent and Roles the main components of ATM. As shown in Figure 7, it includes:

- Airline Operating Centres (AOC), usually referred as Flight Operating Centre (FOC), which manage the airline fleet and passengers,
- Airport Operating Centre (APOC), which provides information on airport operations (turnaround),
- Airport Terminal, providing passengers-associated activities (e.g. gate-to-gate transfer times),
- Flight, to represent and simulate flight operations,
- Network Manager, which can model ATFM regulations,
- E-AMAN and DMAN to manage runway capacities,
- Radar to disseminate flight positions to relevant entities (e.g., E-AMAN).

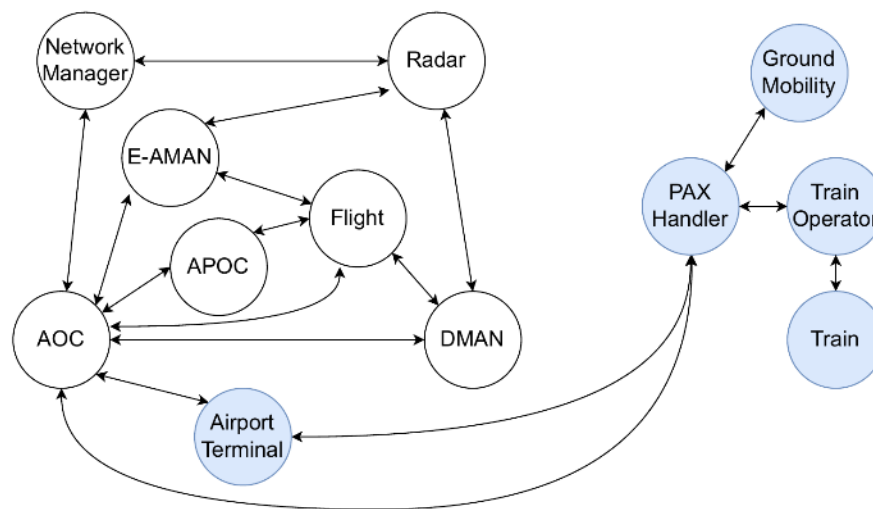


Figure 7: Tactical Evaluator model

Mercury uses an event-driven engine to simulate the main processes and can track individual flights and passengers, capturing their delays (e.g. reactionary delays for flights and missed connections for passengers). A full day of ECAC-wide operations (around 27K flights and 3M pax) can be simulated in under 25 minutes.

A different gate-to-gate platform could have been used as the base for the development of MultiModX's Tactical Evaluator, but Mercury, being open-source and already documented provided already gate-to-gate flight and passenger itineraries modelling capabilities that could be extended to include full multimodal journeys. Note that the **Tactical Multimodal Evaluator developed by extending Mercury is not a technical platform used for the validation of SOL399/SOL1, but it is one of the core elements of the Solution**, i.e., it is the evaluator which enables the assessment of the realisation of the multimodal network on the day of operations. As it is described in the functional requirements, it supports the evaluation of a day of operations and the evaluation of mechanism to manage delay a disturbances in the system. This is one of the standalone tools developed to evaluate multimodality within SOL399/SOL1.

As described in Figure 7, the gate-to-gate model is extended in the following way:

1. The Airport Terminal Agent includes processes to estimate the kerb-to-gate and gate-to-kerb for multimodal passengers.

2. The Train Operator and Train simulate the arrival and departure of trains to the rail stations where multimodality is enabled. The Train Operator could also reallocate passengers to subsequent trains in case of missed connections.
3. The Ground Mobility agent provides estimations and realisation of times to transfer between air and rail infrastructure.
4. The Pax Handler agent proactively captures the decision-making process of passengers (or travel companions) to rebook passengers for subsequent flights or train services.

The model's by-default version represents 'basic' multimodal operations, i.e., multimodal passengers are treated like other passengers. The passengers have the responsibility to rebook their trip if they missed (or are deemed to miss) their connection except rebooking a missed flight at the gate where the decision is delegated to the AOC, as in the case of air-air connections, which are the airline's responsibility. The flexibility of the model enables its extension by creating Modules (which can change the behaviour of Roles) or with External Communications of the model with an external system. This allows, for example, the evaluation of multimodal supporting mechanisms by modifying the by-default behaviour of the agents. For example, modelling a fast-track at the airport to process delays multimodal passengers modifying the Airport Terminal Agent [30] or any other Solutions which impact operations, such as Dynamic Cost Indexing and actively delaying flights to wait for passengers [18]. Overall, these mechanisms and Solutions tend to be reactive.

The input into the Tactical Multimodal Evaluator is the output of the Strategic Multimodal Evaluator (flight schedules, rail timetable, individual passenger itineraries) and information on the disturbances/disruptions that are evaluated (e.g. delays) as represented by 'Other Supply aspects' in Figure 8. Note that the input can be either an originally planned network or a replanned network considering disruptions, e.g., optimised flight schedules and rail timetable considering the outcome of a tool such as Disruption Management Solution (MultiModX's SOL401/SOL3). As shown in Figure 8, a functionality enables the translation of the output of the Strategic Planned Network into the input required by the Tactical Multimodal Evaluator. This is needed as the Tactical Multimodal Evaluator requires some inputs ('Other operational data' in Figure 8) that are not relevant to the Strategic Multimodal Evaluator (e.g. aircraft performance-related aspects such as MTOW or WTC of the aircraft used to operate the schedules). The inputs required by the Tactical Multimodal Evaluator, along with its configuration, will define a tactical experiment.

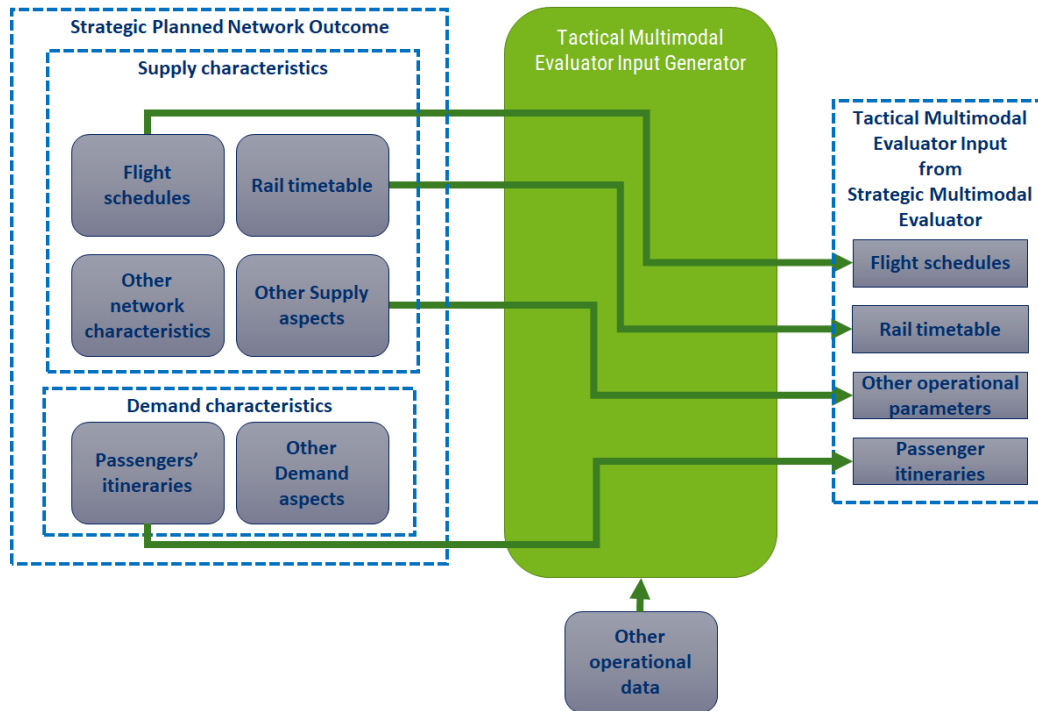


Figure 8: Tactical Multimodal Evaluator input generation from Strategic Multimodal Evaluator output

The output of the Tactical Multimodal Evaluator is the realisation of the itineraries and services throughout the day. Note that the Tactical Multimodal Evaluator model is a stochastic simulator. Therefore, the same configuration must be executed several times to assess the targeted performance indicators (e.g. number of passengers missing connections) statistically significantly.

3.2.7.1 Use cases

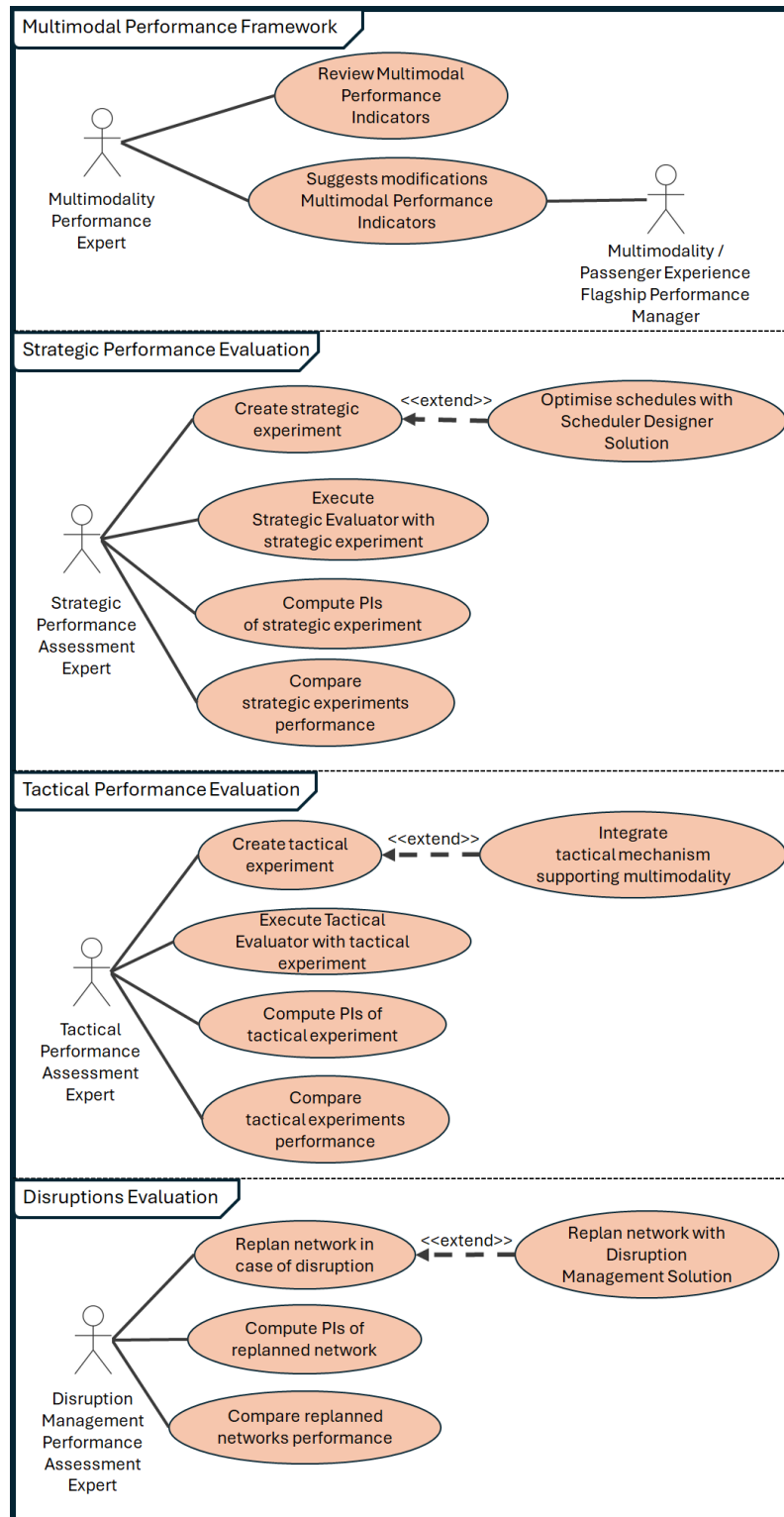


Figure 9: SOL399/SOL1 – Use Cases diagram

Figure 9 presents the use cases diagram for the different components of SOL399/SOL1. Due to the length of their detailed description, the Use Cases are presented in Appendix D – Use Cases Description. Table 2 presents a brief description of the use cases. As shown, even if SOL399/SOL1 is composed of three elements (Multimodal Performance Framework, Strategic Multimodal Evaluator and Tactical Multimodal Evaluator), from a usage perspective, it can be divided into four aspects: Multimodal Performance Framework, Strategic Multimodal Evaluation, Tactical Multimodal Evaluation and Disruptions Evaluations. These capabilities (potential usages) provided by SOL399/SOL1 will be clearer with Figure 10 and its associated details below.

