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Abstract

This document contains a qualitative Cost and Benefits Assessment (CBA) for the SESAR Solution 399 (SOL1), Multimodal Performance Framework and Evaluation. The document is organised as follows: first, SOL399/SOL1 is presented, and then the overall expected benefits and costs derived from its implementation are explained, along with the context and assumptions used to derive them. Each benefit and cost are later discussed individually.

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Nominative authoring compliance

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MultiModX

INTEGRATED PASSENGER-CENTRIC PLANNING OF MULTIMODAL NETWORKS

MultiModX

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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. Note that this is not a SESAR ATM Solution but rather a **transversal evaluator**.

The main stakeholders impacted by the ***performance framework*** are system performance modellers, decision-makers, infrastructure managers, and any other actor concerned with the multimodal definition and monitoring of operations. MultiModX provides the first step in defining an open digital performance catalogue, which could further be developed by the Passenger Experience and Multimodality Flagship. This will bring benefits as a set of commonly agreed indicators (with their definitions) shared across a range of research projects.

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

- A *Strategic Evaluator*, which focuses on the evaluation of flight schedules, rail timetables and other infrastructure characteristics, like minimum connecting times intra and inter-modes, to assess mobility from a passenger-centric perspective, providing metrics at the regional, the infrastructure (airport, rail station) and the operator level.

- A *Tactical 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 *Strategic Evaluator* provides the capabilities needed to evaluate Solutions that optimise the flight and rail schedules, such as SOL400/SOL2 - Schedule Designer Solution. Some of its capabilities also support the assessment of replanned networks in case of disruption, as provided by SOL401/SOL3 - Disruption Management Solution. For example, reassigning passengers into replanned operations (flight schedules and rail timetables) when these are adjusted to deal with disruptions.

Being a what-if transversal multimodality evaluator, there is a range of different stakeholders that could benefit from the Strategic 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.

The *Tactical Evaluator* uses individual flight and rail schedules and passenger itineraries and simulates them through the day of operation. 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 or 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 potential uses and stakeholders who could benefit from such a tactical simulator. For example, air and rail operators, airport managers and policymakers.

Since the Performance Assessment Solution (SOL399/SOL1) aims to evaluate the performance of other multimodal Solutions (such as SOL400/SOL2 and SOL401/SOL3), it can offer benefits in a more general sense by supporting the design, development and assessment of strategic and tactical multimodal solutions. As such, the realised benefits are related to promoting multimodality through the deployment of other Solutions, mechanisms and policies. These benefits are mainly:

- **Social benefits**. The approach of the MultiModX project is passenger-centric, and therefore, most of the expected measured benefits of the Solutions of this project are passenger-related. Benefits include, but are not limited to, reduction of missed connections, resilience, infrastructure connectivity, etc. All these benefits will improve overall passenger satisfaction over multimodal journeys.

- **Economic benefits**. Multimodality presents economic benefits that stem mainly from a more efficient use of resources (due to the cooperative operation of air and rail). Most of these benefits will impact the users of the SOL399/SOL1 (airline and railway operators), but some of them will impact airports, train stations, infrastructure managers and even city planners.

- **Environmental benefits**. The implementation of a coordinated air and rail network entails a more efficient use of the resources and the possibility of replacing short-haul flights by rail, eventually reducing strategically CO_2 emissions. However, as noticed in the experiments, this would need to be accomplished with an increase in the available capacity of the rail network.

The deployment of SOL399/SOL1 would entail direct costs for its main users (airlines and railway operators), mainly due to training and software implementation, and indirect costs could stem from potentially different use of infrastructure in a multimodal operational environment.

As stated in the OSED [19], the environment where the Solution is to be deployed is mid to long-distance trips in different regional archetypes (identified in the project), along with different multimodal policy and disruption packages.

Finally, it is worth reiterating that **SOL399/SOL1 does not provide necessary benefits directly to the performance framework in terms of improved indicators but provides a common framework and understanding of the impact of multimodality into SESAR; and a set of tools which support the evaluation of other Solutions, mechanisms and policies**. Therefore, this ECO-EVAL does not focus on presenting the benefits obtained by those Solutions (e.g. the impact on performance indicators/areas of having synchronised air-rail schedules, as done by SOL400/SOL2), as those benefits would be reported on the corresponding ECO-EVAL of those Solutions. Instead, the focus is on presenting the potential impact of multimodality as a whole and showing the capabilities gained by the community thanks to SOL399/SOL1.

2 Introduction

2.1 Purpose of the document

The purpose of this document is to provide an overview of the SESAR solution and the costs and benefits related to its deployment. This document provides information about the problem addressed by the Solution, the main stakeholders involved with the Solution and how the deployment of the Solution affects them. Since this solution is targeting TRL2, the cost-benefit analysis is mostly qualitative, and the last sections of this document are left blank. Along with the cost/benefit analysis, this document presents a timeline for the deployment of the Solution and a description of future scenarios with and without the deployment and implementation of the Solution. It is worth noting that as a set of tools to evaluate multimodal Solutions, SOL399/SOL1 could be considered to have reached higher TRL, as it has fulfilled its role by supporting the evaluation of SOL400/SOL2 and SOL401/SOL3 with more advanced performance evaluation capabilities in comparison to the evaluation capabilities of those Solutions on their own.

2.2 Scope

According to the latest version of the DES common assumptions document, the timeframe of the analysis is 2026 to 2050.

The scope of the ECO-EVAL is the following:

- Trip type: Mid to long distance trips where air and rail options can be comparable in terms of travel time and can complement each other. We assume throughout the project that multimodal governance is in place.
- Region type: 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 into regional archetypes. Thus, this facilitates the evaluation of the impact of multimodality at the 'travel regions' level, which could then be extrapolated to other regions similar in multimodal applicability, even if not explicitly modelled. 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 analysis identified three regional archetypes within Europe which can be considered as sub-operating environments:

    1. Advanced urban regions with strong travel activity
    2. Conservative regions with median travel activity
    3. Emerging rural regions with low travel activity

The exact sub-operational environments in which the Solution was tested are reported in SOL399/SOL1's Experimental Research Plan (ERP) [11] in Section 3.1.2.

There is a wide range of stakeholders that could benefit from SOL399/SOL1. Among others, transport modellers and policymakers who can assess different what-if scenarios and policy implementation; cities and regional urban planners who can assess the impact of improvements and changes to their infrastructure; airspace users and rail operators who can evaluate the potential impact of multimodal alternatives; infrastructure managers (airports, rail stations), who can assess the connectivity of their nodes; and particularly, other Solution developer who can use SOL399/SOL1 to evaluate their Solutions in the context of multimodality.

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, the partners on the MultiModX project, and those responsible for the development of SOL400/SOL2 and SOL401/SOL3 are indended readers to ensure that the processes and usage are aligned.

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 [9, 15], which already reviewed the current ICAO [6] and SESAR performance schemes [13]. 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 current version of the SESAR Master Plan includes passenger-related indicators, and future developments consider the inclusion of Passenger Experience as a key performance area (KPA) for which 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 [14], MAIA [8], PEARL [12], AMPLE3 [1] and Travel Wise [17]. 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 of 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) [2, 4, 10]. In the context of multimodality, these discrepancies are expected to increase.

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 [3, 4]. 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 [4].

2.5 Structure of the document

The ECO-EVAL presents a preliminary analysis of the economic benefits and costs of the MultiModX SOL399/SOL1. The structure of this document is as follows: in Section 3 the objectives and the scope of the document are presented, including the stakeholders identification. In Section 4 the economic benefits of the solution are listed. In section 5 we present an analysis of the cost associated with the SOL399/SOL1. Since the MultiModX project is aiming at reaching Technology Readiness Level 2 (TRL2), sections 6 to 9 are not applicable and will be completed during the TLR4 developments.

