

DES HE SESAR solution 0400 ECO-EVAL

Deliverable ID:	D6.5
Project acronym:	MultiModX
Grant:	101114815
Call:	HORIZON-SESAR-2022-DES-ER-01
Topic:	HORIZON-SESAR-2022-DES-ER-01-WA2-6
Consortium coordinator:	BHL
Edition date:	31 October 2025
Edition:	02.02
Status:	Official
Classification:	PU

Abstract

This document contains a qualitative Cost and Benefits Assessment (CBA) for the SESAR Solution 401, the Disruption Manager Solution. The document is organised as follows: first SOL401 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 is later discussed individually. As SOL401 will reach TRL2, no quantitative analysis is done.

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Document history

Edition	Date	Status	Organisation author	Justification
01.00 (as D6.5.1)	20.02.2025	Release	MultiModX Consortium	New document for review by the SJU
02.00	13.06.2025	Release	MultiModX Consortium	Updated version considering final results from ERR
02.01	27.07.2025	Release	MultiModX Consortium	Updated version considering SJU comments
02.02	31.10.2025	Release	MultiModX Consortium	Updated version considering SJU comments

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MultiModX

INTEGRATED PASSENGER-CENTRIC PLANNING OF MULTIMODAL
NETWORKS

MultiModX

This document is part of a project that has received funding from the SESAR 3 Joint Undertaking under grant agreement No 101114815 under European Union's Horizon Europe research and innovation programme.



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1 Executive summary

The Disruption Management Solution (SOL401) aims to design tactical (on the day of operations) adjusted passenger-centric schedule adjustments for air and rail to manage disruptions. Those adjustments are designed to optimally manage passenger demands by minimizing the effects of disruptions. The initial passenger flows capture the preferences of passengers as they incorporate the sensitivities of passengers with regard to several travel aspects, such as travel time, when selecting a specific path and mode(s) to reach their desired destination. Therefore, the flows of each path determine the demand to satisfy when managing the disruptions. The Disruption Management Solution adjusts multimodal air-rail schedules to optimally accommodate the given demand under disruptions and, therefore, manages the network in a passenger-centric fashion.

Using the available data, the Disruption Management Solution generates adjusted passenger-centric air and rail schedules, i.e. adjusted arrival times (AAT) and adjusted departure times (ADT), with train rerouting, flight diversions, and service replacements on the day of operations. For brevity, we refer to these as adjusted schedules.

Two versions of the Disruption Management Solution are available for managing disruptions to different levels of centralisation: decentralized disruption management (i.e. cooperation managed only within defined alliances) and fully centralised multimodal passenger-centric across all air and rail operators (i. e., full cooperation between all service providers including airlines and railway undertakings).

The objective function for adjusting the schedules represents, by managing the passenger flows, an integration of the following single objectives:

- minimize the number of disconnected passengers;
- minimize the additional detours of passengers
- minimize additional waiting times for passengers;
- minimize the number of replacement services (e.g. air or rail).

The main benefits of SOL401 are mainly:

- **Social benefits.** The approach of the MultiModX project is passenger-centric and therefore, most of the expected benefits of the Solutions of this project are passenger related. Benefits include, but are not limited to, reduce number of disconnected passengers, additional detours of passengers, additional waiting times for passengers, etc. All of these benefits will improve overall passenger satisfaction and mobility over multimodal journeys during disruptions.
- **Economic benefits.** SOL401 presents as well economic benefits, that stem mainly from a more efficient use of the resources (due to disruption management optimisation). Most of these benefits will impact the users of the SOL401 (air/rail network operators, rail infrastructure managers), but some of them will impact airports, train stations 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 to replace short haul flights by rail travel, reducing CO2 emissions.

The deployment of entails direct costs for its main users (airlines and railway operators), mainly due to training and software implementation, and also indirect costs, stemming from a different use of the infrastructure.

The environment in which the Solution is tested corresponds to a combination of the geographical scope in which the Solution is applied, along with the network definition (which correspond to which itineraries are considered), the nominal (i. e. undisrupted) services provided by airlines and railway undertakings, and the applied multimodal policy packages. SOL401 is aimed at being used by rail operators and airlines wanting to optimise their adjusted schedules jointly (centralised) or within their alliances (decentralised).

The ECO-EVAL analysis shows that the main benefits of SOL401 are focused on passengers, significantly improving outcomes for stranded passengers and replanned journeys. Deployment costs are minimal and mostly impact airlines and rail companies, with some variation in maintenance costs for rail network operators. Further impact assessments are recommended across different infrastructure settings, hub sizes, and multimodal networks to better understand SOL401's effectiveness.