Aspect	Use Case	Actors	Brief description
Multimodal Performance Framework	Review Multimodal Performance Indicators	Multimodal Performance Expert	The Multimodal Performance Expert wants to consult the information on multimodal performance indicators at Level 1, Level 2 and/or Level 3.
Multimodal Performance Framework	Suggest modifications Multimodal Performance Indicators	Multimodal Performance Expert Multimodality / Passenger Experience Flagship Performance Manager	The Multimodal Performance Expert wants to suggest a modification to the multimodal performance indicators catalogue so that the catalogue can be updated accordingly.
Strategic Performance Evaluation	Create strategic experiment	Strategic Performance Assessment Expert	The Strategic Performance Assessment Expert provides information on the supply, infrastructure, demand characteristics and policy packages to be applied to create a strategic experiment. It can modify the parameters that define the parameters of the strategic experiment to create a new version of the experiment, including applying the Schedule Desing Solution (SOL400/SOL2) to optimise the schedules.
Strategic Performance Evaluation	Execute Strategic Evaluator with strategic experiment	Strategic Performance Assessment Expert	The Strategic Performance Assessment Expert provides information on the strategic experiment to generate the planned network, and the potential and possible paths, possible itineraries and their clusters of equivalent itineraries, and the passenger flows between the different origin-destination pairs.
Strategic Performance Evaluation	Compute PIs of strategic experiment	Strategic Performance Assessment Expert	The Strategic Performance Assessment Expert computes multimodal strategic performance indicators (particularly passenger-focus indicators) on the outcome of the Strategic Evaluator (planned network and other outputs of the Strategic Evaluator) for a strategic experiment.

Strategic Performance Evaluation	Compare strategic experiments' performance	Strategic Performance Assessment Expert	The Strategic Performance Assessment Expert compares the multimodal strategic performance indicators of a set of strategic experiments.
Tactical Performance Evaluation	Create tactical experiment	Tactical Performance Assessment Expert	The Tactical Performance Assessment Expert provides a planned network (flight schedules, rail timetable, individual passenger itineraries and infrastructure data) and tactical configuration parameters as specified in Annex A in FRD [23], together with information on (any) disruptions at airports (e.g. in the form of ATFM regulations at airports).
Tactical Performance Evaluator	Execute Tactical Evaluator with tactical experiment	Tactical Performance Assessment Expert	The Tactical Performance Assessment Expert runs the simulation carried out by the Tactical Evaluator using the input prepared by use case 'Create tactical experiment'. The output of the Tactical Multimodal Evaluator is the realisation of the itineraries and services throughout the day in the format specified in Annex A in FRD [23]. Note that Tactical Multimodal Evaluator is a stochastic simulator. Therefore, the same configuration must be executed several times to obtain statistically significant results.
Tactical Performance Evaluator	Compute PIs of tactical experiment	Tactical Performance Assessment Expert	The Tactical Performance Assessment Expert computes the multimodal tactical performance indicators (particularly passenger-focus indicators) on the simulated tactical experiment.
Tactical Performance Evaluator	Compare tactical experiments' performance	Tactical Performance Assessment Expert	The Tactical Performance Assessment Expert compares the multimodal tactical performance indicators of a set of tactical experiments.

Disruptions Evaluation	Replan network in case of disruption	Disruption Management Performance Assessment Expert	The Disruption Management Performance Assessment Expert applies a disruption package to a planned network to create a new planned network (replanned network). Note that the outcome is a planned network and therefore it could be tactically evaluated to see how it materialises (see 'Create tactical experiment ' Use Case).
Disruptions Evaluation	Compute PIs replanned network	Disruption Management Performance Assessment Expert	The Disruption Management Performance Assessment Expert computes multimodal replanning performance indicators (particularly passenger-focus indicators) on the replanned network. Passengers impacted by the replanned operations are identified and, if needed, reaccommodated following the expert preferences, i.e., the flexibility allowed to reaccommodate passengers. Aspects related to the impact of the replanned operations on the passenger itineraries are estimated, such as extra travel time with respect to the initial planned itinerary, shift between planned and replanned mode, or demand not fulfilled. Note that if the Disruption Management Performance Assessment Expert wants to evaluate the realisation of the replanned network, they should use the available Use Cases for the 'Tactical Performance Assessment Expert', as the replanned network is a planned network and therefore can be assessed tactically.
Disruptions Evaluation	Compare replanned networks' performance	Disruption Management Performance Assessment Expert	The Disruption Management Performance Assessment Expert compares the multimodal replanning performance indicators of a set of replanned networks.

Table 6: Use Cases summary for SOL399/SOL1.

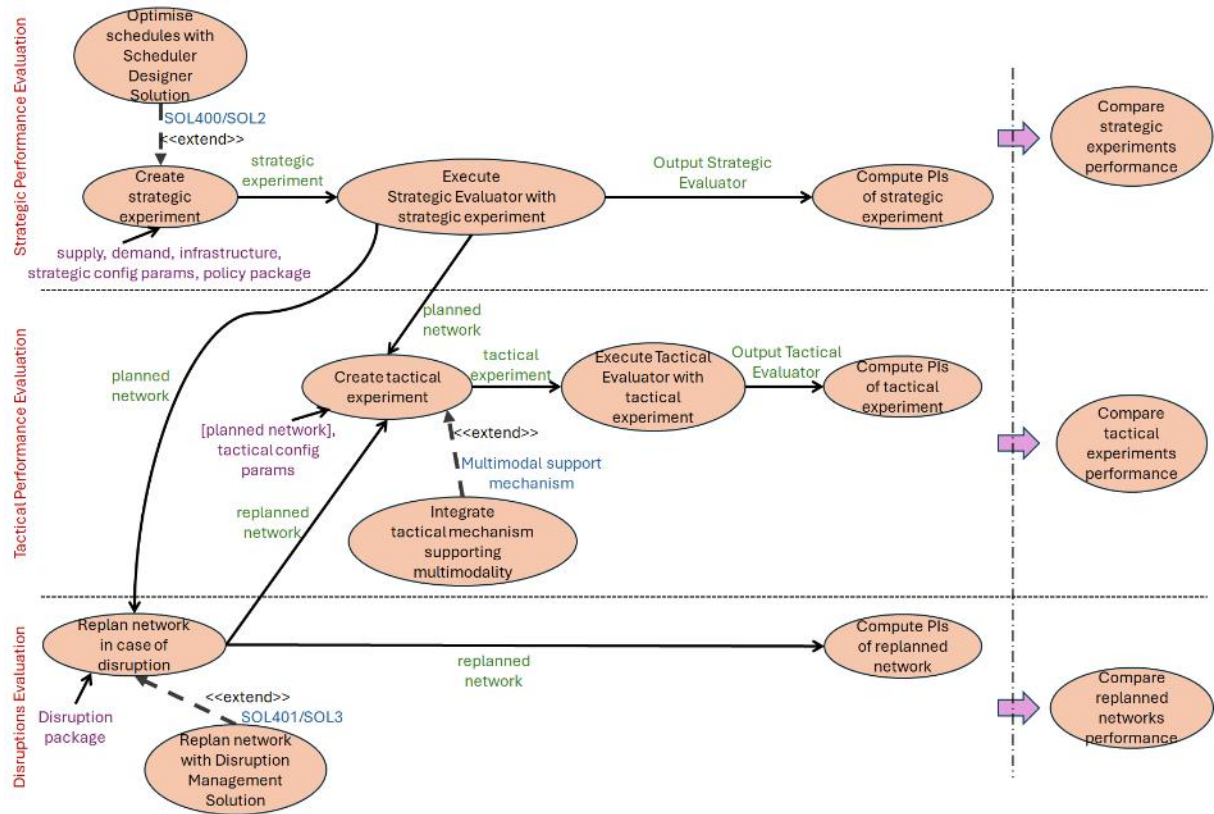


Figure 10: High-level possible interaction between Use Cases of SOL399/SOL1

As described in Table 2 and in detail in Appendix D, the Use Cases of SOL399/SOL1 relate to each other to enable the functionalities of reviewing the multimodal performance framework, evaluating strategically and tactically a mobility network and assessing the impact of disruptions with network-wide impact. Therefore, even if each Use Case can be executed independently (as long as their preconditions are met), Figure 10 provides a high-level overview of their interactions. For a detailed description of the Use Cases with a detailed description of the preconditions, minimal guarantees, success guarantees, trigger, main success scenario and possible extensions, and the data required and generated, the reader is directed once again to Appendix D. Here a high-level view is provided of the main flows that could be used for the three aspects of Strategic Multimodal Evaluation, Tactical Multimodal Evaluation and Disruptions Evaluations; therefore not all the data and processes are described.

Strategic Multimodal Evaluation

- To strategically evaluate a network, the Use Case ‘Create strategic experiment’ is first executed. The supply, demand, infrastructure, strategic configuration parameters and policy packages to be applied are used as inputs (as described in purple in the diagram). The outcome would be a *strategic experiment*. SOL400/SOL2 Schedule Optimiser can then be assessed by replacing the supply characteristics (flight schedules and rail timetables) with the outcome of executing the pertinent Use Case of SOL400/SOL2, so that a strategic experiment where the outcome of SOL400/SOL2 is used instead of the original flight schedules and rail timetables. Note how different *strategic experiments* can be created, for example, by applying different

policy packages or by modifying some of the network characteristics (e.g. minimum connecting times). This allows the creation of different ‘what-if’ *strategic experiments*.

- The ‘Execute Strategic Evaluation with strategic experiment’ Use Case uses the information embedded in a *strategic experiment* to execute the Strategic Evaluator pipeline, as shown in the planned network section of Figure 2 and Figure 3. The outcome is, therefore, a *planned network* (where passenger itineraries are created) and *other outputs of the Strategic Evaluator* (such as potential and possible paths, possible itineraries, a cluster of itineraries, passenger flows (volume of passengers who would like a given cluster of itineraries)). These other outputs are useful for performance analysis (e.g. computing the potential connectivity of regions) and for other Solutions (e.g. SOL400/SOL2 could consider some of these, e.g. passenger flows, as part of their optimisation).
- The outcome of the Strategic Evaluator can be used then by the ‘Compute PIs of strategic experiments’ to compute multimodality strategic performance indicators; and as different *strategic experiments* can be created from the same original supply, demand and infrastructure, the different performance indicators can be compared across the different *planned networks* with the ‘Compare strategic experiments performance’ Use Case. This allows, for example, the Strategic Performance Assessment Expert to assess the benefits of SOL400/SOL2 by comparing the *strategic experiments* with and without the use of the ‘Optimise schedules with Scheduler Design Solution’ extension when creating the *strategic experiments*.

Tactical Multimodal Evaluation

- The *planned network* created by the ‘Execute Strategic Evaluator with strategic experiment’ can be further evaluated by the Tactical Performance Assessment Expert, who will assess how it materialises on the day of operations. For this, the ‘Create tactical experiment’ is used. This Use Case allows the creation of *tactical experiments* which, if required, transform the *planned network* into the format needed by the Tactical Multimodal Evaluator. Note how an ad-hoc planned network not generated from a *strategic experiment* could also be used. Other tactical configuration parameters required by the Tactical Evaluator must be provided to generate the *tactical experiment*. Different *tactical experiments* can be generated from the same planned network, creating ‘what-if’ tactical networks as with the ‘Create strategic experiment’ Use Case. For example, activating Modules to implement multimodal supporting mechanisms such as ‘fast-track’ at airports or providing different levels of disturbance to be assessed. Air network disruptions (ATFM regulations at airports) can also be provided as input when creating *tactical experiments*.
- The ‘Execute Tactical Evaluator with tactical experiment’ Use Case uses the information from the tactical experiment to execute the Tactical Multimodal Evaluator; see Figure 4 and Figure 7. The stochasticity of the Tactical Evaluator requires the *tactical experiment* to be executed *n* times so that statistically representative results can be obtained.
- The outputs of the Tactical Evaluator can then be used by the ‘Compute PIs of tactical experiment’ Use Case to generate the required multimodal performance indicators. Finally, as in the case of the strategic assessment of the network, as several *tactical experiments* can be created from the same original planned network, a comparison of their results can be carried out with the ‘Compare tactical experiments performance’ Use Case.

Disruptions Evaluation

- To assess disruptions which have an impact on the network, the 'Replan network in case of disruption' Use Case is used. The input is a planned network and the disruption package to be applied to the network. These disruptions are assumed to be known ahead of time (see assumption A10). Therefore, the planned network can be adjusted (flight schedules and rail timetables modified to consider the impact of the disruptions). The network can be replanned in different ways, from just cancelling and delaying services to deal with the disruption to providing additional capacity (new services), or by using SOL401/SOL3 Disruption Management Solution to modify the flight and/or rail timetables.
- The Strategic Evaluator will compute which passengers are impacted by the replanned operations, and for those who cannot fulfil their journey (due to cancellations or missed connections), find alternatives which consider the available capacity and parameters which define the flexibility for their potential rebooking. This will depend on the level of integrated ticketing considered and of factors that the expert running the solution might want to assess (e.g. enabling departing the origin before planned, maintaining (or not) the path used). Therefore, given a planned network, different replanned networks can be generated.
- The A replanned network will, therefore, include information on which passengers have been rebooked. Some performance indicators can then be directly computed based on this replanning (e.g. number of passengers stranded, departure and arrival delay). This is done by the 'Compute PIs of replanned network' Use Case; and as in the strategic and tactical case, as several replanning could be done, the performance of these alternatives can be compared among them with the 'Compare replanned networks performance' Use Case.
- Finally, as the *replanned network* has the same format/components as a *planned network*, it is possible to instantiate the network on the day of operations to see how it materialises. This means that the outcome of the 'Replan network in case of disruption' can be used as input to 'Create a tactical experiment', which can then be evaluated as any other *tactical experiment*. The only thing to consider is that the Tactical Evaluator is only able, in its current form, to model ATFM regulations (air network disruptions). Therefore, the impact of rail network disruptions must already be incorporated into the replanned rail timetables. The 'Compute PIs of tactical experiments' will use the information on the replanning (e.g. which itineraries were originally planned by the passengers) when computing the indicators (e.g. computing the total arrival delay with respect to the itinerary used, but also with respect to the initially planned itinerary).