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

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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
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.	Own elaboration
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 [5]).	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 policy packages that are planned to be evaluated [11].	Own elaboration
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 train between two rail 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 [5]) and any other additional required data by the Tactical Evaluator to simulate the network (e.g. disruptions, flight plans).	Own elaboration
ECO-EVAL reference scenario	The scenario against which the solution is compared, i.e. the situation without the proposed SESAR solution (but including other improvements which have been implemented in the meantime).	DES transversal CBA team
ECO-EVAL solution scenario	The scenario with the proposed SESAR solution and other improvements which have been implemented in the meantime.	DES transversal CBA team
Economic evaluation (ECO-EVAL)	The economic evaluation assesses the potential benefits that an innovative idea or application under analysis by an exploratory research project could provide against an initial high-level estimation of the costs that it may imply.	SESAR 3 JU Project Handbook – Programme Execution Framework, edition 01.00, 11 April 2022

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Implementation cost	All costs related to the acquisition and implementation of the SESAR solution.	SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02
Investment cost	The investment cost covers the pre-implementation costs (e.g., feasibility studies) and the implementation costs (e.g., system integration). Note that the pre-implementation costs shall not consider the SESAR R&I costs.	DES transversal CBA team
Operating cost	All costs related to the change in daily operations that is brought about by the SESAR solution.	SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02
Pre-implementation cost	All costs that need to be used up to define the needs, to develop solutions, and to decide which solution best serves the needs. Note that the SESAR R&I costs shall not be included as costs in any DES CBA/ECO-EVAL.	SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02

Table 1: glossary of terms

2.7 List of acronyms

Term	Definition
ABM	Agent Based Model
ATFM	Air traffic flow management
ATM	Air traffic management
BIM	Benefit Impact Mechanisms
DES	Digital European Sky
ERP	Exploratory research plan
ERR	Experimental Research Report
FRD	Functional Requirements document
GDS	Global Distribution Systems
ID	Identifier
KPA	Key Performance Area
KPI	Key Performance Indicator
NUTS	Nomenclature of territorial units for statistics

OSED	Operational service and environment description
PI	Performance Indicator
SESAR	Single European sky ATM research
SESAR 3 JU	SESAR 3 Joint Undertaking
TBD	To be defined
TRL	Technology Readiness Level

Table 2: List of acronyms

3 Objectives and scope of the ECO-EVAL

3.1 Problem addressed by the SESAR solution

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

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. Therefore, as previously discussed, SOL399/SOL1 does not provide benefits on its own, but can provide deeper understanding of the benefits of other Solutions, mechanisms and other aspects such as policies.

Multimodal Performance Framework

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. Therefore, a definition of a shared multimodal performance framework is needed. This should reflect how SESAR KPIs impact multimodality, how multimodality could impact SESAR's indicators and, critically, how the SESAR Performance Framework could be extended to include some of these passenger-centric (multimodal) aspects.

Currently, there is no such thing that can help inform the performance framework and the Passenger Experience KPA.

Strategic Multimodal Evaluator

The detailed representation of multimodal transport supply as a layered network 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 is required to understand passengers' alternatives and preferences when using the network.

There is a need for a platform that enables the evaluation of mobility considering the joint operations of air and rail services as not such tool is currently available. This Strategic Evaluator should enable the assessment of flight schedules and rail timetables under different assumptions (e.g. integrated ticketing between operators) and policies (e.g. CO_2 emissions costs).

The evaluator also enables the assessment of replanned operations when dealing with network-related disruptions reallocating passengers on available capacity.

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Tactical Multimodal Evaluator

The transport network is subject to different types of disruption during their 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) [2, 4, 10]. 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 due to passenger experience.

There are tools that model air and rail operations, albeit with limited representation of passenger itineraries and a lack of combined models.

3.2 SESAR solution description

Multimodal Performance Framework

The multimodal performance framework developed as part of SOL399/SOL1 relies on a literature review of previous work in the field, 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 2 is divided into two categories: Level 2.1, with the indicators selected as candidates to be promoted to Level 1; and Level 2.2, which contains indicators currently modelled/considered by different SESAR Solutions (and projects).
- 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.

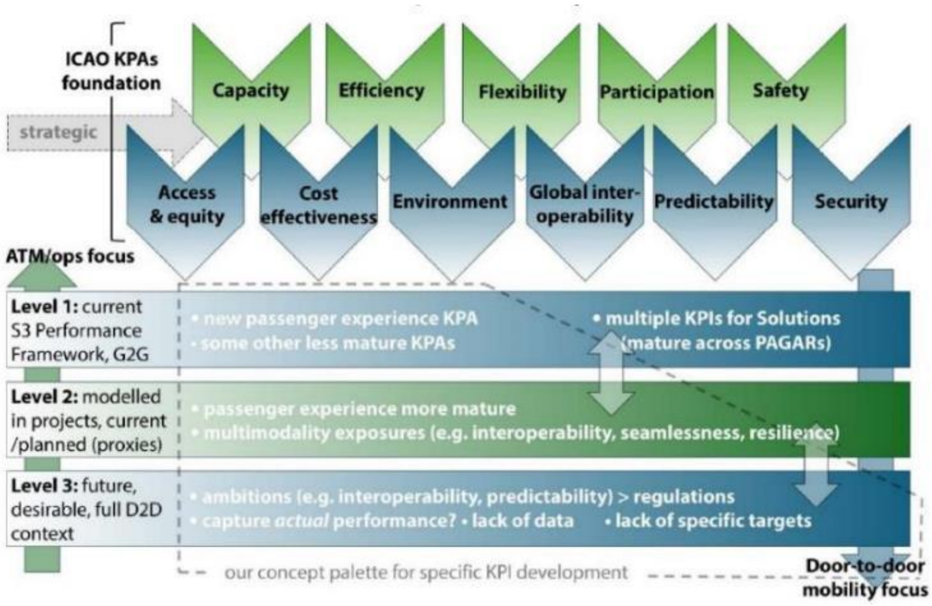

Figure 1: Performance Assessment – Multimodal Performance Framework Concept

It is worth noting 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. The broader objectives are:

1. To build an **open access, digital catalogue** of multimodality and passenger experience indicators across the three levels;
2. To carry out a two-way **gap analysis** between the 'capabilities' in the SESAR Target Architecture and the indicator catalogue;
3. 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 (these are currently reported as Level 2.1 in the digital catalogue). 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 developed further by the Passenger Experience and Multimodality Flagship.

Strategic Multimodal Evaluator

As shown in Figure 2, the Strategic Multimodal Evaluator can be used to represent and analyse the planned (and replanned) network. It comprises of three main elements:

- **Strategic Planned Network Evaluator**, which, from the characteristics of demand (OD demand), 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 [5], and for example of datasets used to create such inputs, see Appendix B – Input data sources examples in the OSED [19].

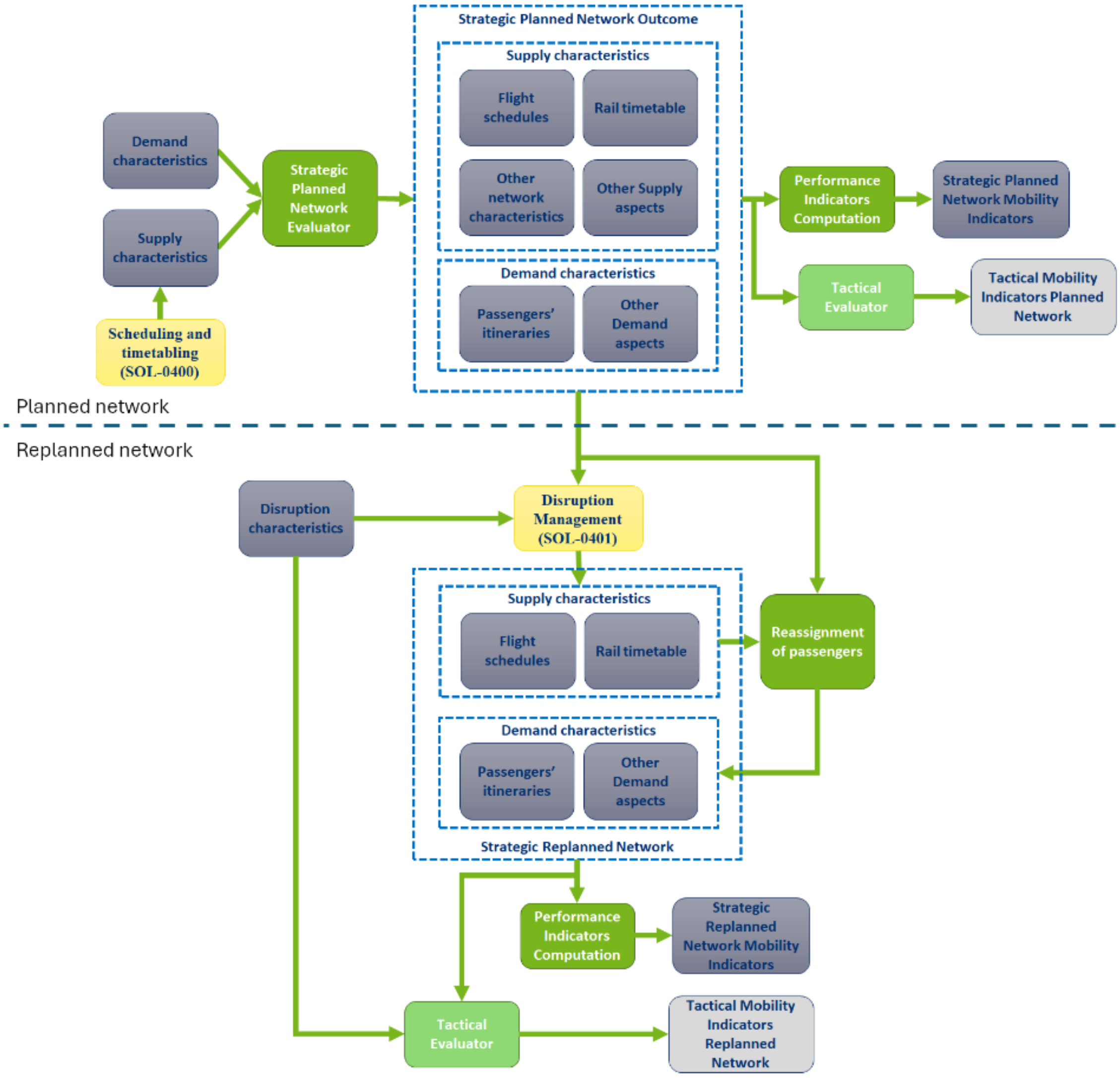

Figure 2: Performance Assessment – Strategic Multimodal Evaluator

The supply could be any flight and rail schedule, 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.