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 documents 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.

2.2 Scope

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

SOL401 aims at finding optimised adjusted schedules for Multimodal journeys. Therefore, the geographical 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. This will facilitate the evaluation of the impact of multimodality at this ‘travel regions’ level, which could then be extrapolated to other regions of the same level even if not explicitly modelled. This creates, therefore, different sub-operational environments based on these regional archetypes. Once the regional archetypes are identified, passenger archetypes are associated with them, thus estimating the average compositions of passenger archetypes within a certain regional archetype. This could facilitate the creation of new experiments by distributing origin-destination demand between regions to demand per passenger archetype. The analysis identified 3 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

As for the geographical scope, all autonomous regions of Spain (which are representative of the three type of regions considered in the project) are considered, and intra Spain trips (i.e. trips that start and finish in Spain) and international trips to/from Spain are taken into account.

In this context, a sub-operational environment could be defined by a sub-set of the regions, itineraries, or geographical locations considered. The analysis of SOL401 is done comparing performance of the

disrupted network with and without applying the Disruption Manager, and calculates PIs defined in Section 4.

2.3 Intended readership

The readers of this document 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 organisations.

2.4 Background

There are no previous ECO-EVALs covering MultiModX SOL401.

2.5 Structure of the document

The ECO-EVAL presents a preliminary analysis of the economic benefits and costs of the MultiModX SOL401. 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 SOL401. 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
<i>ECO-EVAL reference scenario</i>	<i>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).</i>	<i>DES transversal CBA team</i>
<i>ECO-EVAL solution scenario</i>	<i>The scenario with the proposed SESAR solution and other improvements which have been implemented in the meantime.</i>	<i>DES transversal CBA team</i>

<i>Economic evaluation (ECO-EVAL)</i>	<i>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.</i>	<i>SESAR 3 JU Project Handbook – Programme Execution Framework, edition 01.00, 11 April 2022</i>
<i>Implementation cost</i>	<i>All costs related to the acquisition and implementation of the SESAR solution.</i>	<i>SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02</i>
<i>Investment cost</i>	<i>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.</i>	<i>DES transversal CBA team</i>
<i>Operating cost</i>	<i>All costs related to the change in daily operations that is brought about by the SESAR solution.</i>	<i>SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02</i>
<i>Pre-implementation cost</i>	<i>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.</i>	<i>SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02</i>
<i>OD pair</i>	<i>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.</i>	<i>ATPCO Glossary</i>
<i>itinerary</i>	<i>A succession of services (flights or trains) which represent a possible trip for a passenger.</i>	<i>own elaboration</i>

service	A specific train or flight, defined by a succession of stations/airports and its schedule.	own elaboration
unserved demand	Passenger demand that cannot be assigned to specific services either before or after the Schedule optimisation.	own elaboration
air and rail network	Collection of nodes (representing airports or train stations) and relations (connections or transfers) between the nodes.	own elaboration
Adjusted multimodal passenger-centric schedule	Adjusted passenger-centric air and rail schedule includes adjusted arrival times (AAT) and adjusted departure times (ADT), with train rerouting flight diversions and service replacements for a day of operations. For brevity, we refer as to adjusted schedule.	own elaboration
Disruption	Refers to a blocked infrastructure element (e.g. air: airport, terminal, runway; rail: station, track section) or reduced capacity. Disruptions are known several hours (or 1 day) before operations.	own elaboration
Passenger flow	Refers to an aggregated representation of passengers, travelling along a particular passenger path.	own elaboration
Passenger itinerary	Passenger itinerary is a succession of services (flights or trains) which represent a (possible) trip for a passenger.	own elaboration
Passenger path	Passenger path is 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

Table 1: glossary of terms

2.7 List of acronyms

Term	Definition
ATM	<i>Air traffic management</i>
ATS	<i>Air traffic services</i>
CNS	<i>Communication navigation surveillance</i>
DES	<i>Digital European Sky</i>
ERP	<i>Exploratory research plan</i>
GA	<i>Grant agreement</i>
GDPR	<i>General data protection regulation</i>
HE	<i>Horizon Europe</i>
ID	<i>Identifier</i>
OSED	<i>Operational service and environment description</i>
SESAR	<i>Single European sky ATM research</i>
SESAR 3 JU	<i>SESAR 3 Joint Undertaking</i>
SRIA	<i>Strategic research and innovation agenda</i>
TRL	<i>Technology Readiness Level</i>

Table 2: List of acronyms

3 Objectives and scope of the ECO-EVAL

3.1 Problem addressed by the SESAR solution

Europe's long-term vision documents on aviation research, described in the Flightpath 2050 and the new Fly the Green Deal documents (European Commission, 2011 and 2022), envisage a future in which air transport becomes an integrated part of a multimodal transport system that, by the year 2050, makes it possible for 90% of travelers within Europe to complete their door-to-door journey within 4 hours.