3.2.8 Differences between new and previous operating methods

As a standalone Solution with applicability across a diverse range of operational environments and supporting the evaluation of other SESAR Solutions, SOL399/SOL1 provides tools for additional evaluation of Solutions which are not currently available.

Multimodal Performance Framework

A shared set of multimodal strategic and tactical PIs and KPIs are provided in the digital catalogue. Other SESAR Solutions could evaluate these.

Strategic Multimodal Evaluator

A platform to evaluate mobility and strategic multimodal PIs and KPIs is provided. This enables the assessment of schedules and timetables from a multimodal perspective.

Other SESAR Solutions that impact the schedules (including replanning of operations) and/or infrastructure (e.g., MCTs) could use this platform to evaluate their impact.

Tactical Multimodal Evaluator

The Tactical Multimodal Evaluator enables the simulation of a day of operations, including passenger and multimodal components. SESAR Solutions, which modify flight performance, support passenger or airport operations, or manage disruptions by replacing operations, could assess their impact from a mobility perspective.

4 Key assumptions

The table below describes and justifies all the assumptions MultiModX's SOL399/SOL1 considers with respect to the operational environment.

These assumptions are divided between common assumptions, assumptions specific to the Multimodal Performance Framework, assumptions specific to the Multimodal Evaluators, Strategic Evaluator, with its components, and Tactical Evaluator in the FRD document of this Solution, see [23] for these classifications.

ID	Title	Description	Justification	Impact Assessment
A3	Passenger archetypes coverage	It is assumed that the set of passenger archetypes considered represents the entirety of travellers, as required for the disaggregation of demand by the Strategic Evaluator.	Extensive research has been conducted to ensure that those passenger archetypes represent the variety of travellers.	Medium
A4	Data availability	It is assumed that the required data (demand for each passenger archetype, travel times, infrastructure capacity, passenger preferences, distribution of delays and disruptions, etc.) are available in the regions under study. Appendix C summarises the different data sources considered by the Estimators. These are further detailed in Appendix A of the FRD. For the multimodal consideration the main datasets considered include: - Demand between regions by archetype. - From an infrastructure accessibility perspective: average door-to-airport, airport-to-door, door-to-rail_station, rail_station-to-door, which infrastructure nodes are accessible from which region (NUTS). - From an infrastructure management perspective: minimum connecting times, passenger processing times (kerb-to-gate, gate-to-kerb, kerb-to-platform, platform-to-kerb).	Data are required to execute the Strategic and Tactical Evaluators, but modelling assumptions can be established if needed.	Medium

		- From providers perspective: flight schedules, rail timetable, seats available per service, alliances between modes which allow the connection of passengers between them, itineraries costs and emissions.		
A5	Existence of multimodal governance	It is assumed that a multimodal performance scheme and multimodal governance are in place, allowing cooperation between modes of transport in particular between rail and air operators. This includes the sharing of data: - between modes: flight schedules, rail timetable, seats available per service, alliances between modes which allow the connection of passengers between them, itineraries costs and emissions. - if integrated ticketing in place, then by how much connecting time are reduced.	The project is interested in studying the impact of a multimodal and collaborative framework. Therefore, the requirements on data exchanges and availability are out of scope of MultiModX. It is assumed that all the required agreements between parties for data sharing and implementation of ticketing are in place.	High
A7	Coordination between air and rail	The Strategic Evaluator considers the rail and air network, leaving aside other long-distance ground transportation modes such as long-distance buses.	The scope and focus of the project is on air and rail collaboration. For future projects, it would be interesting to include road transport.	Medium
A10	Disruption knowledge	It is assumed to have information on the disruption impacting the operations. This assumption can be relaxed as required.	The Evaluators need to know the information on the external disruption and disturbances for their evaluation.	Low

A11	Close system evaluation	It is assumed that paths, itineraries and strategic and tactical alternatives are considered within the schedules, timetables and paths available in the case study model.	The input of the Strategic and the Tactical Evaluator will consider the network defined in the case studies. Therefore, the scope to compute alternatives and to assess the performance is limited by the scope of these networks.	Medium
A12	Itineraries performance equivalence	It is assumed that itineraries with similar total travel time, total cost, total emissions, number of connections and modes are equivalent.	The passenger archetypes are considered sensitive only to these parameters and, therefore, not impacted by other factors (see A13).	Medium
A13	Passenger archetype sensitivity	It is considered that passenger archetypes are sensitive when selecting an itinerary to total travel time, total cost, total emissions and modes of transport (air, rail, multimodal); and possibly to number of connections, total waiting time and buffers and modes.	Total travel time, total cost, total emissions and mode of transport are the key factors influencing the passenger preference for the different alternatives. This is subject to be reviewed and improved in further versions.	Medium
A14	Equivalence of alternatives when planning network	All itineraries within a given cluster (equivalent as defined by A12) are considered equivalent, and passengers are assigned to individual services with the objective of maximising the total number of passengers served.	As per A12 and A13, the passengers are considered not sensitive to parameters not considered in the cluster definition. Therefore, any itinerary within the cluster of equivalent itineraries is considered	Low

			usable by the passengers from the flow assigned to that cluster.	
A15	Equivalence of alternatives when replanning itineraries	For passengers impacted by a disruption, it is assumed that they no longer consider their preferences in terms of cost, emissions and travel time. All alternatives which take them to their final destination are valid as long as they meet the constraints imposed in the replanning (e.g. maintain (or not) the mode, path, etc.). The objective is to assign the maximum volume of passengers so they can reach their final destination, with the possibility of considering the minimisation of the difference with respect to their initially planned arrival time.	When reassigning passengers being impacted by a disruption in updated flight schedules and rail timetables, the passenger is already on the day of travel (or close). Their preferences were considered when planning the network (before the disruption), but now they just want to get to their final destination as close to their planned time as possible.	Medium
A16	Stock availability	When assigning passengers to itineraries (either in A14 or A15), it is assumed that the stock of seats available per service is accessible through the system. Any required data sharing and coordination are in place (see A5).	When planning the network, the system assumes that multimodal governance exists (e.g. integrated ticketing (see A5)). So, it is assumed that the ticketing system can access seat stocks from all required operators. When replacing the operations due to disruptions, it is assumed that a coordinated approach is performed between operators. Therefore, the required governance should be in place (see A5).	Medium

A17	Passengers rebooking is feasible	When reassigning passengers to itineraries, it is assumed that there is enough time available to notify and rebook the impacted passengers and that the required data and governance infrastructure are in place. This means that some time is expected to exist since the identification of the disruption (or its forecast) and the implementation of the reallocation of passengers into the modified schedules and timetables.	The Disruption Management Solution can replan the flight and rail operations considering the impact of a current (or forecast) disruption in the system. Passengers impacted by the modified services are rebooked into the available seats by the Strategic Evaluator (A15). The data and governance required are already assumed to be in place (see A5, A16); therefore, the technology required to notify passengers impacted is assumed to be in place. If some time is required, this might impact the look-ahead required to replan operations but not necessarily its outcome.	Low
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5 References

5.1 Applicable documents

This OSED complies with the requirements set out in the following documents:

Content integration

[1] ...

Content development

[2] ...

System and service development

[3] ...

Performance management

[4] ...

Validation

[5] ...

System engineering

[6] ...

Safety

[7] ...

Human performance

[8] ...

Environment assessment

[9] ...

Security

[10] ...

Project and programme management

[11]101114815 MultiModX Grant Agreement, 31/05/2023

[12]SESAR 3 JU Project Handbook – Programme Execution Framework, 13/01/2023, 1.0

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Appendix A Stakeholder identification and benefit impact mechanisms (BIM)

A.1 Stakeholders identification and expectations

This Appendix identifies possible stakeholders who could benefit from the different components of SOL399/SOL1 with their potential expectations.

Multimodal Performance Framework

The Multimodal Performance Framework can support stakeholders who want to consider the impact of their Solutions on the overall passenger experience and mobility (with a particular focus on passenger connectivity). Therefore, the target stakeholders include System performance modellers, Decision-makers, Infrastructure managers, and any other actor concerned with the multimodal description and monitoring of the operations.

In particular, SESAR JU could benefit from this, as it supports a better understanding of how multimodality could impact ATM-related PIs and KPIs and vice-versa. This is required when cost-benefit analysis and benchmarking are needed to be established across different solutions that could affect the same PIs and KPIs. This is particularly relevant in the context of the inclusion of Passenger Experience within the SESAR Performance Framework, which activities are led by the SESAR Passenger Experience and Multimodal Flagship.

Strategic Multimodal Evaluator

The Strategic Multimodal Evaluator enables the assessment of current air schedules and train timetable and their impact on possible passenger mobility across regions in mono and multimode trips. As presented in the OSED, the platform enables the evaluation of many different factors (e.g. policies, business models (alliances), infrastructure changes, etc.) Therefore, the Strategic Multimodal Evaluator is a perfect tool for the evaluation of what-if scenarios, enabling the computation of standardised strategic mobility PIs (as defined by the Multimodal Performance Framework) but also the estimation of very low-level connectivity and mobility metrics that can be created ad-hoc for particular analyses (e.g. reachability from a given region and its changes as a function of improvements on minimum connecting times (MCTs) improvements).

Finally, as presented, the Strategic Multimodal Evaluator enables also the assessment of replanned networks. These replanned networks consist of updated services (flights and rail time shifts (delays) and/or cancellations). The Strategic Multimodal Evaluator can then identify which passengers are impacted by these changes and classify them between delayed, stranded (either service cancelled or missed connection) or impacted but not delayed (e.g. passengers who can still make a follow-up non-disrupted connection). Moreover, the Strategic Multimodal Evaluator can find alternative route for those passengers. Therefore, the Evaluator also provides what-if capabilities for the replanning of networks, particularly in case of severe disruptions (e.g. infrastructure closures, high-delays events (e.g. industrial action)).

With these considerations, there is a range of different stakeholders that could benefit from the strategic evaluation platform, such as:

- Air and rail operators could, for example, assess the benefits of establishing alliances with other modes and operators; and the impact (in terms of passengers affected) of replanning operations in case of disruptions.
- Infrastructure managers (airport and rail infrastructure operators) could use the Strategic Evaluator to assess the potential volume of passengers and the connectivity of their infrastructure with the overall network; they could also assess the impact of improving the inter-mode connectivity (e.g. with reduced minimum connecting times which could be achieved by better use of resources or infrastructure adjustments, such as extension of rail lines).
- The Airport Operation Centre (APOC) and the Network Manager (NM) could use some of the capabilities of the Strategic Multimodal Evaluator for the assessment of what-if situations, particularly in case of replanning of operations in the event of disruptions.
- European, national, regional and city mobility-related policymakers and planners could use the Strategic Evaluator to assess the connectivity of their regions as a function of different assumptions (e.g. investing in infrastructure improvements that support intermodal changes or under different policies and incentives such as supporting operations and connectivity of different providers).
- Policymakers could use the Strategic Evaluator to assess the impact of policies which impact the passenger choice (e.g. costs) or supply (e.g. bans), such as changes to taxation (e.g. frequent flyer levy, CO₂ tax charges) or limitation on operations (e.g. flight-bans).
- Global Distribution Systems (GDS) organisations could benefit from the outcome of the Strategic Multimodal Evaluator to better integrate multimodality in transport search engines and identify connecting nodes that could benefit from these types of integrated tickets.
- Passengers' associations could be interested in assessing the impact of multimodality on overall mobility (e.g. expected travel time, costs and CO₂ emissions).
- Other Solutions can use the capabilities of SOL399/SOL1 Strategic Multimodal Evaluator to assess their performance in the framework of multimodality considering the planning (or replanning) of operations.
- The research community overall can benefit from the Strategic Multimodal Evaluator as it is a platform that enables the evaluation of many different approaches to design multimodal itineraries, for example, done in MultiModX with the evaluation of the outcome of SOL400/SOL2 - Schedule Design Solution. This is particularly feasible due to the open source nature of the Evaluator.

Tactical Multimodal Evaluator

As discussed, there are many potential uses and stakeholders who could benefit from a tool with the capabilities of the Tactical Multimodal Evaluator, as it enables the assessment of mobility considering operational uncertainty and allows modellers to evaluate mechanisms and Solutions which impact passenger connectivity. An important factor is that the low-level resolution of the Tactical Multimodal Evaluator enables the tracking of individual passengers with their experienced delay (and missed connections), therefore opening the door for the allocation of liability and the subsequent evaluation of duty of care and compensation initiatives.

Examples of relevant stakeholders include:

- Air and rail operators could evaluate the passengers being impacted by delays and missed connections. They could also evaluate the potential number of passengers needing rebooking on specific services. They can also assess the robustness of their schedules and timetables with respect to nominal and stressed conditions.
- Airport managers could assess the impact of mechanisms to manage multimodal passengers on their infrastructure and the benefit of different Solutions to manage air and ground operations on passenger experience (delays and missed connections).
- Infrastructure managers could assess how changes in the operation of their infrastructure could impact passenger experience (delays and missed connections).
- Policymakers can evaluate different passenger experience policies, such as duty of care and compensation alternatives. The Tactical Multimodal Evaluator could assess their benefit for passengers and the expected cost to different stakeholders.
- SESAR JU could use the Tactical Multimodal Evaluator to assess the impact of different SESAR Solutions on passengers, focusing on multimodal journeys.
- Overall, other Solutions can use the capabilities of SOL399/SOL1 Tactical Multimodal Evaluator to assess their performance in the framework of multimodality considering the unfolding of the operational phase.
- The research community overall can benefit from the Tactical Multimodal Evaluator as it is a platform that enables the evaluation of many different mechanisms that support multimodal journeys (such as fast-track at the airport) and replanning of operation Solutions, such as done in MultiModX with the evaluation of the outcome of SOL401/SOL3 - Disruption Management Solution.