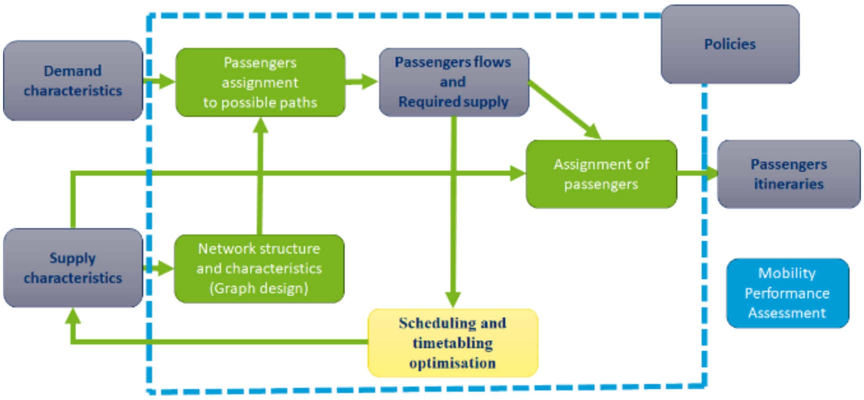

Figure 3: Performance Assessment – Strategic planned network evaluator concept

- **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.

- **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) or business models (e.g. alliances for inter-mode operations).

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 [5]; for information on the calibration of the model and other parameters, see [4].

The model can simulate a variety of conditions, such as day-to-day *nominal* delays, stressed nominal conditions (e.g. ATFM regulations or delays on the ground system linking the rail stations with the airports), or wider disruptions. 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.

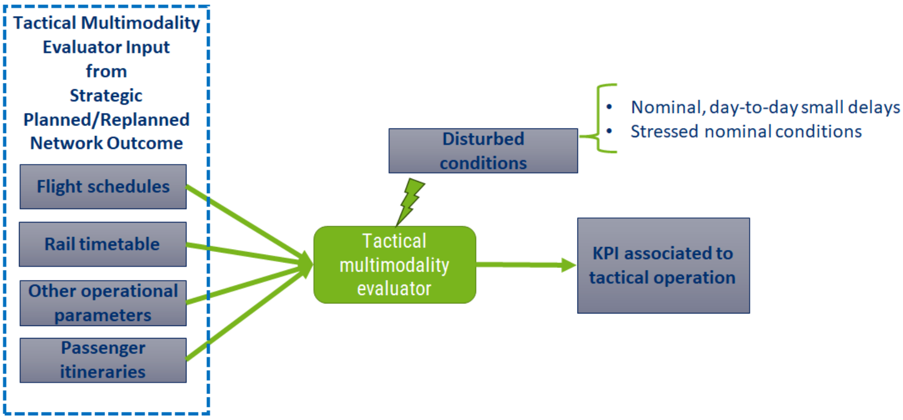

Figure 4: Performance Assessment – Tactical Multimodal Evaluator

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 [3, 4, 18]. 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.

3.2.1 SESAR solution interdependencies

SOL399/SOL1 is a standalone Solution with applicability across diverse operational environments. SOL399/SOL1 is therefore a system enabler which support external solutions.

Multimodal Performance Framework

The Multimodal Performance Framework provides a set of PIs and KPIs that can be used to (partially) capture the multimodal aspects of transport. Therefore, it does not require any particular interactions with external systems.

Strategic and Tactical Multimodal Evaluator

The Strategic and Tactical Multimodal Evaluators are standalone models to assess planned and realised mobility networks. Therefore, they are not expected to interact with external systems for their execution.

However, the Strategic Multimodal Evaluator will interact with MultiModX's Schedule Design Solution, SOL400/SOL2. This will be done by SOL400/SOL2, which will produce a new set of schedules and timetables to be evaluated strategically. As previously described, the Disruption Management Solution SOL401/SOL3 will generate new (updated) schedules and timetables that the Strategic Multimodal Evaluator will use to reassign impacted passengers to the available supply.

The Tactical Multimodal Evaluator can evaluate these planned operations. Therefore, the Tactical Multimodal Evaluator supports the full assessment of the performance of the Schedule Design Solution SOL400/SOL2 and the Disruption Management Solution SOL401/SOL3 by providing insight into the robustness of these planned operations.

Finally, it is worth noticing that the Tactical Multimodal Evaluator can also assess the impact on multimodality and passenger-related metrics of other mechanisms and/or Solutions. This can be done for mechanisms and Solutions which are directly related to multimodality (such as fast-track at the airports for multimodal passengers, as in [18]) or just that impact ATM operations (such as Dynamic Cost Indexing as in [4]). This is achieved by modifying the code of the Evaluator with the use of Modules.

3.3 Objectives of the ECO-EVAL

The objective of this TRL2 ECO-EVAL is to help build an assessment of whether the MultiModX's SOL399/SOL1 is worth deploying, across ECAC, from an economic perspective for the involved stakeholders. This ECO-EVAL provides a consolidated assessment of the costs and benefits of deploying SOL399/SOL1 in the operational environment included in the ECO-EVAL solution scenario (see Section 3.5.2).

This ECO-EVAL includes the evidence gathered to estimate the benefits and costs of the solution. The output is an overview of the high-level impact of costs and benefits per stakeholder group, recommendations and next steps.

As discussed, and due to the transversal nature of SOL399/SOL1, the focus will be to showcase the capabilities that SOL399/SOL1 can provide to assess multimodal networks along with an analysis of the potential impact of multimodality on the SESAR Performance Framework, developed by SOL399/SOL1 as part of the definition of the multimodal digital catalogue of indicators (multimodal performance framework).

3.4 Stakeholder identification

Stakeholder	Deployment locations (or sub-operating environments)	Cost drivers	Benefits in operations	Involvement in the ECO-EVAL analysis
ANSP	N/A	N/A	N/A	Not involved
Airport operators	Hub airports and secondary and regional airports. Connected with rail infrastructure with high connectivity, Connected with rail infrastructure in a secondary rail network, and Not connected with rail infrastructure. Differentiation between collocated or not with rail infrastructure.	N/A	Variation in passenger flow through the airport. Changes to the catchment area of airports and to the required connectivity with other modes.	Members from airports present at the Industry Board meetings
Network manager	ECAC-wide	N/A	Reduced amount of ATFM regulations required due to replanning of operations with SOL401/SOL3 which SOL399/SOL1 enables the evaluation. Changes in demand patterns.	Not involved
Scheduled airlines (mainline and regional)// airline operator	Full-service carriers	Invest in new system Training System maintenance Data collection	Increased aircraft occupancy. Increased sales. Increased customer retention.	Members from airports present at the Industry Board meetings
Business aviation	N/A	N/A	N/A	Not involved

Rotorcraft	N/A	N/A	N/A	Not involved
General aviation IFR	N/A	N/A	N/A	Not involved
General aviation VFR	N/A	N/A	N/A	Not involved
UAS operators	N/A	N/A	N/A	Not involved
Military	N/A	N/A	N/A	Not involved
Common information service provider (CISP)	N/A	N/A	N/A	Not involved
U-space service provider (USSP)	N/A	N/A	N/A	Not involved
Other impacted stakeholders (ground handling, weather forecast service provider, NSA/CAA…)	N/A	N/A	N/A	Not involved
Cities and regional urban planners	Advanced urban regions with strong travel activity, Conservative regions with median travel activity, Emerging rural regions with low travel activity Peripheral regions	Invest in new system Training System maintenance Data collection	Economic growth due to better connectivity	Not involved
Railway companies	National railway operator	Invest in new system Training System maintenance Data collection	Increased train occupancy. Increased sales. Increased customer retention.	Not involved

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Train stations	Connected with airport infrastructure with high connectivity, Connected with airport infrastructure in a secondary air network, and Not connected with airport infrastructure. Differentiation between collocated or not with airport infrastructure.	N/A	Increased passenger flow through the stations. Potentially less spending due to lower waiting times.	Members from airports present at the Industry Board meetings
Rail network maintainers	National rail infrastructure manager	Increased maintenance costs in some segments	Increased demand.	Members from airports present at the Industry Board meetings

Table 3: ***SESAR 399 – Stakeholders***

During the 1st Industry Board workshop held on February 20, 2024, several stakeholders participated in the discussion sessions where potential benefits of multimodality were discussed. This was followed up with the 2nd Industry Board workshop held on November 12, 2025, in Rome.