In parallel, the European Commission's Sustainable and Smart Mobility Strategy (European Commission, 2020) has defined a multitude of goals and respective flagships that pave the way towards zero-emission, resilient and inclusive mobility, creating seamless and efficient connectivity and establishing the European Union as a connectivity hub. One of the goals is a stronger focus on multimodality, which encompasses, inter alia, a fully integrated and seamless multimodal mobility system and a high quality transport network with high-speed rail (HSR) services on short-haul distances and with clean aviation services improving the coverage of long-haul routes. A seamless passenger experience and interoperability between different transport providers will be enabled by integrating airports as multimodal nodes in the air traffic management (ATM) network, contributing to increasing network resilience and the reliability and predictability of journeys. Coordinated planning and collaborative decision-making, based on information sharing and common situational awareness across transport modes, are key enablers to realise this vision (SESAR JU, 2020).

In recent years, a number of research projects have demonstrated the potential of multimodal coordination mechanisms to increase the efficiency and resilience of the transport network. At the strategic level, schedule synchronisation between different transport networks can significantly reduce total door-to-door travel times by optimising transfer times; this will foster multimodal trips, especially when combined with integrated ticketing, facilitating the use of the most efficient transport mode for each leg of the trip (TRANSIT Consortium, 2022). Furthermore, closer cooperation between air and rail may enhance capacity allocation across modes and address shortages on specific routes or at airports, as well as improve access, egress and connectivity between modes at airport nodes expanding the possibility for multimodal itineraries beyond airports with medium and long distance rail stations on them (Modus Consortium, 2021). At the tactical level, coordinated passenger rebooking, rerouting, replanning and dynamic rescheduling can help deal with the many unexpected events that occur in any transport network (Corman & Meng, 2014), rendering the transport system more resilient against disruptive events and improving travel time reliability and passenger experience, especially when used in combination with advanced passenger information services (TRANSIT Consortium, 2022).

The goal of SOL401 is to develop a Disruption Management Solution based on coordinated air and rail tactical schedule adjustments and passenger reallocation, a step towards innovative multimodal solutions and decision support tools for the coordinated planning and management of multimodal transport networks.

3.2 SESAR solution description

The Disruption Management Solution (SOL401) manages disruptions by adjusting coordinated multimodal schedules for air and rail with passenger focus. Taking into account the infrastructure, the service features and the passenger properties, an optimization model is applied to identify the optimal disruption management measures and correspondingly adjust input timetables (s. Figure 1). The model is based on a multimodal network with three layers: infrastructure, services and passengers (s. Figure 2). Based on disruptions of the infrastructure, services are adjusted (i. e. rerouted, cancelled, short-turned and retimed) and passengers are rerouted in the multimodal network or completely cancelled (i. e. cut-off). The used objective function contains different parameters and can be modified to obtain different results.