A.2 Benefits impact mechanisms (BIM)

As previously presented, SOL399/SOL1 has developed a digital catalogue of indicators (<https://nommon.atlassian.net/wiki/external/MzA2ZTJmMjU5MDUyNDNiYzlkNDBmNTMwOTRlMDY4MGY>) classified in three Levels:

- Level 1 are indicators currently part of the SESAR3 Performance Framework. These indicators will have, by their nature, a stronger focus on the gate-to-gate component of the passenger journey..
- Level 2 comprises indicators that are currently (or are planned) to be at least modelled by research projects. These will mature some aspects of passenger experience and focus on multimodal considerations such as reliability.
- Level 3 contains more ambitious indicators that aim to capture the total experience of passengers in their door-to-door journey. These will represent indicators that can be more desirable but currently not feasible due to several limitations, such as data availability.

It is important to note that **SOL399/SOL1 does not provide impact/benefits directly to the SESAR Performance Framework (Level 1) nor to the indicators of Level 2 or Level 3. SOL399/SOL1 is a transversal solution aiming at providing a framework to evaluate multimodality and multimodal solutions. Therefore, the expected benefits and impacts will be for either multimodality overall or for a given implementation of multimodality. SOL399/SOL1 is an enabler for the evaluation of what-if networks (planned, replanned, policies, etc), and other Solutions and mechanisms.**

SOL399/SOL1 does not provide benefits on the indicators themselves. For example, one could consider that if schedules between flights and rails are better synchronised, some indicators would improve; these benefits can be computed by SOL399/SOL1, but the benefits themselves should be attributed to the mechanism (or Solution, e.g. SOL400/SOL2) which produce these optimised schedules.

As future work (outside the scope of MultiModX), SOL399/SOL1 (or some of its components) could be further developed as a what-if evaluator that can be integrated in operational settings (e.g. in the Airport Operation Centre (APOC)). In that case, some benefits on some indicators could be expected, e.g. reduction on passenger delay, as the decision makers will be able to assess different alternatives and select those which provide better outcomes. Again, SOL399/SOL1 would be an enabler for these solutions to be deployed and evaluated.

It is worth noticing that in any case, these benefits would depend on the alternatives being evaluated, and therefore, once again, the impact on indicators might vary as a function of what these alternatives are considering. For example, we could expect some variance in departure delay if flights wait for multimodal connecting passengers. However, that is not a direct and unavoidable relationship, as one could just not wait for them (and therefore not impacting the departure delay) or use a different Solution (e.g. a fast track for multimodal passengers), which might reduce or even eliminate the extra departure delay.

The results of the ERR provide a validation on the capabilities of SOL399/SOL1 to provide a performance framework for the assessment of multimodality and the evaluators to assess planned, replanned and executed air-rail multimodal networks. But, again, it does not provide benefits on the SESAR Performance Indicators directly, but as a function of the alternative networks, policies, and other aspects considered when creating the what-if scenarios.

Regardless of this, **SOL399/SOL1 has carried out**, as part of the definition of the Multimodal Performance Framework, **an analysis on the impact of multimodality overall on the SESAR Performance Indicators**. This analysis is not a benefit of impact of SOL399/SOL1, but a result of the work conducted, and as mentioned, the benefits and impact might vary as a function of how multimodality is implemented. As these are not the results of deploying SOL399/SOL1 they are captured in Appendix B – Potential impact of multimodality on SESAR Performance Framework.

Appendix B Potential impact of multimodality on SESAR Performance Framework

B.1 Scope of the analysis

This Appendix provides an analysis of the potential impact of multimodality into the SESAR Performance Framework. The focus will therefore be **on the indicators from the current SESAR Performance Framework and to provide a representation of how multimodality could impact these not on SOL399/SOL1 per se.**

As explained in the digital catalogue of indicators, the indicators are divided in three Levels (see Section A.2. and the digital catalogue of indicators for more details:

<https://nommon.atlassian.net/wiki/external/MzA2ZTJmMjU5MDUyNDNIYzlkNDBmNTMwOTRIMDY4MGY>).

There are 26 indicators described in Level 2 and Level 3 and used by MultiModX as shown in Table 5 of the main document. The remaining indicators, as explained in the ERR [1], are considered as Level 1, and comprise indicators which are currently part of the SESAR3 Performance Framework. In total, there will be, therefore, 34 indicators from the current performance framework that could be impacted.

It is worth noting that in the current SESAR Performance Framework, the indicators do not describe/capture multimodality, but some of them could be affected by it.

This exercise of assessing how multimodality could potentially impact the SESAR Performance Indicators is performed to provide a better overview of how multimodality could impact the SESAR Performance Framework and, therefore, complements the analysis of Level 1 indicators provided in the digital catalogue of indicators.

Most of the indicators that could be impacted by multimodality from the SESAR Performance Framework have a weak link with multimodality, i.e. only indirectly or medium, i.e., as a function of how it is implemented. The ones with a high link focus on the economic cost of delay, which is beyond the analysis done in SOL399/SOL1. Therefore, it is natural that to assess the networks, SOL400/SOL2 and SOL401/SOL3, the focus is on the ad-hoc indicators defined at Level 2 and Level 3 with a focus on passenger-centric metrics. Once again, all indicators are presented below for completeness on the analysis of Level 1 and multimodality which would benefit other Solutions and projects working on these aspects, and it complements the digital catalogue of indicators.

Finally, it is worth noticing how by using available documentation (e.g. European cost of delay report [2]), it could be possible to transform the impact of Solutions from delay (for flights and passengers) and stranded passengers to their economic value.

B.2 Analysis of potential impact of multimodality on SESAR Performance Framework

Indicators which are classified as Level 1 (34 indicators that could be impacted by multimodality) and will be analysed in the subsequent sections. As explained in the ERR [1], for Level 1, considering the

indicators which are currently part of the SESAR3 Performance Framework, an analysis is done differentiating them between:

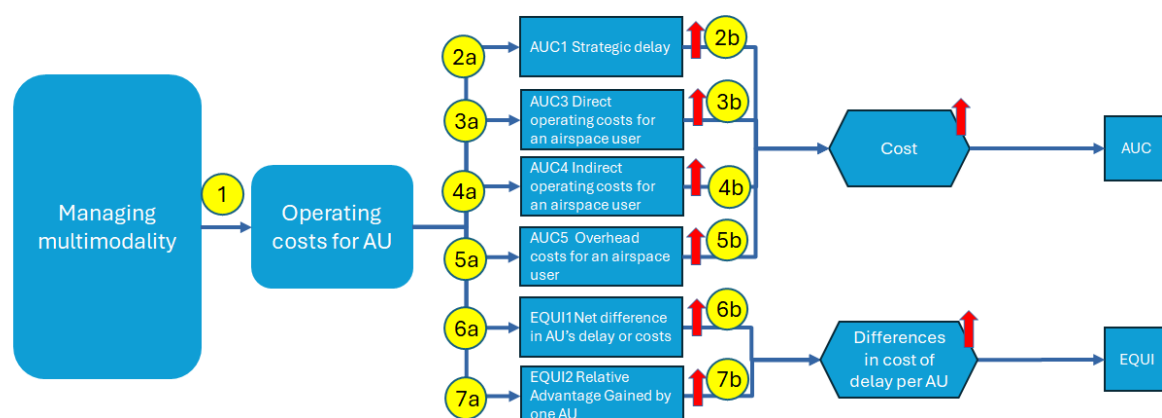
- N/A: Not applicable (no impact expected on this KPA/KPI/PI due to multimodal operations);
- Weak: There could be some impact but in an indirect way (usually due to changes in operations to account for changes in demand/supply);
- Medium: Some impact could be expected (in some cases, depending on how multimodality is implemented);
- High: It is expected that multimodality would impact this KPA/KPI/PI

Overall, for the majority of indicators, multimodality is *not applicable* (76), or *weak* (11 indicators). 13 indicators are considered with a *medium* possible impact. Note that this might depend on how multimodality is implemented. For example, if flights actively wait for delayed multimodal connecting passengers, that could have an impact on PUN1 (Departure punctuality). Most of these impacts are expected in the KPA of Operational Efficiency affecting the predictability of operations if flights are managed considering multimodality.

Finally, 10 indicators might be impacted in a *high* manner by multimodality. Most of them (7) are in the Cost-Effectiveness area, as it is expected that managing multimodal passengers will result in a cost for the operators, including the cost of rebooking and managing connections. This is the case, for example, of AUC3 – Direct operating costs for an airspace user.

The following sections discuss the potential impact of multimodality on these different aspects.

B.2.1 Operating cost for Airspace Users



Feature	Impact Area	Indicators	Positive or negative impacts	KPI/KPA /TA
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Figure 11: BIM managing multimodality operating cost

Figure 11 shows the BIM of managing multimodality overall for airspace users (AU) from an operating cost perspective. Independently of the approach used to implement multimodality, it is expected that the cost will increase. Managing multimodality will impact the operating cost for AU (1). This will be captured by the following indicators if they are extended to capture the total airline cost beyond the ATCO related ones:

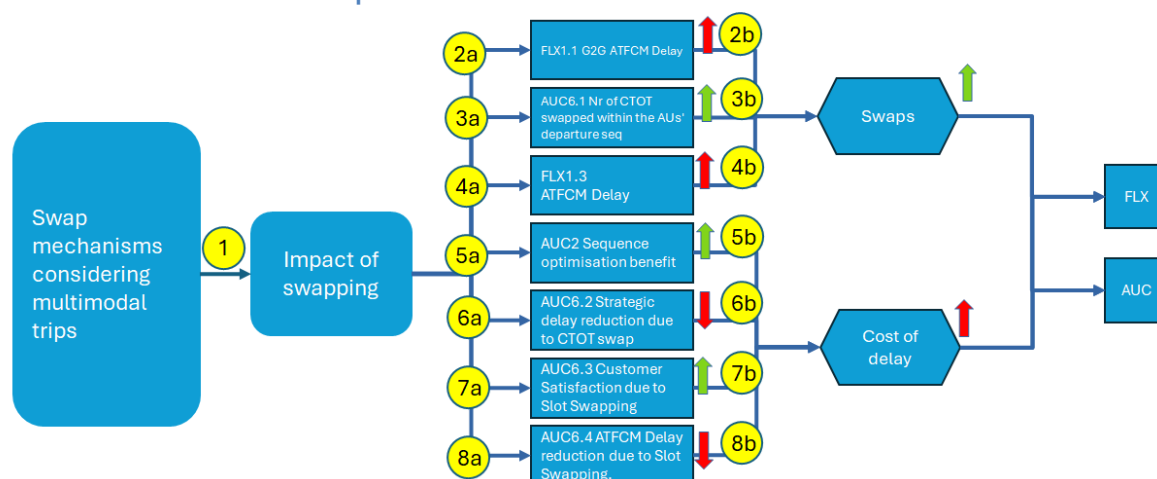
- (2a) AUC1 strategic delay could be expected to increase (4b), (5b).

Similarly, the difference in cost per AU is expected to increase as a function of their relationship with multimodality. Some users might not have multimodal journeys, while others might rely strongly on these types of connections. This means that an impact is expected on Equity:

- (6a) EQUI1, the net difference in AU's delay or costs, are expected to vary due to these different impacts in managing connecting multimodal passengers.

Similarly (7a), EQU2, the relative advantage gained by one AU, might be different

B.2.2 Swap mechanisms



Feature	Impact Area	Indicators	Positive or negative impacts	KPI/KPA /TA
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Figure 12.: BIM managing swaps of slots mechanism

A direct consequence of the analysis conducted in Figure 11 the cost of delay will generally increase but also be different for different AUs and operations. Therefore, it is expected an impact on the factors affecting the swapping of ATFM slots, as depicted in Figure 12.

- The FLX1.1 G2G ATFM delay (2b) and FLX1.3 ATFCM delay (4b) could increase, leading to a reduced delay reduction due to CTOT swap (AUC6.2 (6b)), and therefore, a reduction of the ATFCM delay reduction due to slot swapping (AUC6.4 (8b)). Some flights might benefit more or less from swapping slots due to potential costs associated with missed connections. This means that there might be more variance on costs for the same delay across different flights increasing these factors.

- On the other hand, the number of swaps might increase (AUC6.1 (3b)), the benefit of the sequencing optimisation might increase (AUC2 (5b)) as there is more potential for improvement, and customer satisfaction could conversely also increase e (AUC6.3 (7b)).

All these changes are just an expectation given the higher inequality of the cost of delay (per AU and operation) and the higher costs expected (as described in Figure 11). Cost would play a bigger role when deciding if/how to swap slots rather than delay on its own.