3.5 ECO-EVAL scenarios and assumptions

This section describes the scenarios that are compared in the ECO-EVAL. The aim is to reflect the delta (difference) between the ECO-EVAL reference scenario (where the SESAR solution is not deployed, bottom box in Figure 5) and the ECO-EVAL solution scenario (reflecting the proposed deployment of the SESAR solution across ECAC, box in Figure 5). The comparison between the ECO-EVAL scenarios considers the point in time when the solution is available to be deployed, and hence, the difference between each solution is different.

The delta approach means that the focus is on identifying the impact of the changes between the ECO-EVAL reference and ECO-EVAL solution scenarios. For example, new systems to be deployed, training requirements or changes in operating costs.

Note that **SOL399/SOL1 is not a Solution to be deployed in the ATM system but a performance framework and a set of tools to evaluate other solutions and multimodal mobility**. Therefore, the solution scenario considers that relevant stakeholders have the capabilities of using SOL399/SOL1 over the reference scenario.

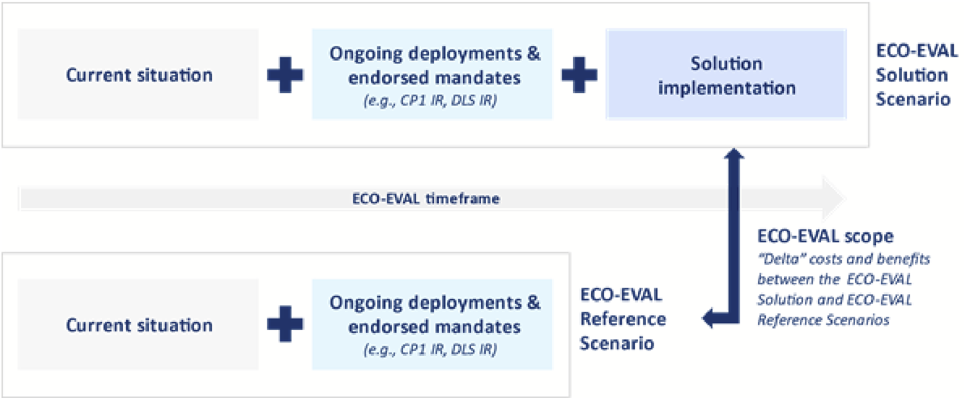

Figure 5: ECO-EVAL scenario overview

At this point, it is worth reiterating that **the transversal nature of SOL399/SOL1 provides capabilities to evaluate multimodality as a whole** (by the definition of the multimodal performance framework in the digital catalogue of indicators) and with the evaluators to assess planned, replanned and tactically executed networks. These can be with or without the introduction of additional solutions (e.g. evaluating synchronised schedules from SOL400/SOL2 or replanned operations to deal with disruptions as provided by SOL401/SOL3). As the objective of the ECO-EVAL is not to assess the expected benefits of those additional solutions (for that the reader is referred to the ECO-EVAL of SOL400/SOL2 [21] and of SOL401/SOL3 [22]), the scenarios presented here focus on a subset of the ones developed in the ERR [20]. **This subset of scenarios is selected to first show the potential impact of multimodality (beyond MultiModX) on the SESAR Performance Framework and on the indicators developed by MultiModX, and second to show how multimodal situations could be assessed by SOL399/SOL1 and the benefit that those would provide**. In this second case, the baseline scenarios already consider that multimodality is present in the system, and the 'solution scenarios' consider the introduction of other Solutions (e.g. SOL400/SOL2 or SOL401/SOL3), mechanisms (e.g. fast-track at airport) and policies.

3.5.1 ECO-EVAL reference scenario

As described in OSED [19], 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 [11] 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 are, therefore, 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 [11] will have to ensure that the different characteristics of the sub-operational environments are captured.

As the different combinations of operational environments can quickly increase the number of experiments, full factorial design is not pursued. Instead, a limited number of scenarios have been identified that are sufficient to satisfy the objectives defined in ERP. The selected scenarios are expected to be the ones providing the largest benefits from multimodal solutions (i.e. operational environments where the multimodal Solutions perform the best). For a more detailed explanation and description of the scenario coding scheme, please refer to ERP [11] in Section 3.1.3. The results of those experiments are detailed in the corresponding ERR [20].

ECO-EVAL focuses on the capabilities of SOL399/SOL1 for:

- Strategic evaluation of planned networks,
- Assessment of the impact disruptions on a multimodal mobility network with the evaluation of replanned networks, and
- The evaluation of mechanisms to support multimodality.

Multimodality policy packages are applied to define the possible evolution of the planned network considering multimodality, as shown in Table 4.

Code	Policy package	Individual policies definition	ECO-EVAL scenario
PP00	Reference (no particular policies)	• Passenger rights and multimodality: No integrated tickets • Limitation of aviation: N/A • Environmental regulations: N/A	reference
PP10	Multimodality incentivised	• Passenger rights and multimodality: Fully integrated (respecting alliances) • Limitation of aviation: N/A • Environmental regulations: CO_2 tax applied to emissions	solution
PP20	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: CO_2 tax applied to emissions	solution

Table 4: Multimodality policy packages

For the policy packages, pp00 represents the reference scenario if the network continues with 'business as usual' which includes multimodality. As the multimodality-enforced policy package (pp20) should result in the most multimodal itineraries (with respect to other policy packages), this one is expected to be the one providing the largest benefits from multimodal solutions (i.e., an operational environment where the multimodal Solutions perform the best). The multimodality incentivised policy package (pp10) is expected to provide some in-between results and travelling pattern shifts due to the reduced multimodal connecting times provided by the integrated tickets.

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 show a range of types of disruptions: rail, air, full closures (closer to crisis management situation), ATFM-related, and significant throughput reduction. A detailed description can be found in ERR Appendix C [20].

Finally, the policies and disruptions need to be applied to a given network. As explained in the ERP [11] and ERR [20], in MultiModX the scenarios focus on intra-Spain mobility (cs10) representative of a potential nominal day in 2030. For the results presented in this ECO-EVAL (as the focus is not to evaluate SOL400/SOL2 or SOL401/SOL3 per se), we will focus on the case where policies are applied (to incentivise or force multimodality) but without the application of the additional solutions.

With all these considerations, two different types of scenarios are defined as references:

- cs10.pp00.nd00.so00.00 → This is the baseline reference to be used as a reference for other experiments and for the calibration of the strategic models. The experiment focuses on intra-Spain mobility with current policies focusing on describing a possible 2030 nominal day of operation constructed from a busy 2019 air traffic schedules, 2023 rail timetables and 2022 passenger demand. This will be used as a reference when compared to networks with multimodal policies in place and disrupted networks.
- For the evaluation of a mechanism to support multimodality, the reference scenario is set to be the cs10.pp20.nd02.so10.01 with 30 minutes of ground mobility delay without any particular mechanisms. See ERR for more details [20].

3.5.2 ECO-EVAL solution scenario

The ECO-EVAL covers the period from 2026 to 2050 as defined in the common assumptions [6]. This means that the net present value is calculated by discounting the cash flows back to 2026 (the end of DES wave 1).

Table 5 lists the key dates used in the ECO-EVAL, these dates are illustrative and selected considering the current maturity of multimodal Solutions, and Figure 6 shows them over a timeline.

Dates	*<SESAR solution 399>*
Start of deployment date (SOD): the start of investments for the first deployment location	*<SOD year> 2030*
End of deployment date: the end of the investments for the final deployment location, same as FOC	*<FOC year> 2035*
Initial operating capability (IOC): the time when the first benefits occur following the *minimum deployment* necessary to provide them. Costs continue after this date as further deployment occurs at other locations.	*<IOC year> 2030*

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Final operating capability (FOC): maximum benefits from the *full deployment* [1] of the SESAR solution at applicable locations. Investment costs are considered to end[2] here although any operating cost impacts would continue.	*<FOC year> 2035*
[1] Where ***full deployment*** means deploying the SESAR solution in all the locations where it makes sense to deploy it (i.e. it does not mean it has to be deployed everywhere) [2] The basic assumption is that infrastructure does not need to be replaced during the ECO-EVAL period.	