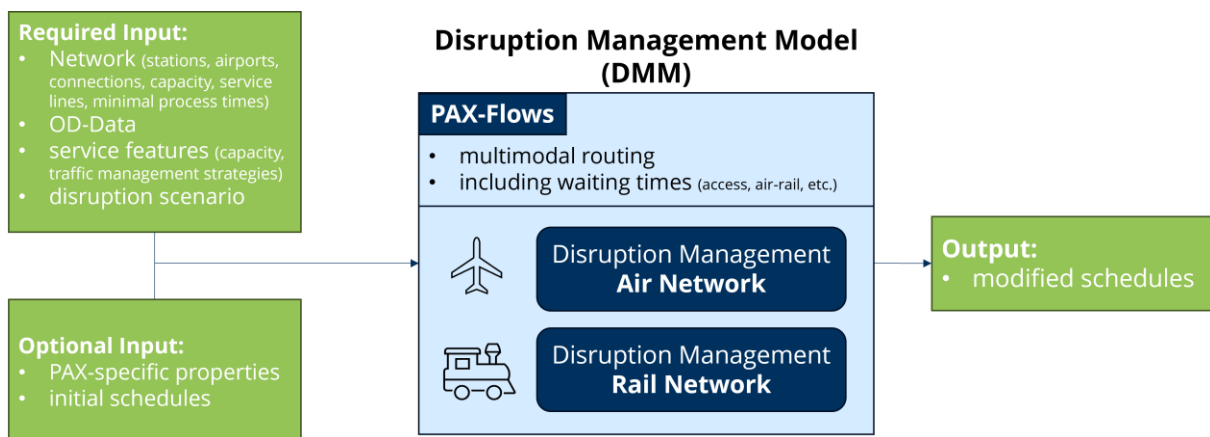


Figure 1: Overview of the DMM structure

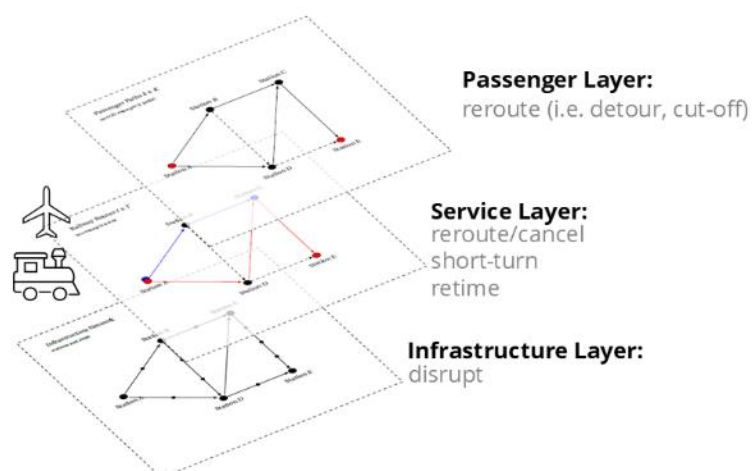


Figure 2: Network layers of the DMM

3.2.1 SESAR solution interdependencies

There are no interdependencies between the Disruption Management Solution and other SESAR solutions.

3.3 Objectives of the ECO-EVAL

The objective of this TRL2 ECO-EVAL is to help build an assessment of whether the MultiModX Disruption Management Solution is worth deploying, across European Civil Aviation Conference (ECAC), from an economic perspective for the involved stakeholders. This ECO-EVAL provides a consolidated assessment of the costs and benefits of deploying the MultiModX Disruption Management Solution in airports and railway operators facilities 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.

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	N/A	N/A	Enhanced operational resilience, improved passenger experience, reduced delay costs	Representatives of different airports present in the 1st industry board meeting

(Multimodal) Network manager	N/A	Invest in new system Training System maintenance Data collection	Enhanced operational resilience, improved passenger experience, reduced delay costs	Members present in the 1st Industry Board meeting
Airlines (mainline and regional)// airline operator	N/A	Invest in new system Training System maintenance Data collection	Increased plane occupancy. Increased costumer retention. Reduction of labour and maintenance costs.	Members of airlines present in the 1st Industry Board meeting
Rail infrastructure managers	N/A	Investment in new decision- support tools, staff training, system integration	Improved coordination with air transport, enhanced passenger connectivity, Enhanced operational resilience, improved passenger experience,	Members present in the 1st Industry Board meeting
Railway Undertakings	N/A	Investment in new decision- support tools, staff training, system integration	Increased train occupancy. Improved passenger experience,	Not involved

Scientific community (researchers, academics, coordinators of ongoing and former relevant projects)	N/A	N/A	Reuse of methodologies, validation of theoretical models, foundation for future studies	Members present in the 1st Industry Board meeting
Cities and regions, urban planners (ARC regional council members)	N/A	N/A	Improved multimodal transport integration, enhanced urban connectivity	Not involved
Cities and regional urban planners	N/A	N/A	Economic growth due to better connectivity	Not involved
Business aviation	N/A	N/A	Increased plane occupancy. Increased sales. Increased customer retention.	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

Table 3: Stakeholders' categories identification

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. The deployment location column is N/A in all cases. SOL401 is fairly independent from the current SESAR architecture, and as a tactical planning tool. Its deployment is not tied to a particular location. The use of SOL401 depends on airlines and rail companies' willingness to cooperate when managing disruptions.

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 1) and the ECO-EVAL solution scenario (reflecting the proposed deployment of the SESAR solution across ECAC, box in Figure 1). The comparison between the ECO-EVAL scenarios considers the point in time when the solution is available to be deployed and hence differs for each solution.
- 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.
- Defining the ECO-EVAL reference scenario has proven to be challenging because of the assumptions that need to be made regarding the 'ongoing deployments' that are relevant for the solution and their impacts.