B.2.3 Reduced demand

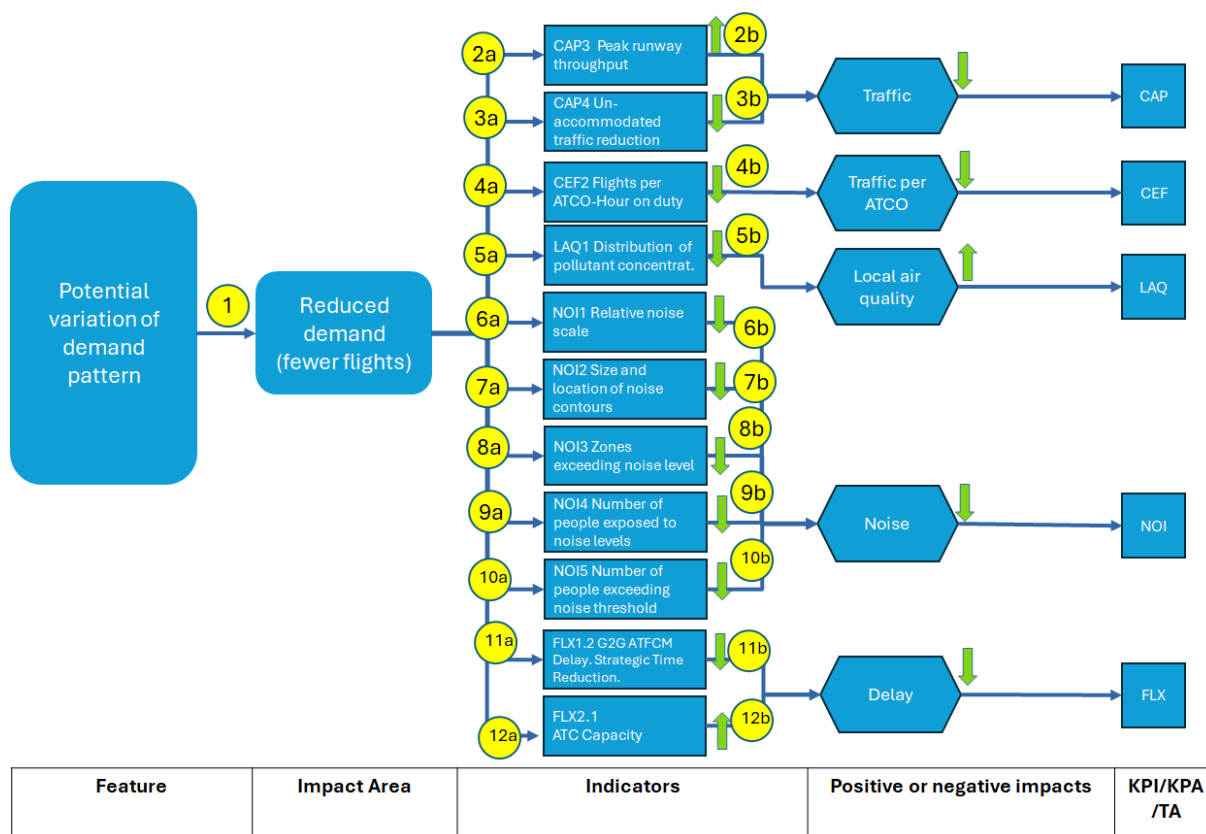


Figure 13: BIM potential reduction in demand

Figure 13 shows an indirect impact of multimodality which could depend on how multimodality is implemented. One could expect that with multimodality some flights might not be needed anymore. For example, this is modelled in MultiModX with the consideration of a policy package which includes a flight ban to short-haul flights while supporting multimodality with integrated ticketing (PP20, see ERR [36]). If that were the case, then a variation in demand would be expected, leading (1) to a reduced demand, which will, in turn, impact Capacity, Cost efficiency, Local air quality, Noise and Flexibility, as shown in Figure 13. It could be expected:

- A reduction in traffic is captured in an increment in throughput at runways (CAP3 (2b)) as there is more capacity available, and a reduction in unaccommodated traffic (CAP4 (3b)).
- The reduction in traffic could lead to a reduction in traffic per ATCO with a reduction in flight per ATCO hour on duty (CEF2 (4b)).

- Fewer traffic would mitigate the environmental impact of aviation with improved local air quality (LAQ1 (5b)), and an overall reduction in Noise (NOI1 (6b), NOI2 (7b), NOI3 (8b), NOI4 (9b) and NOI5 (10b)).
- Finally, lower traffic would mean higher ATC capacity (FLX2.1 (12b)) and a reduction in ATFCM actions (FLX1.2 (11b)).

Once again, note that these are expected possible impacts of multimodality if they represent a reduction in traffic. Quantitative assessments would be required to further confirm and analyse these. The objective would then be the assessment of these policies and not of SOL399/SOL1.

B.2.4 Departure management

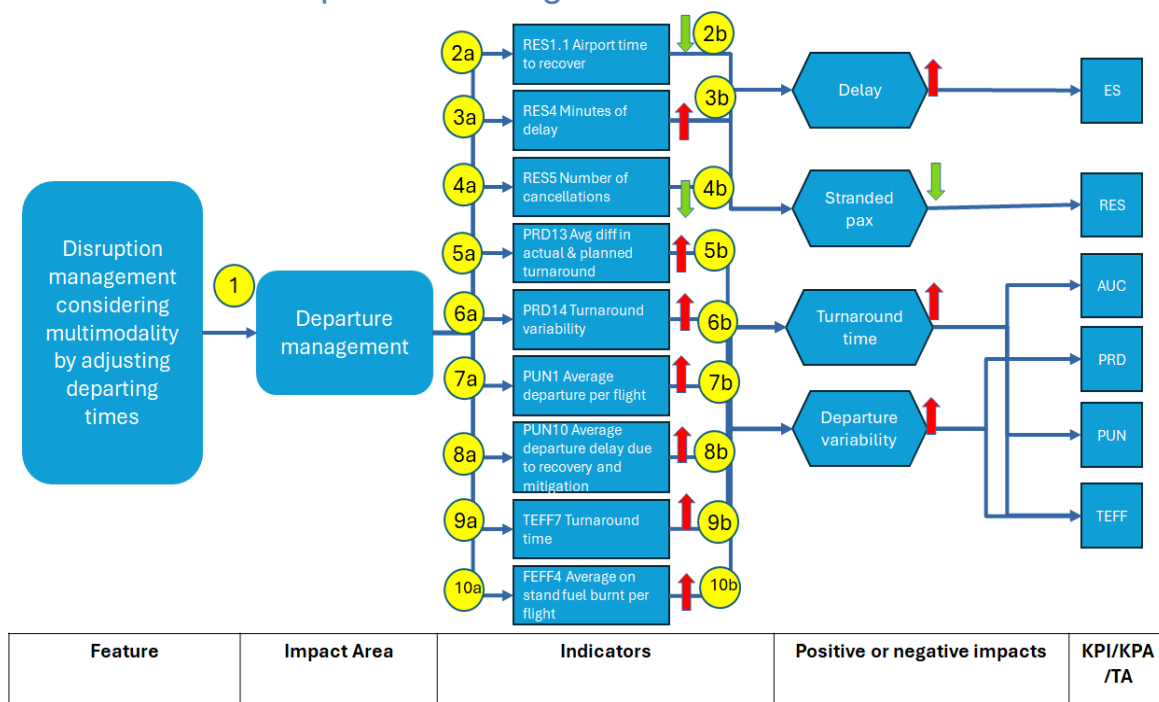


Figure 14. BIM disruption management pre-departure

Related to the expected higher cost of managing multimodal missed connections, one could expect mechanisms such as waiting-for-passengers which could be used pre-departure to reduce these missed connections. As shown in Figure 14, if such Solutions were implemented, one could expect an impact on Delay, the number of Stranded passengers, Turnaround times and Departure variability. These are reflected in a higher number of delayed flights (waiting for the passengers) (RES1.1 (2b), RES4 (3b)), producing an increment in departure delay (PUN1 (7b) and PUN10 (8b)), which could be implemented by having longer turnaround times (TEFF7 (9b)) leading to higher stand fuel burn per flight (FEFF4 (10b)), and higher variability on these processes (PRD13 (5b) and PRD14 (6b)). This management of pre-departure operations could lead to lower cancellations (RES5 (4b)) or at least better-targeted cancellations.

B.2.5 Delay recovery

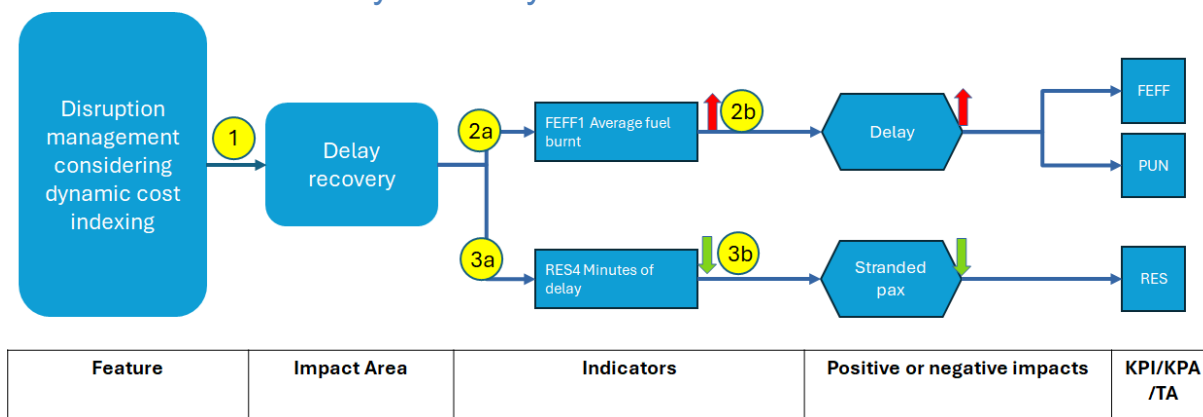


Figure 15: BIM disruptions management dynamic cost indexing

Finally, besides pre-tactically managing flights to ensure multimodal connections, one could expect the use of Dynamic Cost Indexing to recover delay, as done, for example, in [3]. In this case, we expect an impact on reducing the number of stranded passengers by reducing the minutes of delay (RES4 (3b)) but trading this reduction of delay by higher fuel burn (FEFF1 (2b)).

B.3 References for Appendix B

- [1] MultiModX Consortium (2025). Exploratory Research Report (ERR) for SOL1 – Multimodality Performance Framework and Evaluator (SOL399)
- [2] Cook, A. and Tanner, G.: European Airline Delay Cost Reference Values, Updated and Extended Values, University of Westminster, Tech. Rep., 2015, v4.1
- [3] Delgado, L., De la Torre, D., Kuljanin, J. and Prats, X., 2024. Considering Expected TMA Holding into In-flight Trajectory Optimisation, Trans. Japan Society of Aerospace Sciences, Vol. 67, No. 3. pp. 109-118, <https://doi.org/10.2322/tjsass.67.109>

Appendix C Input data sources examples

This section provides a summary of all the inputs used by the Strategic Multimodal Evaluator and Tactical Multimodal Evaluator with some examples of the sources used in MultiModX to create the inputs. Annex A – Input/Output format from the Functional Requirements Document (FRD) [1] contains a detailed description of the format of the input files. Note, that various technical data not related to multimodality (e.g. translation of airport codes from IATA to ICAO) has been collected during previous SESAR ER projects such as Modus and TRANSIT [21, 3].

C.1 Strategic Multimodal Evaluator inputs

Category	Name	Source
Flight schedules	I1. flight_schedules	OAG dataset
Rail Timetables	I2. GTFS rail	UIC based on Renfe dataset
Infrastructure	I3. rail_stations_considered	MultiModX
Heuristics	I4. heuristics_precomputed	Computed by the Strategic Pipeline
Infrastructure	I5. regions access	Analysis of mobile mobility data
Infrastructure	I6. airports coordinates	Previous projects
Infrastructure	I7. airports IATA-ICAO	Previous projects
Infrastructure	I8. MCT air	Complexity Costs project
Infrastructure	I9. MCT rail	UIC
Infrastructure	I10. infrastructure transitions	Analysis of Google Maps
Infrastructure	I11. airport pax processes	Dataset2050
Infrastructure	I12. rail stations pax processes	Estimated
Demand	I13. pax demand	Analysis of mobile mobility data
Logit model	I14. logit model sensitivities	Calibrated analysing mobile mobility data
Flight schedules	I15. air alliances	Previous projects

C.2 Tactical Multimodal Evaluator inputs

The Tactical Multimodal Evaluator extends the gate-to-gate simulator Mercury. Sample data required to calibrate and run the baseline (gate-to-gate) model is provided in [4]. Therefore, this Appendix describes only the inputs related to the multimodality aspect and the generation of the input data for Tactical Multimodal Evaluator originating from the Strategic Multimodal Evaluator. The names of the inputs are divided between Input Required to Process Strategic Output (IRPSO) (related to aircraft performance and airline types to be used in the Tactical Evaluator which are not needed Strategically), and Input (I).

Category	Name	Source
AC airline info	IRPSO1. ac type IATA ICAO	Previous projects
AC airline info	IRPSO2. MTOW	Previous projects
AC airline info	IRPSO3. WTC	Previous projects
AC airline info	IRPSO4. airline IATA ICAO	Previous projects
AC airline info	IRPSO5. airline AO type	Previous projects
Schedules	I1. flight_schedules	Strategic Multimodal Evaluator
GTFS	I2. GTFS rail	Strategic Multimodal Evaluator
Airports	I3. airport pax processes	Dataset2050
Pax	I4. pax.parquet	Strategic Multimodal Evaluator

C.3 References for Appendix C

- [1] MultiModX Consortium (2024). Functional Requirement Document (FRD) for SOL1 – Multimodal Performance Evaluation Framework (SOL399)
- [2] Modus Consortium (2021). D3.2 Demand and supply scenarios and indicators
- [3] TRANSIT Consortium (2021). D3.1 Multimodal Performance Framework
- [4] Gurtner, G., Delgado, L., Tanner, G., and Bolic, T. (2024). Data sample for Mercury simulator (v3.1.0) [Data set]. Zenodo. <https://doi.org/10.5281/zenodo.11384379>

Appendix D Use Cases Description

This Appendix contains the description of the Use Cases of SOL399/SOL1. The Use Cases diagram is presented in the main document in Figure 9, and a high-level diagram representing the potential flow between Use Cases is depicted in Figure 10.