Table 5: ECO-EVAL investment and benefit dates

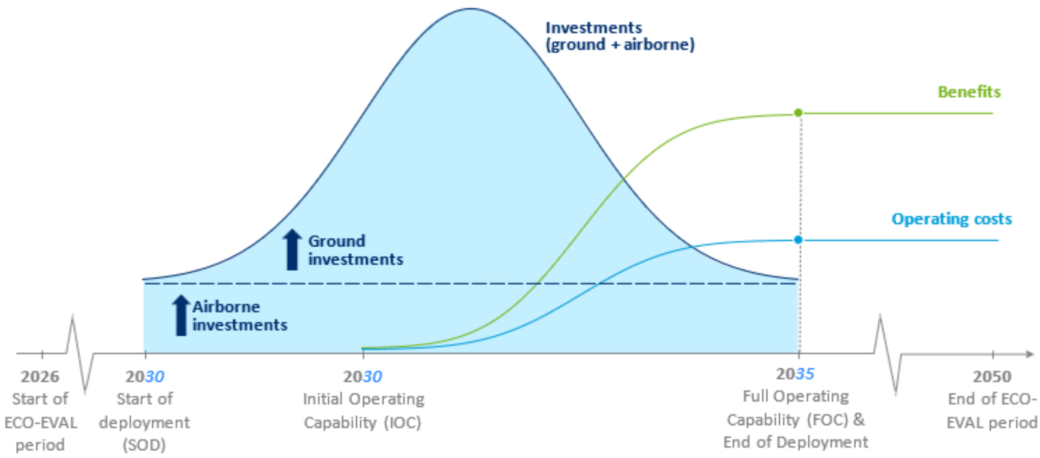

Figure 6: Key dates for ECO-EVAL

Figure 6 shows that:

- Investment costs are the addition of the (i) ground investment costs (spread following a bell curve, based on the diffusion of innovation theory, between the start and end of deployment dates), and (ii) airborne investment costs (spread linearly between the start and end of deployment dates);
- Benefits ramp-up following an 'S' adoption curve between IOC and FOC and then continue up to the end of the ECO-EVAL period;
- Operating cost impacts (increases or decreases) would also start at IOC and ramp-up following an 'S' adoption curve to FOC before continuing for the rest of the ECO-EVAL duration.

As previously explained, the scenarios analysed in the project concerning the validation of SOL399/SOL1 are set to be somehow representative of nominal operations in 2030; see [11] for more details.

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The following solution scenarios are used for the validation exercises, and are reported in the ERR [20]:

TVAL.01.1-MultiModX-0399-TRL2 Validation of the multimodal performance framework

In this case, the solution scenario assumes that the multimodal performance framework is available, i.e., indicators defined, indicators catalogue available, etc. and that research projects can use these definitions for the validation of their Solutions.

TVAL.02.1-MultiModX-0399-TRL2 Strategic and Tactical evaluation of a planned multimodal mobility network:

Four experiments are considered for this validation exercise:

- Experiment 1: Validation of modelling assumptions of the Strategic and Tactical Evaluator
- Experiment 2: Calibration of the Strategic and Tactical Evaluator
- Experiment 3: Strategic and Tactical evaluation of a mobility network
- Experiment 4: Evaluation of SOL400/SOL2 Schedule Optimiser

TVAL.03.1-MultiModX-0399-TRL2 Assessment of the impact disruptions on a multimodal mobility network and mechanisms to support multimodality

Three experiments are considered for this validation exercise:

- Experiment 1: Replanning of the network in case of disruption
- Experiment 2: Tactical evaluation of replanned network
- Experiment 3: Evaluation of mechanism to support multimodality

With all these considerations, in the ECO-EVAL the results will be presented for:

- The potential impact and benefits of multimodality (beyond MultiModX) into the SESAR Performance Framework.
- The performance on MultiModX-specific defined strategic indicators of multimodal networks (cs10.pp10.nd00.so00.00 and cs10.pp20.nd00.so00.00) without the consideration of any additional Solution.
- The performance of MultiModX-specific defined tactical indicators of a network with multimodality and with disturbances on the connectivity between air and rail links when a mechanism to support multimodality (fast-track at airports for multimodal passengers) is deployed (cs10.pp20.nd02.so10.01 with 30 minutes of ground mobility delay), and on the strategic indicators for replanned networks in case of disruption and replanned network.

3.5.3 Assumptions

ID	Title	Description	Justification	Impact Assessment
A1	Existence of multimodal governance	It is assumed that a multimodal performance scheme and multimodal governance are in place, allowing cooperation between modes of transport (shared data, information, incentive…).	The project is interested in studying the impact of a multimodal and collaborative framework.	High
A2	Coordination between air and rail	The schedule coordination occurs between rail and air, leaving aside other long-distance ground transportation means such as long-distance buses.	The scope and focus of the project are on air and rail collaboration. For future projects, it would be interesting to include road transport.	Medium
A3	Fixed prices	It is assumed that the prices of the different paths are fixed as an input of the solution and will not be updated within the solution.	The reaction of the price to the demand through an economic model is considered out of the scope and interest of the project. Price variations may come from the policies defined in the scenarios.	Low
A4	Multimodal Policies	We assume that the policies to be implemented in the ECO-EVAL timeframe regard passenger rights and multimodality, limitations of aviation, and environmental regulations.	This is a result of the desk research realised as part of the project	High
A5	Regional archetypes	We assume that the regional archetypes and the existing infrastructure will not dramatically change during the ECO-EVAL timeframe.	Socio-demographic shifts and the creation of new infrastructure are out of the scope of this project	Low

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A6	Historical pricing	The price of alternatives is computed based on historical information and is not updated.	The important aspect is the relative cost of alternatives. Therefore, the ratio between air and rail alternatives is more relevant than the actual value. Policies such as CO_2 taxes could increase the cost of air alternatives.	Low
A7	Emissions as current	Adequate models are used to estimate the CO_2 of rail and air trips. These are not updated for future scenarios (i.e., emissions are assumed to remain at similar levels per flight as in current operations)	The project's interest is in the multimodality aspects of mobility. As with A6, the impact of emissions would be on the perceived cost for passengers, either as a generalised cost (preference) or due to taxation.	Low

Table 6: ECO-EVAL assumptions

4 Benefits

4.1 Benefits overview

The benefits of SOL399/SOL1 are indirect, as SOL399/SOL1 is not a technical solution to be deployed in the ATM system. However, SOL399/SOL1 will support the promotion of multimodality and, therefore, the expected impacts on SESAR KPIs and PIs emanate from this, such as a reduction of direct operating costs (due to the possible reduction in the number of services coming from coordinated air and rail networks), a possible reduction of delays, reduction in stranded passengers in case of disruptions and a possible reduction of CO_2 emissions per passengers.

However, since this Solution is aimed at multimodality and is passenger-centric, most of the expected benefits currently lie outside the SESAR Performance Framework. Part of the project is bridging this gap by defining a new set of KPIs and PIs related to multimodality. Some of these KPIs/PIs can be implemented in future editions of the SESAR Performance Framework. There is already work in that direction: a workshop named “Multimodality and passenger experience in the SESAR Performance Framework” took place on the 15 of January at the University of Westminster, London. This workshop was attended by members of the MultiModX, PEARL [12], AMPLE3 [1], and SIGN-AIR [14] projects. The main benefits provided by SOL399/SOL1, according to the KPIs/PIs developed in MultiModX, are, a reduction of travel times, including all legs of the journey, (i.e., not only the air legs), a reduction of buffer in itineraries, an increase in modal share, an increase in the number of destinations “available” for the passenger, an increase of the load factor of vehicles (i.e., trains and planes), an increase of the demand of passenger served, and an increase of the airports catchment areas. The performance framework is provided in an open digital catalogue so that it can be reused by any interested party (such as industrial and exploratory research projects): Digital Catalogue (Accessed June 2025).

Being a standalone Solution, SOL399/SOL1 can be applied across diverse operational environments. The Multimodal Evaluators provide more advanced performance evaluation capabilities that the ad-hoc validations that could be carried out by other Solutions (such as SOL400/SOL2 or SOL401/SOL3 independently). Therefore, the most relevant benefits of SOL399/SOL1 are the definition of this common performance framework and these evaluation tools, which provide capabilities to SESAR JU (and the research community more broadly) for the evaluation of other Solutions, mechanisms and policies in the context of multimodality.

4.2 Benefit summary

4.2.1 Potential impact of multimodality on SESAR Performance Framework

Note that as the first element of SOL399/SOL1 is the development of a multimodal performance framework, in this Section we provide an overview of the impact of multimodality into the SESAR Performance Framework. This is not a benefit of SOL399/SOL1, but an assessment to evaluate the need for this multimodal framework by reviewing how multimodality could impact the current framework. The overall benefit of having the framework is the common set of indicators to be used for the evaluation of a number of different Solutions.

The potential impacts of multimodality on the KPAs/KPIs/PIs defined in the Performance Framework (Level 1 as defined in the Multimodal Performance Framework) are qualitatively classified below. Note that these are the indicators that have been identified as potentially having an impact due to multimodality, not necessarily due to SOL399/SOL1. Moreover, this impact could depend on how multimodality is deployed. For this reason, the indicators are divided by their potential impact in:

- WEAK/LOW: 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 from the current SESAR Performance Framework, multimodality is not applicable (76), or just has a weak indirect relationship (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.

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.

For more information, please, refer to the ERR [20] and to the digital catalogue of indicators (Level 1): Digital Catalogue (Accessed June 2025).

Table 7 summarises the solution benefits showing the benefit impact mechanisms (BIMs) impact (positive, negative or neutral). It explains how the estimates are provided. Again, note that here high, medium and low refer to the coupling and potential impact due to the deployment of multimodality. In many cases, this will depend on the function of which Solutions and approaches are used to deploy such multimodality. The analysis is provided here as a complement to the analysis done when developing the multimodal performance framework in SOL399/SOL1 reported in the digital catalogue of indicators.