3.5.1 ECO-EVAL solution scenario

SOL401 deployment and implementation is intrinsically linked with the development of Multimodal policies. SOL401 provides the most benefits if strong policies regarding multimodality are put into place and the sub-operational environments in which the solution will be tested include different implementations of the level of centralisation of SOL401, policy packages, and disruption package.

The current and future European regulatory framework and national policy environment are revised and analysed. In particular, the following policies are considered:

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

These policies are grouped into the following policy packages:

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

Table 4: Policy packages

Hence the policy packages considered in the project are:

- pp00: No policies
- pp10: Some multimodal policies in place (multimodality incentivised)
- pp20: Strong multimodal policies in place (multimodality enforced)

Additionally, the reference scenarios are characterised by the network definition. In a nutshell different network definition correspond to different ways of generating and populating itineraries from the given air and rail timetables. Network definitions may vary among different Solutions. For SOL401, the network definition considers different relations between demand and supply including:

- nd10: Nominal demand
- nd20: Reduced demand
- nd30: Homogeneous demand

The considered region/case study - Intra-Spain+International is coded as cs11.

The disruption type is selected based on the inputs from the Validation exercise #2 and consists of a capacity reduction at the airport of Madrid (LEMD).

Finally, the reference scenarios represent the situation without the application of the SESAR Solution. This will be labelled as dm000.

In conclusion, there are 3 reference scenarios considered for the ECO-EVAL:

- cs11.pp00.nd10.dm000: This is considered the baseline scenario
- cs11.pp20.nd20.dm000: Challenging scenario includes “multimodality enforced”, i.e. limited number of services (wrt the original schedules), and slightly lower passenger demand.
- cs11.pp00.nd30.dm000: Very challenging scenario with the original schedules, and homogenous demand leading to a significant mismatch between supply and demand.

Each of these reference scenarios is compared to two Solution scenarios.

3.5.2 ECO-EVAL solution scenario

ECO-EVAL timeline

The ECO-EVAL covers the period from 2026 to 2050 as defined in the common assumptions <add cross-reference to chapter 10 item identifying the latest applicable version of the DES common assumptions document available in the programme library>. This mean that the net present value is calculated by discounting the cash-flows back to 2026 (the end of DES wave 1).

The following table shall be filled in, taking the SESAR solution specific ECO-EVAL investment and benefit dates into account.

Table 4 lists the key dates used in the ECO-EVAL and Figure 2 shows them over a timeline.

Dates	SESAR solution 401
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 <i>minimum deployment</i> necessary to provide them. Costs continue after this date as further deployment occurs at other locations.	<IOC year> 2030
Final operating capability (FOC): maximum benefits from the <i>full deployment</i> [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

The scenarios analysed in the project concerning the validation of SOL401 take place in 2030. The deployment of SOL401 is minimal and only requires download of the code and minimal training to be able to run and interpret the results. No other interaction with any other SESAR Solution is required. We assume that SOL401 is applied at country level and that alliances with airlines and railway operators exist (according to assumption A2). The solution scenarios are based on the reference scenarios presented in section 3.5.1.

Two variants of SOL401 are evaluated:

- dm100: decentralized disruption management, with several alliances assumed
- dm200: centralized disruption management, with full coordination between air and rail operators

For each reference scenario, there are two corresponding Solution scenarios.

For cs11.pp00.nd10.dm000:

- cs11.pp00.nd10.dm100: This scenario corresponds to the application of SOL401 with decentralized disruption management and with the nominal demand
- cs11.pp00.nd10.dm200: This scenario corresponds to the application of SOL401 with centralized disruption management and with the nominal demand

For cs11.pp20.nd20.dm000:

- cs11.pp20.nd20.dm100: This scenario corresponds to the application of SOL401 with decentralized disruption management, multimodal enforced and with the reduced demand.
- cs11.pp20.nd20.dm200: This scenario corresponds to the application of SOL401 with centralized disruption management, multimodal enforced and with the reduced demand.

For cs11.pp00.nd30.dm000:

- cs11.pp00.nd30.dm100: This scenario corresponds to the application of SOL401 with decentralized disruption management and with homogeneous demand.

- cs11.pp00.nd30.dm200: This scenario corresponds to the application of SOL401 with centralized disruption management and with homogeneous demand.