The Use Cases are grouped by different aspects/functionalities of SOL399/SOL1 as described here:

- Multimodal Performance Framework
 - Review Multimodal Performance Indicators
 - Suggest modifications Multimodal Performance Indicators
- Strategic Performance Evaluation
 - Create strategic experiment → extended by Optimise schedules with Scheduler Design Solution (SOL400/SOL2)
 - Execute Strategic Evaluator with strategic experiment
 - Compute PIs of strategic experiment
 - Compare strategic experiments' performance
- Tactical Performance Evaluation
 - Create tactical experiment → extended by Integrate tactical mechanism supporting multimodality
 - Execute Tactical Evaluator with tactical experiment
 - Compute PIs of tactical experiment
 - Compare tactical experiments' performance
- Disruption Evaluation
 - Replan network in case of disruption → extended by replan network with Disruption Management Solution (SOL401/SOL3)
 - Compute PIs of replanned network
 - Compare replanned networks' performance

D.1 Multimodal Performance Framework

Use Case: Review Multimodal Performance Indicators

Primary Actor: Multimodal Performance Expert

Scope: Multimodal Performance Framework

Stakeholders and interests:

- Multimodal Performance Experts: Wants to review multimodal performance indicators available in the multimodal performance indicators catalogue.
- Multimodal and passenger experience flagship: Wants to provide a multimodal performance indicators catalogue to be reused by experts. Curates the multimodal performance indicator catalogue.
- SESAR JU: Wants for indicators to be standardised across projects.

Brief: The Multimodal Performance Expert wants to consult the information on multimodal performance indicators at Level 1, Level 2 and/or Level 3.

Preconditions: The multimodal performance indicators catalogue is populated and available.

Minimal guarantees: None

Success guarantees: The Multimodal Performance Expert gets the information on the indicators available.

Trigger: The Multimodal Performance Expert wants to review the indicators available.

Main success scenario:

1. The Multimodal Performance Expert accesses the multimodal performance indicators catalogue to obtain information on the multimodal performance indicators available at Level 1, Level 2 and Level 3.
2. The multimodal performance indicators catalogue provides information on the indicators available at Level 1, Level 2 and Level 3.

Extension: Filter indicators

Condition: The Multimodal Performance Expert filters which indicators they want to review.

Step: 1

Scenario:

1. The Multimodal Performance Expert provides filters to be applied when accessing the multimodal performance indicators catalogue.
2. The multimodal performance indicator catalogue filters the indicators based on the information provided by the Multimodal Performance Expert.
3. Go to step 2 of the main success scenario.

Use Case Data:

- Multimodal performance indicator information: Information on the different indicators with a focus on:
 - Level (Level 1, Level 2 or Level 3)
 - Indicator name
 - Definition
 - Why relevant to passengers
 - Why relevant to ATM
 - Data sources
 - Scope
 - How to develop further

Auxiliary definitions:

- Multimodal performance indicators catalogue: Digital catalogue of multimodal performance indicators information curated by the Multimodal and passenger experience flagship.

Use Case: Suggest modifications Multimodal Performance Indicators

Primary Actor: Multimodal Performance Expert, Multimodality / Passenger Experience Flagship Performance Manager

Scope: Multimodal Performance Framework

Stakeholders and interests:

- Multimodal Performance Experts: Wants to provide a possible update to the multimodal performance indicators catalogue.
- Multimodal and passenger experience flagship: Wants to provide a multimodal performance indicators catalogue to be reused by experts, keeping it updated and relevant. Curates the multimodal performance indicator catalogue.
- SESAR JU: Wants for indicators to be standardised across projects and to keep these updated.

Brief: The Multimodal Performance Expert wants to suggest a modification to the multimodal performance indicators catalogue so that the catalogue can be updated accordingly.

Preconditions: The multimodal performance indicator catalogue is populated and available.

Minimal guarantees: When a performance indicator is updated, it is ensured that no two indicators have the same Indicator name and that two indicators with different names describe the same underlying performance aspect.

Success guarantees: The multimodal performance indicator catalogue is updated with the suggestion of the Multimodal Performance Expert.

Trigger: The Multimodal Performance Expert wants to update an indicator, suggest a new one or suggest a modification in the catalogue.

Main success scenario:

1. The Multimodal Performance Expert suggests a modification to the multimodal performance indicator catalogue.
2. The Multimodality / Passenger Experience Flagship Performance Manager reviews the suggested modifications to the catalogue.
3. The Multimodality / Passenger Experience Flagship Performance Manager updates the performance indicator catalogue with the modifications provided by the Multimodal Performance Expert.

Extension: Suggested change not accepted

Condition: The Multimodality / Passenger Experience Flagship Performance Manager rejects the suggested change.

Step: 3

Scenario:

1. The Multimodal Performance Expert informs the Multimodal Performance Expert that their suggestion has been rejected, along with information on the rationale for the rejection.

Use Case Data:

- Multimodal performance indicator information: Information on the different indicators with a focus on:
 - Level (Level 1, Level 2 or Level 3)
 - Indicator name
 - Definition
 - Why relevant to passengers
 - Why relevant to ATM
 - Data sources
 - Scope
 - How to develop further

Auxiliary definitions:

- Multimodal performance indicators catalogue: Digital catalogue of multimodal performance indicators information curated by the Multimodal and passenger experience flagship.

D.2 Strategic Performance Evaluation

Use Case: Create strategic experiment

Primary Actor: Strategic Performance Assessment Expert

Scope: Strategic Performance Evaluator

Stakeholders and interests:

- Strategic Performance Assessment Expert: Wants to define a strategic experiment so that it can be evaluated.

Brief: The Strategic Performance Assessment Expert provides information on the supply, infrastructure, demand characteristics and policy packages to be applied to create a strategic experiment. It can modify the parameters that define the parameters of the strategic experiment to create a new version of the experiment, including applying the Schedule Desing Solution (SOL400/SOL2) to optimise the schedules.

Preconditions: The supply (flight schedules and rail timetables) correspond to the network infrastructure provided.

Minimal guarantees: None

Success guarantees: A planned strategic experiment is defined.

Trigger: The Strategic Performance Assessment Expert wants to create a strategic experiment.

Main success scenario:

1. The Strategic Performance Assessment Expert provides information on supply, infrastructure, demand, strategic configuration parameters and policy package to create a strategic experiment.
2. The Strategic Evaluator applies the policies within the policy package that impact the supply to the strategic experiment as required (e.g., removing flights impacted by a flight ban from the flight schedules).
3. The Strategic Performance Assessment Expert modifies the parameters of the strategic experiment as required to create new experiments (e.g. modifying parameters on the infrastructure).

Extension: Optimise schedules with Scheduler Design Solution

Condition: The Strategic Performance Assessment Expert wants to assess an optimised schedule.

Step: 3

Scenario:

1. The Strategic Performance Assessment Expert executes the Use Case of 'Optimise Schedules' from SOL400/SOL2. See OSED of SOL400/SOL2 [1].

2. The Strategic Performance Assessment Expert uses the outcome of the Scheduler Optimiser as schedules and timetables to be used in the strategic experiment.
3. Go to step 3 of the main success scenario.

Use Case Data:

- Demand: Per origin-destination pair number of passengers (demand) per passenger archetype (see Annex A from FRD [2] for information on format)
- Supply: flight schedules, rail timetables, seats (capacity).
- Infrastructure: Minimum connecting times, access and egress times, inter-modes connecting times, passenger processing times (see Annex A from FRD [2] for information on format and detailed data description).
- Strategic configuration parameters: Parameters to configure how the Strategic Evaluator will compute the paths, itineraries, etc. This includes factors such as thresholds to consider two itineraries to be equivalent from a passenger perspective for clustering, target load factors to use for passenger assignment, etc. These are encoded in a TOML file (see Annex A from FRD [23] for information on format/parameters).
- Policy package: Set of policies to be considered/applied to the network: short-haul bans, frequent flyer levy, rail incentivisation, CO₂ costs, and level of integrated ticketing.
- Flight schedules: flight schedules for the day of assessment (see Annex A from FRD [2] for information on format)
- Rail timetables: Rail timetables (in GTFS format, see Annex A from FRD [2] for information on format)

Auxiliary definitions:

- Strategic experiment: A specific network defined by supply, demand, infrastructure, strategic configuration parameters and policy package.

Use Case: Execute Strategic Evaluator with strategic experiment

Primary Actor: Strategic Performance Assessment Expert

Scope: Strategic Performance Evaluator

Stakeholders and interests:

- Strategic Performance Assessment Expert: Wants to calculate the planned network and other outputs of the Strategic Evaluator (potential and possible paths between origin-destination pairs, possible itineraries, itineraries clusters, demand flows), given a strategic experiment. This can be done to assess the network or to create the input required for other optimisation (e.g. Schedule Optimisation Solution (SOL400/SOL2)).

Brief: The Strategic Performance Assessment Expert provides information on the strategic experiment to generate the planned network, and the potential and possible paths, possible itineraries and their clusters of equivalent itineraries, and the passenger flows between the different origin-destination pairs.

Preconditions: The strategic experiment is already available (see ‘Create strategic experiment’ Use Case). The logit model used to disaggregate demand is calibrated for the archetypes used in the origin-destination demand of the experiment.

Minimal guarantees: Potential and possible paths respect the supply (schedules and timetables), infrastructure (e.g. MCT) and business-related (e.g. alliances) restrictions. The passenger itineraries respect the services capacities (seats available)

Success guarantees: Potential and possible paths (succession of infrastructure nodes) and possible itineraries (succession of services) between the origin-destination regions are computed. Passenger flows are assigned to itinerary clusters and passenger itineraries to itineraries. The planned network is successfully computed. I.e., the output of the Strategic Evaluator is generated.

Trigger: The Strategic Performance Assessment Expert wants to compute the planned network (supply, infrastructure and passenger itineraries), and other outputs of the Strategic Evaluator for a strategic experiment.

Main success scenario:

1. The Strategic Performance Assessment Expert provides the Strategic Evaluator with information on the strategic experiment and requests the planned network and other outputs of the Strategic Evaluator to be computed.
2. The Strategic Evaluator computes for the strategic experiment provided the output of the Strategic Evaluator: planned network and the other outputs of the Strategic Evaluator.

Use Case Data:

- Strategic experiment: A specific network defined by supply, demand, infrastructure, strategic configuration parameters and policy package.
- Demand: Per origin-destination pair number of passengers (demand) per passenger archetype (see Annex A from FRD [2] for information on format)
- Supply: flight schedules, rail timetables, seats (capacity).
- Infrastructure: Minimum connecting times, access and egress times, inter-modes connecting times, passenger processing times (see Annex A from FRD for information on format and detailed data description).
- Strategic configuration parameters: Parameters to configure how the Strategic Evaluator will compute the paths, itineraries, etc. This includes factors such as thresholds to consider two itineraries to be equivalent from a passenger perspective for clustering, target load factors to use for passenger assignment, etc. These are encoded in a TOML file (see Annex A from FRD for information on format/parameters).
- Policy package: Set of policies to be considered/applied to the network: short-haul bans, frequent flyer levy, rail incentivisation, CO₂ costs, and level of integrated ticketing.

- Flight schedules: flight schedules for the day of assessment (see Annex A from FRD for information on format)
- Rail timetables: Rail timetables (in GTFS format, see Annex A from FRD for information on format)
- Planned network: Flight schedules, rail timetable, infrastructure and passenger itineraries. See Annex A from FRD [2] for information on their format.
- Other outputs of the Strategic Evaluator: Potential and possible paths, possible itineraries, cluster of itineraries, passenger flows. See Annex A from FRD [2] for information on their format.

Auxiliary definitions:

- Service: A given flight or a train
- Potential path: A succession of nodes (infrastructure) that could be used to travel from a given origin to a given destination independently of minimum connecting times of services.
- Possible path: A succession of nodes (infrastructure) that could be used to travel from a given origin to a given destination, respecting the minimum connecting times of the services involved.
- Possible itinerary: A succession of services which respect the minimum connecting times of the services involved.
- Itinerary clusters: Group of itineraries considered 'equivalent' from a passenger perspective, i.e. similar performance on total travel time, emissions, cost, number of services and modes (see FRD [2] for more details).
- Passenger itinerary: Number of passengers assigned to an itinerary.
- Passenger flow: Disaggregation of passenger demand between origin-destination over the different available clusters between those origin-destination following the outcome of the logit model, which considers passenger archetypes (and their preferences)
- Logit model: A statistical model which calculates the probability of choosing a specific alternative for each passenger archetype when presented with several options for travelling between a given OD pair.
- Output of Strategic Evaluator: planned network and other outputs of the Strategic Evaluator

Use Case: Compute PIs of strategic experiment

Primary Actor: Strategic Performance Assessment Expert

Scope: Strategic Performance Evaluator

Stakeholders and interests:

- Strategic Performance Assessment Expert: Wants to calculate multimodal strategic performance indicators on the materialisation of a strategic experiment.

Brief: The Strategic Performance Assessment Expert computes multimodal strategic performance indicators (particularly passenger-focus indicators) on the outcome of the Strategic Evaluator (planned network and other outputs of the Strategic Evaluator) for a strategic experiment.