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KPI / PI	**BIM impact**	**How the solution provides the benefit and evaluation (low, medium, high impact)**
AUC1 Strategic delay	- (ECAC level)	• Multimodality should impact the cost of delay of AUs involved. HIGH
AUC2 Sequence optimisation benefit (Average direct benefit by swapping a slot)	+ (ECAC level)	• Multimodality should impact the cost of delay of AUs involved and therefore the average benefit of swapping slots HIGH
AUC3 Direct operating costs for an airspace user	- (ECAC level)	• It is expected that managing multimodality will impact the operating cost of airspace users. HIGH
AUC4 Indirect operating costs for an airspace user	- (ECAC level)	• It is expected that managing multimodality will impact the operating cost of airspace users. HIGH
AUC5 Overhead costs for an airspace user	- (ECAC level)	• It is expected that managing multimodality will impact the operating cost of airspace users. HIGH
AUC6.3 Customer Satisfaction due to Slot Swapping	+ (ECAC level)	• Benefit due to reduction of the number of missed connection flights and/or by AU due to reduction of flight cancellations due to CTOT allocation (ATCM departure slot) • As cost functions are expected to be different, the satisfaction of the swaps is also expected to vary. HIGH

AUC6.4 ATFCM Delay reduction due to Slot Swapping.	+ (ECAC level)	• The economic benefits obtained by the AU are thanks to swapping slots within the same AU's planned flights. • As cost functions are expected to be different, the satisfaction of the swaps is also expected to vary. HIGH
EQUI1 Net difference in AU's delay or costs compared with other AUs	- (ECAC level)	• Only some flights will be impacted by multimodality. HIGH
EQUI2 Relative Advantage Gained by one AU over the Others in weighted by impacted flights	+ (ECAC level)	• Only some flights will be impacted by multimodality. HIGH
FLX1.3 ATFCM Delay Reduction Economic quantification of cost for AUs	- (ECAC level)	• Multimodality should impact the cost of delay of AUs involved and hence of reductions in delay. HIGH
AUC6.1 Number of CTOT swapped within the AUs' departure sequence	+ (ECAC level)	• Depending on the mechanisms used to manage multimodality disruptions and the specific itineraries involved in the flights. MEDIUM
AUC6.2 Strategic delay reduction due to CTOT swapped within the AUs' departure sequence	+ (ECAC level)	• Depending on the mechanisms used to manage multimodality disruptions and the specific itineraries involved in the flights. MEDIUM

FEFF1 Actual average fuel burn per flight	+ (ECAC level)	• If dynamic cost indexing is used to recover delay to mitigate missed connections. MEDIUM
FEFF4 Average on stand fuel burnt per flight	+ (ECAC level)	• Depending if wait-for-pax rules are implemented, increasing the stand time and hence fuel burnt. MEDIUM
FLX1.1 G2G ATFCM Delay. Regulation Time Reduction.	- (ECAC level)	• If mechanisms are in place to consider multimodal trips when dealing with swaps, for example. MEDIUM
PRD13 Average difference in actual & planned turnaround durations	- (ECAC level)	Depending on the mechanisms used to manage multimodality disruptions. MEDIUM
PUN1 Average departure delay per flight	+ (ECAC level)	• If adjusting departing times to account for missed connections is implemented. MEDIUM
PUN10 Average departure delay per flight Airspace due to Recovery and Mitigation of Reactionary Delay	+ (ECAC level)	• Depending on the mechanisms used to manage multimodality disruptions. MEDIUM
RES1.1 Airport time to recover	- (ECAC level)	• If operations are modified to consider multimodal journeys. MEDIUM

RES4 Minutes of delays	+ (ECAC level)	• If operations are modified to consider multimodal journeys. MEDIUM
RES5 Number of cancellations	- (ECAC level)	• If operations are modified to consider multimodal journeys. MEDIUM
TEFF7 Turnaround time	+ (ECAC level)	• Depending on the mechanisms used to manage multimodality disruptions. MEDIUM
CAP3 Peak runway throughput	+ (ECAC level)	• Strategic impact through changes on demand. • Tactical impact through changes on demand (adjusting departing times to account for missed connections) LOW
CAP4 Un-accommodated traffic reduction	+ (ECAC level)	• Through potential variation in demand pattern LOW
CEF2 Flights per ATCO-Hour on duty	- (ECAC level)	Through potential variation in demand pattern LOW
FLX1.2 G2G ATFCM Delay. Strategic Time Reduction.	- (ECAC level)	• Through potential variation in demand pattern LOW

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FLX2.1 ATC Capacity. Reduction avoided.	+ (ECAC level)	• Through potential variation in demand pattern LOW
LAQ1 Geographic distribution of pollutant concentrations	- (ECAC level)	• Through potential variation in demand pattern LOW
NOI1 Relative noise scale	- (ECAC level)	• Through potential variation in demand pattern LOW
NOI2 Size and location of noise contours	- (ECAC level)	• Through potential variation in demand pattern LOW
NOI3 Size and location of zones where a certain number of operations exceed a given noise level threshold	- (ECAC level)	• Through potential variation in demand pattern LOW
NOI4 Number of people exposed to noise levels exceeding a given threshold	- (ECAC level)	• Through potential variation in demand pattern LOW

NOI5 Number of people experiencing a certain number of operations with noise levels exceeding a given threshold	- (ECAC level)	• Through potential variation in demand pattern LOW

Table 7: SESAR Performance Framework KPIs and PIs where Multimodality can have an impact

4.2.2 Assessing planned multimodal network

Table 8 indicates the multimodality benefits of the Strategic Level 2 and 3 indicators from the Multimodal Performance Framework (MultiModX-specific indicators). The estimation of strategic impact is qualitatively based on results in the ERR for scenarios cs10.pp10.nd00.so00.00 and cs10.pp20.nd00.so00.00, which represents a mix of incentivised multimodal policies, including a flight ban (pp20). Note, therefore, that we provide as baseline the case when multimodality is already present (pp00) and how having policies that incentivise and support multimodality could affect the indicators. Again, the benefit of SOL399/SOL1 is the capabilities to perform these types of assessments.

PI Id	KPI/PI	KPA	Type	Impact	How the solution provides the benefit and evaluation (low, medium, high impact)
OPS_PE1	Passengers processing time at infrastructure	Efficiency	Strategic	-	low
OPS_PE2	Total journey time	Efficiency	Strategic	-	low
OPS_PE3	Passengers time efficiency	Efficiency	Strategic	=	low
OPS_PE4	Buffers in itineraries	Efficiency	Strategic	+	low
INT_PE1	Modal share	Interoperability	Strategic	+	low

INT_PE2	Seamless of travel (time)	Interoperability	Strategic	-	low
FLX_PE2	Diversity of destinations	Flexibility	Strategic	-	low
CEF_PE1	Direct operating cost per user	Cost effectiveness	Strategic	=	low
CEF_PE2	Load factor	Cost effectiveness	Strategic	+	low
CAP_PE1	Demand served	Capacity	Strategic	-	low

Table 8: Qualitative assessment of Strategic KPIs/PIs developed by the project.

4.2.3 Replanned multimodal and tactical networks

Table 9 indicates the multimodality benefits of the Tactical and Replanning Level 2 and 3 indicators from the Multimodal Performance Framework. The estimation is based on the replanning of the network under different disruption conditions and multimodal mechanisms such as airport fast-track. Note that the benefits can vary significantly depending on the policies and mechanisms implemented. Once again, here we provide an example of the benefits focusing on the scenarios which encourage and further develop the concept of multimodality; but different results could be expected on different scenarios analysed in the ERR. Once again, **these are not the benefits of SOL399/SOL1 but the benefit of the scenarios analysed. SOL399/SOL1 provides the tools to perform this analysis, and hence, they are reported here.**

PI Id	**KPI/PI**	**KPA**	**Type**	**Impact**	**How the solution provides the benefit and evaluation (low, medium, high impact)**
OPS_PE5.1	Arrival delay (flights)	Efficiency	Tactical	-	medium

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OPS_PE6	Cancellations due to ATFM	Efficiency	Tactical	-	medium
OPS_PE7	Reactionary delay	Efficiency	Tactical	-	medium
OPS_PE8.1	Stranded passengers	Efficiency	Replanning	-	high
OPS_PE8.2	Ratio of stranded passengers	Efficiency	Tactical	-	high
OPS_PE9	Missed connections	Efficiency	Tactical	-	high
PRED_PE1	Variability	Predictability	Tactical	-	high
OPS_PE5.2	Total arrival delay at final destination	Efficiency	Tactical	-	high
FLX_PE1.2	Passenger Resilience replanned	Flexibility	Replanning	+	high
FLX_PE3	Resilience replanned	Flexibility	Replanning	+	high

Table 9: Qualitative assessment of Tactical and Replanning KPIs/PIs developed by the project.