3.5.3 Assumptions

ID	Title	Description	Justification	Impact Assessment
A1	Case studies coverage	It is assumed that the three case studies provide an interesting variety in terms of regional specificities and situations of multimodal transport (national case study and international corridor with an integrated HSR station in an airport).	Regional archetypes have been studied and the case studies cover a national and an international case.	Medium
A2	Regional archetypes	It is assumed that results derived from the Spanish (national), German (national) and the Spanish-German (international) regional archetypes can be translated and upscaled to a EU level using different regional archetypes as examples	The different regional archetypes represent a real combination of air and rail characteristics within a region or a transport corridor, and thus, the variety of multimodal conditions within the EU	Low
A3	Passenger archetypes coverage	It is assumed that the set of passenger archetypes considered are representative for the entirety of travellers.	Extensive research has been conducted to ensure that those passenger archetypes represent the variety of travellers.	Medium
A4	Data availability	It is assumed that the required data (demand, travel times, infrastructure and corresponding capacity, passenger preferences, flight schedules and rail timetables etc.) are available in the regions under study.	Data are required to execute the solution but modelling assumptions could be established if needed.	High

A5	Existence of multimodal governance	It is assumed that a multimodal performance scheme and multimodal governance is in place, allowing cooperation between modes of transport (shared data, information, incentive...) and requiring the network manager to cover multimodal aspects.	The interest of the project lies in studying the impact of a multimodal and collaborative framework.	High
A6	Fixed demand per OD pair	It is assumed that the demand for each OD pair is fixed, meaning that the choice of passengers to travel is independent of the schedules (there will be no more or less demand) and their destination will not change as a result of the disruption management.	It is considered sufficiently precise to have demand flows per OD pair and archetype for each scenario (including the impact of policies). The reaction of demand to the supply is considered to have a potential small impact only.	Medium
A7	Coordination between air and rail	The disruption management occurs between rail and air, leaving aside other long-distance ground transportation means as long-distance buses.	The scope and focus of the project is on air and rail collaboration. For future projects it would be interesting to include road transport.	Medium
A8	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

A9	Considered times	Scenarios, case studies, experiments and use cases will be performed at two distinct times. The reference will be year 2019 using existing pre-COVID data and a baseline targeting a future development in the time frame 2030-2035 with subject data availability.	It is assumed that maturation of the solution from TRL 1 to TRL 2 can be sufficiently performed by using a) historical data and b) one future reference year.	Medium
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Table 6: ECO-EVAL assumptions

Specific assumptions for disruption management

ID	Title	Description	Justification	Impact Assessment
A12	Disruption info	Information about a disruption is completely known, including type, start and end times, and location.	Disruption management decisions require knowledge of the disruption. As our Solution is a tactical approach, it can rely on historical set-ups, where the complete information is available.	Medium
A13	Disruption impact	Services are adapted only if they are directly affected by a disruption	Real-life disruption management measures are usually applied for directly affected services only.	Small
A14	Vehicle and crew	Vehicle rotations and crew schedules are not considered during the disruption management	Due to the tactical scope of our approach and regarding the policy oriented perspective of our project in combination with the steps of operational planning in industry; vehicle rotations and crew schedules are expected to be scheduled at a subsequent planning stage.	Medium
A15	Liabilities	The liabilities for managing the disruptions, e.g. passenger compensation, are not explicitly allocated to the different stakeholders.	As our solution considers the presence of liabilities and the presence of multimodal governance, the liability allocation is expected to have a limited impact on the disruption management outcome.	Low

Specific assumptions for passenger reassignment

ID	Title	Description	Justification	Impact Assessment
A10	Passenger routing	Passengers are routed along the shortest/fastest available paths within the network	Recent research shows that passengers short-term routing decisions depend on the duration of available routing alternatives.	Medium

Specific assumptions for service adjustments

ID	Title	Description	Justification	Impact Assessment
A11	Original schedule	The original timetable is feasible and does not exceed capacities or violate other operational constraints	Initial timetables originate from SOL2 or actual operations and will thus be feasible.	Low

4 Benefits

4.1 Benefits overview

The benefits of SOL401 according to the SESAR KPIs and PIs are mainly a reduction of direct operating costs (due better coordination between air and rail operators), a reduction of delays, and a reduction in stranded passengers.

However, since this Solution is aimed for 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. 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 [13], AMPLE3 [14], and SIGN-AIR [15] projects. The main benefits provided by SOL401 according to the KPIs/PIs developed in MultiModX including stranded passengers, resilience replanned and passengers replanned.