Preconditions: The planned network and the other outputs of the Strategic Evaluator for the strategic experiment have already been computed (see 'Execute Strategic Evaluator with strategic experiment' Use Case).

Minimal guarantees: None

Success guarantees: Multimodal strategic performance indicators are computed using the information on the planned network and on the other outputs of the Strategic Evaluator for the strategic experiment.

Trigger: The Strategic Performance Assessment Expert wants to compute performance indicators for a strategic experiment.

Main success scenario:

1. The Strategic Performance Assessment Expert provides the performance indicator estimator with the planned network and the other outputs of the Strategic Evaluator for the strategic experiment, along with the originally planned network and supply and demand characteristics.
2. The performance indicator estimator estimates the multimodal performance indicators on the provided planned network, other outputs of the Strategic Evaluator and supply and demand from the strategic experiment.

Use Case Data:

- Planned network: Flight schedules, rail timetable, infrastructure and passenger itineraries. See Annex A from FRD [2] for information on their format.
- Other outputs of the Strategic Evaluator: Potential and possible paths, possible itineraries, cluster of itineraries, passenger flows. See Annex A from FRD [2] for information on their format.

Auxiliary definitions:

- Strategic experiment: A specific network defined by supply, demand, infrastructure, strategic configuration parameters and policy package.
- Multimodal strategic performance indicators: performance indicators capturing multimodal aspects of mobility with a particular focus on passenger-centric indicators computed at infrastructure and region levels.

Use Case: Compare strategic experiments' performance

Primary Actor: Strategic Performance Assessment Expert

Scope: Strategic Performance Evaluator

Stakeholders and interests:

- Strategic Performance Assessment Expert: Wants to compare the performance of different strategic experiments. For example, comparing a reference network to a network in which SOL400/SOL2 has optimised the schedules, or to a network in which a flight ban has been applied.

Brief: The Strategic Performance Assessment Expert compares the multimodal strategic performance indicators of a set of strategic experiments.

Preconditions: A set of strategic experiments with the output of the Strategic Evaluator (see 'Execute Strategic Evaluator with strategic experiment' Use Case) and of the computation of the multimodal strategic performance indicators (see 'Compute PIs of strategic experiment' Use Case) are available.

Minimal guarantees: None

Success guarantees: The multimodal strategic performance indicators of the networks are compared.

Trigger: The Strategic Performance Assessment Expert wants to assess the performance of a network by comparing its performance to a set of other networks, i.e., comparing the multimodal strategic performance indicators of a set of strategic experiments.

Main success scenario:

1. The Strategic Performance Assessment Expert provides the information on the planned networks (strategic experiments), on the outcome of the calculation of the paths, itineraries, and passenger demand on the network (other outcomes of the Strategic Evaluator) and on the multimodal strategic performance indicators of the networks to be compared.
2. The Strategic Performance Assessment Expert uses the performance indicator estimator to compare the results of all the strategic experiments' multimodal strategic performance indicators.

Use Case Data:

- Planned network: Flight schedules, rail timetable, infrastructure and passenger itineraries. See Annex A from FRD [2] for information on their format.
- Other outputs of the Strategic Evaluator: Potential and possible paths, possible itineraries, cluster of itineraries, passenger flows. See Annex A from FRD [2] for information on their format.

- Multimodal strategic performance indicators: From the 'Compute PIs of strategic experiment' Use Case: performance indicators capturing multimodal aspects of mobility with a particular focus on passenger-centric indicators computed at infrastructure and region levels.

Auxiliary definitions:

- Strategic experiment: A specific network defined by supply, demand, infrastructure, strategic configuration parameters and policy package.
- Output of Strategic Evaluator: planned network and other outputs of the Strategic Evaluator
- Network: Planned network

D.3 Tactical Performance Evaluation

Use Case: Create tactical experiment

Primary Actor: Tactical Performance Assessment Expert

Scope: Tactical Performance Evaluator

Stakeholders and interests:

- Tactical Performance Assessment Expert: Wants to define tactical experiment to be evaluated.

Brief: The Tactical Performance Assessment Expert provides a planned network (flight schedules, rail timetable, individual passenger itineraries and infrastructure data) and tactical configuration parameters as specified in Annex A in FRD [2], together with information on (any) disruptions at airports (e.g. in the form of ATFM regulations at airports).

Preconditions: The planned network is self-consistent, i.e., passenger itineraries are compatible with flight schedules, rail timetables, and infrastructure data.

Minimal guarantees: None

Success guarantees: The planned network is in the format (as defined in Annex A of FRD [2]) required by the Tactical Evaluator (planned tactical network), along with the information required on disruptions and tactical configuration parameters, creating a tactical experiment.

Trigger: Tactical Performance Evaluator: Wants to define a tactical experiment.

Main success scenario:

1. The Tactical Performance Assessment Expert provides the Tactical Evaluator with information on the planned network, tactical configuration parameters and disruptions at airports (if any) to create a tactical experiment with the planned tactical network. Note that only disruptions at airport are modelled by the Tactical Evaluator, if there are disruptions at the rail network,

their impact on the train services should already have been considered by the rail timetable (see 'Replan network in case of disruption' Use Case).

2. The Tactical Performance Assessment Expert modifies the parameters of the tactical experiment as required to create new experiments (e.g. modifying Modules in the Tactical Multimodal Evaluator).

Extension: Generate tactical experiment from (re)planned strategic network

Condition: The planned (or replanned) network is in the format obtained as output of the Strategic Multimodal Evaluator (see 'Execute Strategic Evaluator with strategic experiment' Use Case).

Step: 1

Scenario:

1. As required, the Tactical Multimodal Evaluator modifies the planned network from the Strategic Multimodal Evaluator to have the format (and datasets) required by the Tactical Multimodal Evaluator. In particular, the structure of the flight schedules and of the passenger itineraries, which need to consider any requirement and/or limitation of the Tactical Multimodal Evaluator, e.g. rail legs are considered only the beginning or the end of a journey by the Tactical Multimodal Evaluator. The Tactical Multimodal Evaluator requires information on the flight plans, which is not required (and therefore not considered (and possibly not available)) by the Strategic Multimodal Evaluator. In particular, aspects related to the aircraft performance used to operate the schedules (e.g. MTOW, WTC). The Tactical Multimodal Evaluator transforms, therefore, the planned network into the planned tactical network and ensures that additional required data is available (e.g. flight plans).
2. Go to step 1 of the main success scenario.

Extension: Integrate tactical mechanisms supporting multimodality

Condition: The Tactical Performance Assessment Expert (e.g. Airport management) wants to use the tactical evaluator to assess the impact of mechanisms to support multimodality on missed connections given the conditions expected for the day of operations. For example, modelling a fast-track at the airport to process delayed multimodal passengers.

Step: 2

Scenario:

1. The Tactical Performance Assessment Expert will modify the tactical configuration parameters and activate the relevant modules. Note that if the required module is unavailable, it must be developed beforehand.
2. Go to step 2 of the main success scenario.

Use Case Data:

- Planned network: supply (flight schedules and rail timetable), demand (passenger itineraries) and infrastructure (access/egress times, minimum connecting times, inter-modes connecting times, passenger processing times).
- Planned tactical network: A planned network in the format required by the Tactical Evaluator (see Annex A from FRD [2])

- Disruption at airports: ATFM regulations at airports (airport, capacity reduction and period of time)
- Flight schedules: flight schedules for the day of assessment (see Annex A from FRD [2] for information on format)
- Rail timetables: Rail timetables (in GTFS format, see Annex A from FRD [2] for information on format)
- Infrastructure information: Airport pax processes (kerb-to-gate and gate-to-kerb times)
- Passenger itineraries: Number of passengers assigned to itineraries.
- Tactical configuration parameters: Parameters required by the Tactical Evaluator in TOML format, including information on any Module to be loaded by the Evaluator (see Annex A from FRD [2] for more details).
- Flight plans: For each origin-destination and aircraft type available in the flight schedules, a pool of precomputed 4D trajectories (routes, vertical and speed profile) so that the Tactical Evaluator can simulate the flights. See [3] for more information.

Auxiliary definitions:

- Module: Python code that modifies the behaviour of the Roles of the Agents in the Tactical Multimodal Evaluator. The flexibility of the Tactical Multimodal Evaluator enables the extension of the model by creating modules that enable the evaluation of multimodal supporting mechanisms by modifying the by-default behaviour of the agents.
- Tactical experiment: A planned network (supply (flight schedules, rail timetable), demand (passenger itineraries) and infrastructure (access/egress times, minimum connecting times, inter-modes connecting times, passenger processing times)) in the format required by the Tactical Evaluator (see Annex A from FRD [2])) and any other additional required data by the Tactical Evaluator to simulate the network.
- Replanned network: A planned network that has been modified to consider Disruptions (see 'Replan network in case of disruption' Use Case)
- Additional required data: Any additional data required by the Tactical Evaluator to simulate the planned tactical network with the calibrated model. See Annex A from FRD [2] and [3] for more details.
- Service: a flight or a train.
- Itinerary: A succession of services which respect the minimum connecting times of the services involved.

Use Case: Execute Tactical Evaluator with tactical experiment

Primary Actor: Tactical Performance Assessment Expert

Scope: Tactical Performance Evaluator

Stakeholders and interests:

- Tactical Performance Assessment Expert: Wants to evaluate how a planned tactical network will materialise on the day of operations.

Brief: The Tactical Performance Assessment Expert runs the simulation carried out by the Tactical Multimodal Evaluator using the input prepared by use case 'Create tactical experiment'. The output of the Tactical Multimodal Evaluator is the realisation of the itineraries and services throughout the day in the format specified in Annex A in FRD [2]. Note that Tactical Multimodal Evaluator is a stochastic simulator. Therefore, the same configuration must be executed several times to obtain statistically significant results.

Preconditions: Input data as specified in Annex A in FRD [2]

Minimal guarantees: Capacities of services are respected if passengers are reallocated in case of missed connections.

Success guarantees: The Tactical Evaluator simulates the passenger itineraries and services on the day of operations.

Trigger: The Tactical Performance Assessment Expert wants to simulate the tactical experiment, i.e. the realisation of the itineraries and services on the day of operations.

Main success scenario:

1. The Tactical Performance Assessment Expert provides to the Tactical Evaluator the tactical experiment and request it to be simulated times.
2. The Tactical Evaluator simulates the planned tactical network with the considerations of the tactical experiment n times and stores the output of the Tactical Evaluator of each simulation.

Use Case Data:

- Planned tactical network: A planned network in the format required by the Tactical Evaluator (see Annex A from FRD [2])
- Planned network: supply (flight schedules and rail timetable), demand (passenger itineraries) and infrastructure (access/egress times, minimum connecting times, inter-modes connecting times, passenger processing times).
- Output of the Tactical Evaluator: realisation of the itineraries and services

Auxiliary definitions:

- Tactical experiment: A planned network (supply (flight schedules, rail timetable), demand (passenger itineraries) and infrastructure (access/egress times, minimum connecting times, inter-modes connecting times, passenger processing times)) in the format required by the Tactical Evaluator (see Annex A from FRD [2])) and any other additional required data by the Tactical Evaluator to simulate the network.

- Additional required data: Any additional data required by the Tactical Evaluator to simulate the planned tactical network with the calibrated model. See Annex A from FRD [2] and [3] for more details.

Use Case: Compute PIs of tactical experiment

Primary Actor: Tactical Performance Assessment Expert

Scope: Tactical Performance Evaluator

Stakeholders and interests:

- Tactical Performance Assessment Expert: Wants to calculate multimodal tactical performance indicators on the realisation of the itineraries and services on the day of operations for a tactical experiment.

Brief: The Tactical Performance Assessment Expert computes the multimodal tactical performance indicators (particularly passenger-focus indicators) on the simulated tactical experiment.

Preconditions: The realisation of the itineraries and services within the tactical experiment have already been simulated, i.e., the output of the Tactical Evaluator for the tactical experiment is available (see 'Execute Tactical Evaluator with tactical experiment' Use Case).

Minimal guarantees: None

Success guarantees: Multimodal tactical performance indicators are computed using the information on itineraries and services within the network.

Trigger: The Tactical Performance Assessment Expert wants to compute multimodal tactical performance indicators on the simulated tactical experiment.

Main success scenario:

1. The Tactical Performance Assessment Expert provides the performance indicator estimator the outcome of the Tactical Evaluator of the n executions of the tactical experiment.
2. The performance indicator estimator estimates the multimodal tactical performance indicators on the provided realisations of the itineraries and services.

Extension: Consider replanned passengers

Condition: The tactical experiment contains a replanned network as computed by the 'Replan network in case of disruption' Use Case.

Step: 1

Scenario:

1. The Tactical Performance Assessment Expert provides the performance indicator estimator also information on the replanned network, including the multimodal replanning performance indicator from the 'Compute PIs of replanned network' so that the performance indicator estimator can use this information to adequately compute passenger-centric indicators, such as stranded passengers or total delay with respect to initially planned itinerary.
2. Go to step 1 of the main success scenario.

Use Case Data:

- Output of the Tactical Evaluator: realisation of the itineraries and services.
- See Annex A from FRD [2] for information on their format.