4.3 SESAR Performance Framework Indicators

Indicators at Level 1 are indicators currently part of the SESAR3 Performance Framework. These indicators have, by their nature, a stronger focus on the gate-to-gate component of the passenger journey. A list of Level 1 indicators, a summary of the logic explained in the BIMs and their magnitude is already explained in Table 7. A digital catalogue of indicators has been set up and can be found at Digital Catalogue (Accessed June 2025). This digital catalogue is a live document which is expected to evolve as different projects define and re-utilise the performance indicators.

4.4 MultiModX Performance Framework

In the following sections, we present the expected benefits related to the KPIs/PIs developed within MultiModX. These will, therefore, present Level 2 and 3 indicators as defined in the Multimodal Performance Framework (as reported in Table 8 and Table 9). These indicators mature some aspects of passenger experience and focus on multimodal considerations such as reliability. Also, included are indicators that aim to capture the total experience of passengers in their door-to-door journey. The analysis is presented in a one-by-one way for each indicator.

As SOL399/SOL1 does not provide benefits on its own, here we capture the characteristics of the metrics within the MultiModX's performance framework that SOL399/SOL1 defines (as part of the multimodal performance framework) **and can estimate** (as part of the Strategic and Tactical Multimodal Evaluators). Therefore, the benefits are the capability to evaluate these indicators for other Solutions, mechanisms and policies.

SOL399/SOL1 works as a system enabler that supports external Solutions. Within MultiModX it can act as an optional enabler for SOL400/SOL2 and SOL401/SOL3, extending their individual evaluation capabilities.

4.4.1 OPS_PE1 Passengers processing time at infrastructure

This metric measures the time it takes to do all the airport processes, i.e., security, border control, and displacements until a traveller reaches the designated gate. Since multimodal Solutions will have an impact on the passenger flows at a given airport, their implementation might have a small impact on this metric. This is especially the case when multimodal supporting mechanisms targeting airport processes are implemented, such as 'fast-track' at airports for multimodal passengers. The reduction observed could be also attributed to a reduction of passengers in some airports, which means that in proportion, more passengers are using rail where processes are shorter.

4.4.2 OPS_PE2 Total journey time

Total travel time represents the "door-to-door" time of a journey. The total journey time is expected to increase slightly due to the higher use of multimodal journeys. However, with the flight ban, the total travel time decreases slightly, even if flights are removed. This is due to the fact that only flights with trains with similar door-to-door time are banned (up to 180 minutes), the rail demand increases, and the overall demand satisfied is reduced.

4.4.3 OPS_PE3 Passenger time efficiency

This indicator comes from the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop. Strategically, it represents the **best possible** journey time (from schedules) compared to the planned time travel (from planned operations). The results are very similar across the scenarios compared.

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4.4.4 OPS_PE4 Buffers in itineraries

This metric refers to the amount of time used as buffers in connections in itineraries. This metric increased but not in a significant way. This was expected as schedules are not optimised (only connecting time is reduced with the introduction of integrated ticketing (in pp10 and pp20)). Therefore, the average waiting time is not optimised and similar. We could expect that when SOL400/SOL2 is implemented, these values would be reduced.

4.4.5 INT_PE1 Modal share

This metric computes the share of transport modes in passenger itineraries on a specific origin-destination pair. The introduction of incentivised policies (pp10) and enforced policies (pp20) reduce the absolute number of air passengers while increasing multimodal passengers, but still in a limited way. With the enforced policies (pp20), there is a slight increase in multimodal journeys but mainly a reduction of air share and an increase in rail demand.

4.4.6 INT_PE2 Seamlessnes of travel (time)

This metric refers to the journey transition time (between modes and stops). We can observe a small reduction, which could be attributed to the use of integrated ticketing, which reduces the inter-mode connecting times. We acknowledge that this time also depends on the layout of the existing infrastructure, which is difficult to modify.

4.4.7 FLX_PE2 Diversity of destinations

This is the number of destinations which can be reached from a given origin. Despite the flight ban in pp20, this does not translate into a significant reduction in the destinations that can be reached from each NUTS.

4.4.8 CEF_PE1 Direct operating costs per user

This metric is an expansion of the already mentioned (AUC3) PI. The direct operating cost per user is estimated by adding the cost of the services (rail and flights) used by the passengers. There was no significant change in average on the cost for passengers to travel within Spain.

4.4.9 CEF_PE2 Load factor

This metric accounts for the number of passengers over the number of seats per operator. There was no significant change in average of this indicator. A slight increase can be expected due to shifting more demand to rail.

4.4.10 CAP_PE1 Demand served

This metric measures the number of people who want to travel and are both able to travel (due to the availability of itineraries in the network). At the aggregated level, the demand served remained similar.

4.4.11 CAP_PE2 Catchment area of airports

This known metric was proposed in the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop to be included in this framework. The results showed a variation of this indicator depending on the airport. Some airports experienced an increase in connectivity and relevance for the wider region where they are located. This shows the impact of reducing the multimodal connecting times due to integrated ticketing. Also, with the flight ban, alternatives that before were less appealing are used. It is expected that with the consideration of international connections, hubs like Madrid will significantly increase their multimodal journeys as the long-distance flights will be fed by rail alternatives; even if some spillage to other hubs can be expected (as now is the case towards regional airports).

4.4.12 ENV_PE1 CO_2 emissions per trip

This metric represents a modification of SESAR PI (ENV1). It measures the total emissions of services used (both air and rail) and can be normalised per passenger. Several aspects of multimodality might have an impact on this metric, namely:

- Increased service occupancy and better use of the available rolling stock reduces the CO_2 emissions per passenger.
- The potential replacement of some connections from air to rail will reduce the overall CO_2 emissions of some trips.

However, at aggregated level, the indicator remained similar. It is worth noting, that the potential benefit is limited by the lack of available capacity in the train system on links with high demand.

4.4.13 FLX_PE1.1 Resilience alternatives

This metric was proposed in the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop. The impact of multimodal Solutions on this metric is expected to be medium and depends on the policies implemented. From the results, it is possible to observe how, overall, the flight ban that pp20 implements represents a significant reduction of air alternatives between the regions impacted by the ban (as those flights are removed) and also between regions which rely on air-air connections (which now might have a lower number of alternatives). On the other hand, with integrated ticketing, which reduces the multimodal connecting times, the number of alternatives increased.

4.4.14 CAP_PE3 Capacity available

The total capacity available in the system (seats available) is similar for the incentivised case (pp10). This can be expected as the demand served is similar. In pp20, the extra capacity of the system was reduced. In this case, the reasons are two-fold: first, flights are banned; the second reason is the increase in rail demand and the indirect effect of services. The train system gets saturated on links with high demand. On the air side, the seats directly removed limit the possible seats available when considering the possible connections that could have been made with those services.

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4.4.15 INT_PE3 Infrastructure connectivity

By increasing the number of multimodal trips, this metric is expected to increase. The results show that in the multimodality-enforced case, the number of connecting passengers increased.

4.4.16 OPS_PE5.1 Arrival delay (flights)

This metric was proposed in the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop. The impact of multimodal Solutions on this metric is expected to be medium, if adjusting departing times to account for missed connections is implemented. Airlines can use the Tactical Evaluator to assess the robustness of their schedules and timetables with respect to nominal and stressed conditions.

4.4.17 OPS_PE56 Cancellations due to ATFM

This indicator was proposed in the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop as a measure to support passenger experience. However, the current model is not able to cancel flights due to specific reasons such as ATFM so this distinction won't be captured by SOL399/SOL1. It is expected, however, that replanning operations with consideration of multimodal journeys might be able to better use the capacity available in case of disruptions, potentially reducing the number of these types of cancellations.

4.4.18 OPS_PE7 Reactionary delay

This metric was proposed in the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop. The impact of multimodal Solutions on this metric is expected to be medium depending on the mechanisms used to manage multimodality disruptions (e.g. waiting-for-passengers).

4.4.19 OPS_PE8.1 Stranded passengers

The impact of multimodal Solutions on this metric is expected to be high. By implementing a mechanism to support multimodality such as fast-track for multimodal connecting passengers at the airport, this metric decreased. Implementing different degrees of flexibility to rebook passengers impacted by a disruption also reduced significantly the number of passengers that end up stranded in such situations.

4.4.20 OPS_PE8.2 Ratio of stranded passengers

This metric was proposed in the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop. The impact of multimodal Solutions on this metric is expected to be high. By implementing a mechanism to support multimodality such as fast-track for multimodal connecting passengers at the airport or providing flexibility to rebook impacted passengers in case of disruption, this metric decreased.

4.4.21 OPS_PE9 Missed connections

This metric was proposed in the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop. The impact of multimodal Solutions on this metric is expected to be high. By implementing a mechanism to support multimodality such as fast-track for multimodal connecting passengers at the airport, this metric decreased.

4.4.22 PRED_PE1 Variability

This metric calculates the share of passengers arriving late (within pre-defined time slot). The impact of multimodal Solutions on this metric is expected to be high. By implementing a mechanism to support multimodality such as fast-track for multimodal connecting passengers at the airport, this metric decreased.