4.2 Benefit summary

Table 5 summarises the solution benefits showing the benefit impact mechanisms (BIMs) impact (positive, negative or neutral). It explains how the solution provides estimates.

KPI / PI	BIM impact	How the solution provides the benefit and evaluation (low, medium, high impact)
RES5 Number of cancellations	- (ECAC level)	medium
Diversions	+ (ECAC level)	low
PUN1 Average departure delay per flight	- (ECAC level)	medium

Table 7: SESAR performance framework KPIs and PIs where SOL401 can provide benefits

KPI / PI	KPA	BIM impact	How the solution provides the benefit and evaluation (low, medium, high impact)
Arrival delay (flights)	Efficiency	-	medium
Total journey time	Efficiency	-	medium
Total arrival delay at final destination	Efficiency	-	medium
Stranded passengers	Efficiency	+	high
Resilience replanned	Flexibility	+	high
Passengers replanned	Flexibility	+	high

Table 8: KPIs/PIs developed by the project where the SOL401 can benefits.

Table 4 presents the benefits of the application of SOL401 with respect to the PIs developed in the MultiModX project. Note that SOL401 aims to reduce the number of stranded passengers as much as possible while balancing it against oper metrics including delays, journey times. Therefore, transporting more passengers during a disruption may induce some increases to one or more other PIs, e.g. journey time.

In the following sections we present the expected benefits related to the KPIs/PIs developed within MultiModX.

4.3 Number of cancellations (RES5)

SOL401 provides most promising service cancellations to maintain connectivity between air and rail services during disruptions. This metric is expected to remain constant or decrease due to diversion alternatives, depending on the particular disruption scenario and network considered.

4.4 Diversions (TEFF1)

SOL401 provides most promising diversions to increase connectivity between air and rail services during disruptions. This metric is expected to increase, which would lead to better rerouting options for passengers, and thus less stranded ones, decreasing travel times, restoration of long-distance itineraries or more frequent travel opportunities (i. e. departures).

4.5 Average departure delay per flight (PUN1)

SOL401 provides a better connectivity and better coordination between services during disruption. Therefore, this metric is expected to decrease. In some specific cases, it may increase slightly if beneficial for providing new connections to passengers (e.g. a train waiting for a delayed flight).

4.6 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. Airlines can use the Tactical Evaluator to assess the resilience of their schedules and timetables. By implementing Multimodal Solutions such as Disruption Management Solution (SOL401), better connections can be established for originally disrupted passengers and thus arrival delay minimised.

4.7 Total journey time

Total travel time represents the “door-to-door” time of a journey. The main objective of the generation of multimodal synchronised schedules is the reduction of total travel time, especially in multimodal journeys. Therefore we expect a high impact here. For transporting the same number of passengers, this PI is expected to (significantly) reduce. However, in some cases, it may increase due to more passengers being transported, particularly if some long apart origins and destinations are reconnected.

4.8 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 Multimodal Solutions such as Disruption Management Solution (SOL401), this metric is expected to decrease by rerouting passengers (for example to rail) and other measures.

4.9 Stranded passengers

The impact of multimodal Solutions on this metric is expected to be high. By implementing a Multimodal Solutions such as Disruption Management Solution (SOL401), this metric is expected to decrease by rerouting passengers (for example to rail) and providing new connections (e.g. with replacement services) and other measures.

4.10 Passenger 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 Multimodal Solutions such as Disruption Management Solution (SOL401), this metric is expected to increase by rerouting passengers to mitigate disruption. As a result, more passengers would be transported.

4.11 Resilience replanned

This metric captures the applied changes and adaptations in the replanned schedules such as rerouted train services, diverted flights, replacement services, retimed/delayed services. The impact of multimodal Solutions on this metric is expected to be high. By implementing a Multimodal Solutions such as Disruption Management Solution (SOL401), services are adjusted to mitigate the disruption. This metric may increase, compared to reference scenario, and more passengers could be transported.