Auxiliary definitions:

- Service: A flight or a train.
- Tactical experiment: A planned network (supply (flight schedules, rail timetable), demand (passenger itineraries) and infrastructure (access/egress times, minimum connecting times, inter-modes connecting times, passenger processing times)) in the format required by the Tactical Evaluator (see Annex A from FRD [2])) and any other additional required data by the Tactical Evaluator to simulate the network.
- Multimodal tactical performance indicators: Performance indicators capturing multimodal aspects of mobility with a particular focus on passenger-centric indicators (e.g. missed connections, total arrival delay) on the realisation of the planned tactical network.
- Realisations of the itineraries and services: outcome of simulating passenger itineraries and services by the Tactical Evaluator.
- Replanned network: A planned network that has been modified to consider Disruptions (see 'Replan network in case of disruption' Use Case)
- Multimodal replanning performance indicator: Performance indicators capturing multimodal aspects of mobility with a particular focus on passenger-centric indicators for passengers impacted by the disruptions (e.g. number of passengers rebooked, extra planned travelling time, mode changes, and stranded passengers).

Use Case: Compare tactical experiments' performance

Primary Actor: Tactical Performance Assessment Expert

Scope: Tactical Performance Evaluator

Stakeholders and interests:

- Tactical Performance Assessment Expert: Wants to compare the performance of different tactical experiments. For example, comparing a reference network to a network where

SOL400/SOL2 has optimised the schedules, or to a network where a mechanism to support multimodality is applied (e.g. fast-track at the airport).

Brief: The Tactical Performance Assessment Expert compares the multimodal tactical performance indicators of a set of tactical experiments.

Preconditions: A set of tactical experiments with the output of the Tactical Evaluator (see 'Execute Tactical Evaluator with tactical experiment' Use Case) and of the computation of the multimodal tactical performance indicators (see 'Compute Pls of tactical experiment' Use Case) are available.

Minimal guarantees: None

Success guarantees: The multimodal tactical performance indicators of the different tactical experiments are compared.

Trigger: The Tactical Performance Assessment Expert wants to assess the performance of a network by comparing its performance to a set of other networks, i.e., comparing multimodal tactical performance indicators of a set of tactical experiments.

Main success scenario:

1. The Tactical Performance Assessment Expert provides the information on the planned tactical networks (tactical experiments), on the outcomes of the Tactical Evaluator and on the multimodal tactical performance indicators of the tactical experiments to be compared.
2. The Tactical Performance Assessment Expert uses the performance indicator estimator to compare the results of all the tactical experiments' multimodal tactical performance indicators.

Use Case Data:

- Multimodal tactical performance indicators: Performance indicators capturing multimodal aspects of mobility with a particular focus on passenger-centric indicators (e.g. missed connections, total arrival delay) on the realisation of the planned tactical network.
- Planned tactical network: A planned network in the format required by the Tactical Evaluator (see Annex A from FRD [2]).
- Planned network: Flight schedules, rail timetable, infrastructure and passenger itineraries. See Annex A from FRD [2] for information on their format.

Auxiliary definitions:

- Tactical experiment: A planned network (supply (flight schedules, rail timetable), demand (passenger itineraries) and infrastructure (access/egress times, minimum connecting times, inter-modes connecting times, passenger processing times)) in the format required by the Tactical Evaluator (see Annex A from FRD [2])) and any other additional required data by the Tactical Evaluator to simulate the network.
- Output of Tactical Evaluator: realisation of the itineraries and services
- Network: Planned tactical network

D.4 Disruptions Evaluation

Use Case: Replan network in case of disruption

Primary Actor: Disruption Management Performance Assessment Expert

Scope: Strategic Performance Evaluator

Stakeholders and interests:

- Disruption Management Performance Assessment Expert: wants to replan the network, generating available possible itineraries (succession of services) for passengers impacted by disruptions to reassign passengers in those available possible itineraries.

Brief: The Disruption Management Performance Assessment Expert applies a disruption package to a planned network to create a new planned network (replanned network) and reallocates passengers whose itineraries are impeded into available possible itineraries. Note that the outcome is a planned network and therefore it could be tactically evaluated to see how it materialises (see 'Create tactical experiment ' Use Case).

Preconditions: Planned network available.

Minimal guarantees: Available possible itineraries respect the infrastructure (e.g., MCT) and business-related restrictions (e.g. alliances) as defined in the strategic experiment. The passenger itineraries respect the service capacities (seats available), and only passengers impacted by the disruptions are reallocated.

Success guarantees: A new planned network (replanned network) is computed, generating a new strategic experiment, reallocating as many passengers impacted by the disruptions as possible in the available itineraries.

Trigger: The Disruption Management Performance Assessment Expert wants to replan a network to deal with a given disruption package.

Main success scenario:

1. The Disruption Management Performance Assessment Expert uses the Strategic Evaluator to compute available itineraries between the origin-destination itineraries for which services are impacted by the disruption package.
2. The Disruption Management Performance Assessment Expert requests the Strategic Evaluator to reassign the passengers impacted by the disruption by identifying the passenger itineraries that are not feasible and reallocating as many of those passengers into the available itineraries to create the replanned network. This reassignment is performed considering the configuration of the disruption management evaluation.

Extension: Replan rail timetable

Condition: Rail network disruptions are part of the disruption package and Disruption Management Solution (SOL401/SOL3) is not used.

Step: 1

Scenario:

1. The rail timetables are adjusted to reflect the disrupted capacity in the rail system (either reduced throughput at some nodes and/or links, or closure of links).
2. Go to step 1 of the main success scenario.

Extension: Replan network with Disruption Management Solution

Condition: The Disruption Management Performance Assessment Expert wants to use the Disruption Management Solution (SOL401/SOL3) to modify the supply (flight schedules and/or rail timetables) of the network, considering the disruption package.

Step: 1

Scenario:

1. The Disruption Management Performance Assessment Expert executes the 'Replan network considering disruption' Use Case of the Disruption Management Solution (SOL401/SOL3). See OSED of SOL401/SOL3 [4].
2. The flight schedules and/or rail timetables that the Disruption Management Solution have modified are also modified in the planned network.
3. Go to step 1 of the main success scenario.

Use Case Data:

- Flight schedules: flight schedules for the day of assessment (see Annex A from FRD [2] for information on format)
- Rail timetables: Rail timetables (in GTFS format, see Annex A from FRD [2] for information on format)
- Itineraries of passengers impacted by the disruption (see Annex A from FRD [2] for information on format)
- Passenger itinerary: Number of passengers assigned to an itinerary.
- Itinerary: A succession of services which respect the minimum connecting times of the services involved.
- Planned network: Flight schedules, rail timetable, infrastructure and passenger itineraries. See Annex A from FRD [2] for information on their format.
- Replanned network: Infrastructure, and flight schedules and rail timetables that have been modified to consider the impact of the disruption package; and passenger itineraries have been reallocated in the available possible itineraries.
- Infrastructure: Minimum connecting times, access and egress times, inter-modes connecting times, and passenger processing times (see Annex A from FRD [2] for information on format and detailed data description).
- Disruption package: Set of disruptions that are applied at the same time to the planned network.
- Disruptions: Rail or air network disruptions which are known in advance and produce a significant reduction in supply on the infrastructure of the networks.

- Rail network disruption: Reduced throughput at nodes (rail stations) and/or links, and/or closure of links.
- Air network disruption: Significant ATFM regulations applied at airports.
- Configuration of the disruption management evaluation: parameters required to configure how the passengers are assigned into the available possible itineraries.

Auxiliary definitions:

- Strategic experiment: A specific network defined by supply, demand, infrastructure, strategic configuration parameters and policy package.
- Available possible itineraries: Itineraries available between a given origin-destination pair considering the modified flight schedules and rail timetables due to the impact of the disruption package.

Use Case: Compute PIs of replanned network

Primary Actor: Disruption Management Performance Assessment Expert

Scope: Strategic Performance Evaluator

Stakeholders and interests:

- Disruption Management Performance Assessment Expert: Wants to calculate multimodal replanning performance indicators on the replanned network, considering passengers impacted by the disruption.

Brief: The Disruption Management Performance Assessment Expert computes multimodal replanning performance indicators (particularly passenger-focus indicators) on the replanned network. Aspects related to the impact of the replanned operations on the passenger itineraries are estimated, such as extra travel time with respect to the initial planned itinerary, shift between planned and replanned mode, or demand not fulfilled. Note that if the Disruption Management Performance Assessment Expert wants to evaluate the realisation of the replanned network they should use the available Use Cases for the 'Tactical Performance Assessment Expert', as the replanned network is a planned network and therefore can be assessed tactically.

Preconditions: The replanned network has already been computed.

Minimal guarantees: None

Success guarantees: Multimodal replanning performance indicators for the impacted passengers are computed using the information from the replanned network.

Trigger: The Disruption Management Performance Assessment Expert wants to compute multimodal replanning performance indicators on the replanned network.

Main success scenario:

1. The Disruption Management Performance Assessment Expert provides the performance indicator estimator for the replanned network.
2. The performance indicator estimator estimates the multimodal replanning performance indicators on the replanned network considering the impacted passengers.

Use Case Data:

- Planned network: Flight schedules, rail timetable, infrastructure and passenger itineraries. See Annex A from FRD [2] for information on their format.

Auxiliary definitions:

- Replanned network: Infrastructure, and flight schedules and rail timetables that have been modified to consider the impact of the disruption package; and passenger itineraries have been reallocated in the available possible itineraries.
- Multimodal replanning performance indicators: Performance indicators capturing multimodal aspects of mobility with a particular focus on passenger-centric indicators for passengers impacted by the disruptions (e.g. number of passengers rebooked, extra planned travelling time, mode changes, and stranded passengers).

Use Case: Compare replanned networks performance

Primary Actor: Disruption Management Performance Assessment Expert

Scope: Strategic Performance Evaluator

Stakeholders and interests:

- Disruption Management Performance Assessment Expert wants to compare KPIs of different alternatives of replanned networks.

Brief: The Disruption Management Performance Assessment Expert compares the multimodal replanning performance indicators of a set of replanned networks.

Preconditions: A set of alternative replanned networks have been computed using the 'Replan network in case of disruption' Use Case.

Minimal guarantees: None

Success guarantees: The multimodal replanning performance indicators of the different replanned networks are compared.

Trigger: Disruption Management Performance Assessment Expert wants to compare the multimodal replanning performance indicators of different replanned networks. Note that to compare the tactical realisation of the networks they would use the relevant Use Cases from the Tactical Performance Evaluation.

Main success scenario:

1. The Disruption Management Performance Assessment Expert provides the information on multimodal replanning performance indicators of the replanned networks to be compared.
2. The Disruption Management Performance Assessment Expert uses the performance indicator to compare the results of the replanned networks' multimodal replanning performance indicators.

Use Case Data:

- Multimodal replanning performance indicators: Performance indicators capturing multimodal aspects of mobility with a particular focus on passenger-centric indicators for passengers impacted by the disruptions (e.g. number of passengers rebooked, extra planned travelling time, mode changes, and stranded passengers).

Auxiliary definitions:

- Replanned network: Infrastructure, and flight schedules and rail timetables that have been modified to consider the impact of the disruption package; and passenger itineraries have been reallocated in the available possible itineraries.

D.5 References for Appendix D

- [1] MultiModX Consortium (2025). Operational Service and Environment Definition (OSED) for SOL2 – Schedule Design Solution (SOL400)
- [2] MultiModX Consortium (2024). Functional Requirement Document (FRD) for SOL1 – Multimodal Performance Evaluation Framework (SOL399)
- [3] Gurtner, G., Delgado, L. and Valput, D. (2021). An agent-based model for air transportation to capture network effects in assessing delay management mechanisms. Transportation Research Part C: Emerging Technologies, Vol. 133, 103358. <https://doi.org/10.1016/j.trc.2021.103358>
- [4] MultiModX Consortium (2025). Operational Service and Environment Definition (OSED) for SOL3 - Disruption Management Solution (SOL401)

Appendix E – Operational requirements

This Annex presents the operational requirements, these requirements will complement the functional requirements captured in the Functional Requirements Document (FDR).

E.1 Multimodal Performance Framework

E.1.1 REQ-SOL399-OP-MPF01.001

Identifier	REQ-SOL399-OP-MPF01.001	
Title	Provide multimodal PIs and KPIs	
Requirement	SOL399/SOL1 Multimodal Performance Framework shall provide a set of PIs and KPIs that capture the mobility's multimodal aspects.	
Status	In progress	
Rationale	Defined in SOL399/SOL1 OSED	
Category	Operational	
Relationship	Linked Element Type	Identifier
ALLOCATED_TO	SESAR Solution	SOL399

E.2 Strategic Multimodal Evaluator

E.2.1 REQ-SOL399-OP-SME01.001

Identifier	REQ-SOL399-OP-SME01.001	
Title	Assess mobility between regions planned and reallocate passengers if replanned operations	
Requirement	SOL399/SOL1 Strategic Evaluator model shall assess the mobility between regions (and infrastructure) given a set of flight and rail schedules and timetables, infrastructure characteristics (e.g. connecting times between modes), origin-destination demand and their characteristics. It shall also reassign passenger itineraries if a replanned network is provided.	
Status	In progress	
Rationale	Defined in SOL399/SOL1 OSED	
Category	Operational	
Relationship	Linked Element Type	Identifier
ALLOCATED_TO	SESAR Solution	SOL399

E.3 Tactical Multimodal Evaluator

E.3.1 REQ-SOL399-OP-TME01.001

Identifier	REQ-SOL399-OP-TME01.001	
Title	Assess a day of operations	
Requirement	SOL399/SOL1 Tactical Evaluator model shall assess a day of operations, including the <i>nominal</i> disturbances of the system and larger disruptions.	
Status	In progress	
Rationale	Defined in SOL399/SOL1 OSED	
Category	Operational	
Relationship	Linked Element Type	Identifier
ALLOCATED_TO	SESAR Solution	SOL399