4.4.23 OPS_PE5.2 Total arrival delay at final destination

This metric was proposed in the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop. The impact of multimodal Solutions on this metric is expected to be high. By implementing a mechanism to support multimodality, such as a fast-track for multimodal connecting passengers at the airport, the number of missed connections decreased, thus reducing this indicator.

4.4.24 FLX_PE1.2 Passenger Resilience replanned

This metric captures the difference between planned and replanned itineraries. The impact of multimodal Solutions on this metric is expected to be high. By implementing a mechanism to support multimodality, such as a fast-track for multimodal connecting passengers at the airport or providing flexibility to rebook impacted passengers in case of disruption, the number of missed connections decreased, thus improving this indicator.

4.4.25 FLX_PE3 Resilience replanned

This metric captures the applied changes/adaptations in the replanned schedules, such as rerouted train services, diverted flights, replacement services, and retimed/delayed services. The impact of multimodal replanning on this metric is expected to be high as services are adjusted to mitigate the disruption.

5 Cost assessment

As SOL399/SOL1 is a performance framework and a set of standalone tools to evaluate multimodality they do not represent a cost to the stakeholders. However, SOL399/SOL1 can support the evaluation of other Solutions (mechanisms and policies) who will enhance the deployment of multimodality. Therefore, in this Section, we provide an overview of costs that are expected by stakeholders when deploying multimodal solutions evaluated by SOL399/SOL1 in the context of MultiModX, i.e., SOL400/SOL2 and SOL401/SOL3, and who could use SOL399/SOL1 to evaluate these.

Stakeholder	**Cost category**	**Yes/No**	**Cost driver**	**Deployment locations (or sub-operating environments)**
Airport operators	Investment cost	*Yes*	Invest in new system	Airports that are part of multimodal journeys
	Operating cost	*Yes*	Labour costs + data collection	
Scheduled airlines	Investment cost	*Yes*	Invest in new system	Full-service carriers participating in multimodal agreements
	Operating cost	*Yes*	Labour costs + data collection	
Railway Companies	Investment cost	*Yes*	Invest in new system	Rail operators that are part of multimodal agreement
	Operating cost	*Yes*	Labour costs + data collection	
Train stations	Investment cost	*No*	-	N/A
	Operating cost	*No*	-	
Rail network maintainers	Investment cost	*No*	-	National rail infrastructure operators
	Operating cost	*Yes*	Increased maintenance in segments with higher use	
Cities and regional urban planners	Investment cost	*No*	-	N/A
	Operating cost	*No*	-	

Table 10: Cost identification

5.1 ANSPs costs

The stakeholder is not required to invest in the SESAR solution, as they do not form part of the users.

5.2 Airport operators costs

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. As primary users of the solution, they will invest in a new system, training, maintenance of the system, and data collection and maintenance.

5.3 Network manager costs

Infrastructure managers could assess how changes in the operation of their infrastructure could impact passenger experience (delays and missed connections). As primary users of the solution, they will invest in a new system, training, maintenance of the system, and data collection and maintenance.

5.4 Airspace user costs

Airlines participating in multimodal agreements might have associated costs related to managing the multimodal connections and the required data exchanges.

5.5 Military costs

The stakeholder is not required to invest in the SESAR solution, as they do not form part of the users.

5.6 U-space stakeholder costs

The stakeholder is not required to invest in the SESAR solution, as they do not form part of the users.

5.7 Other relevant stakeholders

5.7.1 Scheduled airlines and railway companies

The primary users (Multimodal Performance Expert, Strategic Performance Assessment Expert, Tactical Performance Assessment Expert, Disruption Management Performance Assessment Expert), as defined in OSED [19], will bear most of the direct costs related to SOL399/SOL1. The most typical users are expected to be airline or rail operators' schedule designers. As primary users of the solution, they will invest in a new system, training, maintenance of the system, and data collection and maintenance.

6 CBA model

N/A as SOL399/SOL1 is at TRL2.

7 CBA results

N/A as SOL399/SOL1 is at TRL2.

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8 Sensitivity and risk analysis

N/A as SOL399/SOL1 is at TRL2.

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9 Recommendations and next steps

SOL399/SOL1 does not provide necessary benefits directly to the performance framework in terms of improved indicators but provides a common framework and understanding of the impact of multimodality into SESAR; and a set of tools which support the evaluation of other Solutions, mechanisms and policies. Therefore, this ECO-EVAL does not focus on presenting the benefits obtained by those Solutions (e.g. the impact on performance indicators/areas of having synchronised air-rail schedules, as done by SOL400/SOL2), as those benefits would be reported on the corresponding ECO-EVAL of those Solutions. Instead, the focus is on presenting the potential impact of multimodality as a whole and showing the capabilities gained by the community due to SOL399/SOL1.

The benefits were evaluated by the Multimodal Performance Framework developed in this project in the following areas:

- indicators currently part of the SESAR3 Performance Framework (Level 1 in the Multimodal Performance Framework),
- other indicators from the Multimodal Performance Framework related to Passenger experience (Level 2 and 3 in the Multimodal Performance Framework).

The potential impacts of multimodality on the KPAs/KPIs/PIs defined in the Performance Framework (Level 1 as defined in the Multimodal Performance Framework) were qualitatively classified and beyond the scope of MultiModX. Note that these indicators have been identified as potentially having an impact due to multimodality, not necessarily due to SOL399/SOL1. Moreover, this impact could depend on how multimodality is deployed.

Overall, for the majority of indicators from the current SESAR Performance Framework, multimodality is not applicable (76), or just has a weak indirect relationship (11 indicators). 13 indicators are considered with a medium possible impact. Note again that this might depend on how multimodality is implemented. 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.

For Level 2 and 3 indicators, an example of the benefits focused on the scenarios which encourage and further develop the concept of multimodality, including the use of multimodality mechanisms; but different results could be expected for different scenarios. The benefits presented are not of SOL399/SOL1 but the benefit of the scenarios analysed. SOL399/SOL1 provides the tools to perform this analysis, and hence, they were reported here. We have selected scenarios that are representative of multimodality as a whole.

Overall, for 11 indicators the impact has been found to be low. However, the impact has been found to be highly regional and potentially high in certain cases, i.e., there is a need to analyse the results on a scenario basis and with a low-level focus on particular nodes and itineraries. 6 indicators resulted in a medium impact and 8 with a high impact.

One of the reasons for a low impact in some indicators is the very low number of multimodal passengers in the intra-Spain scenario. As such, any benefits are small on the aggregate level. It is expected that these impacts might increase once international connections are considered (under development).

In summary, benefits were observed in the following areas:

- **Social benefits**. The approach of the MultiModX project is passenger-centric, and therefore, most of the expected measured benefits of the Solutions of this project are passenger-related. Benefits include, but are not limited to, reduction of missed connections, resilience, infrastructure connectivity, etc. All of these benefits will improve overall passenger satisfaction over multimodal journeys.
- **Economic benefits**. Multimodality presents economic benefits that stem mainly from a more efficient use of resources (due to the cooperative operation of air and rail). Most of these benefits will impact the users of the SOL399/SOL1 (airline and railway operators), but some of them will impact airports, train stations, infrastructure managers and even city planners.
- **Environmental benefits**. The implementation of a coordinated air and rail network entails a more efficient use of the resources and the possibility of replacing short-haul flights by rail, eventually reducing strategically CO_2 emissions. However, as noticed in the experiments, this would need to be accomplished with an increase in the available capacity of the rail network.

There are different aspects that could be considered as future lines of research to be conducted by the SOL399/SOL1. Here a few key aspects are highlighted:

- Not only developing international flight cases (which is a change on the input in the current model) but also considering how competition within international hubs can drive passengers in the case of long-haul distance mobility. It is expected that with the consideration of international connections, hubs like Madrid will significantly increase their multimodal journeys as the long-distance flights will be fed by rail alternatives; even if some spillage to other hubs can be expected (as now is the case towards regional airports).
- The Strategic Multimodal Evaluator should consider more accurate emissions and costs associated with access and egress.

Particularly, the development of international flight cases may bring wider benefits as the proportion of multimodal passengers would increase. Note that this is not necessarily a limitation no the current results as intra-Spain includes ‘equivalent’ situations with the flights from the Balearic and, particularly, the Canary Islands.

Finally, further work is required to achieve a higher TRL for the monitoring of the suggested performance framework in operations, as passenger-centric indicators would be required. Likewise, the use of SOL399/SOL1 as a common evaluator for SESEAR Solutions in the framework of multimodality requires the definition of common operational environments which go beyond the current SESAR focus. This means that standardised passenger-centric datasets should be provided.

10 References

10.1 Applicable documents

This ECO-EVAL complies with the requirements set out in the following documents:

SESAR solution pack

[1] ...

Content integration

[2] ...

Content development

[3] ...

System and service development

[4] ...

Performance management

[5] ...

Validation

[6] ...

System engineering

[7] ...

Safety

[8] ...

Human performance

[9] ...

Environment assessment

[10] ...

Security

[11] ...

Programme management

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

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