5 Cost assessment

Stakeholder	Cost category	Yes/No	Cost driver	Deployment locations (or sub-operating environments)
ANSPs	Investment cost	<i>No</i>		N/A
	Operating cost	<i>No</i>		
Airport operators	Investment cost	<i>No</i>		N/A
	Operating cost	<i>No</i>		
(Multimodal) Network manager	Investment cost	<i>Yes</i>	Invest in new system	within current scope (all ECAC traffic)
	Operating cost	<i>Yes</i>	Labour costs + data collection	
Airlines	Investment cost	<i>Yes</i>	Invest in new system	relevant for airlines 'participating' in multimodality (e.g. member of multimodal alliances)
	Operating cost	<i>Yes</i>	Labour costs + data collection	
Rail infrastructure manager (IMs)	Investment cost	<i>Yes</i>	Invest in new system	<i>at each state</i>
	Operating cost	<i>No</i>	Labour costs + data collection	
Rail operators (IMs)	Investment cost	<i>Yes</i>	Invest in new system	<i>at each state</i>
	Operating cost	<i>No</i>	Labour costs + data collection	

Table 9: Cost identification ANSPs costs

From SOL2: The deployment location column is N/A in all cases. SOL400/SOL2 is fairly independent from the current SESAR architecture, and as a planning tool its deployment is not tied to a particular location. The use of SOL400/SOL2 depends on airlines and rail companies' willingness to coordinated and adjust their schedules during disruptions.

From SOL1: The deployment location column presents preliminary information, because it is still being discussed within the project. Once the exact sub-operation environments and validation exercises are identified, this will be reflected in the final version of the ERP [11].

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

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

5.3 Network manager costs

Network managers can design adjusted schedules taking into account passenger experience (delays and missed connections). They are considered as primary users of the solution, thus will invest in a new system, training, maintenance of the system, and data collection and maintenance.

5.4 Airspace user costs

The implementation and use of SOL401 requires minimal costs for airlines, that are compensating with reduction of personnel with the optimisation of adjusted schedules, so we do not predict an impact on airspace users.

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

Airlines and railway companies will bear most of the direct costs related with SOL401. As primary users of the solution, they will spend in investing in a new system, training, maintenance of the system, and

on the data collection and maintenance (SOL401 needs planned services, infrastructure data from the network, the demand, i.e. how many people travel from place to place, and disruption). This cost would be greatly compensated and expectedly exceeded due to better more coordinated and connected operations for passengers leading to more passengers reaching their destinations.

Note: these costs would bear only airlines and railway companies that are willing to 'participate' in multimodality (e.g. being a member of multimodal alliances).

6 Recommendations and next steps

The Disruption Management Solution (SOL401) adjusts coordinated multimodal schedules for air and rail with passenger focus for a given set of disruptions. Taking into account the infrastructure, the service features and the passenger properties, an optimization model is applied to identify the optimal disruption management measures and correspondingly adjust original input timetables.

The objectives when adjusting the schedules represent an integration of the following single objectives:

- minimize the number of disconnected passengers;
- minimize the additional detours for passengers
- minimize additional waiting times for passengers;
- minimize the number of replacement services (e.g. air or rail);

by managing the passenger demand.

This Solution enhances multimodal travel efficiency by coordinating adjusted schedules with passenger needs and industry constraints.

This ECO-EVAL reflects that the main benefits of SOL401 are passenger centric. In particular, the PIs for which SOL401 has the highest influence are:

- Stranded passengers
- Resilience replanned
- Passengers replanned

The cost of the deployment of SOL401 are marginal and affect mostly airlines and railway companies, as they have to install the software, and train their personnel. As a consequence of the application of SOL401 maintenance costs will vary for rail network maintainers.

To further assess the impacts of SOL401:

- Future analysis could complement the global analysis performed during the project with complementary analysis of different sub-operating environment based on the present infrastructure. Example of interesting sub-operating environment could be:
 - Large/medium/small hubs and their surrounding cities, especially if those hubs have an integrated rail station
 - Different regional archetypes
 - Different locations of disruptions
- Additionally, in order to assess better the impacts of this Solution, further analysis could consider networks with a higher percentage of Multimodal and connecting itineraries, such as different European countries and/or larger regions in Europe.

7 References

7.1 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](#)

[1] 101114815 MultiModX Grant Agreement, 31/05/2023

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

7.2 Reference documents

- [1] PEARL -- Performance Estimation, Assessment, Reporting and simulation -- [Performance Estimation, Assessment, Reporting and simulation | PEARL Project | Fact Sheet | HORIZON | CORDIS | European Commission](#)
- [2] AMPLE3 -- SESAR3 ATM Master Planning and Monitoring – [SESAR3 ATM Master Planning and Monitoring | AMPLE3 Project | Fact Sheet | HORIZON | CORDIS | European Commission](#)
- [3] SING-AIR -- Implemented Synergies. Data Sharing Contracts and Goals between transport modes and air transportation – <https://sign-air.eu/>